

# **Distribution of Sulphur Pools as Influenced by Long Term Application of Fertilizers and Manure in a Vertisol**

**THESIS**

*Submitted to the*

**Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur**

**In partial fulfilment of the requirements for  
the Degree of**

**MASTER OF SCIENCE**

*In*

**AGRICULTURE  
(Soil Science and Agricultural Chemistry)**

**Jarupula Suman**

**Department of Soil Science and Agricultural Chemistry  
College of Agriculture, Jabalpur 482004  
Jawaharlal Nehru Krishi Vishwa Vidyalaya  
Jabalpur, Madhya Pradesh**

**2015**

## CERTIFICATE- I

*This is to certify that the thesis entitled “Distribution of sulphur pools as influenced by long term application of fertilizers and manure in a Vertisol” submitted in partial fulfilment of the requirement for the degree of **MASTER OF SCIENCE in Agriculture (Soil Science and Agricultural Chemistry)** of Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur is a record of the bonafide research work carried out by **Mr. Jarupula Suman** under my guidance and supervision. The subject of the thesis has been approved by the Student’s Advisory Committee and the Director of Instructions.*

*All the assistance and help received during the course of the investigation has been acknowledged by him.*

Place : Jabalpur

**(B.S. Dwivedi)**

Date :

**Chairman of the Advisory Committee**

### THESIS APPROVED BY THE STUDENT’S ADVISORY COMMITTEE

Committee	Name	Signature
Chairman	Dr. B.S. Dwivedi	.....
Member	Dr. A.K. Dwivedi	.....
Member	Dr. S.K. Pandey	.....
Member	Dr. H.L. Sharma	.....

## CERTIFICATE-II

*This is to certify that the thesis entitled “Distribution of sulphur pools as influenced by long term application of fertilizers and manure in a Vertisol” submitted by Mr. Jarupula Suman to the Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur in partial fulfilment of the requirements for the degree of Master of Science in Agriculture, in the Department of Soil Science and Agricultural Chemistry has been, after evaluation, approved by the External Examiner and by the Student’s Advisory Committee after an oral examination on the same.*

Place: Jabalpur

(B.S. Dwivedi)

Date:

Chairman of the Advisory Committee

### MEMBERS OF THE ADVISORY COMMITTEE

Committee	Name	Signature
Chairman	Dr. B.S. Dwivedi	.....
Member	Dr. A.K. Dwivedi	.....
Member	Dr. S.K. Pandey	.....
Member	Dr. H.L. Sharma	.....
Head of the Department	Dr. A. K. Rawat	.....
Director of Instructions	Dr. G.S. Rajput	.....

## **Declaration and Undertaking by the Candidate**

I, Jarupula Suman S/o Shri J.B. Nayak certify the work embodied in thesis entitled “Distribution of sulphur pools as influenced by long term application of fertilizers and manure in a Vertisol” is my own first hand bonafide work carried out by me under the guidance of Dr. B.S. Dwivedi at Department of Soil Science and Agricultural Chemistry, College of Agriculture, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur and place during 2014-2015.

The matter embodied in the thesis has not been submitted for the award of any other degree/diploma. Due credit has been made to all the assistance and help.

I, undertake the complete responsibility that any act of misinterpretation, mistakes, errors of fact are entirely of my own.

I, also abide myself with the decision taken by my advisor for the publication of material extracted from the thesis work and subsequent improvement, on mutually beneficial basis, provided the due credit is given, thereof.

Place: Jabalpur

Date:

**Jarupula Suman**

**Copyright ©Jawaharlal Nehru Krishi Vishwa Vidyalaya,  
Jabalpur, Madhya Pradesh**

**Copyright Transfer Certificate**

Title of the Thesis : Distribution of sulphur pools as influenced by long term application of fertilizers and manure in a Vertisol

Name of the candidate : Jarupula Suman

Subject : Agriculture

Department : Soil Science and Agricultural Chemistry

College : College of Agriculture, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh

Year of thesis submission : 2015

**Copyright Transfer**

The undersigned Jarupula Suman assigns to the Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur Madhya Pradesh, all right under Copyright Act, that may exists in and for the thesis entitled "Distribution of sulphur pools as influenced by long term application of fertilizers and manure in a Vertisol" submitted for the award of M.Sc. (Ag).

Date:

Place: Jabalpur

**Dr. B.S. Dwivedi**  
**Major Advisor**

**(Jarupula Suman)**  
**Student**

## ACKNOWLEDGEMENT

I praise God for enabling me to accomplish this task of thesis work in his grace for his glory.

I find no words to express my sincere feelings of gratitude towards my guide and chairman of advisory committee Dr. B.S. Dwivedi, Scientist, Department of Soil Science and Agricultural Chemistry, JNKVV, Jabalpur, who deserves my most sincere thanks and respect for inspiring and excellent guidance and helping attitude throughout the investigation and preparation of the manuscript.

I extend my sincere gratitude to other members of my advisory committee Dr. S.K. Pandey, Scientist, Department of Plant Breeding and Genetics and Dr. H.L. Sharma, Professor and Head, Department of Agricultural Engineering and Statistics, College of Agriculture, JNKVV, Jabalpur for their valuable comments and helpful suggestions and supports in completion of the present study.

I am indeed thankful to Dr. A.K. Rawat, Professor and Head, Department of Soil Science and Agricultural Chemistry for his guidance, encouragement and all necessary help needed during the course of this investigation.

I express my sincere thanks to Dr. B. Sachidanand, Dr. B.L. Sharma, Dr. A.K. Dwivedi, Dr. H.K. Rai, Shri S.S. Baghel, Dr. G.D. Sharma, Dr. R.K. Thakur and Shri Narendra Chouhan for their help, constant encouragement and suggestions at various stages during the course of this study.

I am very much thankful to Dr. V. S. Tomar, Hon'ble Vice-Chancellor, JNKVV, Dr. S.S. Tomar, Director of Research Services, Dr. G.S. Rajput, Director of Instructions and Dr. Om Gupta, Dean, College of Agriculture, JNKVV, Jabalpur for providing facilities and encouragement for the research work.

I have no words to express my gratitude to my father Shri J.B. Nayak and mother (Smt.) Vinoda, elder sister Sunitha Sreenivas whose love, blessings, constant inspiration and care throughout my life enabled me in my ascent to the present accomplishment.

I would like to extend my profound thanks to my seniors Mr. Arpit Suryawanshi, Mr. S.S. Porte, Mr. Vinod Kumar and Class mates who have inspired me in all respects during the course of my study to which i remain indebted forever.

I will always be thankful to laboratory staff of Department of Soil Science and Agricultural Chemistry and central library staff for providing necessary facilities during the course of study and research work.

Place: Jabalpur

Date:

**(Jarupula Suman)**

## List of Contents

<b>Chapter No.</b>	<b>Title</b>	<b>Page No.</b>
1.	Introduction	1-3
2.	Review of Literature	4-17
3.	Material and Methods	18-27
4.	Results	28-41
5.	Discussion	42-49
6.	Summary, Conclusions and Suggestions for further work	50-54
Summary	50	
Conclusions	53	
Suggestions for further work		54
	References	55-62
	Curriculum Vitae	

## List of Tables

<b>Table No.</b>	<b>Titles</b>	<b>Page No.</b>
3.1	Physico-chemical properties of soil (0-20 cm depth) at the start of the Long-Term Fertilizer Experiment (1972)	19
3.2	Mean weekly meteorological observations recorded during the crop growth period (2014-15)	20
4.1	Physico-chemical properties of soil	29
4.2	Effect of continuous addition of fertilizers and manure on distribution of available nutrients	32
4.3	Effect of continuous addition of fertilizers and manure on distribution of sulphur pools	35
4.4	Effect of long term fertilizers and manures on grain yield ( $\text{kg ha}^{-1}$ ) of soybean	40
4.5	Zero order matrix correlation studies between sulphur pools with available sulphur and soybean yield	41

## List of Figures

<b>Figure No.</b>	<b>Title</b>	<b>Page No. (in between)</b>
1.	Layout of Long-term Fertilizer Experiment, JNKVV, Jabalpur	22
2.	Depth wise distribution of soil pH	42-43
3.	Depth wise distribution of soil EC	42-43
4.	Depth wise distribution of soil organic carbon	43-44
5.	Depth wise distribution of soil available nitrogen	43-44
6.	Depth wise distribution of soil available phosphorus	44-45
7.	Depth wise distribution of soil available potassium	44-45
8.	Depth wise distribution of available sulphur	45-46
9.	Depth wise distribution of water soluble sulphur	45-46
10.	Depth wise distribution of heat soluble sulphur	47-48
11.	Depth wise distribution of organic sulphur	47-48
12.	Depth wise distribution of total sulphur	49-50
13.	Soybean yield at different treatments	49-50
14.	Relationship with in soil sulphur pools	49-50
15.	Relationship between soil sulphur pools and soybean yield	49-50

## Vitae

The author of this thesis, Mr. Jarupula Suman S/o Shri J.B. Nayak and Smt. Vinoda was born on 18<sup>th</sup> June 1991 at Gudur, Distt. Warangal (TS).



After graduation, for further study, he got admission in M.Sc. (Ag.) for specialization in Agriculture (Soil Science & Agricultural Chemistry ) at the College of Agriculture, JNKVV, Jabalpur (M.P) where successfully completed all the course requirement for master's degree with OGPA 7.2 out of 10 point scale in the year 2015.

For the partial fulfillment of the master's degree "Distribution of sulphur pools as influenced by long term application of fertilizers and manure in a Vertisol" under Jabalpur condition, which was successfully conducted by him and being submitted in the form of this thesis.

He took admission for B.Sc. (Ag.) in the College of Agriculture, Jagtial, ANGRAU, (TS) in the year 2009. He has successfully completed his graduation with 7.46 OGPA in the year 2013.

He passed his High School (10<sup>th</sup>) with first division (86%) in the year 2006 and Higher Secondary School (12<sup>th</sup>) with first division (86%) in the year 2008.

## INTRODUCTION

Soybean (*Glycine max* L. Merrill) is an important leguminous and oilseed crop which has played significant role in the yellow revolution in India. Since, it is rich in oils (17-21%) and protein (38-42%), it is considered suitable for feeding humans as well as animals (Ibrahim and Kandil 2007).

During the past four decades the use of high yielding varieties of crops and inorganic fertilizers has resulted in rapid increase in agricultural production. Fertilizer is one of the key inputs responsible to increasing agricultural production, but it must be realized that their cost and other constraints frequently discouragement farmers from using them in recommended quantities and balanced proportion. Further, the imbalance use of chemical fertilizer also deteriorated soil health. Indian agriculture, particularly when there is more and more use of non-sulphur containing fertilizers and lesser use of organic manures (Raina and Tanawade 2005). Removal of S by crops in India is about 1.26 million tonne (Mt), where its replenishment through fertilizers is only about 0.76 Mt (Tiwari and Gupta 2006). Furthermore, the use efficiency of added S through external sources is also very low, being only 8-10% (Hedge and Murthy 2005). Sulphur deficiencies in Indian soils were estimated to occur in about 130 districts (Tandon 1991). About 45% districts of the country showed more than 40% S deficiency (Singh 2000). The fertilizer responsive varieties have accelerated the depletion of S reserves in the soil, even from lower soil depths (Pillai 1994). Sulphur is a mobile nutrient element in the soil system which moves down to the lower soil layers due to various pedological as well as frequent irrigations and rains that further enhanced the extent of S movement and alteration in soil system (Tripathi and Hazara 2000).

Sulphur deficiency in crop is gradually becoming widespread in different soils in several states of India due to fast depletion of natural soil resource of sulphur through the continuous use of sulphur free

fertilizers, inadequate recycling of crop residues, input exhaustive high yielding crop varieties, high sulphur requiring crops, practice of intensive multiple cropping system and leaching losses through down the profiles. More than 70-90% of soil sulphur is in the organic form (as that of N) in combination with C and N. The inorganic sulphur (10-30%) is present as sulphate/sulphide ( $\text{SO}_4^{-2}$ ) form. Availability of sulphur is influenced by various soil factors and hence its availability varies widely with soil type (Balanagoudar and Satyanarayana 1990).

Under intensified cultivation crop removal is the main source of nutrient depletion and there is a negative balance due to inadequate replacement of the depleted nutrients, which lowers the productive capacity of soils in turn deteriorating the quality of future crop. In view of the above facts, the present study was undertaken to find out the influence of fertilizer on the distribution of sulphur in Vertisol under soybean-wheat cropping sequence.

In recent years, an increased frequency of sulphur deficiency has been observed all over the world. When sulphur is deficient, both quantity and quality of the crops are reduced. Sulphur deficiency symptoms show a pale green coloration of younger leaves first as sulphur is not very mobile in the plant. In severe cases of sulphur deficiency the entire plant can be stunted and pale green. Affected plants may be thin stemmed and spindly. Source of sulphur Organic matter, Soil minerals, the atmosphere, pesticides organic wastes, irrigation water and fertilizer.

It also plays an important role in the synthesis and formation of certain essential amino acids like cysteine, cystine and methionine, the building blocks for the proteins. In the absence of sufficient sulphur, several essential enzymatic activities and physiological functions are inhibited. Thus, maintenance of an optimum level of sulphur in the soil in relation to other nutrients is essential for maximum crop production and its quality aspects.

Soil is the main source of sulphur nutrition of crops and its availability is dependent on sulphur fractions. Sulphur in soil can be broadly grouped into five forms viz. available-S, water soluble-S, heat soluble-S, organic-S and total-S. Among these sulphur pools, organic-S dominantly controls the level of plant available sulphur. Soil structure can protect soil organic matter against microbial attack by providing physical protection within water stable soil aggregates. Organic sulphur is reported to constitute between 5% and 98% of the available sulphur in Indian soils.

The knowledge of relative distribution of sulphur at different soil depth may be helpful in formulation of a sound fertilizer programme in realizing higher economic productivity under Long Term Fertilizer use in a cropping system.

The present study is planned to evaluate the “Distribution of sulphur pools as influenced by long term application of fertilizers and manure in Vertisol” with the following objectives.

### **Objectives**

1. To determine the effect of continuous addition of fertilizer and manure on status of soil sulphur pools.
2. To work out the relationship between the fraction of sulphur with availability of sulphur in soil.

## REVIEW OF LITERATURE

The present investigation on impact of various nutrients input through fertilizers and manure on aggregate associated sulphur pools in a Vertisol was to assess the extent of soil aggregation and the contents in sulphur pools associated with them. Also to evaluate the effect of amount of soil available nutrients in soil surface and subsurface layers on sulphur fractions and their relationship with different soil parameters. Relevant literature on these aspects is reviewed in this section below.

### 2.1 Soil pH

Patiram and Singh (1993) after three years of continuous application of manures and nitrogenous fertilizers in acid Inceptisols of Sikkim found that application of manure increased the pH due to decrease of Al and release of basic cations during decomposition of manure whereas, application of nitrogenous fertilizers decreased the pH of the soil.

Sharma et al. (2000) reported decrease in pH with the application of FYM. In contrary to this, Balaguravaiah et al. (2005) reported an increase in pH with application of FYM continuously for eighteen years.

Zhang et al. (2008) observed the decrease in soil pH by 0.2 to 1.1 units from the initial value (pH 5.3). The maximum fall in soil pH was due to application of N alone either as urea (pH 4.7) or ammonium sulphate (pH 4.4). This is due acid producing nature of these nitrogenous fertilizers. With an increase in the levels of NPK from 50 to 150 per cent of optimal dose there was a corresponding decrease in soil pH. Inclusion of organic manure along with NPK fertilizers resisted drastic fall in pH due to buffering action of organic matter (Sudhir et al. 2002). Similar trend was observed in sub surface layer (Hati et al. 2008).

Verma et al. (2010) studied the integrated nutrient management on soil properties under long term field experiment (LTFE) in a Typic Haplustept at Udaipur. They observed that application of 20 tone FYM

ha<sup>-1</sup> and combined use of NPK with 10 tone FYM ha<sup>-1</sup> showed no marked changes in soil pH over the 9 years of experimentation.

Birla (2012) studied the continuous application of fertilizers and manure to crops grown with soybean-wheat in sequence. He observed the range of pH between 7.50 (50% NPK) to 7.62 (100% NPK and 150% NPK) in various treatments at 0-20 cm depth. There was no any significant effect of continuous use of fertilizers and manure on soil pH.

Patel (2014) reported that the there was no significant effect of continuous use of fertilizers and manure on soil pH and it was ranged between 7.46 to 7.60 in various treatments after 42 cropping cycle of continuous application of fertilizers and manure.

From the perusal of literature it is clear that the pH of soil may decrease if fertilizers having residual acidity are continuously used in acid soil while, it may remain almost unchanged if fertilizer are used in normal soil having high buffering capacity. Further it also appears that use of organic manure (FYM) may act as and stabilizing factor (Dwivedi et al. 2007).

## **2.2 Soil EC**

Khiani and More (1984) carried out long term field experiment on cotton and sorghum in medium black clay loam soil of Pune under rainfed condition on cotton and sorghum. The finding indicates that the EC of soil remain unaltered when continuous application of FYM applied to these crops over a period of 10 years @ 6.2 tonne ha<sup>-1</sup>. Similar finding was observed by Santhy et al. (1999).

Grewal et al. (1999) reported that under pearl millet wheat cropping sequence at Hisar, continuous fertilizers for 13<sup>th</sup> years caused a non significant difference in EC of the sandy loam soil covering surface and subsurface horizons.

In this connection, It has been established that continuous use of inorganic fertilizer over a long period of time have no marked influence on EC of the soil and conjoint use of FYM and fertilizer may cause

meager change which could be due to addition of organic manure which increased the buffering capacity of the soil (Dwivedi et al. 2007).

Raghuvanshi (2013) studied the continuous application of fertilizers as affected by EC. He observed that EC ranged between 0.12 (100% NPK-S) to 0.18 dSm<sup>-1</sup> (150% NPK) in various treatments. It was found that various doses of fertilizers and manure did not result in any significant effect on soil EC at 20 cm depth in vertisol.

Patidar (2014) observed that the EC of the soil at 0-20 cm depth ranged 0.12 to 0.18 dSm<sup>-1</sup>. It indicates that imposition of different treatments had not affected any significant change in soil EC.

### **2.3 Organic carbon**

Tomar (2003) from their studies in Typic Haplustert clay soil following soybean-wheat crop sequence receiving inorganic fertilizers either alone or with FYM continuously for 31 years had observed that organic carbon content was 1.02%(100% NPK + FYM) as compared to 0.58% in control. Similarly, Verma et al. (2005) also reported that the application of 100% NPK through FYM 10 t ha<sup>-1</sup> and FYM 20 t ha<sup>-1</sup> significantly improved the organic carbon content of soils.

Bajpai et al. (2006) found that organic carbon content increased from 22.9 to 27.4 per cent over the initial level (5.1 g kg<sup>-1</sup>) and from 27.5 to 31.2 per cent over control by continuous application of FYM over the years. An overall increase in organic carbon was observed in surface layer.

Behera and Singh (2009) reported an increase in SOC with the application of fertilizers. Difference in OC content due to application of fertilizers might be the result of differential rate of oxidation of organic matter by microbes.

Tabassum et al. (2010) reported that integrated use of chemical fertilizers and organic sources maintained initial status of soil organic carbon after 4 years of cropping. But, the integrated use of 50 per cent NPK with 5 t FYM / 1t poultry manure / 5 t urban compost per hectare to

soybean and 100 per cent NPK to wheat and use of FYM alone significantly improved the soil organic carbon status in surface soil as compared to control and initial status.

Lakaria et al. (2012) reported that the soil organic carbon storage with turnover rates of biomass under different IPNS modules in a vertisol had improved in carbon sequestration through balanced and integrated nutrient management. The highest C addition and storage was recorded under 16 and 8 t ha<sup>-1</sup> FYM addition to soybean and wheat respectively.

Persual of above literature shows that the continuous use of inorganic fertilize alone or with FYM tends to improve organic carbon content of the soil.

#### **2.4 Available nitrogen content of the soil**

Tyagi and Bhardwaj (1994) examined soil samples for variation in N, P and K availability with depth. They reported that the maximum value (235 kg ha<sup>-1</sup>) of available N in surface layer and minimum (70 kg ha<sup>-1</sup>) in deeper layer of soil. .

Singh et al. (2002) noticed the highest available N content in surface and subsurface layer with application of 100% NPK+FYM as compare to control and it frequently decline with increasing soil depth.

Sonune et al. (2003) reported that after ten years of continuous cropping and manuring, highest available N content was recorded in treatment where FYM was applied in conjunction with chemical fertilizers followed by super optimal (150% NPK) dose of chemical fertilizers.

Kumar and Singh (2010) reported that combined application of 100 per cent NPK + green gram + 5.0 t FYM each year resulted in significantly higher available N, P and K in post-harvest soil at the end of six years cycle in rice-wheat cropping system.

Thakur et al. (2011) found that after thirty-six years conjoint use of FYM with 100 per cent NPK significantly improved the available N, P

and S by 126.8, 25.5 and 28.5 kg ha<sup>-1</sup> in soil over its initial values, thereby indicating significant contribution towards sustaining the soil health.

Singh et al. (2012) concluded that the estimated amount of N<sub>2</sub> fixed by soybean annually varied from 62.8 to 161.1 Kg ha<sup>-1</sup>. However the net gain of N in soil after offsetting the N derived by soybean from soil varied from 24.2 to 66.5 kg ha<sup>-1</sup> annually. The highest percentage of N derived from the atmosphere was recorded in the control treatment, but the highest amount of N<sub>2</sub> fixed was found in the 100% NPK treatment.

Patel (2014) reported that the available nitrogen content of soil varied from 193 to 329 kg ha<sup>-1</sup>. The highest value of available N was recorded in 100% NPK +FYM treatment (329 kg ha<sup>-1</sup>). Available N content in soil increased successively and significantly from 214 to 287 and 310 kg ha<sup>-1</sup> as the doses of fertilizer increased from 50% to 100% and 150% NPK, respectively.

## **2.5 Available phosphorus content of the soil**

Sharma (1992) reported that the highest build up in soil available phosphorus was 66.2 kg ha<sup>-1</sup> and 54.6 kg ha<sup>-1</sup> respectively in surface and sub surface soil layers with the application of FYM and crop residue treated plots as compare to control plot. It was attributing to their beneficial effect on soil physiochemical and microbiological properties.

Reddy and Surekha (1999) concluded that the chickpea has the ability to access P normally not available to other crops in a Vertisol by mobilizing sparingly soluble Ca-P due to acidification of rhizosphere through it's citric acid exudates.

Bhattacharya and Ghosh (2001) studied on Typic Ustochrept of Delhi and they reported that available P content in soil increased due to application of highest levels of phosphorus. Perusal of above information reveals that increasing levels of P application continuously either alone or with organic manure helps in improving the available P

content of soil with time. It may also cause changes in its spatial distribution.

Mann et al. (2006) observed that continuous growing of maize - wheat-cowpea cropping sequence over the years with the recommended dose of NPK and FYM significantly increased the available N, P and K content of the soil. Similarly Behera and Singh (2009) reported a build-up in the available P under all the treatments except control as compared to initial value after 31 years of continuous cropping and fertilizer use in maize-wheat system.

Kumar and Singh (2010) reported that combined application of 100 per cent NPK + green gram + 5.0 t FYM each year resulted in significantly higher available N, P and K in post-harvest soil at the end of six years cycle in rice-wheat cropping system.

Singh et al (2013) reported that the sub surface (15-30 cm) soil showed lower content of various P as compared to surface soil. Sharma and Paliwal (2014) reported that bicarbonate extractable organic P increased over the initial content in all the treatments.

## **2.6 Available potassium content of the soil**

Singh (2002) reported that the highest available K content in surface, sub surface and third layer of soil with application of 100% NPK + FYM as compare to other treatments. The maximum amount of K depletion was recorded from 30-50 cm soil layer of the Typic Haplustert. Intensive cropping with high yielding varieties makes a considerable effect on the soil natural resources therefore even the soils, which are currently sufficient in K, may begin to show response to K when higher amounts on P or N applied (Swarup and Rao 1999). In this connection, Tyagi and Bhardwaj (1994) have noted the variation in K availability with depth. The maximum availability ( $152.5 \text{ kg ha}^{-1}$ ) was reported on surface layer and minimum ( $27.5 \text{ kg ha}^{-1}$ ) in deepest layer.

Yadhuvanshi and Swarup (2006) studied the distribution pattern of soil K at various depths of soil profile indicate that a major portion of

applied K remained in the top 30 cm soil and moved in successively decreasing amounts down the profile to a depth of 60 cm in the plots receiving K fertilizer. The highest and lowest values were obtained in 150% NPK and 100% NP for estimation treatments, respectively.

Bhattacharya et al. (2007) noticed that the crop removal of K often equals or exceeds that of nitrogen under intensive cropping with high yielding varieties and imparity in nutrient use, K form soil getting depleted is evident form number of field experiments conducted across the country under the AIRCP on long term fertilizer experiment. The K is thus recognized as deficient element after N and P in Indian soil.

Singh and Wanjari (2012) found that available K in soil significantly increased in 100% NPK and 100% NPK + FYM treatments, whereas in other treatments changes in available K was statistically non-significantly. Similar findings were also found by Singh et al. (2014).

Sawarkar et al. (2013) found maximum available K with 100% NPK +FYM (295.2 kg ha<sup>-1</sup>), followed by 150% NPK (284.2 Kg ha<sup>-1</sup>). All the K fractions at 0-20 cm soil depth exhibited significant and positive correlation with yield. Hence, much attention is required for potassium fertilizers to maintain K status of soil and to prevent K mining.

## **2.7 Effect of continuous addition of fertilizers and manure on distribution of sulphur pools**

### **2.7.1 Available sulphur content of the soil**

Singh et al. (2001) have found that rice-wheat grown in sequence and supplied P through single super phosphate since 1991 caused an increase in the available S content. This increase was further accentuated when FYM was included in the treatment.

Tiwari et al. (2002) studied on the status of soil nutrients, their depletion and build up and crop productivity after 28 years (1972-00) of intensive cropping under various fertilizer and manorial treatment on Typic Haplusterts of Jabalpur. They showed that the omission of

sulphur in the fertilizer schedule has caused a continuous depletion in the available sulphur status of soil.

Setia and Sharma (2005) found that available sulphur content in the plough layer (0-15 cm) ranged from 10.1 to 16.7 mg kg<sup>-1</sup>. They also found that all forms of S decreased with increasing soil depth but this effect was more noticeable up to 45-60 cm soil depth.

Sharma and Chaudhary (2007) studied status of available sulphur contained in Shiwalic foot hills of Himachal Pradesh and found that it varied from 11.2-38.2 kg ha<sup>-1</sup> with a mean value of 22.7 kg ha<sup>-1</sup>.

Thakur and Sawarkar (2009) reported that the successive addition of S fertilizer increased the available S status from its initial status (15.6 kg S ha<sup>-1</sup>) and the highest deposition (44.12 kg S ha<sup>-1</sup>) was observed in the treatment receiving 100% NPK+FYM followed by 150% NPK (39.83 kg S ha<sup>-1</sup>). While the lowest status was recorded where continuous S free fertilizers were added (14.43 kg S ha<sup>-1</sup>) at 0-20 cm soil depth, and declined progressively due to the intensive cultivation. The available S contents increased in subsoil 20-40 cm soil layer and thereafter the value reduced significantly with increasing soil depth.

Birla (2012) reported that the available sulphur was successively increased with the increasing in fertilizer doses from 50% NPK (23.94 kg ha<sup>-1</sup>) to 100% NPK (34.32 kg ha<sup>-1</sup>) and 150% NPK (38.67 kg ha<sup>-1</sup>). However, the lowest content was observed in control (17.94 kg ha<sup>-1</sup>) followed by 100% NPK-S (20.36 kg ha<sup>-1</sup>). Similarly Kaleeswari (2012) observed the available sulphur content from 1.25 to 198.75 mg kg<sup>-1</sup> with the mean value of 48.64 mg kg<sup>-1</sup> in surface soil.

Paul and Mukhopadhyay (2014) reported that the range of water soluble, sulphate, adsorbed, organic form and total sulphur were 6.91 to 26.23, 13.73 to 30.38, 3.19 to 42.91, 150.27 to 372.73 and 178.57 to 433.09 ppm, respectively. The critical level of available sulphur for moong bean (B1, Sonali) grown on acid soils of terai tract of Eastern India, was 18.0 mg kg<sup>-1</sup>.

### **2.7.2 Water soluble sulphur**

Balik et al. (2009) found that after twenty six years of continuous cultivation total sulphur decreased by about 3-8 per cent; water soluble S by 65-68 per cent and absorbed S by 39-44 per cent in the topsoil.

Karthikeyan and Shukla (2011) reported that the water soluble sulphur, sulphate sulphur and heat soluble sulphur increased with increasing levels of sulphur. At same level of sulphur with increasing levels of boron, the water soluble sulphur and sulphate sulphur were found to decrease, but the heat soluble sulphur did not show significant change in the soils.

Patel et al. (2011) reported that different forms of sulphur decreased with depth. All the forms of sulphur had significant positive relationship with organic carbon. The electrical conductivity of soil was positively correlated with sulphate sulphur, water soluble sulphur and heat soluble sulphur while it was negatively correlated with total sulphur, organic sulphur and non-sulphate sulphur.

Paul and Mukhopadhyay (2014) reported that the surface soil samples of some terai soils of Eastern India were collected and analysed to evaluate different forms of sulphur status and soil test methods for predicting response of moong bean crop to sulphur application. The range of water soluble, sulphate adsorbed, organic form and total sulphur were 6.91 to 26.23, 13.73 to 30.38, 3.19 to 42.91, 150.27 to 372.73 and 178.57 to 433.09 ppm, respectively.

### **2.7.3 Heat soluble sulphur**

Setia and Sharma (2005) reported that heat soluble sulphur in surface layer (0-15 cm) ranged between 22 to 42 mg kg<sup>-1</sup>. This form of sulphur also exhibited a decline in its status with increasing soil depth. The extent of decrease was higher up to 45-60 cm soil depth. It is obvious because this form of S is associated with organic S and organic S decreased with depth as reported by Mishra et al. (1990).

Reddy et al. (2009) reported increasing level of FYM application increased the content of sulphur in all fractions. The content of heat soluble sulphur increased from 22.14 to 127.55 mg kg<sup>-1</sup> and 11.15 to 84.26 mg kg<sup>-1</sup> in surface and sub-surface soils, respectively.

Birla (2012) reported that the highest value of heat soluble S 32.75 mg kg<sup>-1</sup> was obtained in 100% NPK when applied with FYM followed by 150% NPK (31.00 mg kg<sup>-1</sup>) while the lowest value 23.75 mg kg<sup>-1</sup> was found in control followed by 100% NPK-S (25.75 mg kg<sup>-1</sup>). He also observed the content of heat soluble sulphur was found to be declined with the depth and comparatively lower content was noted at 20-40 cm depth than that of surface soil.

#### **2.7.4 Organic sulphur**

Organic form of sulphur is estimated from the soil using NaH<sub>2</sub>PO<sub>4</sub> extracting solution (Bardsley and Lancaster 1960). In humid and semi arid region, it is mostly found in the form of organic compound, while in arid region as an inorganic compound, mostly as sulphate salts of different cations like Ca, Mg, Na and K.

Anonymous (2001) recorded that intensive cropping with continuous use of 100% NPK without sulphur resulted in depletion of organic sulphur concentration by 17.80% over control in 27 year old long term experiment. While increasing level of FYM application increased the content of sulphur in all fractions. Organic sulphur content increased from 98.20 to 745.07 mg kg<sup>-1</sup> in surface soils and 49.30 to 371.12 mg kg<sup>-1</sup> in sub-surface soils (Reddy et al. 2009).

Raut and Mali (2003) observed the organic sulphur content in Vertisols, Inceptisols and Entisols ranged from 0.4 to 36.8, 3.4 to 30.4 mg kg<sup>-1</sup>, respectively. In this connection the average organic sulphur values were higher in Vertisols than in Inceptisols at surface and decreased with depth (Bhatnagar and Trivedi 2005).

Kumar et al. (2011) reported that the movement of sulphur down the depth was more from surface soil treated with organic S but at the

same time it restricted the downward movement up to only 45 cm in the organic-manure- and crop-residue-treated soils.

Scherer et al. (2012) reported that organic sulphur is the main S binding form in soils and contributes up to 95 per cent of total soil S in cultivated temperate soils. However, this generalization does not apply in the tropics.

Singh et al. (2013) reported a wide horizontal variation in total S (261 to 760 mg kg<sup>-1</sup>) in surface soil and organic S was the dominant fraction throughout the profile. Although contributed total S decline with depth.

### **2.7.5 Total sulphur**

The total sulphur is estimated from the soil by digesting it with KNO<sub>3</sub>+ HNO<sub>3</sub> (Choudhary and Cornfield 1996). The total sulphur content of the soil depends on genetic soil type, humus content, and mechanical composition and parent materials.

Sakal and Singh (2001) reported that high yielding crop varieties and multiple cropping, coupled with use of high analysis S-free fertilizers and restricted use of organic manures, in a long run, has accelerated the depletion of soil S reserves. The similar findings were also reported by Reddy et al. (2004) they concluded that distribution of different farms of sulphur was observed in decreasing trend with depth in both Inceptisols and Vertisols.

Das et al. (2006) observed higher amount of total-S, organic S and available S in the surface layer than the corresponding underlying layers which was attributed to leaching of sulphate down the horizon through excess irrigation and inadequate sulphur fertilization to recharge subsurface soils.

Patel and Patel (2008) found that the total, organic, adsorbed and available S showed a decreasing trend with increase in profile depth. The sulphate S distribution remained more or less constant in soil profiles of most of the soil series. While, increasing level of FYM

application increased the content of sulphur in all fractions (Reddy et al. 2009). Similarly Kumar et al. (2011) also reported that increasing fertility levels significantly augmented total and available S content which was higher under inorganic S-treated plots.

Das et al. (2012) observed total S content varied from 268 to 901 mg kg<sup>-1</sup>. Organic-S constituted the dominant form (65.9 to 79.6%) of total S followed by non-sulphate-S (14.9 to 27.4%). Water soluble S (3.37 to 6.24%), available S (5.56 to 6.25%) and adsorbed S (0.95 to 2.95%) constituted only small fractions of the total S, respectively.

Basumatary and Das (2012) studied the forms of sulphur and their relationships with soil properties and sulphur availability indices were investigated Assam. The abundance of various forms of sulphur was in the decreasing order i.e. total S > organic S (83.12-87.17%) > heat soluble S (4.78-6.12%) > sulphate S > water soluble S > adsorbed S.

## **2.8 Effect on long term application of fertilizers and manure on soybean yield**

Majumdar et al. (2002) reported that the higher yield of soybean due to farmyard manure application may be due to additional nutrients supplied by it as well as improvement in physical and biological properties of soil.

Sonune et al. (2003) showed that the application of recommended dose of NPK (100:50:40 for sorghum and 120:60:60 kg ha<sup>-1</sup> for wheat) and 10 t FYM ha<sup>-1</sup> recorded the highest grain and straw yield of sorghum and wheat and also improved available NPK and organic carbon content of soil.

Selvi et al. (2004) reported that without fertilizer application and 100% N alone the values of yields were lower. Application of 100% NPK + FYM recorded significantly the highest grain yield, straw yield and biomass C, N, P followed by 150% NPK application.

Kundu et al. (2007) reported that the unfertilized plot supported 0.56 mg ha<sup>-1</sup> of soybean yield. Soybean responded to inorganic NPK

application and the yield increased significantly to 0.87 mg ha<sup>-1</sup> with NPK. Maximum yield of soybean (2.84 mg ha<sup>-1</sup>) were obtained in the plots under NPK + farmyard manure (FYM) treatment, which were significantly higher than yields observed under other treatments. The study also showed that the combined NPK and FYM application sustained long-term productivity of the soybean-wheat system.

Thakur and Sawarkar (2009) reported that the application of recommended dose of N, P and K with manure at 15 tones ha<sup>-1</sup> helped in sustaining the yields of soybean. The results of the experiment revealed that the yield of soybean significantly improved with increasing the levels of fertilizer and manure. These findings indicate that application of integrated use of optimal fertilizer dose with manure is successful in maintaining high level of soybean productivity and in the maintenance and improvement of soil fertility.

Thakur et al. (2011) reported that after thirty-six years of intensive cropping application of recommended dose of N, P and K with organic manure @ 15 t FYM ha<sup>-1</sup> resulted in 145 and 292 per cent increase in soybean yield over control.

Khaim et al. (2013) reported that the highest grain yield (2699 kg ha<sup>-1</sup>) was obtained in 100% RDF. which has statistically identical to 75% RDF +1 tone poultry manure ha<sup>-1</sup> and lowest grain yield (1570 kg ha<sup>-1</sup>) was recorded from control.

## **2.9 Relationship with in sulphur pools**

Tripathi and Singh (1992) reported that and organic sulphur ranged from 106.6 to 325 and 65 to 228.4 ppm and 5.5 to 21.2 mg kg<sup>-1</sup>. They found the relationship between total sulphur and other forms of sulphur was positive and significant. While Sakal and Singh (2001) observed that total and available sulphur was positively and significantly correlated with pH, EC and organic carbon.

Sharma and Jaggi (2001) reported that a significant positive correlations were obtained between organic S and total S (r=0.97), total

water soluble S and sulphate S ( $r=0.79$ ) as well as heat soluble-S ( $r=0.71$ ), and heat soluble S and sulphate-S ( $r=0.70$ ) in 13 representative surface soils of acid Alfisols of Kangra district suggesting an interrelated dynamic equilibrium among all the forms of S. Stepwise correlations revealed that by and large free  $\text{CaCO}_3$ , OC, pH and CEC affected large variations in the sulphur availability indices (49-71%) and its forms (86.88%).

Rashid et al. (2000) studied the soils of Pakistan and reported that 0.15%  $\text{CaCl}_2$  extractable sulphur content indicated sulphur deficiency in 40% fields in two Chakwal and Attok district of rain fed Potahar plateau. Sulphur availability in soils was positively related with clay ( $r=0.26^{**}$ ) and organic matter content ( $r=0.33^{**}$ ) and negatively Y related with sand content( $r=-0.31$ ).

Dutta (2009) revealed that all the forms of sulphur *viz.*, available, water soluble, heat soluble, organic and total sulphur were significantly and positively correlated with yield and uptake of sulphur in grain and straw/stover of both the crops. Sulphur uptake by wheat was 61.76, 65.62, 58.51 and 62.42 per cent, respectively.

## **MATERIAL AND METHODS**

The present study was conducted to assess the extent of secondary nutrients additions through fertilizers and the effect of amount of fertilizer and manure on the movements of nutrients in the surface and subsurface of a Vertisol. The study was conducted in the All India Coordinated Research Project on Long Term fertilizer Experiment (LTFE). This experiment was started with maize fodder as the first crop in summer season of 1972. Since then soybean (Kharif), Wheat (Rabi), maize fodder (summer) crop rotation was adapted to 1994. However, since 1994 the cultivation of maize fodder was discontinued and the cropping sequence being followed is soybean (kharif) and wheat (Rabi). The LTFE is laid out on a permanent site at the Experimental field Department of Soil Science and Agricultural Chemistry, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur (MP). The materials used and the methods adopted during the estimation of various parameters are being described in the following sub-sections.

### **3.1 Soil**

The soil of the experimental field is medium black belonging to Kheri series of fine montmorillonitic hepertherimc family of Typic Haplustert. At the beginning of this experiment in 1972, pooled soil sample was collected before application of the treatments. Soil of the experiment site was clay in texture with available N and P in low range while available K in medium range. The available sulphur was 17.47 kg ha<sup>-1</sup> below critical level. The pH of soil was 7.6 with neutral normal in reaction. The pooled soil sample was analyzed for different soil properties and the data for various parameters are given in Table 1.

**Table 3.1.** Physico-chemical properties of soil (0-20 cm depth) at the start of the Long-Term Fertilizer Experiment (1972)

S.No.	Soil Properties	Unit	Value
1.	Mechanical composition		
	i. Sand	%	25.27
	ii. Silt	%	17.91
	iii. Clay	%	56.82
2	Textural class	-	Clay
3.	Bulk density	Mg m <sup>-3</sup>	1.3
4.	Particle density	Mg m <sup>-3</sup>	2.5
5.	Cation exchange capacity	C mol (P <sup>+</sup> )kg <sup>-1</sup>	49.0
6.	pH (1:2.5)	--	7.6
7.	Electrical conductivity (1:2.5)	dSm <sup>-1</sup>	0.18
8.	Organic carbon	g kg <sup>-1</sup>	5.70
9.	Calcium carbonate	%	4.60
10.	Available nitrogen	kg ha <sup>-1</sup>	193.0
11.	Available phosphorus	kg ha <sup>-1</sup>	7.60
12.	Available potassium	kg ha <sup>-1</sup>	370.0
13.	Available sulphur	kg ha <sup>-1</sup>	17.47
14.	Available zinc	mg kg <sup>-1</sup>	0.33

Source: Annual report (2014) of AICRP on Long-Term Fertilizer Experiment, JNKVV, Jabalpur.

### 3.2 Climate

Jabalpur region has a peculiar semi arid and subtropical climate with a characteristics feature of dry summer and cold winter. The experimental site is situated at 23<sup>0</sup>10”N latitude and 79<sup>0</sup>57”E longitude and located at 393 meters above the mean sea level. In winter season (i.e. from November to February) the average temperature ranges from 8.9<sup>0</sup>C to 34.5<sup>0</sup>C and the relative humidity varies from 70% to 90%. Dry and warm weather usually persist during the month of March to June. During summer the temperature may attain a value as high as 46<sup>0</sup>C. Monsoon season extends from mid June to mid September. The temperature during this period varies from 22<sup>0</sup>C to 35<sup>0</sup>C and the relative

humidity ranges between 41% to 92%. The average annual rainfall of the region ranges between 1130 to 1440 mm (11 to 14 cm).

**Table 3.2.** Mean weekly meteorological observations recorded during the crop growth period (2014-15)

Months	Standard Meteorological Weeks (SMW)	Temperature (°C)		Relative humidity (%)		Wind Velocity (kmhr <sup>-1</sup> )	Rainfall (mm)	Sunshine hours
		Max.	Min.	Max.	Min.			
July	27	34.5	26.1	71	41	7.4	296.8	6.5
	28	31.3	25.6	79	59	7.1	116.0	5.9
	29	32.3	24.5	90	79	5.8	117.5	3.2
	30	28.2	23.3	91	79	5.5	119.9	3.4
Aug.	31	26.3	24.6	92	79	5.4	32.4	2.3
	32	27.7	23.7	86	73	7.9	145.8	4.9
	33	28.2	24.0	86	63	6.1	101.8	5.0
	34	30.2	25.1	83	65	4.1	84.4	6.7
	35	31.9	24.2	88	65	4.1	3.0	7.8
Sep.	36	30.8	23.7	91	71	4.1	52.2	2.4
	37	30.7	23.4	91	72	4.8	87.4	3.8
	38	30.8	23.5	89	55	4.2	11.0	8.5
	39	31.9	21.6	85	41	2.5	0	10
Oct.	40	33.4	21.0	86	53	2.3	2.3	9.4
	41	32.4	20.4	88	55	4.7	0	8.4
	42	32.5	18.8	91	44	2.3	0	7.9
	43	31.6	16.6	89	41	1.7	0	8.8
	44	27.9	14.4	87	29	1.6	0	8.6
Nov.	45	28.2	13.9	87	29	2.6	0	8.2
	46	28.6	14.4	83	26	2.5	0	6.0
	47	27.9	8.9	82	20	1.8	0	8.6
	48	28.4	10.2	85	24	2.1	0	8.6
Dec.	49	28.7	8.0	88	24	2.5	0	8.7
	50	29.0	11.8	89	52	2.6	3.2	6.2
	51	25.3	5.6	86	32	2.2	0	7.6
	52	23.8	4.8	87	32	2.1	0	8.5

Source: Meteorological section, JNKVV, Jabalpur (MP)

### 3.3 Experiment

The layout of the experiment is presented in Fig. 1. The experiment consists of 8 treatments replicated four times in a randomized block design. The gross plot size being 17x10.8 m with 1 m spacing in between the treatments and 2 m spacing between the replications. An additional strip is also retained as no crop control (Fallow strip) by the side of the main experiment. The recommended fertilizer dose (100%NPK) for each crop was estimated on the basis of soil test value. The details of the treatments are:-

### Treatments

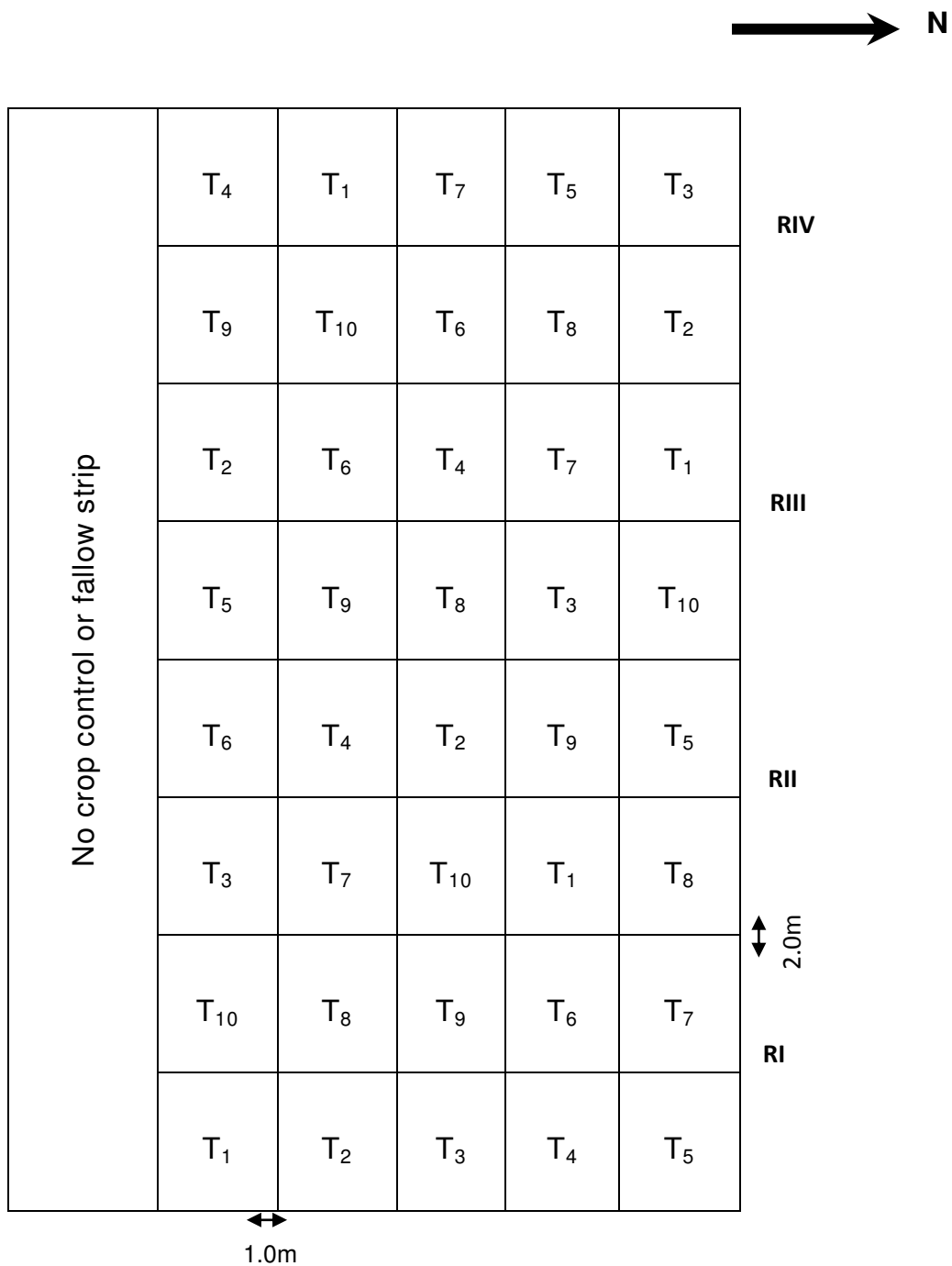
The study was conducted on following eight treatments marked as (\*) out of treatments.

*T <sub>1</sub>	=	50%NPK
*T <sub>2</sub>	=	100%NPK
*T <sub>3</sub>	=	150% NPK
T <sub>4</sub>	=	100% NPK + Handweeding
T <sub>5</sub>	=	100% NPK + Zn (as ZnSO <sub>4</sub> )#
*T <sub>6</sub>	=	100% NP
*T <sub>7</sub>	=	100% N
*T <sub>8</sub>	=	100% NPK + FYM
*T <sub>9</sub>	=	100% NPK-S (Sulphur free)
*T <sub>10</sub>	=	Control

# (Due to high build up of Zn in the treatment, the application of Zn as ZnSO<sub>4</sub> was discontinued since, 1987).

### 3.4 Experimental details

Design used	:	Randomized block design
Replication	:	04
Treatments	:	8
Plot size	:	17x10.8 m (183.6 m <sup>2</sup> )
Space between replications	:	2m
Space between plots	:	1 m
Experimental area	:	146X58 m
Cropping sequence	:	Soybean-wheat
RDF soybean	:	20:80:20 kg ha <sup>-1</sup> NPK



**Fig 1.** Layout of Long-term Fertilizer Experiment, JNKVV, Jabalpur

## Nutrient sources

i.	Nitrogen	Urea (46% N)
ii.	Phosphorus	Single superphosphate (16% P <sub>2</sub> O <sub>5</sub> ) while, Diammonium – phosphate (46% P <sub>2</sub> O <sub>5</sub> ) in T <sub>9</sub>
iii.	Potassium	Muriate of potash (60% K <sub>2</sub> O)

These treatments were applied to each crop of kharif soybean and rabi wheat. However, the application of FYM @ 5 t ha<sup>-1</sup> is being practiced only to soybean crop during kharif season. The sources of nutrients NPK were urea, single super phosphate (SSP) and muriate of potash, respectively. In sulphur free treatment instead of SSP, Diammonium phosphate is being used.

### 3.5 Collection of soil samples

#### 3.5.1 Sampling area

For the present study, soil samples were collected from the long-term fertilizer experiment on a permanent site at the Experimental Research Station of J.N. Krishi Vishwa Vidyalaya, Department of Soil Science and Agricultural Chemistry, Jabalpur (M.P.).

#### 3.5.2 Soil sampling

For the present investigation soil samples were collected with the help of tube auger and screw auger from each plot of the above mentioned treatments. The samples were drawn from surface downwards up to 30 cm depth at an interval of 15 cm (0-15 and 15-30 cm) after the harvest of soybean crop 2014.

Composite representative soil samples were obtained from these samples for each plot. Each composite sample consisted of a mixture of four sub samples from different locations of each plot to secure representative sample of the plot selected for sampling. The mass of

each collected sample was reduced to about 500 g by adopting the technique of quartering. These soil samples were cleaned, air-dried, crushed by wooden pestle and mortar passed through 2 mm stainless steel sieve and stored in polythene bags at room temperature until analysis. These soil samples were used for analysis.

### **3.6 Methods of soil analysis**

#### **3.6.1 Soil pH**

Soil pH was determined in a 1:2.5 soil water suspension by glass electrode pH meter (Piper, 1950).

#### **3.6.2 Electrical conductivity**

The soil suspension used for pH determinations were allowed to settle down and conductivity of supernatant liquid was determined by using conductivity meter (Piper, 1950). The results are expressed in  $\text{dSm}^{-1}$  at  $25^{\circ}\text{C}$ .

#### **3.6.3 Organic Carbon**

Determination of organic carbon was done by Walkley and Black's rapid titration method (1934) as described by Piper (1950).

#### **3.6.4 Available nitrogen**

Available nitrogen in soil sample was determined by adapting the alkaline permanganate method of Subbiah and Asija (1956).

#### **3.6.5 Available phosphorus**

The phosphorus content of soil was estimated by extraction procedure as described by Olsen et al. (1954). Soil available phosphorus was extracted using 0.5 M  $\text{NaHCO}_3$  (pH 8.5) and determination was done by ascorbic acid method as described by Miller and Keeney (1982). The transmittance or absorbance of the blue color

so developed was read after 10 minutes, on spectrophotometer at 660 nm wavelength.

### **3.6.6 Available potassium**

The available potassium was extracted with neutral normal ammonium acetate with flame photometer (Muhr et al. 1965).

### **3.6.7 Determination of sulphur pools**

#### **3.6.7.1 Available sulphur**

Soil was extracted by 0.15% solution of chloride and sulphur was determined by turbidimetric method (Chesin and Yien 1951). The transmittance or absorbance of the solution was read on spectrophotometer wavelength at 420 nm

#### **3.6.7.2 Water soluble sulphur**

Soil was extracted by de ionized water and sulphur was determined by turbidimetric method (Chesin and Yien 1951). The transmittance or absorbance of the solution was read on spectrophotometer wavelength at 420 nm.

#### **3.6.7.3 Heat soluble sulphur**

Heat soluble sulphur was determined by taking 5g of air dried soil into a silica crucible to which 20ml of distilled water added. Then this was placed on a boiling water bath and evaporated to dryness. After cooling it was heated in a hot air oven at 102°C for 60 min. After cooling it was transferred in to a 50ml centrifuge tube and extracted with 33ml of 1% NaCl. An aliquot of 25ml aliquot was pipette in to a silica basin and evaporated to dryness with 2ml of 3% H<sub>2</sub>O<sub>2</sub>. The crucible was heated in a hot air oven at 102°C for 60 min to ensure the removal of excess H<sub>2</sub>O<sub>2</sub>. After cooling the residue was taken up in 25 ml distilled water, transferred to a centrifuge tube and centrifuged to remove

suspended matter. Sulphur was then determined, by taking a suitable aliquot, turbidimetrically (Williams and Steinbergs, 1959).

#### **3.6.7.4 Organic sulphur**

This was determined by taking the weighed quantity (1g) of air dried (20 mesh) soil with 1g of  $\text{NaHCO}_3$  in a porcelain crucible. Ignite the mixture at  $500^\circ\text{C}$  in an electric furnace (muffle) for 3 hrs. After cooling, transferred the contents of the crucible to a 100 ml flask and add 25ml of the extracting solution (Dissolve 4.6g  $\text{NaH}_2\text{PO}_4 \cdot \text{H}_2\text{O}$  1 liter of 2N acetic acid). After the reaction subsides the contents of the flask were shaken for half an hour. Afterward the solution was filtered through a dry Whatman No.1 filter paper. An aliquot of the filtrate was for the eturbidimetrically determination of sulphate (Bardsley and Lancaster 1960).

#### **3.6.7.5 Total sulphur**

One gram of air dried soil (ground to pass 0.5 mm sieve) was taken in 250 ml beaker, 10 ml of digesting solution (100g AR grade  $\text{KNO}_3$ +350 ml concentrated  $\text{HNO}_3$  and dilute to 1 liter) was added. The contents were evaporated to dryness on a stem bath. Then the beaker was placed in an electric furnace, heat to  $500^\circ\text{C}$  and maintain at this temperature for three hours (Chaudhary and Cornfield 1966).

After cooling 5ml of 25%  $\text{HNO}_3$  was added and again digested the contents for one hour on steam bath to dryness. Extracted the soluble salts with distilled water and solution was filtered through a whatman filter paper no. 42. Filtrate was dilute to know volume. Aliquot was taken for determination of sulphur turbidimetrically (Chaudary and Cornfield 1966).

### **3.7 Soybean grain yield**

The grain yields were recorded after harvest of soybean crop.

### **3.8 Statistical analysis of the experimental data**

The data thus generated on soil parameter and seed yield were statistically analyzed to draw suitable inference as per standard method described by Panse and Sukhatme (1970).

## **RESULTS**

The result obtained from the experiment carried out to study on distribution of sulphur pools as influenced by long term application of fertilizers and manure in a Vertisol and relevant data are presented in this chapter.

### **4.1 Physico- chemical properties of soil**

#### **4.1.1 Soil pH at two depths**

The experiment was started in 1972 when the initial value was 7.6 at 0-20 cm soil depth. The pH values at different soil depth as influenced by the continuous imposition of the different treatments are presented in Table 4.1.

##### **Soil pH at 0-15 cm**

Initial value of the soil pH (0-20 cm) when the experiment started in 1972 was 7.6. However, the pH values as influenced by the continuous imposition of the different treatment are presented in Table 4.1. The result revealed that the soil pH (0-15 cm) ranged between 7.47 to 7.59.

##### **Soil pH at 15-30 cm**

The pH value at 15-30 cm depth ranged between 7.58 (100% N) to 7.67 (150% NPK) in various treatments. The value is slightly higher as compared to the pH values at surface. Treatment which includes for study intermediate between two and indicated that pH of the soil was not much affected by the imposition of treatments.

**Table 4.1.** Physico-chemical properties of soil

Treatments	Physico-chemical properties of soil					
	pH		EC (dS m <sup>-1</sup> )		OC (g kg <sup>-1</sup> )	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
50% NPK	7.51	7.61	0.15	0.17	6.25	5.28
100% NPK	7.56	7.64	0.17	0.20	7.25	6.65
150% NPK	7.59	7.67	0.19	0.21	8.04	7.12
100% NP	7.55	7.63	0.17	0.19	6.70	5.75
100% N	7.47	7.58	0.16	0.17	5.32	4.82
100% NPK + FYM	7.55	7.60	0.18	0.19	9.31	7.93
100% NPK (S FREE)	7.57	7.61	0.16	0.17	6.74	5.57
CONTROL	7.56	7.59	0.15	0.16	4.98	3.87
SEm±	0.18	0.17	0.01	0.02	0.30	0.31
CD (P=0.05)	NS	NS	NS	NS	0.89	0.91

#### **4.1.2 Soil EC at two depths**

Initial EC value of the soil (0-20 cm) when the experiment was started in 1972, was  $0.18 \text{ dS m}^{-1}$ . The EC values at different depths in soil as influenced by continuous application of the various treatments are showed in Table 4.1

##### **Soil EC at 0-15 cm**

The result revealed that the EC of the soil at 0-15 cm depth ranged between  $0.15 \text{ dSm}^{-1}$  (50% NPK and control) to  $0.19 \text{ dSm}^{-1}$  (150% NPK) in various treatment and noticed that the continuous application of different doses of fertilizers and manure did not resulted in any significant effect on soil EC.

##### **Soil EC at 15-30 cm**

The EC value slightly higher as compared to those observed in 0-15 cm depth and ranged between 0.16 (control) to  $0.21 \text{ dSm}^{-1}$  (150% NPK). However, the differences were found to be non-significant.

#### **4.1.3 Distribution of organic carbon in soil at two depths**

Soil organic carbon content at surface (0-20 cm) was  $5.70 \text{ g kg}^{-1}$  when the experiment was started in 1972. The soil organic carbon content as influenced by the imposition of different treatments as described (Table 4.1).

##### **Soil OC Content at 0-15 cm**

The data observed in Table 4.1 showed that the organic carbon significantly increased with increase in the doses of fertilizers. The lowest value was noticed in control ( $4.98 \text{ g kg}^{-1}$ ) which was increased to 6.25, 7.25 and  $8.04 \text{ g kg}^{-1}$  respectively due to use of 50% NPK, 100% NPK and 150% NPK of RDF. The highest content  $9.31 \text{ g kg}^{-1}$  was observed in 100% NPK+FYM treatment.

##### **Soil OC Content at 15-30 cm**

Soil organic carbon content at 15-30 cm depth found to be lower as compared to the content found at 0-15 cm depth. However, it was

found that with increasing level of fertilizer OC content of soil continued to increase and the values were found to be higher as compared to control. The lowest value was noticed  $3.87 \text{ g kg}^{-1}$  in control whereas inclusion of FYM along with 100% NPK ( $7.93 \text{ g kg}^{-1}$ ) treatment increased the OC content followed by 150% NPK ( $7.12 \text{ g kg}^{-1}$ ) treatment. However, 50% NPK and 100% NPK ( $5.28$  and  $6.65 \text{ g kg}^{-1}$ ) found lower as compared to 150% NPK ( $7.12 \text{ g kg}^{-1}$ ).

## **4.2 Effect of continuous addition of fertilizers and manure on distribution of available nutrients**

### **4.2.1 Distribution of available N at two depths**

Available N content in surface soil (0-20 cm) was  $193.00 \text{ kg ha}^{-1}$  when the experiment was started. The available N content values in soil as influenced by the continuous addition of fertilizers and manure are presented in Table 4.2.

#### **Content of available N at 0-15 cm**

The result revealed that the available N content in soil increased successively and significantly from  $217$  to  $275 \text{ kg ha}^{-1}$  and  $291 \text{ kg ha}^{-1}$  as the doses of fertilizer increased from 50%, 100% and 150% NPK treatment respectively (Table 4.2). The highest value of available N ( $310 \text{ kg ha}^{-1}$ ) was recorded in 100% NPK+FYM treatment. While, the lowest value of available N was observed in control ( $182 \text{ kg ha}^{-1}$ ).

#### **Content of available N at 15-30 cm**

The available content of N in soil decreased with soil depth. The highest available N content ( $280 \text{ kg ha}^{-1}$ ) was recorded in 100% NPK+FYM whereas the lowest values was noticed as  $165 \text{ kg ha}^{-1}$  in control followed by 100% N ( $180 \text{ kg ha}^{-1}$ ). The slightly higher value of available N content was obtained in 100% NPK ( $238 \text{ kg ha}^{-1}$ ) as compared to 100% NPK-S ( $217 \text{ kg ha}^{-1}$ ).

**Table 4.2.** Effect of continuous addition of fertilizers and manure on distribution of available nutrients

Treatments	Available nutrients status					
	N (kg ha <sup>-1</sup> )		P (kg ha <sup>-1</sup> )		K (kg ha <sup>-1</sup> )	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
50% NPK	217.00	182.00	22.61	20.16	243	234
100% NPK	275.00	238.00	33.18	28.95	275	253
150% NPK	291.00	260.00	40.55	39.15	296	275
100% NP	240.00	215.00	30.75	28.88	225	180
100% N	198.00	180.00	11.26	10.80	207	172
100% NPK + FYM	310.00	280.00	42.88	40.81	328	297
100% NPK (S FREE)	248.00	217.00	30.15	27.86	255	245
CONTROL	182.00	165.00	10.01	9.80	208	165
SEm±	12.18	12.90	2.20	2.05	11.14	11.51
CD (P=0.05)	35.35	37.44	6.40	5.94	32.34	33.39

#### **4.2.2 Distribution of available P at two depths**

Available P content in surface soil (0-20 cm) was 7.6 kg ha<sup>-1</sup> when the experiment was started. The available P content values in soil as influenced by the continuous addition of fertilizers and manure are presented in Table 4.2.

##### **Content of available P at 0-15 cm**

Available P content in soil increased successively and significantly from 10.01 kg ha<sup>-1</sup> (control) to 22.61, 33.18 and 40.60 kg ha<sup>-1</sup> in 50, 100 and 150% NPK treatments (Table 4.2) respectively. The highest value 42.88 kg ha<sup>-1</sup> was noticed with 100% NPK when applied along with FYM. However, the difference in P content was almost equal and at par in 100% NPK (33.15 kg ha<sup>-1</sup>) and 100% NPK-S (30.15 kg ha<sup>-1</sup>) while the lowest value observed in control (10.10 kg ha<sup>-1</sup>) followed by 100% N (11.26 kg ha<sup>-1</sup>).

##### **Content of available P at 15-30 cm**

The result presented in Table 4.2, showed that the available P content declined with the depth. The available P content raised significantly from 9.80 kg ha<sup>-1</sup> (control) to 40.81 kg ha<sup>-1</sup> (100% NPK+FYM). The content of available P was higher in 100% NPK (28.95 kg ha<sup>-1</sup>) as compared to 100% NPK-S (27.86 kg ha<sup>-1</sup>). However, the buildup of available P in 150% NPK was higher 39.15 kg ha<sup>-1</sup> in comparison to 28.95 kg ha<sup>-1</sup> in 100% NPK while maximum value (40.80 kg ha<sup>-1</sup>) was coincide with 100% NPK+FYM.

#### **4.2.3 Distribution of available K at two depths**

The available K content was 370 kg ha<sup>-1</sup> when the experiment was started. The available K content as influenced by different doses of fertilizers and manure are presented in Table 4.2.

### **Content of available K at 0-15 cm**

It was noticed that the available K content was increased with successive addition of fertilizers from 50% (243 kg ha<sup>-1</sup>), 100% (275 kg ha<sup>-1</sup>) and 150% NPK (296 kg ha<sup>-1</sup>) treatment respectively, whereas the highest value (328 kg ha<sup>-1</sup>) was noted where 100% NPK applied along with FYM. However, the value 255 kg ha<sup>-1</sup> was observed in 100% NPK sulphur free lower as compare to 100% NPK (275 kg ha<sup>-1</sup>). The available content of K was found at par in 50% NPK (243 kg ha<sup>-1</sup>) and 100% NP (225 kg ha<sup>-1</sup>). The minimum content of available K was found in control (208 kg ha<sup>-1</sup>).

### **Content of available K at 15-30 cm**

The highest value of available K (297 kg ha<sup>-1</sup>) was recorded in 100% NPK+FYM followed by 150% NPK (275 kg ha<sup>-1</sup>) whereas; the lowest value (165 kg ha<sup>-1</sup>) was observed in control followed by 172 ha<sup>-1</sup> in 100% N. The content of available K was found to be higher in 100% NPK (253 kg ha<sup>-1</sup>) as compared to 100% NPK-S (245 kg ha<sup>-1</sup>). The data also showed that available K status was declined from surface to lower depth.

## **4.3 Effect of continuous addition of fertilizer and manure on distribution of sulphur pools**

### **4.3.1 Distribution of available sulphur form at two depths**

The initial value of available sulphur content was 17.47 kg ha<sup>-1</sup> when the experiment was started. The effect of long term application of fertilizers and manure on available sulphur is presented in Table 4.3 and same are described below.

### **Content of available sulphur form at 0-15 cm**

Perusal of the data showed (Table 4.3) that the content of available sulphur was successively and significantly increased with the increasing in fertilizer doses from 50% NPK (24.17 kg ha<sup>-1</sup>) to 100% NPK (34.98 kg ha<sup>-1</sup>) and 150% NPK (39.30 kg ha<sup>-1</sup>). The content

**Table 4.3.** Effect of continuous addition of fertilizers and manure on distribution of sulphur pools

Treatments	Sulphur pools (kg ha <sup>-1</sup> )									
	Available S		Water soluble S		Heat soluble S		Organic S		Total S	
	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30
50% NPK	24.17	22.34	15.66	10.15	34.67	31.40	65.42	49.12	193.25	175.94
100% NPK	34.98	32.64	25.92	18.95	38.30	34.48	71.02	54.63	211.17	193.60
150% NPK	39.30	37.21	30.97	20.02	40.08	36.44	73.00	66.79	216.71	197.19
100% NP	30.82	27.40	24.56	18.13	34.57	30.11	55.31	49.65	209.01	180.35
100% N	15.08	14.63	10.29	8.03	25.12	22.33	45.81	36.75	152.54	132.68
100% NPK + FYM	42.66	38.47	31.55	29.88	49.72	37.38	79.01	64.48	234.53	204.99
100% NPK (S FREE)	15.94	14.63	11.51	8.50	25.23	23.56	44.91	37.59	152.37	133.75
CONTROL	13.95	12.72	10.59	7.52	24.48	21.30	43.31	35.39	149.17	130.00
SEm±	0.81	0.97	1.17	1.14	1.74	1.42	2.20	1.60	5.45	6.05
CD (P=0.05)	2.39	2.85	3.45	3.33	5.12	4.17	6.47	4.71	16.04	17.79

of available sulphur high amount found in 100% NPK + FYM (42.66 kg ha<sup>-1</sup>). The content of available sulphur was found significantly higher in 100 % NPK (34.98 kg ha<sup>-1</sup>) as comparatively to 100% NPK-S (15.94 kg ha<sup>-1</sup>) whereas the content of available sulphur was found to be higher in 100% NP (30.82 kg ha<sup>-1</sup>) as compared to 50% NPK (24.17 kg ha<sup>-1</sup>). However, the highest and lowest content of available S was observed in 100% NPK + FYM (42.66 kg ha<sup>-1</sup>) and control (13.95 kg ha<sup>-1</sup>) respectively.

#### **Content of available sulphur form at 15-30 cm**

The data presented in Table (4.3) that the maximum buildup of available sulphur was observed in 100% NPK+FYM (38.47 kg ha<sup>-1</sup>) as well as in 150% NPK (37.21 kg ha<sup>-1</sup>). However, the minimum content of available sulphur was observed in control (12.72 kg ha<sup>-1</sup>) followed by 100% NPK-S (14.63 kg ha<sup>-1</sup>). Whereas, the content of available sulphur was found significantly higher in 100% NPK (32.64 kg ha<sup>-1</sup>) as compared to 100% NPK-S (14.63 kg ha<sup>-1</sup>). Further the available sulphur content was also significantly higher in 50% NPK (22.34 kg ha<sup>-1</sup>) comparatively with 100% N (14.98 kg ha<sup>-1</sup>). This was also found that the content of available sulphur decreased with soil depth.

#### **4.3.2 Distribution of water soluble sulphur form at two depths**

The effect of long term application of fertilizers and manure on water soluble sulphur is presented in the Table 4.3.

#### **Content of water soluble sulphur form at 0-15 cm**

Perusal of the data showed (Table 4.3) that the content of water soluble sulphur was significantly increased with the increasing in fertilizer doses from 50% NPK (15.66 kg ha<sup>-1</sup>) to 100% NPK (25.92 kg ha<sup>-1</sup>) and 150% NPK (30.97 kg ha<sup>-1</sup>). The highest content of water soluble sulphur found in 100% NPK + FYM (31.55 kg ha<sup>-1</sup>). The content of water soluble sulphur was found to be higher in 100 % NPK (25.92 kg ha<sup>-1</sup>) as comparatively to 100% NPK-S (11.51 kg ha<sup>-1</sup>). Whereas the content of water soluble sulphur was found to be higher in 100% NP

(24.56 kg ha<sup>-1</sup>) as compared to 50% NPK (15.66 kg ha<sup>-1</sup>). However, the lowest content was observed in control (10.50 kg ha<sup>-1</sup>) followed by 100% NPK-S (11.51 kg ha<sup>-1</sup>).

#### **Content of Water soluble sulphur form at 15-30 cm**

The data presented in Table 4.3 that the maximum buildup of water soluble sulphur was observed in 100% NPK+FYM (29.88 kg ha<sup>-1</sup>) as well as in 150% NPK (20.02 kg ha<sup>-1</sup>). However, the minimum content of water soluble sulphur was observed in control (7.52 kg ha<sup>-1</sup>) followed by 100% NPK-S (8.50 kg ha<sup>-1</sup>). Whereas the content of water soluble sulphur was found higher in 100% NPK (18.95 kg ha<sup>-1</sup>) as compared to 100% NPK-S (8.50 kg ha<sup>-1</sup>). This was also found that the water soluble sulphur content was higher in 50% NPK (10.15 kg ha<sup>-1</sup>) comparatively with 100% N (8.03 kg ha<sup>-1</sup>). This was also found that the content of water soluble sulphur decreased with soil depth.

#### **4.3.3 Distribution of heat soluble sulphur form at two depths**

The data presented in Table 4.3 showed the influence of fertilizers and manure on heat soluble sulphur and described below.

#### **Content of heat soluble sulphur form at 0-15 cm**

The data presented in Table 4.3 showed that the content of heat soluble sulphur was increased successively and significantly from control (24.48 kg ha<sup>-1</sup>) to 50% NPK (34.67 kg ha<sup>-1</sup>), 100% NPK (38.30 kg ha<sup>-1</sup>) and 150% NPK (40.08 kg ha<sup>-1</sup>) and 100% NPK + FYM (49.72 kg ha<sup>-1</sup>). While the lowest content of Heat soluble sulphur was confined in control (24.48 kg ha<sup>-1</sup>) as well as in 100% N (25.12 kg ha<sup>-1</sup>).

#### **Content of heat soluble sulphur form at 15-30 cm**

The data presented in Table 4.3 showed that the highest value of heat soluble sulphur was (37.38 kg ha<sup>-1</sup>) obtained in 100% NPK when applied with FYM followed by 150% NPK (36.44 kg ha<sup>-1</sup>) while the lowest value 21.30 kg ha<sup>-1</sup> was found in control followed by 100% N (22.33 kg ha<sup>-1</sup>). The content of heat soluble sulphur was found lower in 50% NPK (31.40 kg ha<sup>-1</sup>) as compared to 100% NPK (34.48 kg ha<sup>-1</sup>).

Heat soluble sulphur was also significantly higher in 100% NP (30.11 kg ha<sup>-1</sup>) to 100% N (22.33 kg ha<sup>-1</sup>).

The data also revealed that the content of heat soluble sulphur was found to be declined with the depth and comparatively lower content was noted at 15-30 cm depth than that of surface soil.

#### **4.3.4 Distribution of Organic sulphur form at two depths**

The effect of continuous use of fertilizers and manure on content of organic-S is showed in the Table 4.3 and same are described below

##### **Content of Organic-S form at 0-15 cm**

Perusal of the data (Table 4.3) revealed that continuous cropping and fertilization the highest content was noticed in 100% NPK + FYM (79.01 kg ha<sup>-1</sup>) treatment followed by 150% NPK (73.00 kg ha<sup>-1</sup>). The organic sulphur was progressively increased from 50% NPK (65.42 kg ha<sup>-1</sup>) to 100% NPK (71.02 kg ha<sup>-1</sup>) and 150% NPK (73.00 kg ha<sup>-1</sup>). Organic sulphur content was significantly higher in 150% NPK (73.00 kg ha<sup>-1</sup>) as compared to 50% NPK (65.42 kg ha<sup>-1</sup>) while the lowest content of organic sulphur was noticed in control (43.31 kg ha<sup>-1</sup>) as well as in 100% NPK-S (44.91 kg ha<sup>-1</sup>).

##### **Content of organic-S form at 15-30 cm**

The data presented in the Table 4.3 showed that the highest value (64.48 kg ha<sup>-1</sup>) was observed in 100% NPK+FYM while the lowest value (35.39 kg ha<sup>-1</sup>) was noted in control. The organic sulphur content was comparatively higher in 100% NP (49.65 kg ha<sup>-1</sup>) as that was observed in 100% N (36.75 kg ha<sup>-1</sup>). It was also found that the content of organic sulphur was higher in 100% NPK (54.63 kg ha<sup>-1</sup>) as compared to 100% NPK-S (37.59 kg ha<sup>-1</sup>). It was also noticed that the content of organic sulphur was comparatively lower as compared to the content observed at surface soil.

#### **4.3.5 Distribution of Total-S form at two soil depths**

The effect of long term application of fertilizers and manure on total sulphur is presented in the Table 4.3.

##### **Content of total-S at 0-15 cm**

The data presented in Table 4.3 showed that the maximum build up of total sulphur form was observed in 100% NPK+FYM (234.59 kg ha<sup>-1</sup>), followed by 150% NPK (216.71 kg ha<sup>-1</sup>) while the minimum content of total sulphur was found in control (149.17 kg ha<sup>-1</sup>). The content of total-S was lower in 100% N (152.37 kg ha<sup>-1</sup>) in comparison to 100% NP (209.01 kg ha<sup>-1</sup>). However, total sulphur content was also lower in 50% NPK (193.25 kg ha<sup>-1</sup>) as compare to 100% NP (209.01 kg ha<sup>-1</sup>).

##### **Content of total-S at 15-30 cm**

The data presented in Table 4.3 showed that the content of total sulphur form were progressively and successively increased from 50% NPK (175.94 kg ha<sup>-1</sup>), 100% NPK (193.60 kg ha<sup>-1</sup>) and 150% NPK (197.19 kg ha<sup>-1</sup>) where as the maximum build up 204.99 kg ha<sup>-1</sup> confined when 100% NPK applied along with FYM. The lowest content of total sulphur was recorded in control (130.00 kg ha<sup>-1</sup>) followed by 100% N (132.88 kg ha<sup>-1</sup>). It was also observed that the total sulphur content was higher in 100% NP (180.35 kg ha<sup>-1</sup>) as compared to 100% N (132.00 kg ha<sup>-1</sup>). The data also showed that the content of total sulphur decreased with the depth as content was comparatively higher at surface.

#### **4.4 Effect of long term application of fertilizers and manure on soybean seed yield**

The data presented in Table 4.4 revealed that the seed yield of soybean increased with increasing fertilizer doses from 50% (925 kg ha<sup>-1</sup>) to 100% (1100 kg ha<sup>-1</sup>) and 150% NPK (1225 kg ha<sup>-1</sup>). However, the maximum seed yield (1300 kg ha<sup>-1</sup>) of soybean was obtained when optimal dose (100% NPK) of fertilizer was applied along with FYM

while, the lowest seed yield was observed in control (513 kg ha<sup>-1</sup>) where no fertilizer was applied since 1972 which was followed by 100% N (675 kg ha<sup>-1</sup>). The seed yield of 100% NPK (1100 kg ha<sup>-1</sup>) was higher as compared to 100% NPK-S (988 kg ha<sup>-1</sup>) where S was not included in fertilizer schedule. This was also found that the seed yield of 100% NP (925 kg ha<sup>-1</sup>) is comparatively lower to 100% NPK (1100 kg ha<sup>-1</sup>).

**Table 4.4.** Effect of long term fertilizers and manures on seed yield (kg ha<sup>-1</sup>) of soybean

Treatments	seed yield
50% NPK	925
100% NPK	1100
150% NPK	1225
100% NP	925
100% N	675
100% NPK + FYM	1300
100% NPK (S FREE)	988
CONTROL	513
SEm±	59.62
CD (P=0.05)	173.02

#### 4.5 Relationship with in sulphur pools and seed yield of soybean

The data clearly indicated in the Table 4.5 that the all sulphur pools were highly significant relationship with available sulphur. The correlation coefficient values were 0.982\*\*, 0.923\*\*, 0.879\*\* and 0.959\*\* respectively for water-S S, heat-S S, organic-S and total-S.

**Table 4.5.** Zero order matrix correlation studies between sulphur pools with available sulphur and soybean seed yield

Parameter	Coefficient of correlation with ( $r^2$ values)				
	Available sulphur	Water soluble sulphur	Heat soluble sulphur	Organic sulphur	Total sulphur
Available sulphur	-	0.982**	0.923**	0.879**	0.959**
Yield	0.769	0.726	0.734	0.733	0.697

\*Significant at 1% level of significance

\*\*Significant at 5% level of significance

Sulphur pools show highly significant and positive correlation with soybean seed yield. The correlation coefficient values are 0.769, 0.726, 0.734, 0.733 and 0.697 respectively for available-S S, water-S S, heat-S S, organic-S and total S.

## DISCUSSION

The present investigation was conducted the part of All India Coordinated Research Project on Long Term Fertilizer Experiment. This study aims to evaluate the distribution of sulphur pools as influenced by long term application of fertilizers and manure in a Vertisol.

This chapter deals with discussion on the experimental finding along with specific reasoning under following appropriate sub head as under:-

### **5.1 Effect of continuous addition of fertilizers and manure on chemical properties of soil**

The chemical properties of the soil are the chemical environment such as pH, EC, organic carbon and the status of available nutrients etc. are of great significance as they favorably influence the fertility of the soil for subsequent plant development, growth and yield potential. They are discussed as follows.

#### **5.1.1 Soil pH**

The result of the present investigation indicated that the soil pH values did not changes significantly by continuous application of fertilizers and manure. The initial pH of surface soil when the experiment commenced was 7.6 in 1972. After the harvesting the pH values from various treatments, of the surface and sub surface layer ranged from 7.47 to 7.67 respectively (Table 4.1 and Figure 3). It appeared that no substantial changes occurred due to treatments as reported earlier by use of chemical fertilizer like urea net residual acidity could not create significant alteration in pH values of the soil. This effects appears to have controlled by the presence of calcium carbonate Dwivedi et al. (2007), Verma et al. (2010) and Patel (2014) concluded that use of organic manure (FYM) might act as stabilizing factor for maintaing the soil reactions in the cultivated soils.

### **5.1.2 Soil EC**

The EC measured (Table 4.1 and Figure 4) also did not show any appreciable changes over the years due to continuous application of fertilizers and manure in almost all the treated plots. This could also be due to the peculiar characteristics of black soils that possessed inherent high buffering capacity (Dwivedi et al. 2007) which affected the slight alterations in EC of soil due to fertilizer addition as stated earlier by Grewal et al. (1999).

There were no considerable changes in EC of the soil with depth as a result of continuous addition of fertilizers and manure. These results are also in agreement with the finding of Raghuvanshi (2013) and Patidar (2014).

### **5.1.3 Organic carbon**

The response of long term manuring and fertilizer use is an intensive cropping are illustrated in Table 4.1 and Figure 5. The data revealed that the lowest organic carbon content ( $3.87 \text{ g kg}^{-1}$ ) was noted in control where no fertilizer was practiced. However, the organic carbon values improved significantly with proportionate increment in fertilizer addition at 50% NPK ( $6.25 \text{ g kg}^{-1}$ ) and 100% NPK ( $7.25 \text{ g kg}^{-1}$ ) and 150% NPK ( $8.04 \text{ g kg}^{-1}$ ) doses. This finding appeared to be due to enhanced root development of crop resulting higher residues as a result of intensive farming with continuous fertilizer applications. These results are also in agreement with the finding of Tabusam et al. (2010) and Lakari et al. (2012). Thus, FYM addition had a pronounced effect on organic carbon build up of the soil (Bajpai 2006 and Verma et al. 2005) thereby integration of chemical fertilizer along with organic manure proved to be beneficial to sustaining the soil health and crop productivity (Tomar 2003).

The higher organic carbon content was obtained at surface and declined progressively with depth. The magnitude of organic carbon was higher on surface and declined with depth could possibly due to the

fact that cultivation enhanced and promote the decomposition of plant organic residues at surface level (Behra and Singh 2009).

## **5.2 Effect of continuous addition of fertilizers and manure on distribution of available nutrients**

### **5.2.1 Available N**

Available N content as affected by various treatments were presented in the Table 4.2 and Figure 6, which indicated that higher values of N content was obtained from surface soil could be due to the presence of residues after the harvest of crop as suggested by Tyagi and Bhardwaj (1994) and Singh et al. (2012). However, due to addition of fertilizer doses 50%NPK, 100% NPK and 150%NPK, N content was correspondingly improved indicating an impact of fertilizer application on enrichment of N pools (Thakur et al. 2011 and Patel 2014). The highest N content was registered in 100% NPK+FYM (310 kg ha<sup>-1</sup>) treatments followed by 150% NPK (291 kg ha<sup>-1</sup>) could be resulted due to better biological activities in presence of FYM (Sonune et al. 2013; Kumar and Singh 2010).

It has also been noted that higher status of N was obtained on the surface while progressively declined with depth but the rate of depletion was more apparent from surface to subsurface (Singh et al. 2002) while, it was stabilize below 40 cm down profile. Thus, could be attributed to higher root biomass in the rhizospheric upper soil layer and which declined with increasing soil depth. Similar observations have also been reported by Tyagi and Bhardwaj (1994).

### **5.2.2 Available P**

Result on available P status (Table 4.2 and Figure 7) was revealed that continuous fertilization and manuring remarkably improved the available P in almost all treatments receiving P annually as compared to application of fertilizer without P. The large difference in P content monitored from various fertility treatments receiving 50% NPK, 100% NPK and 150% NPK doses of nutrient indicating higher P

build up respectively. Further more the highest content was found when integrated application of fertilizer was practiced with FYM (42.88 kg ha<sup>-1</sup>) followed by 150% NPK (40.55 kg ha<sup>-1</sup>) treatments indicating the beneficial effect of FYM on mineralization of P to a greater extent in soil, Mann et al. (2006), Bhattacharya and Ghosh (2001).

The doses also emphasized that accumulation of P was higher at surface as compared to the lower depth. Such a behavior was attributed to the fixation of applied P with the soil and its subsequent restricted movement Singh et al. (2013).

### **5.2.3 Available K**

The changes in available K status as a result of continuous cropping and fertilizers application were illustrated in Table 4.2 and Figure 8. The data revealed that the application of 100% NPK and 150% NPK doses resulted in depletion of available K leading to a negative balance and ultimately at reflects on consequent loss of K fertility in further successive years (Bhattacharya et al. 2007). Hence the soil initially well supplied (370 kg ha<sup>-1</sup>) would decline in available K status.

A declining trend in available K status was found with depth and maximum content which gradually declined to lower depths as reported earlier by Yadhuvanshi and Swarup (2006).

## **5.3 Effect of continuous addition of fertilizers and manure on distribution of sulphur pools at various soil depths**

### **5.3.1 Available sulphur**

Results showed (Table 4.3 and Figure 8) that content of available sulphur form was increased with addition of S over without additions i.e. in control (13.95 kg ha<sup>-1</sup>) and 100% NPK-S (15.94 kg ha<sup>-1</sup>) which could be due to higher transformation of added fertilizer S to available S retention in soil. Singh et al. (2001) have found that rice-wheat grown in sequence and supplied P through single super phosphate since 1991 caused an increase in the available S content. This increase was further

accentuated when FYM was included in the treatment. It has also been noted that a significantly higher content of available S was observed with successively higher addition of S from 100% NPK to 150% NPK dose which might be due to the differential conversion of applied S in available S form as a result of varying transformation (Sharma and Choudhary 2007). However, addition of FYM along with optimal dose resulted in maximum build up of available S this could be due to the release of organic acids during the decomposition of organic matter ultimately causing resolution of applied as well as native S into available S compounds thereby it increases the activity and concentration of available S in soil (Thakur and Sawarkar 2009 and Birla 2012).

### **5.3.2 Water soluble sulphur**

Results showed (Table 4.3 and Figure 9) that content of water soluble sulphur form was increased with addition of S over without additions i.e. in control ( $10.50 \text{ kg ha}^{-1}$ ) and 100% NPK-S ( $11.51 \text{ kg ha}^{-1}$ ) which could be due to higher transformation of added fertilizer S to available S retention in soil. Singh et al. (2001) have found that rice-wheat grown in sequence and supplied P through single super phosphate since 1991 caused an increase in the available S content. This increase was further accentuated when FYM was included in the treatment. It has also been noted that a significantly higher content of available S was observed with successively higher addition of S from 100%NPK to 150%NPK dose which might be due to the differential conversion of applied S in available S form as a result of varying transformation (Sharma and Choudhary, 2007). However, addition of FYM along with optimal dose resulted in maximum build up of available S this could be due to the release of organic acids during the decomposition of organic matter ultimately causing resolution of applied as well as native S pools into soluble S compounds thereby it directly increases the activity and concentration of available S status in soil Thakur and Sawarkar (2009) and Birla (2012).

### 5.3.3 Heat soluble sulphur

Results showed (Table 4.3 and Figure 10) that content of heat soluble-S form was increased with addition of S over without additions i.e. in control (24.48 kg ha<sup>-1</sup>) and 100% NPK-S (25.23 kg ha<sup>-1</sup>) which could be due to higher transformation of added fertilizer S to Heat soluble-S retention in soil. The higher concentration in surface soil is probably due to the mineralization of organic matter left after harvesting of crop and higher organic carbon in the surface soil. These results are in consonance with the finding of Reddy et al. (2009). This form of sulphur also exhibited a declined in its status with increasing soil depth. It is obvious because this form of sulphur is associated with organic-S and organic-S decreased with depth as reported by Setia and Sharma (2005). The highest content of heat soluble sulphur was obtained in 100%NPK+FYM as reported by Birla (2012).

### 5.3.4 Organic sulphur

Organic sulphur content in sub surface soil was found to be at par in 100% NPK+FYM and 150%NPK treatment. The ratio of total to organic sulphur in these treatment were around 30% indicating that these soil retained around 28-30% of sulphur in the organic form in surface soil layer and sub surface layer. However, it varied from 20-33% in different treatments at different depth. Organic sulphur is the main binding form in soil and contributes up to around 95% to total sulphur in cultivated temperate soil. Scherer et al. (2012) also reported similar findings and concluded that higher organic sulphur content was confined to the surface soil and decrease down the profile.

Application of increasing doses of fertilizers increased the content of organic-S form in the surface soil (Table 4.3 and Figure 11) as the subsequent addition of S with higher transformation thereby lower content was noted in control (43.31 kg ha<sup>-1</sup>) and 100% NPK-S (44.91 kg ha<sup>-1</sup>) due to absence of addition of S. Anonymous (2001) recorded that intensive cropping with continuous use of 100% NPK without sulphur

resulted in depletion of organic sulphur concentration by about 17.80% over control in a 27 year old experiment.

The organic-S was progressively declined with depth and the highest accumulation was observed at surface. Similar finding was also reported by Kumar et al. (2011) and Singh et al. (2013).

### **5.3.5 Total sulphur**

The effect of continuous cropping and fertilizer applications on content of Total-S form revealed that (Table 4.3 and Figure 12) the lower content was recorded in control ( $149.17 \text{ ha}^{-1}$ ) followed by 100% NPK-S ( $152.37 \text{ kg ha}^{-1}$ ) which could be because of the fact that without application of fertilizer and or without S inclusion in fertilizer schedule has obviously resulted in its lower content. On the other hand successive additions of S from 50%, 100% and 150% NPK resulted in proportionate increase in Total-S in soil. It might be due to proportionate higher transformation of S from inherent and applied sources into Total-S. Increase in availability of sulphur with increasing fertilizer dose from 50% NPK to 100% NPK (Kumar et al. 2011). However, maximum content was found when 100% NPK was applied with FYM indicating synergistic influence of FYM on accelerating the rate of transformation into the Total-S in soil for subsequent utilization by crop plants (Sakal and Singh 2001 and Patel and Patel 2008).

A declining trend in Total-S form was found with depth and highest content of Total-S form confined to surface and gradually declined to lower depths. This could be due to lower movement of Total-S which restricted further movement to lower depths (Das et al. 2006).

## **5.4 Effect of long term application of fertilizer and manure on soybean seed yield**

The perusal of the data (Table 4.4 and Fig. 13) indicated that the lowest seed yield ( $513 \text{ kg ha}^{-1}$ ) was recorded in control. While, it was found to be increased ( $925 \text{ kg ha}^{-1}$ ) in treatment receiving sub optimal

fertilizer dose (50% NPK), which was significantly higher than that obtained with application of 100% N alone (675 kg ha<sup>-1</sup>). These results indicated that even if 50% of recommended optimal dose applied it was found to be much beneficial in comparison to the application of imbalanced nutrient application. Application of recommended optimal dose (100% NPK) resulted in productivity of seed yield for 1100 kg ha<sup>-1</sup> but exclusion of sulphur (i.e. 100% NPK-S) dose had resulted in comparatively lower seed yield (988 kg ha<sup>-1</sup>) amounted to decline yield of soybean for about 31.31%. On the other hand, the seed yield obtained in 100% NPK + FYM treatment (1300 kg ha<sup>-1</sup>) was higher than 150% NPK treatment (1225 kg ha<sup>-1</sup>).

There, it could also be concluded that long term application of FYM in combination with 100% NPK significantly improved the biochemical properties of soil as well as productivity of crops grown in black soils (Khaim et al. 2013).

### **5.5 Relationship with in sulphur pools and soybean seed yield**

The data of the Table 4.5 and Figure 14 clearly indicated that the all forms sulphur pools was significantly correlated with available sulphur. The correlation coefficient values of available sulphur were 0.982, 0.923, 0.879 and 0.959 respectively for water soluble sulphur, heat soluble sulphur, organic S and total S. sulphur availability in soils was positively correlated with clay ( $r=0.26^{**}$ ) and organic matter content ( $r=0.33^{**}$ ) and negatively related with sand content ( $r=0.31^{**}$ ) (Rashid et al. 2000).

The data of the Table 4.5 and Figure 15 clearly indicated that the all forms sulphur pools was significantly correlated with soybean seed yield. Correlation values of yields were 0.769, 0.726, 0.734, 0.733 and 0.697 respectively for available S, water S S, heat S S, organic S and total sulphur. Dutta (2009) revealed that all forms of sulphur viz., available S, water S S, heat S S, organic S and total S were significantly correlated with seed yield.

## **SUMMARY, CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK**

Long term fertilizer experiment at JNKVV, Jabalpur was initiated at fixed site of experimental field during 1972. The present investigation entitled “Distribution of sulphur pools as influenced by long term application of fertilizers and manure in a Vertisol” was carried out during kharif 2014-15. Further, the present investigation was conducted to evaluate the different pools of S along with status of available major nutrients i.e. N, P and K, as well as physicochemical parameters of soil under study in fertility treatments of long term fertilizer experiments. The present study was carried out with 8 treatments out of 10 treatments with 4 replications in a randomized block design. The fertilizers were applied @ 20:80:20 kg ha<sup>-1</sup> N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O in soybean.

### **6.1 Effect of continuous addition of fertilizers and manure on distribution of physico-chemical properties of soil**

#### **6.1.1 pH and EC**

No appreciable changes have been found in pH and EC of the experimental soil over its initial value (7.6 and 0.18 dSm<sup>-1</sup>). No remarkable variation in status of pH and EC was also exhibited with lower soil depths as well as that noted on surface soil.

#### **6.1.2 Organic carbon content**

A significant positive enrichment in organic carbon content was observed with continuous additions of fertilizers manures. Over its initial value (5.7 g kg<sup>-1</sup>) thereby lower content was noted when no fertilizer was used or imbalanced applications were practiced. However, maximum content (9.31 g kg<sup>-1</sup>) was found in treatment 100% NPK+FYM (5 ton ha<sup>-1</sup>).

## **6.2 Effect of long term application of fertilizers and manure on distribution of available nutrients**

### **6.2.1 Available N**

The continuous application of fertilizers and manure significantly increased the available N content over its initial value ( $193 \text{ kg ha}^{-1}$ ). The application of 100% NPK along with FYM had highest content of available N ( $310 \text{ kg ha}^{-1}$ ). The surface soil contained higher N while it decreased with the increasing depth.

### **6.2.2 Available P**

Available P status of the soil showed wide variations from its initial value  $7.60 \text{ kg ha}^{-1}$ . Inclusion of P with fertilizer remarkably increased its status from 22.61, 33.18 and  $40.55 \text{ kg ha}^{-1}$  at 50% NPK, 100% NPK and 150% NPK application of fertilizer. The maximum content was obtained when NPK was applied with FYM ( $42.88 \text{ kg ha}^{-1}$ ). It has also been noted that available P status generally decreased from surface to subsurface soil.

### **6.2.3 Available K**

The continuous additions of fertilizers and manure had resulted in continuous depletion of available K over its initial status ( $370 \text{ kg ha}^{-1}$ ). The highest content  $328 \text{ kg ha}^{-1}$  was obtained when 100% NPK fertilizer applied with FYM whereas the lowest content  $208 \text{ kg ha}^{-1}$  was found in control plot. This was also found that the content of available K declined progressively with increasing soil depth.

## **6.3 Effect of continuous addition of fertilizers and manure on distribution of sulphur pools**

### **6.3.1 Available sulphur**

Available S status of the soil showed remarkably increased on its status from 24.17 to  $34.98 \text{ kg ha}^{-1}$  and  $39.30 \text{ kg ha}^{-1}$  at 50% NPK, 100% NPK and 150% NPK application with S. The maximum content was obtained when NPK was applied with FYM ( $42.66 \text{ kg ha}^{-1}$ ). It has also

been noted that available S status generally decreased from surface to subsurface and tends to decline further to a deeper layers.

### **6.3.2 Water soluble sulphur**

Water soluble sulphur status of the soil showed the while inclusion of S with fertilizer remarkably increased its status from 15.66 to 25.92 kg ha<sup>-1</sup> and 30.97 kg ha<sup>-1</sup> at 50% NPK, 100% NPK and 150% NPK application. The maximum content was obtained when NPK was applied with FYM (31.55 kg ha<sup>-1</sup>). It has also been noted that available S status generally decreased from surface to subsurface and tends to decline further to a deeper layers.

### **6.3.3 Heat soluble sulphur**

In this connection, lower content of heat soluble-S was found in control (24.48 kg ha<sup>-1</sup>) followed by 100% NPK-S (25.23 kg ha<sup>-1</sup>) where S was not included while, a remarkably higher buildup was associated when proportionally higher NPK was applied. However, the maximum content was coinciding with 100% NPK+FYM (49.72 kg ha<sup>-1</sup>). Comparatively a higher content was found on the surface and it declined in lower depth.

### **6.3.4 Organic sulphur**

The continuous application of fertilizer and manure has resulted in significantly higher accumulation of organic-S in the soil which ranged from 43.31 kg ha<sup>-1</sup> (control) to 79.01 kg ha<sup>-1</sup> (100% NPK+FYM). With respect to the depth organic-S content was confined to the surface in higher amounts and declined with increasing soil depth.

### **6.3.5 Total sulphur**

There was a mark improvement in the content of Total-S due to continuous addition of fertilizer as compared to without addition of fertilizer. This improvement was more pronounced in treatments particularly receiving balanced application over imbalanced one. The highest content was found with 100% NPK+FYM (234.53 kg ha<sup>-1</sup>). Total-

S content generally lower in 15-30 cm soil depth as compared to surface soil i.e. 0-15 cm depth.

#### **6.4 Effect of continuous addition of fertilizers and manure on grain yield of soybean**

The continuous application of fertilizer and manure resulted in significantly higher yield which ranged from 513 kg ha<sup>-1</sup> (control) to 1300 kg ha<sup>-1</sup> (100% NPK+FYM). However, when 100% NPK was applied with organic manure i.e. 100% NPK+FYM rank most superior treatment.

##### **6.4.1 Relationship with in sulphur pools and soybean seed yield**

Sulphur pool was highly significant correlation with available sulphur. The correlation coefficient values of available sulphur were 0.982, 0.923, 0.879 and 0.959 respectively for water soluble –S, heat soluble-S, organic-S and total-S. Also significant relationship was recorded amongst seed yield of soybean with all sulphur pools. Correlation values of yields were 0.769, 0.726, 0.734, 0.733 and 0.697 respectively for available S, water S S, heat S S, organic S and total S.

#### **6.5 Conclusions**

1. From the results obtained under long term experiment with continuous addition of fertilizers and manures in a Vertisol of Jabalpur improved the physicochemical properties of the soil it rendered the remarkable improvement in organic carbon content.
2. The distribution pattern of sulphur in soil revealed that all the sulphur pools decreased with increasing soil depth, irrespective of the treatments and it is dependent upon rate of fertilizer application.
3. The total-S form was found to be predominantly in higher amounts followed by organic-S, heat soluble-S available-S.
4. The productivity of soybean was gently influenced with balanced fertilizer application over imbalanced applications. However,

maximum yield was noted when 100% NPK+FYM was in practiced specially soybean-wheat grown under intensive cultivation of crops grown on in black soil (Vertisol) of central India.

## **6.6 Suggestions**

The finding of this study provides some suggestion on which further line of work could be taken up.

1. The experiment should be conducted in Vertisol of different agro climatic zones of M.P. with predominated cropping system.
2. Benefits of different sources of nutrients should also be evaluated considering their economics and keeping in view other nutrients being applied indirectly through fertilizers.
3. Assessment of heavy metal content in the experimental soil needs monitoring for evaluation of soil health.
4. Effect of integrated application of balanced fertilizers along with organic manure on physical and chemical environment of the soil needs to be investigated in further understandings.
5. Identification of climate parameter influencing soil and crop productivity needs incorporated for prediction of crop productivity.

## REFERENCES

- Anonymous 2000-2001. All India Coordinated Research Project on Long Term Fertilizer Experiment to Study Changes in soil quality, crop productivity and sustainability. Annual Report Dept of Soil Science & Agril. Chemistry, JNKVV, Jabalpur pp 23-24.
- Bajpai RK, Chitale S, Upadhyay SK and Urkurkar JS. 2006. Long-term studies on soil physico-chemical properties and productivity of rice-wheat system as influenced by integrated nutrient management in Inceptisol of Chhattisgarh. Journal of the Indian Society of Soil Science 54: 24-29.
- Balaguravaiah D, Adinarayana G, Prathap S and Reddy TY. 2005. Influence of long term use of inorganic and organic manures on soil fertility and sustainable productivity of rainfed groundnut in Alfisols. Journal of the Indian Society of Soil Science 53: 608-611
- Balanagoudar SR and Satyanarayana T. 1990. Depth wise distribution of different forms of sulphur in Vertisols and Alfisols. J Indian Soc Soil Sci 38:634-640.
- Balík J, Kulhanek MJ, Cerny J, Szakova D, Pavlíkova Cermak P. 2009. Forms of sulphur and evaluation to the sulphur test methods for Moong bean in some terai soils of Eastern India. International Journal of Agriculture, Environment & Biotechnology 6(1): 137-144.
- Bardsley CE and Lancaster JD. 1960. Determination of integrated nutrient supply system on secondary nutrients of soil. Oryza 36:266-267.
- Basumatary Anjali and Das KN. 2012. Forms of sulphur and their relationship with soil properties in some soils of north bank plain zone of Assam. Agropedology 22(1):43-49.
- Behera SK and Singh D. 2009. Effect of 31 years of continuous cropping and fertilizer use on soil properties and uptake of micronutrients by Maize (*Zea mays*)-wheat (*Triticum aestivum*) system. Indian Journal of Agricultural Sciences 79 : 264-267.
- Behera SK, Singh D, Dwivedi BS and Bhadraray S. 2009. Fractions of copper availability and uptake by maize-wheat cropping sequence. Journal of Plant Nutrition 32: 1092-1107.
- Bhatnagar RK and Trivedi SK. 2005. Vertical distribution of sulphur fractions and its relationship among carbon, nitrogen and sulphur in Inceptisol and Vertisols of District Shivpuri of Madhya Pradesh. Jawaharlal Nehru Krishi Vishwa Vidyalaya Research Journal 39:33-36.
- Bhattacharya P and Ghos G. 2001. Phosphorus use efficiency in Brinjal with FYM and S. Journal of Indian Society of Soil Science 49:456-562.
- Bhattacharyya T, Pal DK, Chandran P, Ray SK, Durge SL, Mandal C, Telpande B and Wani SP. 2007. Available "K" reserve of two major crop growing regions (Alluvial and Shrink-swell soil) in India. Indian J Ferti 3:41-46.
- Birla Kamelesh.2012. Distribution of various forms of sulphur as influenced by long term application of fertilizer and manure in a vertisol. M.Sc. thesis JNKVV, Jabalpur.69

- Chanchlesh Raghuwanshi. 2014. Effect of long term application of fertilizers and manure on major nutrient contents in soil, plant and the crop residue of soybean in a vertisol. M.Sc.(Ag.) Thesis, JNKVV, Jabalpur.
- Chesnin L and Yien CH. 1950. Turbidimetric determination of available sulphate. Soil Science Society of America Proceedings 15 : 149-151.
- Chesnin L and Yien CH. 1950. Turbidimetric determination of sulphur. Soil Science Society of America Proceedings 15: 134-136
- Chesnin L and Yien CH. 1951. Turbid metric determination of available sulphate. Soil Science Society of America Proceedings 15 : 149-151.
- Choudhary IA and Cornfield AH. 1966. The determination of total sulphur in soil and plant materials. Analyst 9:586-589.
- Dardsley Ce and Lancaster JD. 1960. Determination of integrated nutrient supply system on secondary nutrients of soil. Oryza 36 : 266-267.
- Das I, Ghosh K, Ray SC, Mukhopadhyay PK and Ghosh SK. 2006. Status and distribution of sulphur vis-a-vis taxonomic class wise distribution of sulphur in selected soil series of inceptisol in West Bengal. Journal of the Indian society of Soil Science 54: 368-371
- Das KN, Basumatari A and Borkotoki B. 2012. Forms of sulphur in some rapeseed growing soils of Assam. Journal of the Indian Society of Soil Science 60: 13-19
- Dutta J. 2009. Long-term effect of chemical fertilizers and amendments on sulphur sorption under maize-wheat system. M Sc Thesis, p 125. Department of Soil Science, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, India.
- Dwivedi AK, Singh M, Kauraw DL, Wanjari RH and Chauhan SS. 2007. Research bulletin on impact of fertilizer and manure use for three decades on crop productivity and sustainability and soil quality under Soybean-Wheat system on a Vertisol in central India. IISS (ICAR), Bhopal.
- Gajendra Patel. 2014. Microbiological and enzymatic studies in a Vertisol as influenced by long term application of fertilizer and FYM on soybean. M.Sc.(Ag.) Thesis, JNKVV, Jabalpur.
- Grewal KS, Singh D, Mehta SC and Karwasra SP. 1999. Effect of long-term fertilizer application on physico-chemical properties of soil. Journal of the Indian Society of Soil Science 47: 538-541.
- Hati KM, Swarup A, Mishra B, Manna MC, Wanjari RH, Mandal KG and Misra AK. 2008. Impact of long-term application of fertilizer, manure and lime under intensive cropping on physical properties and organic carbon content of an Alfisol. Geoderma 148: 173-179.
- Hedge DM and Murthy IYLN. 2005. Management of secondary nutrients achievements and challenges. Indian Journal of Fertilizers 1; 93-100.
- Ibrahim SA and Kandil Hala 2007. Growth, yield and chemical constituents of Soybean (*Glycine max* L.) plants as affected by plant spacing under different irrigation intervals. Research Journal of Agriculture and Biological Science 3(6): 657-663.

- K. Karthikeyan and Shukla IM. 2011. Different forms of boron and sulphur and their effect on Band S contents in mustard (*Brassica juncea* L.) and sunflower (*Helianthus annus* L.) Agropedology 21(1) : 28-34.
- Kamlesh Birla. 2012. Distribution of various farms of sulphur as influenced by long term application of fertilizers and manure in Vertisol. M.Sc.(Ag.) Thesis, JNKVV, Jabalpur.
- Karthikeyan K and Shukla IM. 2011. Different forms of boron and sulphur and their effect on Band S contents in mustard (*Brassica juncea* L.) and sunflower (*Helianthus annus* L.) Agropedology 21(1) : 28-34.
- Khaim S, Chowdary MAH and Saha BK. 2013. organic and inorganic fertilization on the yield and quality of soybean. Journal of Bangladesh agricultural university 11(1) : 23-28.
- Khiani KN and More DA. 1984. Long term effect of tillage operation and FYM application on soil properties and crop yield in a Vertisol. J Indian Soc Soil Sci 32: 392-393.
- Kumar V and Singh AP. 2010. Long-term effect of green manuring and farmyard manure on yield and soil fertility status in rice-wheat cropping system. Journal of the Indian Society of Soil Science 58: 409-412
- Kumar V and Singh AP. 2010. Long-term effect of green manuring and farmyard manure on yield and soil fertility status in rice-wheat cropping system. Journal of the Indian Society of Soil Science 58: 409-412.
- Kumar V, Pandey AK, Prasad RK and Prasad B. 2011. Long-term influence of organic and inorganic sulphur and fertility levels on yields, distribution and build-up of sulphur under rice-wheat cropping system in Calciorrhents. Journal of the Indian Society of Soil Science 59: 278-282.
- Kumar V, Pandey AK, Prasad RK and Prasad B. 2011. Long-term influence of organic and inorganic sulphur and fertility levels on yields, distribution and build-up of sulphur under rice-wheat cropping system in Calciorrhents. Journal of the Indian Society of Soil Science 59: 278-282.
- Kundu S, Bhattacharya Ranjan, Gupta Ved Prakash, Pathak HS and Ladha H. 2007. Long term yield trend and sustainability of rainfed soybean wheat system through farmyard manure application in a sandy loam soil of the Indian Himalayas. Biology and Fertility of Soils 43 (3) : 271-280.
- Lakaria BL, Singh Muneshwar, Reddy RS, Biswas AK, Jha P, Chaudary RS and Ladha H. 2012. Long-term yield trend and sustainability of rainfed soybean-wheat system through farmyard manure application in a sandy loam soil of the Indian Himalayas. Biology and fertility of soil 43(3): 271-280.
- Majumdar BL, Nagar RK and Singh P. 2002. Effect of nutrients and microbial inoculants on growth and yield of soybean. J Soils Crops 13(1):14-17.
- Mann KK, Brar BS and Dhillon NS. 2006. Influence of long-term use of farmyard manure and inorganic fertilizers on nutrient availability in a Typic Ustochrept. Indian Journal of Agricultural Sciences 76: 477-480
- Millar RH and Keeney DR. 1982. Method of soil Analysis. Part-II American Society Agronomy Madison Wiscosin, USA.

- Misra UK, Das CP and Mitra GN. 1990. Forms of sulphur in some soils of Orissa in relation to relevant soil properties. *Journal of the Indian Society of Soil Science* 38: 61-69.
- Muhr GR, Data NP, Subramany HS, Leley VK and Dunahue RL. 1965. *Soil testing*. India Asian Press, New Delhi.
- Olsen, SR, Cole CV, Vatanabe FS and Dean LA. 1954. Estimation of available phosphorus in soil by extraction with sodium bicarbonate. *Circulation of US department of Agriculture* 939 : 1-19.
- Panse VG and Sukhatme SV. 1970. *Statistical methods for Agril. Workers*. ICAR Publication.
- Patel Gajendra.2014. Microbiological and Enzymatic studies in as vertisol as influences by long term application of fertilizer and FYM on soybean. M.Sc. thesis JNKVV, Jabalpur.57p.
- Patel JC and Patel KC. 2008. Profile distribution of different forms of sulphur in prominent soil series of South Gujarat. *An Asian Journal of Soil Science* 3: 24-29
- Patel JM, Patel MV, Jadav NJ and Patel PV. 2011. Sulphur fractions and their relationships with soil properties in Banaskantha district, Gujarat. *Agropedology* 20(2): 35-41.
- Patidar Samrath.2014. Effect of long term application of fertilizer and FYM on biochemical attributes, yield and Quality of soybean. M.Sc. thesis JNKVV, Jabalpur.59p.
- Patiram and Singh KA. 1993. Effect of continuous application of manure and nitrogenous fertilizer on some properties of acid Inceptisol. *Journal of the Indian Society of Soil Science* 41: 430-433.
- Paul Sankar Ch, Mukhopadhyay Prabir 2014. Forms of sulphur and evaluation to the sulphur test methods for Moongbean in some terai soils of Eastern India. *International Journal of Agriculture Environment & Biotechnology* 6(1): 137-144.
- Pillai RN. 1994. Sulphur status of black soils and responses to sulphur in Andhra Pradesh. In: *Workshop on Sulphur in Balanced Use in Andhra and Maharashtra* pp 14-15., TSI/FAI/IFA Workshop, Hyderabad, India.
- Piper CS. 1950. *Soil and Plant Analysis*. Intel Science Publishers, Inc. New York.
- Raghuwanshi chanchlesh.2013. Effect of long term application of fertilizers and manure on major nutrients content in soil and plant and crop residue of soybean in a vertisol.M.Sc. thesis JNKVV, Jabalpur.61
- Raina AK and Tanawade SK. 2005. Delineation of sulphur deficient areas of Maharashtra and crop responses to sulphur application. *Indian Journal of fertilizers* 1: 61-64.
- Rashid A, Iqbal S, Naeem MA and Rafique E. 2000. Nutrient indexing of sulphur in Rainfed Peanut Grown in Potahar Plateau of Pakistan. *Journal of Indian Society of Soil Science* 48(1): 124-129.
- Raut PD and Mali CV. 2003. Total sulphur and its fractions in relation to pH and organic carbon in different soils of Latur district in Maharashtra. *Journal of Maharashtra Agricultural University* 28:109-111.

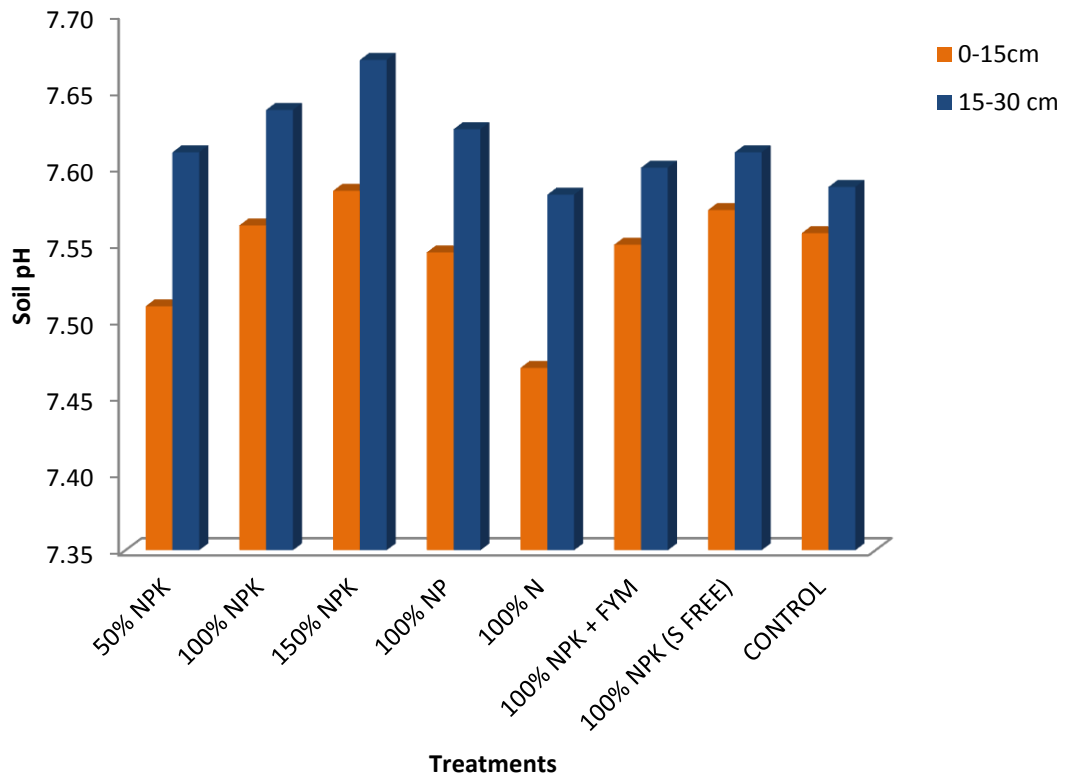
- Reddy AR, Balwan Singh and Narwal RP. 2009. Effect of long term FYM and nitrogen application in Bajra–wheat cropping system on fraction of sulphur in soil. *Annals of Agriculture Bio Research* 14(1) : 33-45.
- Reddy KS, Singh M, Tripathi AK, Swarup A and Dwivedi AK. 2004. Changes in the organic and inorganic fractions S mineralization in a Typic Haplustert after long-term cropping with different fertilizers and organic manure inputs. *Australian Journal of Soil Research* 39: 737-748.
- Reddy KS, Singh M, Tripathi AK, Swarup A and Dwivedi AK. 2004. Changes in the organic and inorganic fractions S mineralization in a Typic Haplustert after long-term cropping with different fertilizers and organic manure inputs. *Australian Journal of Soil Research* 39: 737-48.
- Reddy M Narayan and Surekha K. 1999. Role of chickpea in enhancing available P in chickpea-upland Rice-system in Vertisols. *J Indian Soc Soil Sci* 47:805-808.
- Sakal R and Singh AP. 2001. Sulphur status of Ustifluvents and response of crops to sulphur application. *Fertilizer News* 46: 61-65.
- Samrath Patidar. 2014. Effect of long term application of fertilizer and FYM on biochemical attributes, yield and quality of soybean. M.Sc.(Ag.) Thesis, JNKVV, Jabalpur.
- Sankar Ch. Paul and Prabir Mukhopadhyay 2014. Forms of Sulphur and Evaluation to the Sulphur Test Methods for Moongbean in Some terai Soils of Eastern India, *International Journal of Agriculture, Environment & Biotechnology* 6(1): 137-144 March 2014.
- Santhy P, Velusamy MS, Muragappan V and Seli D. 1999. Effect of inorganic fertilizers and fertilizer- manure combination on soil phisici-chemical properties and dynamics of microbial biomass in an Inceptisols. *J Indian Soc Soil Sci* 47:479-482.
- Sawarkar SD, Khamparia NK, Thakur Rishikesh, Dewda MS and Singh Muneshwar. 2013. Effect of Long term application of inorganic fertilizers and manure and organic manure on yield, potassium uptake and profile distribution of potassium fractions in vertisols under soybean wheat cropping system. *Journal of the Indian society of soil science* 61 (2) : 94-98.
- Scherer HW, Welp G and Forster S. 2012. Sulfur fractions in particle-size separates as influenced by long-term application of mineral and organic fertilizers. *Plant Soil Environment* 58: 242-248.
- Selvi D, Santhy P, Dhakshinamoorthy M and Maheshwari M. 2004. Microbial population and biomass in rhizosphere as influenced by continuous intensive cultivation and fertilization in an Inceptisol. *Journal of the Indian Society of Soil Science* 52: 254-257.
- Setia RK and Sharma KN. 2005. Effect of long term differential fertilization on depth- distribution of forms of sulphur and their relationship with sulphur nutrition of wheat under maize wheat sequence. *Journal of Indian Society of Soil Science* 53:91-96.
- Sharma HP, Bali S and Gupta DK. 2000. Crop yield and properties of Inceptisol as influenced by residue management under rice-wheat cropping sequence. *Journal of the Indian Society of Soil Science* 48: 506-509.

- Sharma JC and Choudhary, S.K. 2007. Status of available sulphur and soil suitability for mustard in Shiwalika foot hills of Himachal Pradesh. *Annals of Plant Soil Research* 9:162-164.
- Sharma R and Jaggi RC. 2001. Relationship of forms and availability indices of sulphur with properties of soil of Kangra Himachal Pradesh. *Journal of Indian Society of Soil Science* 49:698-772.
- Sharma RK and Jaggi RC. 2001. Relationships of forms and availability indices of sulphur with properties of soils of Kangra, Himachal Pradesh. *Journal of the Indian Society of Soil Science* 49: 698-702.
- Sharma RK. 1992. Nutrient removal by soybean, wheat and maize fodder taken in sequence as influenced by long term fertilizer application on Typic Chromustert. Ph.D. Thesis, JNKVV, Jabalpur.
- Singh Muneshwar and Wanjari RH. 2012. Measures to Sustain and Restore Declined Productivity in Alfisols under Long-Term Fertiliser Experiments *Indian J of Fertilizers* 9(2):24-32.
- Singh Muneshwar, Wanjari RH, Agrawal and Shrama Pankaj. 2014b. Biological N<sub>2</sub> Fixation and Contribution to Soil in 40-year-old Experiment on Alfisols of Rachi *Journal of the ISSS*, Vol. 62. 1.pp 56-61 (2014).
- Singh Muneshwar, Wanjari RH, Dwivedi Anil and Dalal Ram. 2012. Yield response to applied nutrients and estimates of N<sub>2</sub> fixation in 33 year old soybean wheat experiment on a vertisol. *Expl agric* 48(3) : 311-325.
- Singh S, Singh RN, Prasad J and Binod K. 2002. Effect of green manuring, FYM and Biofertilizer in relation to fertilizer nitrogen on yield and major nutrient uptake by upland rice. *Journal of Indian Society of Soil Science* 50:313-314.
- Singh S, Singh RN, Prasad J and Binod K. 2002. Effect of green manuring, FYM and Biofertilizer in relation to fertilizer nitrogen on yield and major nutrient uptake by upland rice. *Journal of Indian Society of Soil Science* 50:313-314.
- Singh Virinder, Sharma YK, Singh AK and Bordoloi LJ. 2013. Sulphur distribution in Inceptisol of Northern India and genotypic difference in sulphur uptake of rice. *African Journal of Agricultural Research*, 8(10): 855-867.
- Sonune BA, Tayade KB, Gabhane VV and RB Puranik. 2003. Long term effect of manuring and fertilization on fertility and crop productivity of Vertisols under sorghum-wheat sequence. *Crop Research*, Hisar. 25(3): 460-467.
- Sonune BA, Tayade KB, Gabhane VV and Purank RB. 2003. Long-term effect of manuring and fertilization on fertility and crop productivity of Vertisols under sorghum-wheat sequence. *Crop Research* 25: 460-467.
- Subbiah BV and Asija EC. 1956. A rapid procedure for estimation of available nitrogen in soil. *Current Science*, 25 : 259-260.
- Sudhir K, Srikanth K and Jayaprakash SM. 2002. Sustained crop production under long term fertilizer use in red soil in India. 17<sup>th</sup> WCSS, 14-21 August 2002, Thailand. 108: 1-10.

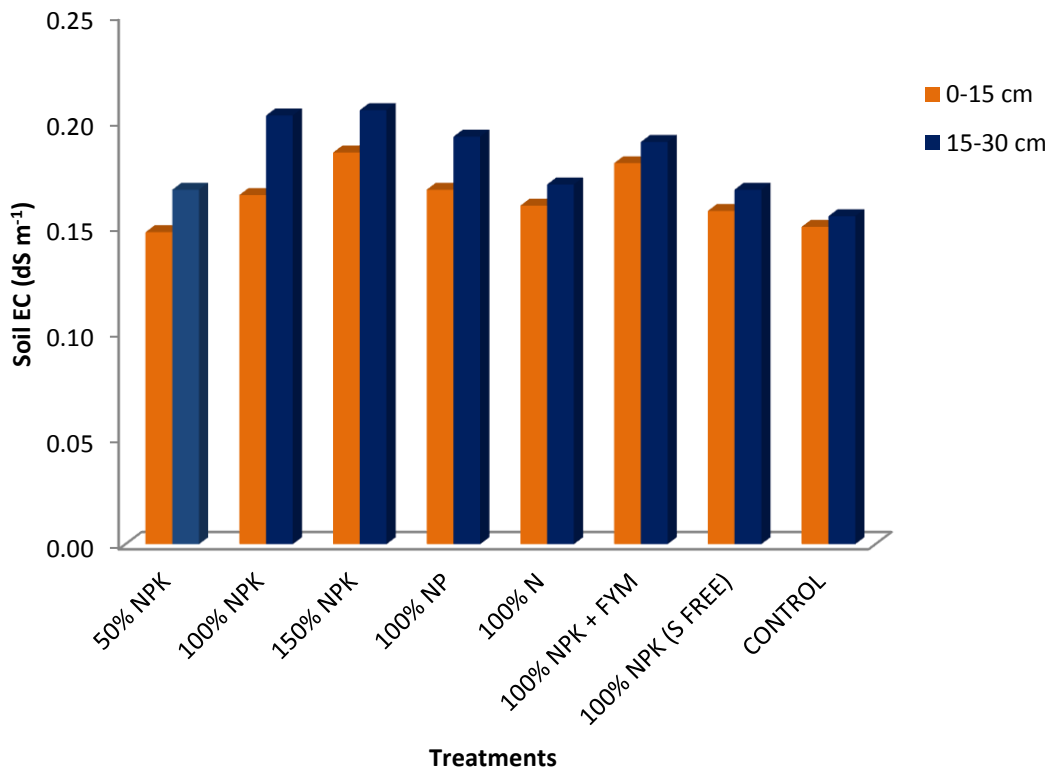
- Swarup A and Rao CS. 1999. Current status of crop sponsored to fertilizers in different agro climatic zones. Experience of AICRP on long term fertilizer experiments. Special issue on current status of crop response of fertilizers in different agro-climatic zonal. *Fertilizer News* 44:27-30.
- Tabassum S, Sammy RK, Vaishya UK, Singh M and Biswas AK. 2010. Changes in organic and inorganic forms of nitrogen in a Typic Haplustert under soybean-wheat system due to conjoint use of inorganic fertilizers and organic manures. *Journal of the Indian Society of Soil Science* 58: 76-85.
- Tabatabai MA and Bremner JM. 1972. Assay of urease activity in soil. *Soil Biology and Biochemistry* 4: 479-487.
- Tandon HLS. 1991. Phosphorus research and agricultural production in India, Fertilizer Development and Consultation Organization (FDCO), New Delhi.
- Thakur R and Sawarkar SD. 2009. Influence of long term continuous application of nutrients and spatial distribution of sulphur on soybean-wheat cropping sequence. *Journal of Soil and Crops* 19 (2): 225-228.
- Thakur R, Sawarkar SD, Vaishya UK and Singh M. 2011. Impact of continuous use of inorganic fertilizers and organic manure on soil properties and productivity under soybean-wheat intensive cropping of a Vertisol. *Journal of the Indian Society of Soil Science* 59: 7481
- Thakur Rishikesh, Sawarkar SD, Kaurav DL and Singh Muneshwar. 2010. Effect of inorganic and organic sources on nutrient availability in a Vertisol. *Agropedology* 20(1): 53-59.
- Thakur Rishikesh, Sawarkar SD, Vaishya UK and Singh Muneshwar. 2011. Impact of continuous use of Inorganic Fertilizer and Organic Manure on Soil Properties and Productivity under Soybean-Wheat intensive cropping of a Vertisol. *Journal of Indian Society Soil Science* 59: 74-81.
- Tiwari A, Dwivwadi AK and Dixit PR. 2002. Long term influence of organic and inorganic fertilization on soil fertility and productivity of soybean-wheat system in a vertisol. *Journal of Indian Society of Soil Science* 50:472-475.
- Tiwari KN and Gupta BR. 2006. Sulphur for sustainable high yield of agriculture in U.P. *Indian Journal of fertilizer* 1: 37-52.
- Tomar VK. 2003. Spatial distribution of inorganic and organic content of P and S as influenced by long term application of fertilizers and manure in Typic *Haplustert*. M.Sc. Thesis JNKVV Jabalpur, MP.
- Tripathi D and Singh K. 1992. Vertical distribution of S in representative soil groups of Himachal Pradesh. *Journal of Indian Society Science* 41:447-453.
- Tripathi SB and Hazare CR. 2000. Sulphur in balanced fertilization in red and black soils of bundelkhand region of Uttar Pradesh. In: Workshop on sulphur in balanced fertilization (M.C. Sarkar, B.C. Biswas and S. Das, Eds.) pp. 43-54. TSI/FAI/IFA Workshop, New Delhi, India.
- Tyagi VV and Bhardwaj V. 1994. Effect of continuous cropping and fertilizer on the status of available nutrient in mollisol soil. *Journal of Potassium Research* 10(4): 384-391.

- Verma A, Nepalia V and Kanthaliya PC. 2005. Effect of continuous cropping and fertilization on crop yields and nutrient status of a Typic Haplustept. *Journal of the Indian Society of Soil Science* 53: 365-368.
- Verma Gayatri, Mathur AK, Bhandari SC and kanthaliya PC. 2010. Long term effect of integrated nutrient management on properties of a typic haplustept under maize wheat cropping system. *Journal of the Indian society of soil science* 58(3); 299-302.
- Walkley A and Black CA. 1934. An Examination for Degt-Jrefff method for determination soil organic matter and proposal for modification of the chromic acid titration method. *Soil Science* 37 : 29-38.
- Williams CH and Steinbergs A. 1959. Soil sulphur fractions as chemical indices of available S in some Australian soils. *Australian Journal of Agricultural Research* 10 : 349-351.
- Yaduvanshi NPS and Anand Swarup 2006. Effect of long term fertilizer and manuring on potassium balance and non-exchangeable K release in a reclaimed sodic soil. *Journal of Indian Society of Science* 54:203-207.
- Zhang H, Wang B and Xu M. 2008. Effects of inorganic fertilizer inputs on garin yields and soil properties in a long-term wheat-corn cropping system in south China. *Communications in Soil Science and Plant Analysis* 39: 1583-1599.

**Fig. 2. Depth wise distribution of soil pH**



**Fig. 3. Depth wise distribution of soil EC**

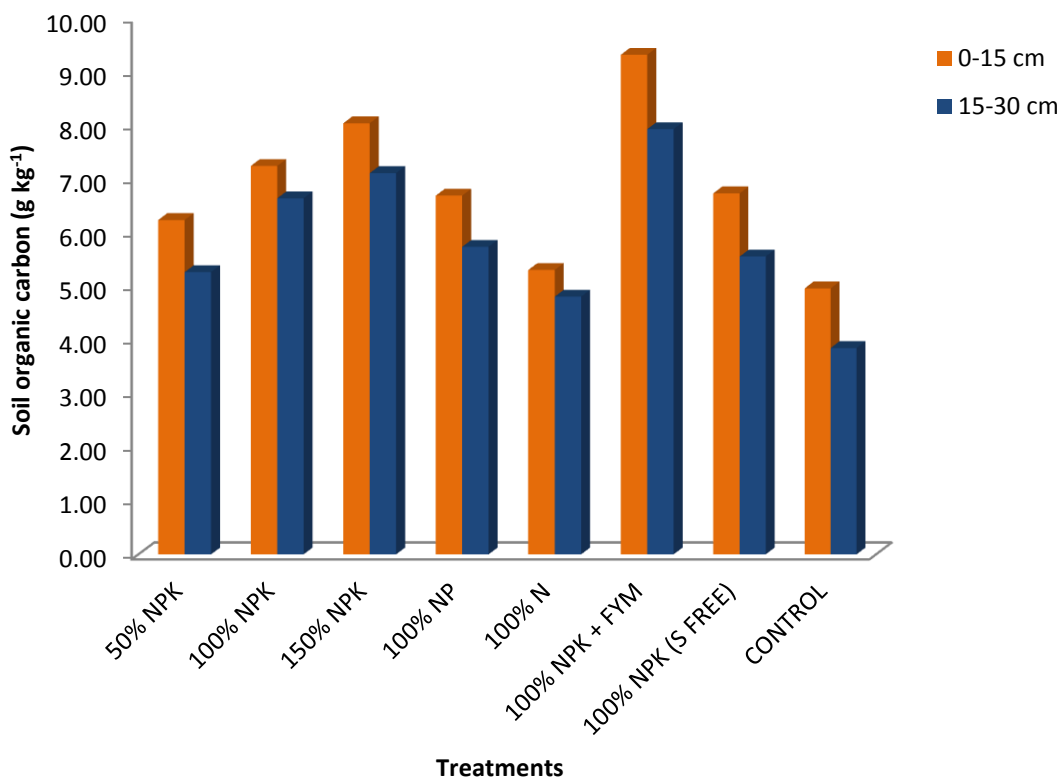


	0-15cm	15-30 cm
50% NPK	7.51	7.61
100% NPK	7.56	7.64
150% NPK	7.59	7.67
100% NP	7.55	7.63
100% N	7.47	7.58
100% NPK + FYM	7.55	7.60
100% NPK (S FREE)	7.57	7.61
CONTR OL	7.56	7.59

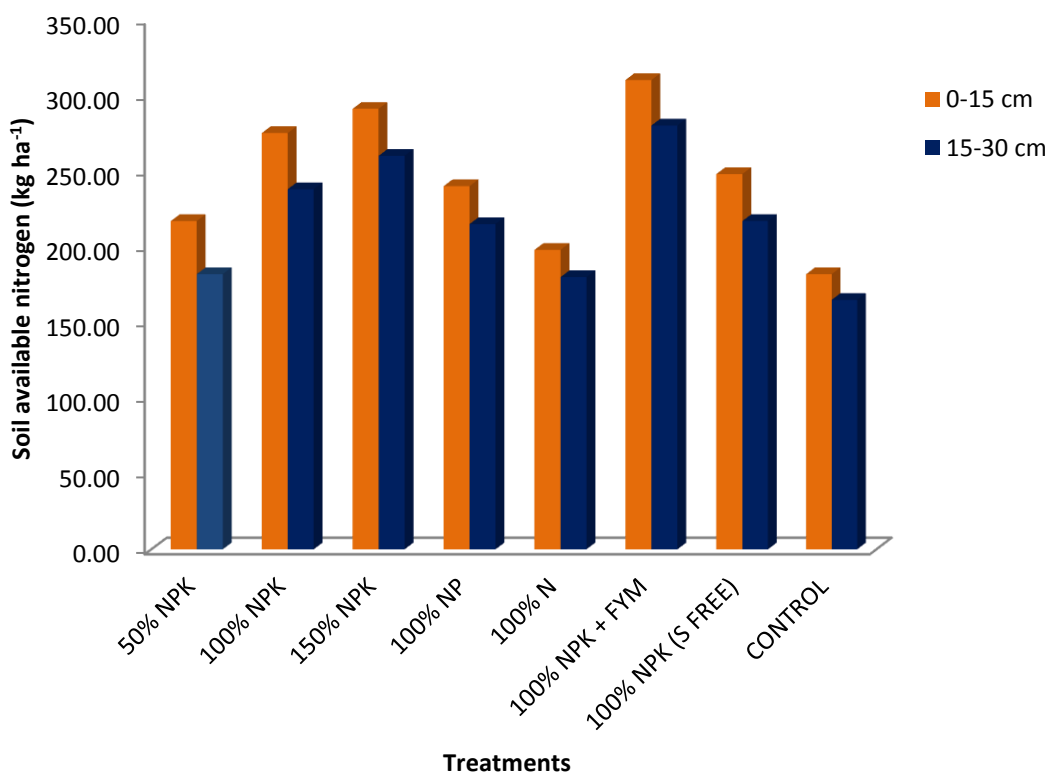
	0-15 cm	15-30 cm
50% NPK	0.15	0.17
100% NPK	0.17	0.20
150% NPK	0.19	0.21
100% NP	0.17	0.19
100% N	0.16	0.17
100% NPK + FYM	0.18	0.19
100% NPK (S FREE)	0.16	0.17
CONTR OL	0.15	0.16




**Fig. 4. Depth wise distribution of soil organic carbon**



**Fig. 5. Depth wise distribution of soil available nitrogen**

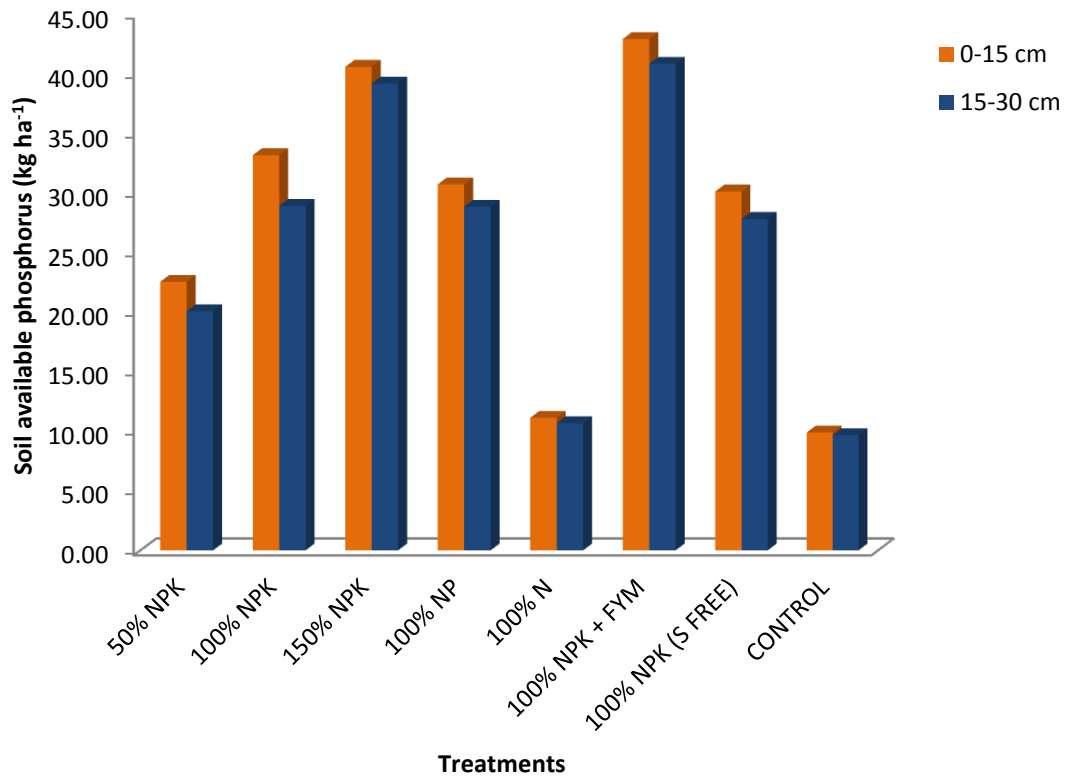


	0-15 cm	15-30 cm
50% NPK	6.25	5.28
100% NPK	7.25	6.65
150% NPK	8.04	7.12
100% NP	6.70	5.75
100% N	5.32	4.82
100% NPK + FYM	9.31	7.93
100% NPK (S FREE)	6.74	5.57
CONTR OL	4.98	3.87

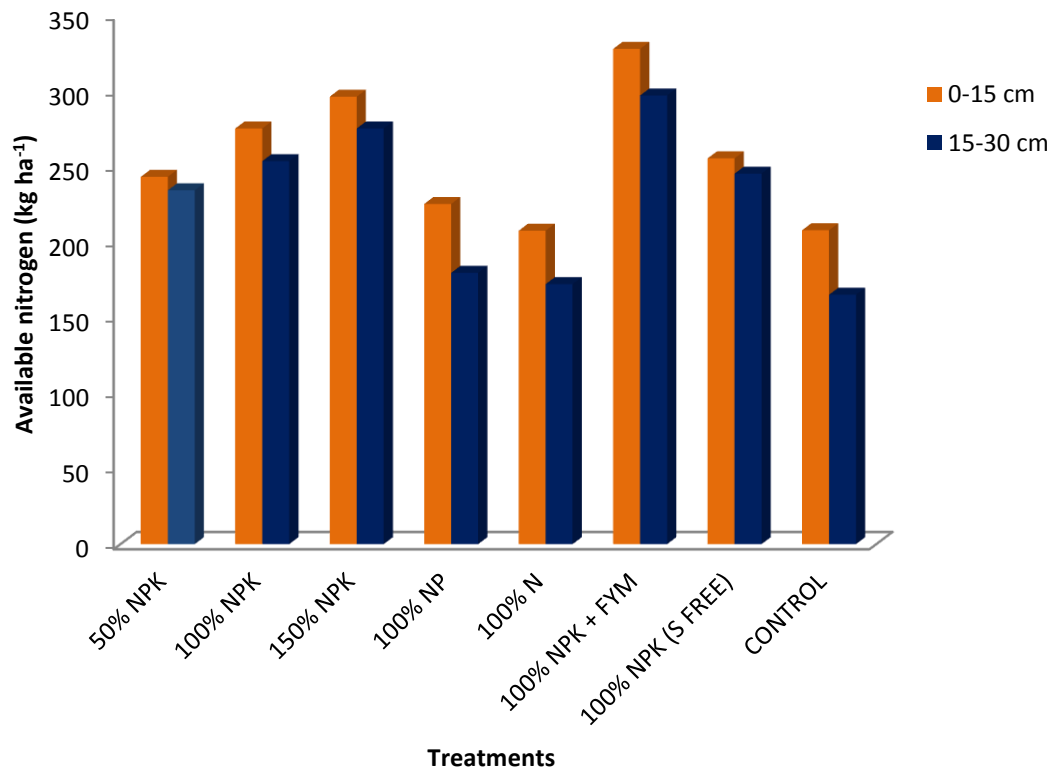
	0-15 cm	15-30 cm
50% NPK	217.00	182.00
100% NPK	275.00	238.00
150% NPK	291.00	260.00
100% NP	240.00	215.00
100% N	198.00	180.00
100% NPK + FYM	310.00	280.00
100% NPK (S FREE)	248.00	217.00
CONTR OL	182.00	165.00




**Fig. 6. Depth wise distribution of soil available phosphorus**



**Fig. 7. Depth wise distribution of available potassium**

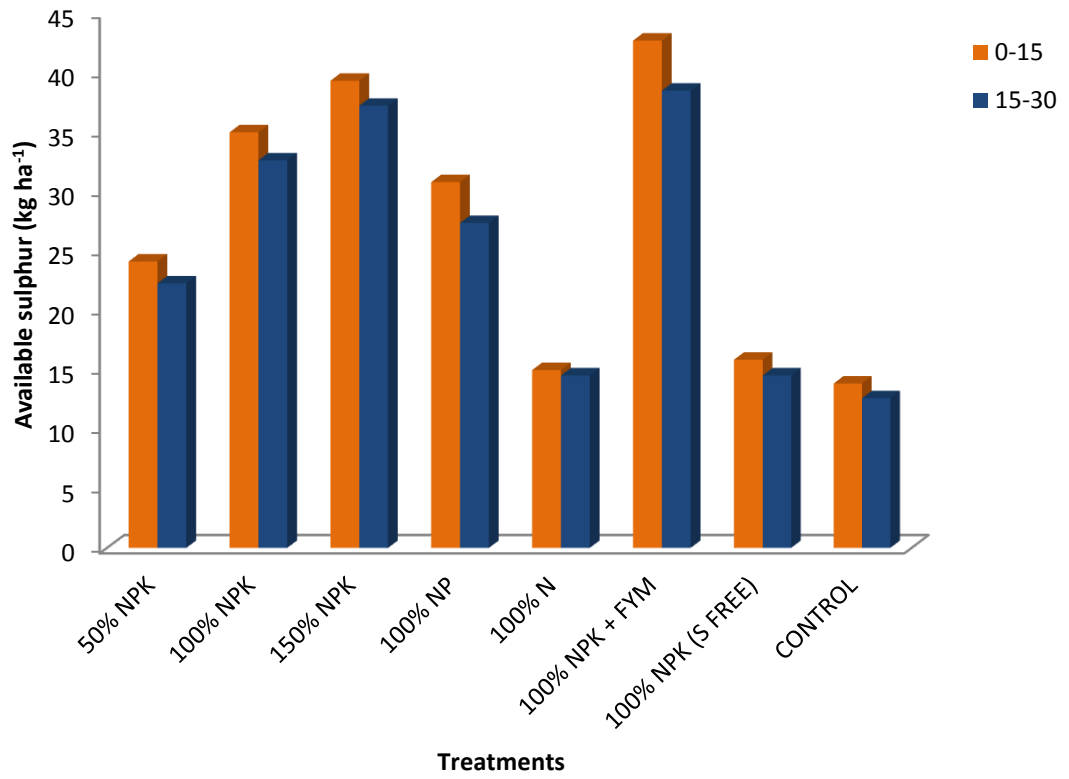


	0-15 cm	15-30 cm
50% NPK	22.61	20.16
100% NPK	33.18	28.95
150% NPK	40.55	39.15
100% NP	30.75	28.88
100% N	11.26	10.80
100% NPK + FYM	42.88	40.81
100% NPK (S FREE)	30.15	27.86
CONTR OL	10.01	9.80

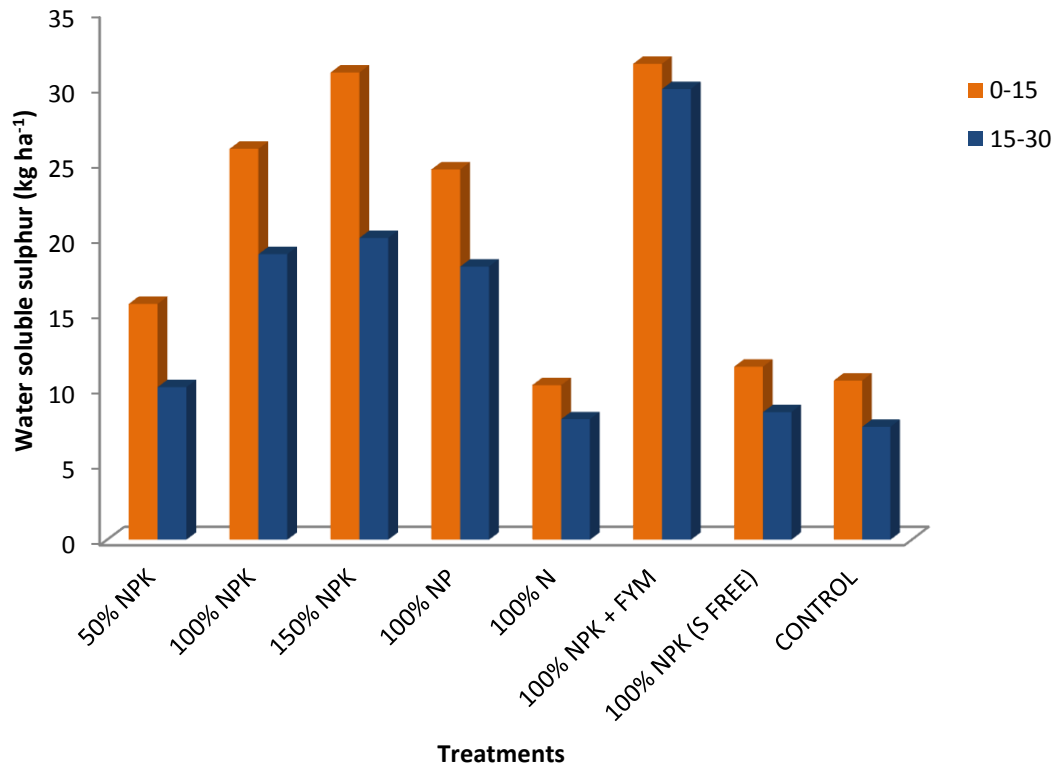
	0-15 cm	15-30 cm
50% NPK	243	234
100% NPK	275	253
150% NPK	296	275
100% NP	225	180
100% N	207	172
100% NPK + FYM	328	297
100% NPK (S FREE)	255	245
CONTR OL	208	165




**Fig. 8. Depth wise distribution of available sulphur (kg ha<sup>-1</sup>)**



**Fig. 9. Depth wise distribution of water soluble sulphur (kg ha<sup>-1</sup>)**



	0-15	15-30
50% NPK	24.17	22.34
100% NPK	34.98	32.64
150% NPK	39.3	37.21
100% NP	30.82	27.4
100% N	15.08	14.63
100% NPK + FYM	42.66	38.47
100% NPK (S FREE)	15.94	14.63
CONTR OL	13.95	12.72

	0-15	15-30
50% NPK	15.66	10.15
100% NPK	25.92	18.95
150% NPK	30.97	20.02
100% NP	24.56	18.13
100% N	10.29	8.03
100% NPK + FYM	31.55	29.88
100% NPK (S FREE)	11.51	8.5
CONTR OL	10.59	7.52

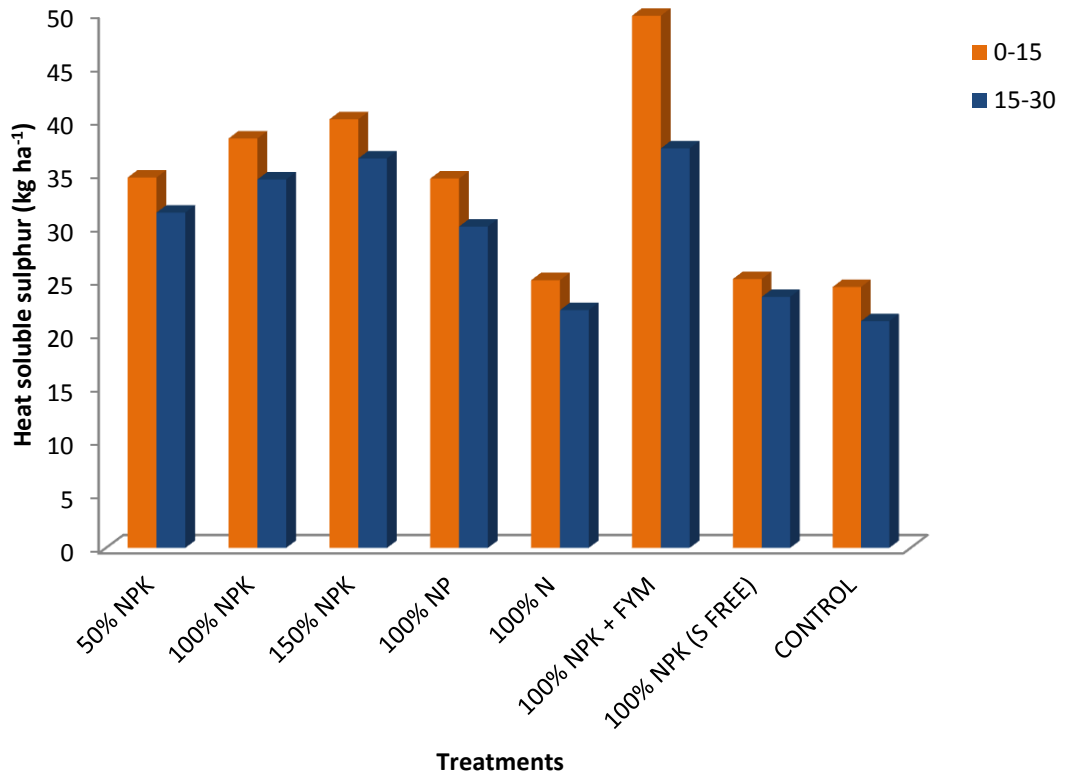
	0-15	15-30
T <sub>1</sub> -50% N	34.67	31.4
T <sub>2</sub> -100%	38.3	34.48

T <sub>3</sub> -150%	40.08	36.44
T <sub>6</sub> -100%	34.57	30.11
T <sub>7</sub> -100%	25.12	22.33
T <sub>8</sub> -100%	49.72	37.38
T <sub>9</sub> -100%	25.23	23.56
T <sub>10</sub> -CON	24.48	21.3

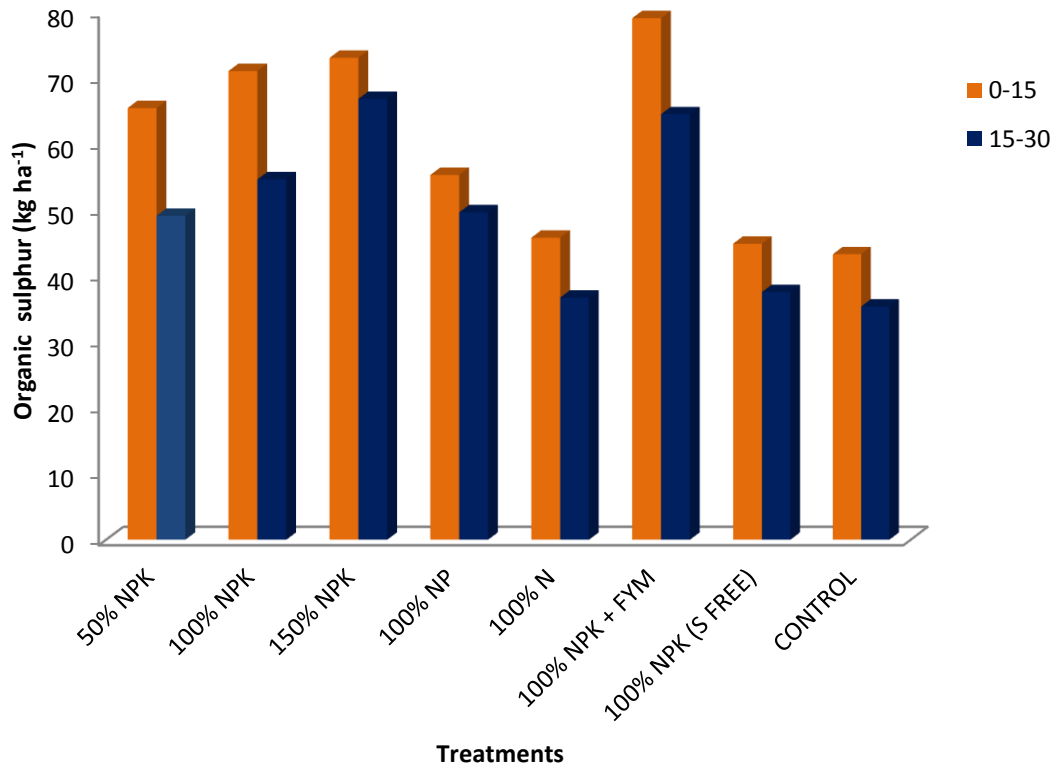
	0-15	15-30
T <sub>1</sub> -50% N	65.42	49.12
T <sub>2</sub> -100%	71.02	54.63
T <sub>3</sub> -150%	73	66.79
T <sub>6</sub> -100%	55.31	49.65
T <sub>7</sub> -100%	45.81	36.75
T <sub>8</sub> -100%	79.01	64.48
T <sub>9</sub> -100%	44.91	37.59
T <sub>10</sub> -CON	43.31	35.39

	0-15	15-30
T <sub>1</sub> -50% N	193.25	175.94
T <sub>2</sub> -100%	211.17	193.6
T <sub>3</sub> -150%	216.71	197.19
T <sub>6</sub> -100%	209.01	180.35
T <sub>7</sub> -100%	152.54	132.68
T <sub>8</sub> -100%	234.53	204.99
T <sub>9</sub> -100%	152.37	133.75
T <sub>10</sub> -CON	149.17	130

**Fig. 10. Depth wise distribution of heat soluble sulphur ( $\text{kg ha}^{-1}$ )**



**Fig. 11. Depth wise distribution of organic sulphur ( $\text{kg ha}^{-1}$ )**



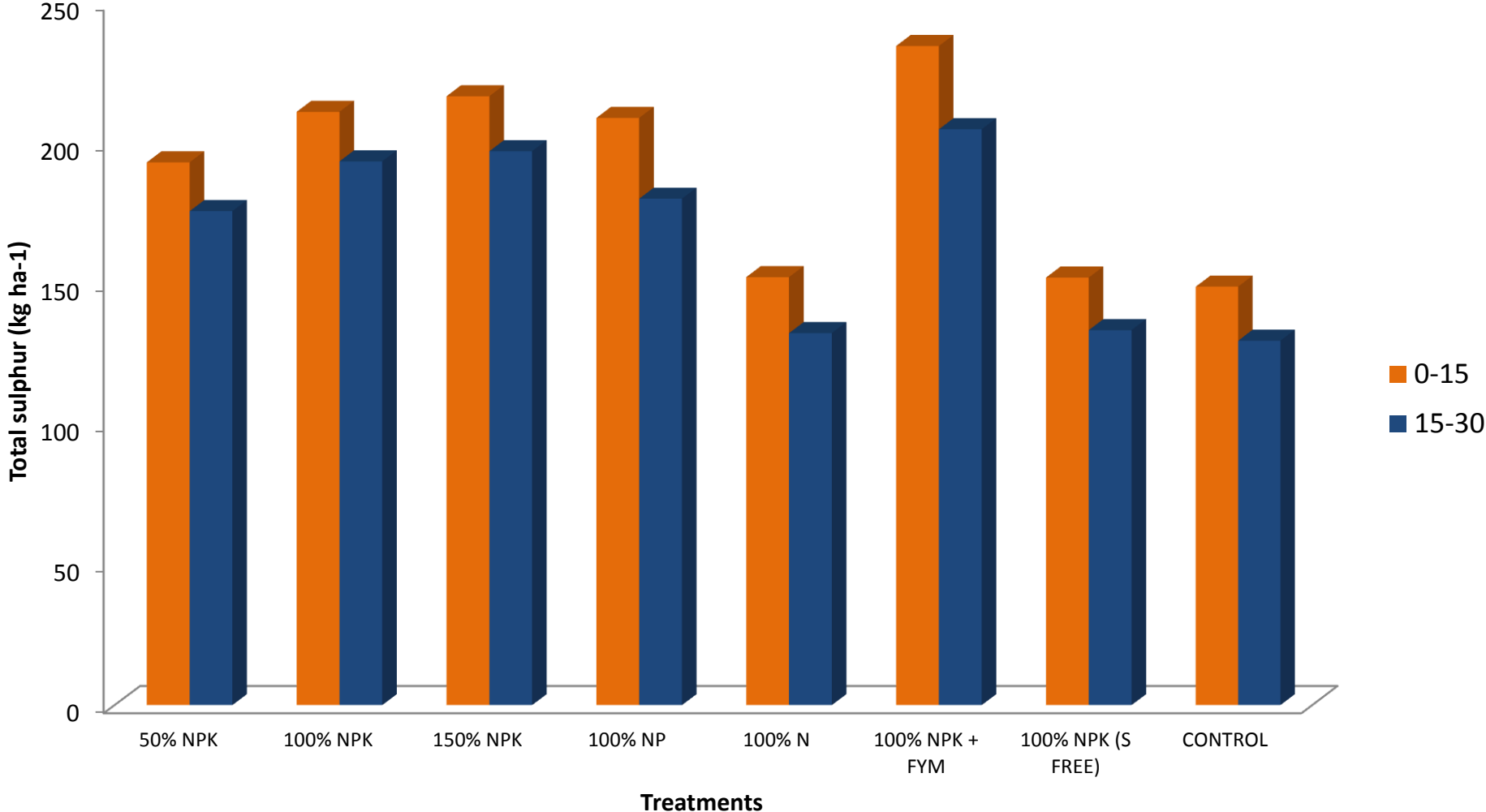
	0-15	15-30
50% NPK	34.67	31.4
100% NPK	38.3	34.48
150% NPK	40.08	36.44
100% NP	34.57	30.11
100% N	25.12	22.33
100% NPK + FYM	49.72	37.38
100% NPK (S FREE)	25.23	23.56
CONTR OL	24.48	21.3

	0-15	15-30
50% NPK	65.42	49.12
100% NPK	71.02	54.63
150% NPK	73	66.79
100% NP	55.31	49.65
100% N	45.81	36.75
100% NPK + FYM	79.01	64.48
100% NPK (S FREE)	44.91	37.59
CONTR OL	43.31	35.39




	0-15	15-30
T <sub>1</sub> -50% N	193.25	175.94
T <sub>2</sub> -100%	211.17	193.6
T <sub>3</sub> -150%	216.71	197.19
T <sub>6</sub> -100%	209.01	180.35
T <sub>7</sub> -100%	152.54	132.68
T <sub>8</sub> -100%	234.53	204.99
T <sub>9</sub> -100%	152.37	133.75
T <sub>10</sub> -CON	149.17	130

Fig. 12. Depth wise distribution of total sulphur (kg ha<sup>-1</sup>)



	0-15	15-30
50% NPK	193.25	175.94
100% NPK	211.17	193.6
150% NPK	216.71	197.19
100% NP	209.01	180.35
100% N	152.54	132.68
100% NPK + FYM	234.53	204.99
100% NPK (S FREE)	152.37	133.75
CONTR OL	149.17	130

925

1100

1225

925

675

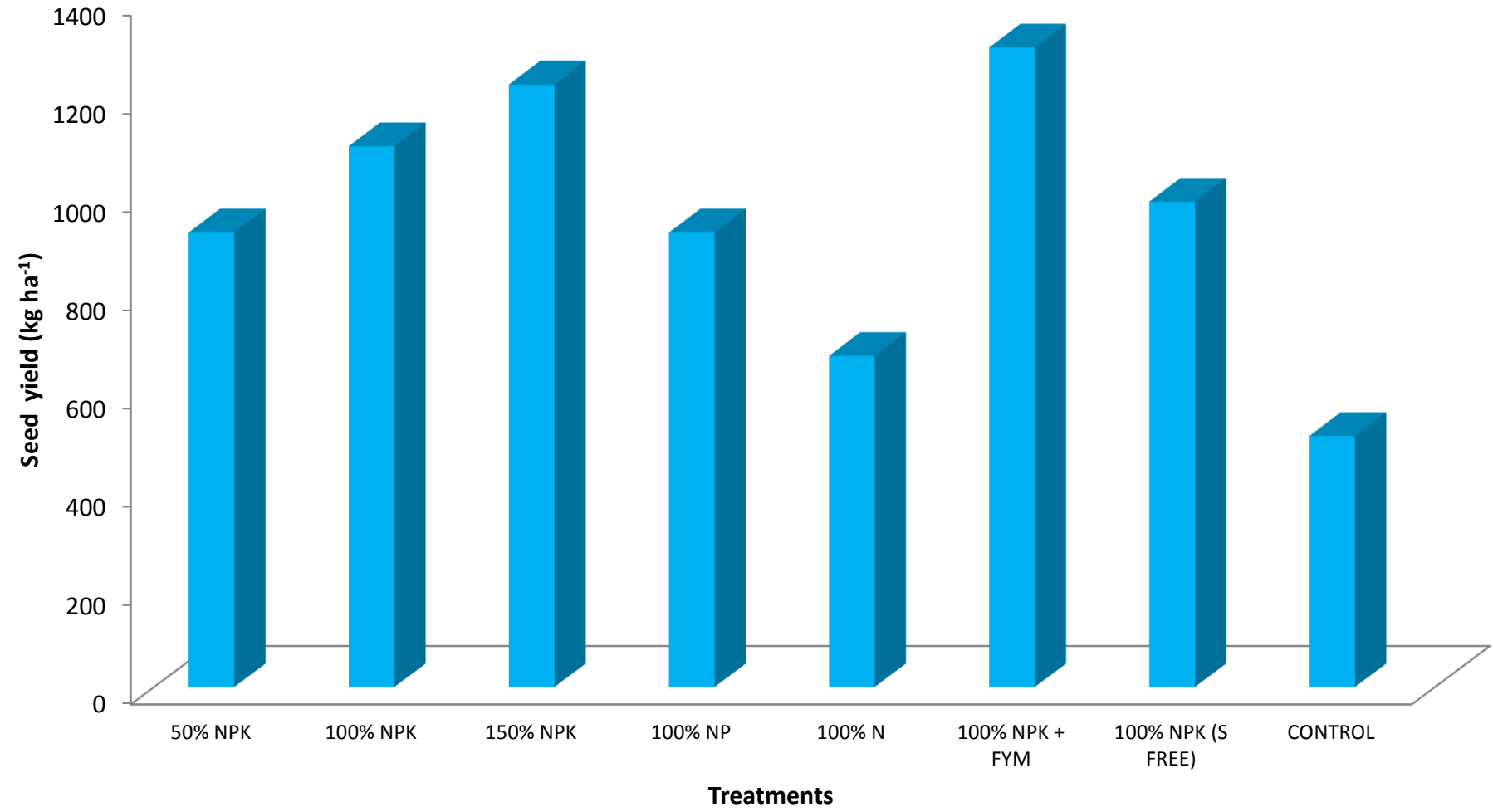
1300

987.5

512.5



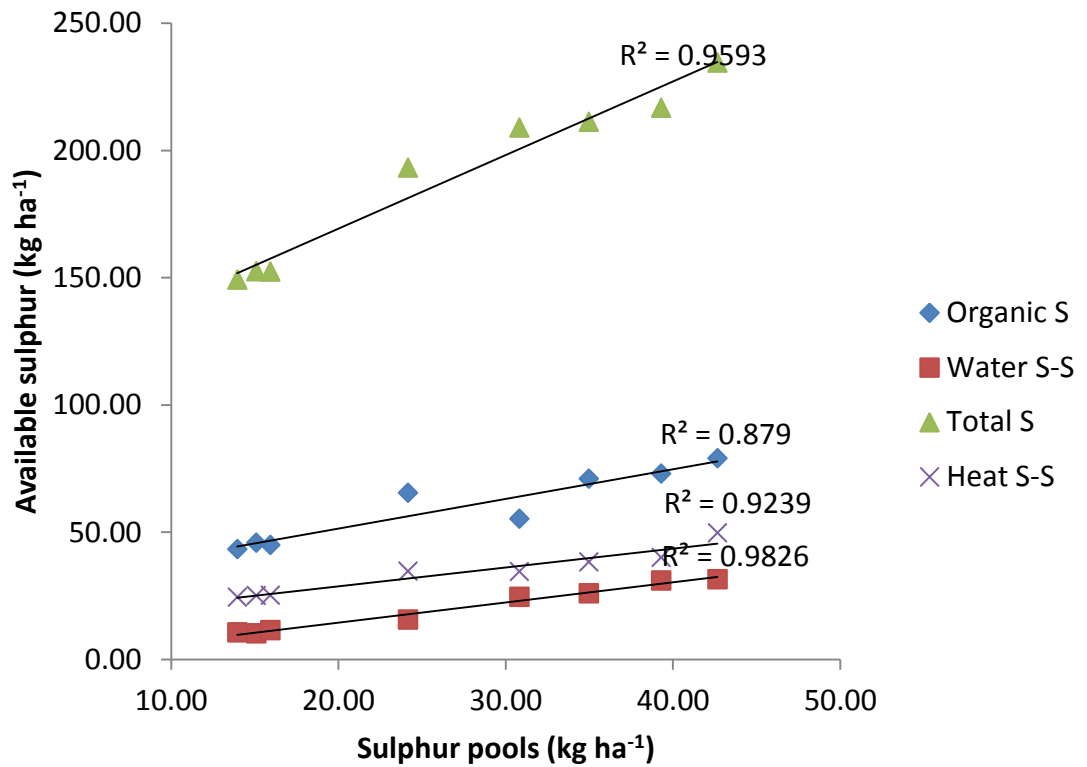
**Fig. 13. Soybean yield at different treatments**



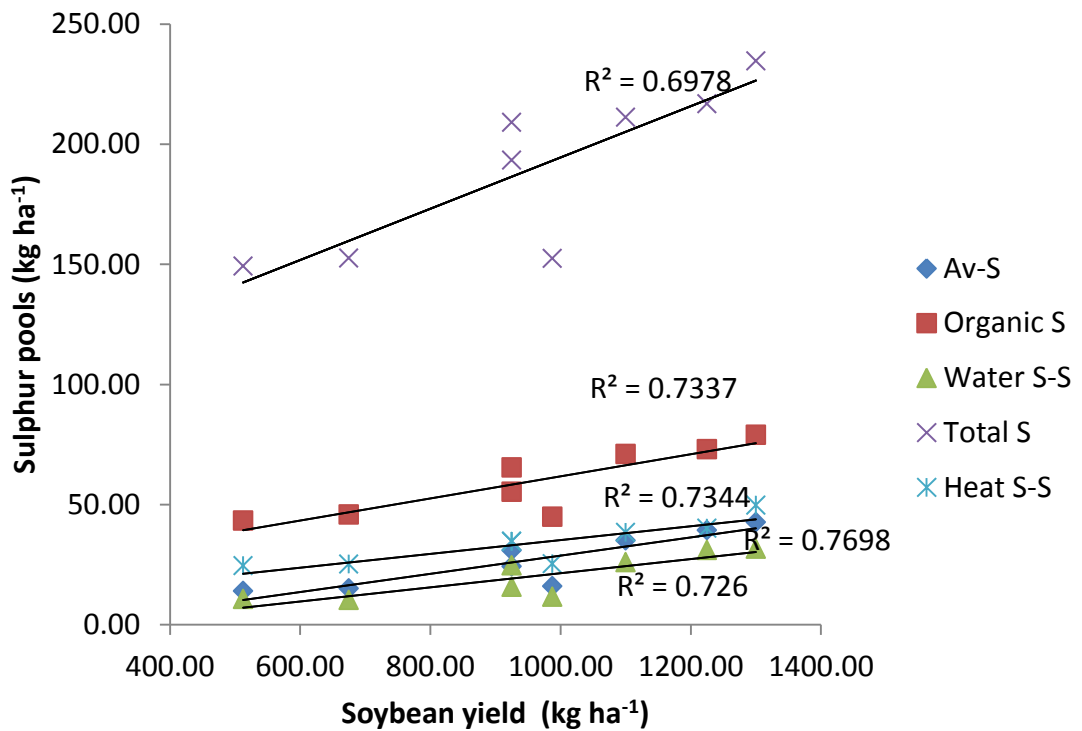
	Mean
50% NPK	925
100% NPK	1100
150% NPK	1225
100% NP	925
100% N	675
100% NPK + FYM	1300
100% NPK (S FREE)	987.5
CONTR OL	512.5



**Fig. 14. Relationship within soil sulphur pools**



**Fig. 15. Relationship between sulphur pools and soybean yield**







<b>Av-S</b>	<b>Organic S</b>	<b>Water S</b>	<b>Total S</b>	<b>Heat S-S</b>
24.17	65.42	15.66	193.25	34.67
34.98	71.02	25.92	211.17	38.30
39.30	73.00	30.97	216.71	40.08
30.82	55.31	24.56	209.01	34.57
15.08	45.81	10.29	152.54	25.12
42.66	79.01	31.55	234.53	49.72
15.94	44.91	11.51	152.37	25.23
13.95	43.31	10.59	149.17	24.48

<b>YIELD</b>	<b>Av-S</b>	<b>Organic S</b>	<b>Water S</b>	<b>Total S</b>	<b>Heat S-S</b>
925.00	24.17	65.42	15.66	193.25	34.67
1100.00	34.98	71.02	25.92	211.17	38.30
1225.00	39.30	73.00	30.97	216.71	40.08
925.00	30.82	55.31	24.56	209.01	34.57
675.00	15.08	45.81	10.29	152.54	25.12
1300.00	42.66	79.01	31.55	234.53	49.72
987.50	15.94	44.91	11.51	152.37	25.23
512.50	13.95	43.31	10.59	149.17	24.48