

**EFFECT OF DIFFERENT LEVELS OF ZEOLITE FOR  
IMPROVEMENT OF SODIC SOIL**

by

**Miss Abhang Koyal Prashant**

**(Reg. No. 018/078)**

**A thesis submitted to the  
MAHATMA PHULE KRISHI VIDYAPEETH  
RAHURI - 413 722, DIST.AHMEDNAGAR  
MAHARSHTRA, INDIA**

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

**of**

**MASTER OF SCIENCE IN (AGRICULTURE)**

**in**

**SOIL SCIENCE AND AGRICULTURAL CHEMISTRY**



**DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL  
CHEMISTRY**

**POST GRADUATE INSTITUTE**

**MAHATMA PHULE KRISHI VIDYAPEETH**

**RAHURI - 413 722, DIST-AHMEDNAGAR**

**MAHARASHTRA, INDIA**

**2021**

**EFFECT OF DIFFERENT LEVELS OF ZEOLITE FOR  
IMPROVEMENT OF SODIC SOIL**

by

**Miss Abhang Koyal Prashant**

**(Reg. No. 018/078)**

**A thesis submitted to the  
MAHATMA PHULE KRISHI VIDYAPEETH  
RAHURI-413 722, DIST-AHMEDNAGAR  
MAHARASHTRA, INDIA**

In the partial fulfillment of the requirements for the degree

of

**MASTER OF SCIENCE (AGRICULTURE)**

in

**SOIL SCIENCE AND AGRICULTURAL CHEMISTRY**

Approved by

**Dr. S. R. Shelke**

(Chairman and Research Guide)

**Dr. A. D. Kadlag**  
(Committee Member)

**Dr. A. G. Durgude**  
(Committee Member)

**Dr. U. S. Surve**  
(Committee Member)

**Dr. C.A. Nimbalkar**  
(Committee Member)

**DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL  
CHEMISTRY**

**POST GRADUATE INSTITUTE  
MAHATMA PHULE KRISHI VIDYAPEETH  
RAHURI - 413 722, DIST. AHMEDNAGAR  
MAHARASHTRA, INDIA**

**2021**

## CANDIDATE'S DECLARATION

I hereby declare that this thesis or part  
thereof has not been submitted  
by me or other person to any  
other University or Institute  
for a Degree or  
Diploma

Place: MPKV., Rahuri

Date: / / 2020

(Miss Abhang K. P.)

**Dr. S. R. Shelke**

Assistant Professor

Post Graduate Institute

Department of Soil Science and Agricultural Chemistry

Mahatma Phule Krishi Vidyapeeth, Rahuri- 413 722

Dist. Ahmednagar, Maharashtra

## **CERTIFICATE**

This is to certify that the thesis entitled, “**EFFECT OF DIFFERENT LEVELS OF ZEOLITE FOR IMPROVEMENT OF SODIC SOIL**” submitted to the Faculty of Agriculture, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahmednagar in partial fulfilment of the requirements for the award of **MASTER OF SCIENCE (AGRICULTURE)** in **SOIL SCIENCE AND AGRICULTURAL CHEMISTRY**, embodies the result of a piece of bonafide research work carried out by **MISS ABHANG KOYAL PRASHANT**, under my guidance and supervision of **Dr. S.R. Shelke**, Assistant Professor, Post Graduate Institute, Department of Soil Science and Agril. Chemistry, M.P.K.V., Rahuri and that no part of the thesis has been submitted for any other Degree or Diploma.

Place: MPKV, Rahuri

**(S.R. Shelke)**

Date:     /     / 2021

**Dr. B. D. Bhakare**

Head

Department of Soil Science and Agricultural Chemistry

Mahatma Phule Krishi Vidyapeeth, Rahuri- 413 722

Dist. Ahmednagar, Maharashtra

## **CERTIFICATE**

This is to certify that the thesis entitled, **“EFFECT OF DIFFERENT LEVELS OF ZEOLITE FOR IMPROVEMENT OF SODIC SOIL”** submitted to the Faculty of Agriculture, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahmednagar in partial fulfilment of the requirements for the award of **MASTER OF SCIENCE (AGRICULTURE)** in **SOIL SCIENCE AND AGRICULTURAL CHEMISTRY**, embodies the result of a piece of bonafide research work carried out by **MISS ABHANG KOYAL PRASHANT**, under the guidance and supervision of **Dr. S.R. Shelke**, Assistant Professor, Post Graduate Institute, Department of Soil Science and Agril. Chemistry, M.P.K.V., Rahuri and that no part of the thesis has been submitted for any other Degree or Diploma.

Place: MPKV., Rahuri

**(B.D. Bhakare)**

Date:     /     / 2021

**Dr. P.N. Rasal**  
Associate Dean  
Post Graduate Institute  
Mahatma Phule Krishi Vidyapeeth  
Rahuri - 413 722, Dist- Ahmednagar  
Maharashtra, India

## **CERTIFICATE**

This is to certify that the thesis entitled, **“EFFECT OF DIFFERENT LEVELS OF ZEOLITE FOR IMPROVEMENT OF SODIC SOIL”**, submitted to the Faculty of Agriculture, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist-Ahmednagar in partial fulfilment of the requirements for the award of **MASTER OF SCIENCE (AGRICULTURE) in SOIL SCIENCE AND AGRICULTURAL CHEMISTRY**, embodies the results of piece of bonafide research work carried out by **MISS ABHANG KOYAL PRASHANT**, under the guidance and supervision of **Dr. S.R. Shelke**, Assistant Professor, Post Graduate Institute, Department of Soil Science and Agril. Chemistry, M.P.K.V., Rahuri and that no part of the thesis has been submitted for any other university for Degree or Diploma.

Place: MPKV., Rahuri

**(P.N. Rasal)**

Date: / /2021

## ACKNOWLEDGEMENT

*Work is workship. The almighty “Lord Ganesha” who lives in every soul truly manifests through work, First of all, I ascribe all glory to the gracious “Lord Ganesha” for his heartfelt benediction and silent blessing which always acts as my saviour in the face of all sorts of peril and paved the path of my life.*

*Mahatma Phule Krishi Vidhyapeeth, Rahuri is not only the reservoir of knowledge but also a flowing river of research and development, fondly coined as “Karmabhoomi” where many stalwarts, versatile scientists, monks preach their disciples. One such amongst is my research guide. It is matter of pride and privilege of expressing my deepest sense of gratitude and indebtedness to my research guide Dr. S. R. Shelke, Assistance Professor, Dept. of Soil Science & Agril. Chemistry MPKV., Rahuri, for his keen interest, constant inspiration, practical suggestions, talented and versed advice and his untiring efforts in preparation of peerless manuscript of this thesis. He has instilled in me the element of scientific thinking and stimulated my deep love for research.*

*I am highly obliged to Dr. K.P. Vishwanatha, Honorable Former Vice Chancellor and Dr. A.S. Dhawan, Honorable Vice Chancellor, MPKV, Rahuri for providing proper administration during the entire course of study.*

*I wish to express my profound sense of gratitude to Dr. A.L. Pharande, Dean, Faculty of Agriculture and Director of Instructions, Dr. P.N. Rasal, Associate Dean (PGI), M.P.K.V., Rahuri and Dr. B.D. Bhakare, Head, Department of Soil Science and Agril. Chemistry, MPKV, Rahuri for giving permission and providing necessary facilities for undertaking the research work.*

*I express my sincere thanks to Dr. A.D. Kadlag, Ex. Soil Chemist (STCR), Department of Soil Science & Agril. Chemistry, Post Graduate Institute, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dr. A.G. Durgude, Analytical Chemist, Micronutrient Research Scheme, Department of Soil Science & Agril. Chemistry, Dr. U.S. Surve, Professor, Department of Soil Science & Agril. Chemistry, Dr. C.A. Nimbalkar, Professor, Department of Statistics, MPKV, Rahuri, for being a members of my advisory committee and also for their honest coaching, extensive help and valuable suggestions during the course of my investigation.*

*It is my pleasure to thank, Dr. N.J. Ranshur, Professor, Dr. M.R. Chauhan, Professor, Dr. S.R. Patil, Associate Professor, Dr. S.D. Kale, Assistant Professor, Shri. I.R. Bagwan, Jr. Research Assistant, Department of Soil Science and Agricultural Chemistry, for their guidance in completing the course work and research work successfully.*

*I extend my special thanks to all the staff members Shri. P.C. Adhav, Shri. Harishchandre, Agril. Assitant for their timely and important help and co-operation and thank Shri. P.Y. Dhage, Agril. Assist. SSAC and help from Shri. Gawade Sanjay, Shri. Ranjit Patil and all office staff for their immense cooperation.*

*The logistical support and advice from my seniors, Mr. Sakore, Mr. Suradkar, Miss Pratiksha, Miss Manisha, Miss. Darshana, Mr. Ajabe, Miss Shital, Miss Nikita, Miss Pooja, Miss Aishwarya and Miss Pradnya gratefully acknowledged.*

*I like to specially thank from the bottom of my heart my classmates Akash, Vishal, Tejas, Girish, Ganesh, Akshay, Shubham, Shashikant, Priyanka, Vinitha and Priyanka for their help, support and uplifting the spirit in every step of my research work. I also like to remember the company of my juniors.*

*Words are not enough to express my gratitude, love and affection to my loving grandmother Laxmibai Gore, my parents Abhang Prashant (papa) and Nirmala Abhang (Aai),*

*my most loving sister Komal Vidhate, my sweet nephew Shlok Vidhate, Subhash Gore (Mama), Prakash Gore (Mama), Mangal Birdawade (Mavashi) who always stood like a lighthouse for illumination in the pathway of my life, moulding me and building up my educational career, without whom I could not have made it here. I am feeling blessed for my lovable little cousins Kajal, Achal, Samruddhi, Meghana, Chaitntya, for making my life colourful and joyful*

*I shall be failing in my duties, if I do not express my heart felt gratitude to my Evergreen best friends Ankita, Mrugaja, Dnyaneshwar, Tushar, Sachin, Ganesh and Shubham, for being the source of encouragement, patience, and for having faith in me and supporting my decisions and gave me moral strength and emotional support during my study and same will continue for my entire life.*

*I am also deeply obliged to all those authors and scientists, past and present, whose contribution were of immense help to understand the research finding as their literature has been aptly cited in the present investigation.*

*While travelling on this path of education many hands pushed me fourth, learned hearts put me on the right track enlightened by their knowledge and experience. I ever rest thank to all of them.*

*Place : MPKV., Rahuri*

*Date : / /2021*

*(Abhang K. P.)*

## CONTENTS

Chapter No.	Title	Page No.
	<b>CANDIDATES DECLARATION</b>	I
	<b>CERTIFICATE OF RESEARCH GUIDE</b>	II
	<b>CERTIFICATE OF HEAD OF THE DEPARTMENT</b>	III
	<b>CERTIFICATE OF ASSOCIATE DEAN</b>	IV
	<b>AKNOWLEDGEMENT</b>	V
	<b>CONTENTS</b>	VII
	<b>LIST OF TABLES</b>	IX
	<b>LIST OF ABBREVIATIONS</b>	X
	<b>ABSTRACT</b>	XII
<b>1</b>	<b>INTRODUCTION</b>	1
<b>2</b>	<b>REVIEW OF LITERATURE</b>	5
	2.1 Extent of sodic soil in India and Maharashtra	5
	2.2 Characteristics of sodic soil	5
	2.3 Zeolite as soil amendment for improvement of sodic soil	9
	2.4 Zeolite	9
	2.5 Types of zeolite	10
	2.6 Properties of zeolite	11
	2.6.1 Effect of Zeolite on Ion Exchange of Sodic Soil	11
	2.6.2 Effect of Zeolite on Cation Exchange Capacity (CEC) of Sodic Soil	11
	2.7 Effect of application of gypsum on sodic soil	12
	2.8 Effect of application of gypsum on chemical properties of sodic soil	14
	2.8.1 Soil pH	14
	2.8.2 Electrical Conductivity (EC <sub>e</sub> )	14
	2.8.3 Exchangeable Sodium Percentage (ESP)	15
	2.8.4 Sodium	16
	2.9 Effect of different levels of zeolite application on soil available nutrient	17
	2.10 Effect of zeolite application on soil properties	18
	2.10.1 Effect of Zeolite Application on Physical Properties of Soil	18
	2.10.2 Effect of Zeolite Application on Chemical Properties of Soil	19
	2.11 Effect of zeolite application on water use efficiency	21
	2.12 Effect of zeolite application for reclamation of sodic soil	21
	2.13 Optimum level of zeolite for improvement of sodic soil	21
	2.14 Effect of application of zeolite on Periodical release and movement of salt in soil column	22
	2.15 Effect of application of gypsum on Periodical release and movement of salt in soil column	22
	2.16 Effect of zeolite application on depth wise movement and concentration of different salt	23

<b>3</b>	<b>MATERIAL AND METHODS</b>		24
	3.1	Material	24
	3.1.1	Location	24
	3.1.2	Soils	24
	3.1.3	Climate	24
	3.1.4	Sources of Amendment	24
	3.1.5	PVC Pipe Procurement	26
	3.2	Method	26
	3.2.1	Experimental Details	26
	3.2.2	Preparation of Soil Column	27
	3.3	Details of laboratory analysis	28
	3.3.1	Laboratory Material	28
	3.4	Statistical analysis	29
<b>4</b>	<b>RESULTS AND DISCUSSION</b>		30
	4.1	Effect of amendment on leaching behaviour of soil	31
	4.2	Effect of amendment on characteristics of leachate	32
	4.2.1	Effect of Graded Levels of Zeolite on Periodical pHs Leachate in Sodic Soils	32
	4.2.2	Effect of Graded Levels of Zeolite on Periodical Electrical Conductivity of Leachate in Sodic Soils	33
	4.2.3	Effect of Graded Levels of Zeolite on Periodical Calcium Content of Leachate in Sodic Soils	34
	4.2.4	Effect of Graded Levels of Zeolite on Periodical Magnesium Content of Leachate in Sodic Soil	35
	4.2.5	Effect of Graded Levels of Zeolite on Periodical Sodium Content of Leachate in Sodic Soil	36
	4.2.6	Effect of Graded Levels of Zeolite on Periodical Potassium Content of Leachate in Sodic Soil	38
	4.2.7	Effect of Graded Levels of Zeolite on Periodical Bicarbonate Content of Leachate in Sodic Soil	39
	4.2.8	Effect of Graded Levels of Zeolite on Periodical Chloride Content of Leachate in Sodic Soil	40
	4.2.9	Effect of Graded Levels of Zeolite on Periodical Sulphate Content of Leachate in Sodic Soil	41
	4.3	Impact of amendment on chemical properties of soil	42
	4.3.1	Effect of Graded Levels of Zeolite on Depth wise pHs in Column of Sodic Soil	42
	4.3.2	Effect of Graded Levels of Zeolite on Depth wise Electrical Conductivity in Column of Sodic Soil	43
	4.3.3	Effect of Graded Levels of Zeolite on Depthwise Calcium Content in Column of Sodic Soil	44
	4.3.4	Effect of Graded Levels of Zeolite on Depth wise Magnesium Content in Column of Sodic Soil	45
	4.3.5	Effect of Graded Levels of Zeolite on Depth wise Sodium Content in Column of Sodic Soil	45

	4.3.6	Effect of Graded Levels of Zeolite on Depth wise Potassium Content in Column of Sodic Soil	46
	4.3.7	Effect of Graded Levels of Zeolite on Depth wise Bicarbonate Content in Column of Sodic Soil	47
	4.3.8	Effect of Graded Levels of Zeolite on Depth wise Sulphate Content in Column of Sodic Soil	48
	4.3.9	Effect of Graded Levels of Zeolite on Depth wise chloride Content in Column of Sodic Soil	48
	4.3.10	Effect of Graded Levels of Zeolite on Depth wise Cation Exchange Capacity in Column of Sodic Soil	49
	4.3.11	Effect of Graded Levels of Zeolite on Depth wise Sodium Adsorption Ratio in Column of Sodic Soil	50
	4.3.12	Effect of Graded Levels of Zeolite on Depth wise Exchangeable Sodium Percentage in Column of Sodic Soil	51
	4.4	Impact of amendment on physical properties of soil	51
	4.4.1	Effect of Graded Levels of Zeolite on Depth wise Bulk Density in Column of Sodic Soil	51
	4.4.2	Effect of Graded Levels of Zeolite on Depth wise Hydraulic Conductivity in Column of Sodic Soil	52
<b>5</b>	<b>SUMMARY AND CONCLUSION</b>		54
	5.1	Effect of graded levels of zeolite application on chemical properties of soil after 120 days	54
	5.1.1	pHs	54
	5.1.2	Electrical Conductivity (ECe)	54
	5.1.3	Calcium	54
	5.1.4	Magnesium	54
	5.1.5	Sodium	54
	5.1.6	Potassium	54
	5.1.7	Bicarbonate	55
	5.1.8	Chloride	55
	5.1.9	Sulphate	55
	5.1.10	Cation Exchange Capacity	55
	5.1.11	Sodium Adsorption Ratio	55
	5.1.12	Exchangeable Sodium Percentage	55
	5.2	Effect of graded levels of zeolite application on physical properties of soil after 120 days	55
	5.2.1	Bulk Density	55
	5.2.2	Hydraulic Conductivity	55
	5.3	Conclusion	55
<b>6</b>	<b>LITERATURE CITED</b>		56
<b>7</b>	<b>VITAE</b>		67

## LIST OF TABLES

Table No.	Description	Page No.
3.1	Initial properties of soil	25
3.2	Characterization of amendment	26
3.3	Treatment details	26
3.4	Observation recorded in experiment	27
3.5	Standard methods for analysis of soil and zeolite sample	28
4.1	Effect of amendment on leaching behaviour of soil	31
4.2	Effect of graded levels of zeolite on periodical pHs of leachate in sodic soil	32
4.3	Effect of graded levels of zeolite on periodical electrical conductivity of leachate in sodic soil	33
4.4	Effect of graded levels of zeolite on periodical calcium content of leachate in sodic soil	34
4.5	Effect of graded levels of zeolite on periodical magnesium content of leachate in sodic soil	35
4.6	Effect of graded levels of zeolite on periodical sodium content of leachate in sodic soil	36
4.7	Effect of graded levels of zeolite on periodical potassium content of leachate in sodic soil	38
4.8	Effect of graded levels of zeolite on periodical bicarbonate content of leachate in sodic soil	39
4.9	Effect of graded levels of zeolite on periodical chloride content of leachate in sodic soil	40
4.10	Effect of graded levels of zeolite on periodical sulphate content of leachate in sodic soil	41
4.11	Effect of graded levels of zeolite on depth wise pHs in column of sodic soil	42
4.12	Effect of graded levels of zeolite on depth wise electrical conductivity in column of sodic soil	43
4.13	Effect of graded levels of zeolite on depth wise calcium content in column of sodic soil	44
4.14	Effect of graded levels of zeolite on depth wise magnesium content in column of sodic soil	45
4.15	Effect of graded levels of zeolite on depth wise sodium content in column of sodic soil	46
4.16	Effect of graded levels of zeolite on depth wise potassium content in column of sodic soil	46
4.17	Effect of graded levels of zeolite on depth wise bicarbonate content in column of sodic soil	47
4.18	Effect of graded levels of zeolite on depth wise sulphate content in column of sodic soil	48
4.19	Effect of graded levels of zeolite on depth wise chloride content in column of sodic soil	49
4.20	Effect of graded levels of zeolite on depth wise cation exchange capacity in column of sodic soil	49
4.21	Effect of graded levels of zeolite on depth wise sodium adsorption ratio in column of sodic soil	50
4.22	Effect of graded levels of zeolite on depth wise exchangeable sodium percentage in column of sodic soil	51
4.23	Effect of graded levels of zeolite on depth wise bulk density in column of sodic soil	52
4.24	Effect of graded levels of zeolite on depth wise hydraulic conductivity in column of sodic soil	52

## LIST OF FIGURES

<b>Fig. No.</b>	<b>Description</b>	<b>Between page</b>
4.1	Effect of graded levels of zeolite on pHs of leachate in sodic soil	34-35
4.2	Effect of graded levels of zeolite on Electrical conductivity of leachate in sodic soil	34-35
4.3	Effect of graded levels of zeolite on periodical calcium content of leachate in sodic soil	36-37
4.4	Effect of graded levels of zeolite on periodical magnesium content of leachate in sodic soil	36-37
4.5	Effect of graded levels of zeolite on periodical sodium content of leachate in sodic soil	38-39
4.6	Effect of graded levels of zeolite on periodical potassium content of leachate in sodic soil	38-39
4.7	Effect of graded levels of zeolite on periodical bicarbonate content of leachate in sodic soil	40-41
4.8	Effect of graded levels of zeolite on periodical Chloride content of leachate in sodic soil	40-41
4.9	Effect of graded levels of zeolite on periodical Sulphate content of leachate in sodic soil	42-43
4.10	Effect of graded levels of zeolite on depth wise pHs in column of sodic soil	44-45
4.11	Effect of graded levels of zeolite on depth wise Electrical conductivity in column of sodic soil	44-45
4.12	Effect of graded levels of zeolite on depth wise Calcium content in column of sodic soil	46-47
4.13	Effect of graded levels of zeolite on depth wise Magnesium content in column of sodic soil	46-47
4.14	Effect of graded levels of zeolite on depth wise sodium content in column of sodic soil	46-47
4.15	Effect of graded levels of zeolite on depth wise Potassium content in column of sodic soil	46-47
4.16	Effect of graded levels of zeolite on depth wise bicarbonate content in column of sodic soil	48-49
4.17	Effect of graded levels of zeolite on depth wise sulphate content in column of sodic soil	48-49
4.18	Effect of graded levels of zeolite on depth wise Chloride content in column of sodic soil	50-51
4.19	Effect of graded levels of zeolite on depth wise cation exchange capacity in column of sodic soil	50-51
4.20	Effect of graded levels of zeolite on depth wise sodium adsorption ratio in column of sodic soil	52-53
4.21	Effect of graded levels of zeolite on depth wise Exchangeable sodium percent in column of sodic soil	52-53
4.22	Effect of graded levels of zeolite on depth wise bulk density in column of sodic soil	52-53
4.23	Effect of graded levels of zeolite on depth wise Hydraulic conductivity in column of sodic soil	52-53

**LIST OF PLATES**

<b>Plate. No.</b>	<b>Description</b>	<b>Between page</b>
3.1	General View of Soil Column	26-27

## LIST OF ABBREVIATIONS

%	: Percent
@	: At the rate of
<	: Less than
>	: Greater than
BD	: Bulk density
CaCO <sub>3</sub>	: Calcium Carbonate
CD	: Critical Difference
CEC	: Cation exchange capacity
cm	: Centimeter
cm hr <sup>-1</sup>	: Centimeter per hour
cmole (p <sup>+</sup> ) kg <sup>-1</sup>	: Centimol positive charge per kg of soil
CRD	: Completely Randomized Design
DOL	: Days of leachate
dS m <sup>-1</sup>	: Deci Siemen per meter
DW	: Distilled water
EC	: Electrical Conductivity
ECe	: Electrical conductivity of soil extract
ESP	: Exchangeable sodium percentage
<i>et al.</i>	: Et alli. (any other)
etc.	: Etcetera (and so on)
Ex.	: Exchangeable
Fig.	: Figure
FYM	: Farm yard manure
GR	: Gypsum requirement
ha	: Hectare
i.e.	: Id est (That is)
J.	: Journal
Kg	: Kilogram(s)
kg ha <sup>-1</sup>	: Kilogram (s) per hectare
me L <sup>-1</sup>	: Milli equivalent per litre
Mg m <sup>-3</sup>	: Megagram per cubic meter
M ha	: Million hectare
No.	: Number
NS	: Non-significant
pH	: Negative logarithm of hydrogen ion activity

pHs	:	pH of soil saturation paste extract
ppm	:	Parts per million
PVC	:	Polyvinyl chloride
q ha <sup>-1</sup>	:	Quintal per hectare
SE	:	Standard error
SE(m)	:	Standard error of mean
SAR	:	Sodium absorption ratio
t ha <sup>-1</sup>	:	tonn per hectare
wt	:	Weight
<i>Viz.</i>	:	Vide licent (namely)

---

---

**ABSTRACT**


---

**EFFECT OF DIFFERENT LEVELS OF ZEOLITE FOR IMPROVEMENT OF SODIC SOIL**

by

**Miss Abhang Koyal Prashant**

A candidate for the degree

of

MASTER OF SCIENCE (AGRICULTURE)

in

SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

2021

**Research Guide : Dr. S.R. Shelke**

Department : Soil Science and Agricultural Chemistry

The present investigation was carried out in Department of Soil Science and Agricultural Chemistry, Post Graduate Institute, MPKV, Rahuri to study the “Effect of different levels of zeolite for improvement of sodic soil”.

The soil samples were taken from PGI Farm field in the month of April 2019 at 0-30, 30-60, 60-90 cm depth. The sampling site was the representative black sodic soil. Soil amendments *viz.*, Gypsum, Zeolite with FYM were added in the soil column. The saturated soil columns were allowed to leach out with water collected from column for 120 days. The experiment was laid out in completely randomized design with nine treatments and three replications. The treatments were T<sub>1</sub> : Absolute control, T<sub>2</sub> : Gypsum as per GR, T<sub>3</sub> : Zeolite @ 400 kg ha<sup>-1</sup>, T<sub>4</sub> : Zeolite @ 600 kg ha<sup>-1</sup>, T<sub>5</sub> : Zeolite @ 800 kg ha<sup>-1</sup>, T<sub>6</sub> : Zeolite @ 1000 kg ha<sup>-1</sup>, T<sub>7</sub> : Zeolite @ 1200 kg ha<sup>-1</sup>, T<sub>8</sub> : Zeolite @ 1400 kg ha<sup>-1</sup>, T<sub>9</sub> : Zeolite @ 600 kg ha<sup>-1</sup> + 100% Gypsum as per GR

The pHs and electrical conductivity (EC<sub>e</sub>) of leachate were decreased due to application of zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR with successive leaching. During leaching, the concentration of magnesium, sodium, chloride, bicarbonate and sulphate in leachate was maximum at first day of leaching and decreases thereafter. The result showed that the application of zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR was effective in reducing the salts from soil followed by Gypsum as per GR.

The pHs of saturation paste extract of soil after continuous leaching decreased in all treatments at all three depth as compared to initial value. The pHs considerably decreased with the application of Zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR which was superior over all other treatments, the decrease in pHs were 8.10, 8.15 and 8.21 at 0-30, 30-60 and 60-90 cm depths respectively.

Electrical conductivity of saturation paste extract of soil after continuous leaching with application of Zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR was increased at all three depth i.e. 0-30, 30-60 and 60-90 cm over initial value. The maximum value was recorded with zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR.

The calcium content in saturation paste extract of soil increased and maximum calcium was recorded with the application of Zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR and it was increased with increasing depth. The concentration of magnesium increases as the depth of soil increases. The maximum increase in magnesium was found in T<sub>9</sub>.

Sodium content after leaching in soil was decreased over initial value at all three depth and maximum sodium was decreased with application of zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR. The potassium content in saturation paste extract of soil was reduced over initial

value at all three layers of soil and it was reduced by the application of Zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR followed by gypsum as per GR.

The bicarbonate content in saturation paste extract of soil after leaching with amendments was maximum recorded at all the depth in T<sub>9</sub> treatment. The chloride content in soil was decreased over initial value at all the depth and the maximum reduction was observed with zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR. Sulphate content in saturation paste extract of sodic soil was increased by the application of Zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR.

The cation exchange capacity of soil decreased in all the treatment and the maximum reduction was observed in T<sub>9</sub>. The sodium adsorption ratio of saturation paste extract was decreased after leaching over initial value in all treatment. The maximum reduction in SAR was recorded in T<sub>9</sub> treatment among all other treatment at all three depths. The ESP value decreased considerably by leaching. The ESP value was decreased in all treatment and the maximum reduction in ESP was recorded with zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR ie. 1.69, 5.03 and 6.34 % with 0-30, 30-60 and 60-90 cm depth respectively.

Bulk density of soil was decreased by application of zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR over initial after leaching whereas hydraulic conductivity was increased considerably after leaching with zeolite and gypsum.

From these results it is clear that when soil was irrigated with available irrigation water, amendments play a key role to remove the salts and hazardous ions from soil up to some extent and the results revealed that the amendment can help in improving sodic soil condition.

## 1. INTRODUCTION

In India, the area under saline and sodic soil extend up to 6.73 million hectares (saline- 2.95 M ha and sodic- 3.77 M ha) with states of Gujrat (2.23 M ha), UP (1.37Mha), WB (0.44 M ha), Rajsthan (0.38 M ha) (Sharma *et al.*, 2015). In Maharashtra, area affected under salt affected soil is 0.61 M ha (saline-0.184 M ha and sodic-0.422 M ha) due to the salinity and alkalinity in cotton growing tracts. Salinity is one of the causes to convert the cultivated soil into unproductive form due to indiscriminate use of irrigation water, imbalance use of chemical fertilizers and lack of organic matter. Out of the several reasons of declining cotton yield in the State during last two decades one major cause is ascribed due to saline sodic soils.

Soil salinity/sodicity is one of the most serious forms of soil quality degradation affecting approximately 10 per cent of the total land surface of the globe. The problem occurs in varying intensities in more than 120 countries and is more prominently increased in the arid and semi-arid region. Irrigation induced problems of water logging, secondary salinization and sodification goes hand in hand. These problem goes a great threat to the sustainable agricultural productivity. In Maharashtra, the problem of saline and sodic soils has assumed a greater importance with the introduction of new irrigation projects. With increasing irrigation potential, the danger of soil deterioration has also increased. Varade *et al.* (1985) reported that approximately 10-12 per cent of irrigable shrink-swell vertisol soil in each irrigation project of Maharashtra is adversely affected due to the salts and water lodging problem and have turned into saline and sodic.

Among the different categories of salt affected soils in India, the Verstisols region is one of the important groups where secondary salinization has claimed large area in western and southern India. In Maharashtra about 0.54 M ha of black soils were initially reported to be salt affected (Abhange *et al.*, 1986) which have been increased to 1.06 M ha i.e. 3.4 per cent of the total geographical area (Gaikwad and Challa, 1996). Durgude (1999) reported that after 27 years of introduction of canal irrigation system, out of total area of 3548.30 ha. of Central Research Farm, M.P.K.V., Rahuri, 227.2 ha. Soils were salt affected. The area under saline soil was 23.30 ha, saline-sodic soil 83.12 ha. and sodic soil was 120.76 ha.

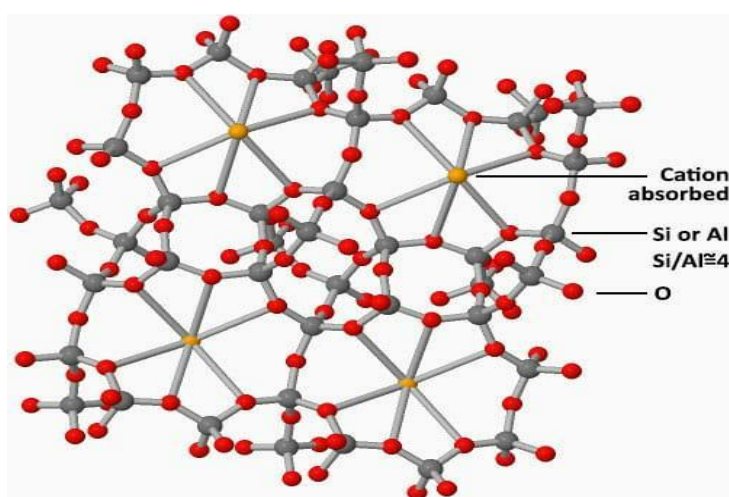
The distinguishing characteristics of sodic soils are high exchangeable sodium per cent ( $ESP > 15$ ),  $E_{c} < 4 \text{ dS m}^{-1}$ ,  $pH > 8.2$  and presence of higher amounts of carbonate and bicarbonates of  $\text{Na}^+$ . sodic soils, due to high ESP, possess poor physical and chemical properties. The high exchangeable  $\text{Na}^+$  content of these soils leads to dispersion of fine clay particles resulting into low permeability, crusting and hardening of the surface soil upon drying. As a result, the aeration, soil-water movement and root growth hampered. The soil has poor aggregate stability, low organic matter content, toxic concentration of  $\text{CO}_3^{2-}$  and  $\text{HCO}_3^-$ , poor microbial activity due to strong alkaline pH and reduced availability of N, K, Zn and Fe which affect the productivity of these soils (Sen, 2003). The presence of high amount of salts in soil profile

adversely affect the availability and uptake of mineral nutrients and consequently the crop growth and its quality.

Zeolites were first introduced by a Swedish Mineralogist, A.F. Cronstedt in 1756, with the discovery of the mineral Stilbite. By heating with a blowpipe flames this mineral lost water. He called this mineral “zeolite” from the Greek ‘zeo’, to boil and ‘lithos’, stone. Since their discovery, zeolites are one of the most abundant minerals on earth which have been recognized as a separate group of minerals. After the discovery of zeolites work was carried out on ion exchange, hydration and dehydration. Other useful chemical and physical properties include: high void volume (50%), low density (2.1- 2.2 g cm<sup>-1</sup>), excellent molecular sieve properties and high cation exchange capacity (CEC) of 150–250 cmol (p<sup>+</sup>) kg<sup>-1</sup> (Bhattacharyya *et al.*, 2015), cation selectivity, specifically for cations like ammonium, potassium, cesium, etc. (Auerback *et al.*, 2003).

Zeolites are hydrated aluminosilicate minerals made from interlinked tetrahedra of alumina (AlO<sub>4</sub>) and silica (SiO<sub>4</sub>). In simpler words, they are solids with a relatively open, 3-dimensional crystal structure built from the element aluminum, oxygen, and silicon, with alkali or alkaline earth metals (such as sodium, potassium, and magnesium) plus water molecules trapped in the gaps between them. Zeolites form with many different crystalline structures, which have large open pores (sometimes referred to as cavities) in a very regular arrangement and roughly the same size as small molecules.

Zeolites are used successfully in the cultivation of a wide variety of crops including cereals, vegetables, grapes and other fruits (Burriesci *et al.*, 1984; Anonymous, 2004ab).



**Fig. 1.1 The tetrahedral framework of clinoptilolite zeolite**

Zeolites are composed of pores and corner sharing aluminosilicate (AlO<sub>4</sub> and SiO<sub>4</sub>) tetrahedrons, joined into 3-dimensional frame works. The pore structure is characterized by cages approximately 12 Å in diameter, which are interlinked through channels about 8 Å in diameter, composed of rings of 12 linked tetrahedrons (Kaduk and Faber, 1995). The pores are

interconnected and form long wide channels of varying sizes depending on the mineral. These channels allow the easy movement of the resident ions and molecules into and out of the structure. Zeolites have large vacant spaces or cages within and resemble honey comb or cage like structures.

Zeolites have the ability to lose and gain water reversibly, without the change of crystal structure, they could be used as fertilizers, stabilizers and chelators (Perez-Caballero *et al.*, 2008). As an example, a study has shown that zeolites enable both inorganic and organic fertilizers to slowly release their nutrients (Perez Caballero *et al.*, 2008). However, there is lot of information on the right amount of zeolites to be used with for instance inorganic and organic fertilizers.

Natural zeolite minerals in India were reported in amygdaloidal vesicles in the Deccan lava flows. Since the 1970s, the state of Maharashtra has provided zeolites that have come out of the enormous lava flows called the Deccan Traps were reported way back in the 18<sup>th</sup> century itself (Dana, 1854), regarding their formation and distribution in the lava flows. These minerals do not occur everywhere in the Western Deccan Traps, but are restricted to certain localities around Mumbai (Bombay), Vadodara (Baroda), Pune (Poona) and Nasik (Sukheswala *et al.*, 1974). Heulandites (most popular zeolites of the world) zone was found in the high lands of plateau in the region around Pune (Maharashtra) which is the top-most region up to the highest point Kalsubai. In this region, around 30% of the rock is occupied by zeolites (Phadke, 1984). It has been shown that zeolites, with their specific selectivity for ammonium ( $\text{NH}_4^+$ ), can take up this specific cation from either farmyard manure, composts or ammonium-bearing fertilizers, thereby reducing losses of nitrogen to the environment (Kocakusak *et al.*, 2001).

Gypsum is chemically  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$  and is a white mineral that occurs extensively in natural deposits. It must be ground before it is applied to the soil. Gypsum is soluble in water to the extent of about one-fourth of 1 per cent and is, therefore, a direct source of soluble calcium. Gypsum reacts with both the  $\text{Na}_2\text{CO}_3$ , and the adsorbed sodium. Gupta *et al.* (2016) reported that the combined application of gypsum and organic amendments in sodic soils improved soil properties, resulting in decreased soil bulk density, electrical conductivity (EC), and exchangeable sodium percentage (ESP), but also increased soil biological activity. The effective solubility of gypsum when mixed with a sodic soil is increased because the exchange phase acts as a sink for  $\text{Ca}^{2+}$  until both the gypsum dissolution and exchange reactions reach equilibrium. The electrical conductivity of a soil solution in equilibrium with both gypsum and an exchangeable sodium fraction (E Na) of 0.0 and 0.43 is 2.3 and 14  $\text{dS m}^{-1}$ . Thus, mixing gypsum into the soil hastens reclamation and provides higher solution amount of gypsum dissolved, expressed in moles of charge (equivalents), is a linear function of the moles of exchangeable  $\text{Na}^+$  replaced. With the above background information, the present investigation entitled, "Effect of

different levels of zeolite for improvement of sodic soil” was carried with the following objectives

1. To find out the optimum levels of zeolite for improvement of sodic soil.
2. To study the periodical release and movement of salts in the soil column.
3. To study the depth wise movement and concentration of different salts by zeolite.

## 2. REVIEW OF LITERATURE

### 2.1 Extent of Sodic Soil in India and Maharashtra

Murthy *et al.* (1982) reported that sodic soils of the Indo-Gangetic plains alone account for roughly one-third of the 7 million hectares of the salt affected soils in India. They have attempted classification of salt affected soils in India, according to Soil Taxonomy, into 12 distinct units at the great group - association level. Coastal salt affected soil of arid region in Gujrat state having area 0.714 M ha. 1.394 M ha area are found under deltaic coastal salt affected soils of the humid region in west Bengal, orisha, Andhra Pradesh and Tamil Nadu region. Sodic soils of the Indo-Gangetic pains having area 2.500 M ha in Haryana, Punjab, Uttar Pradesh, Bihar, Rajasthan and Madhya Pradesh.

Ford *et al.* (1993) reported that sodic soils cover approximately 59 % of Victoria and at least 73 % of the state agricultural land.

Gaikwad and Challa (1996) and Abhange *et al.* (1986) stated that among the different categories of salt affected soils in India, the verstisols region is one of the important groups where secondary salinization has claimed large area in western and southern India. In Maharashtra about 0.54 M ha of black soils were initially reported to be salt affected which have been increased to 1.06 M ha i.e. 3.4 per cent of the total geographical area.

In Maharashtra, about 0.54 M ha of black soils were initially reported to be salt affected (Abhang *et al.*, 1986) which have been increased to 1.06 M ha i.e. 3.4 per cent of the total geographical area (Gaikwad and Challa, 1996).

Tanji (1990) reported that salt affected soils are widely spread in many arid and semiarid regions of the world and increasingly threatening agricultural expansion and productivity. An important category of salt affected soils is saline-sodic soils with worldwide occurrence of 560 M ha.

Gharaibeh *et al.* (2009) studied that more than one-third of the land suitable for agriculture (~0.5 M ha) is salt affected soil in the Jordan Valley.

Oster *et al.* (1996) observed that salts affected soil (salinity and sodicity) are common occur in arid and semi-arid regions of the world.

Varade *et al.* (1985) reported that problem of saline and sodic soils has assumed a greater importance with the introduction of new irrigation projects. With increasing irrigation potential, the danger of soil deterioration has also increased. Approximately 10-12 per cent of irrigable shrink-swell vertisol soil in each irrigation project of Maharashtra is adversely affected due to the salts and water lodging problem and have turned into saline and sodic.

### 2.2 Characteristics of Sodic Soil

Sunitha *et al.* (2010) studied on characterized salt affected soils of Dodda seebi tank command area of Tumkur district of Karnataka and reported that the soils were alkaline in

reaction, with pH ranging from 8.5-9.0 with tendency to increase with depth. Electrical conductivity of the surface soil ranged from 1.94 - 2.78 dS m<sup>-1</sup>, organic carbon ranged from 2.59 to 4.60 g kg<sup>-1</sup>. Cation exchange capacity of these soils varied from 20 to 27 cmol (p<sup>+</sup>) kg<sup>-1</sup>, having dominance of Ca<sup>2+</sup> followed by Na<sup>+</sup>, Mg<sup>2+</sup> and K<sup>+</sup>. ESP varied from 24 to 35 which increase with depth. The saturated paste extract cations followed the order of Na<sup>+</sup> > K<sup>+</sup> > Ca<sup>2+</sup> > Mg<sup>2+</sup>.

Kharche *et al.* (2004) studied the Sodic Vertisols of Mula command area and concluded that soil reaction was moderately to strongly alkaline. The ECe was more than 4 dS m<sup>-1</sup> (4.84 to 13.89 dS m<sup>-1</sup>) in the Vertisols. The exchange complex of soil is dominated by calcium, followed by magnesium or sodium and potassium

Sen (2003) reported that the distinguishing characteristics of sodic soils are high exchangeable sodium per cent (ESP > 15), ECe < 4 dS m<sup>-1</sup>, pH > 8.2 and presence of higher amount of carbonates and bicarbonate of Na<sup>+</sup>. Due to high ESP, sodic soil possesses poor physical and chemical properties. The high exchangeable Na<sup>+</sup> content of these soils leads to dispersion of fine clay particles resulting into low permeability, crusting and hardening of the surface soil upon drying. As a result, the aeration, soil-water movement and root growth hampered. The soil has poor aggregate stability, low organic matter content, toxic concentration of CO<sub>3</sub><sup>2-</sup> and HCO<sub>3</sub><sup>-</sup>, poor microbial activity due to strong alkaline pH and reduced availability of N, K, Zn and Fe which affect the productivity of these soils.

Suarez (2001), Qadir and Schubert (2002) reported that sodic and saline-sodic soils exhibit structural problems such as slaking, swelling, dispersion of clay and surface crusting. Such problems may impede water and air movement, decrease plant-available water, reduce nutrient availability, root penetration and seedling emergence, and increase run off and erosion potential.

Prapagar *et al.* (2012) reported that in saline and sodic soil, salts tend to accumulation in the upper surface soil and may be affect it's physical and chemical properties.

Abrol *et al.* (1988) studied that most problem of salinity soil occurs as a result of increased use of poor-quality water, waste water, industrial water, low rainfall and high-water evaporation in land agriculture.

Durgude *et al.* (2004) studied that sodic soils of MPKV, Rahuri farm reported that the pHs of soil ranged from 8.5 to 8.9 indicating strongly alkaline in reaction with low electrolyte concentration (ECe 0.6 to 2.66 dS m<sup>-1</sup>). Cationic concentration showed decreasing trend in order of SO<sub>4</sub><sup>2-</sup> > Cl<sup>-</sup> > HCO<sub>3</sub><sup>-</sup> > CO<sub>3</sub><sup>2-</sup>.

Todmal (2011) reported that characterization of salt-affected soil of Rahuri tehsil of Ahmednagar District was carried out to study the chemical properties of salt-affected soils. The significant increase of pHs (Moderately to strongly alkaline) was observed in sodic soil followed

by saline-sodic and normal soil. Increase in ECe was observed in saline-sodic soil followed by sodic soil and it was found good in normal soil. In normal soil and saline-sodic soil, the trend of cationic concentration showed decrease in the order of  $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$  whereas, sodic soil showed decreasing cationic trend in the order  $\text{Na}^+ > \text{Mg}^{2+} > \text{Ca}^{2+} > \text{K}^+$ . The anionic concentration in normal and saline-sodic soils showed decrease in the order of  $\text{Cl}^- > \text{SO}_4^{2-} > \text{HCO}_3^-$  and sodic soils showed decrease in the order of  $\text{HCO}_3^- > \text{SO}_4^{2-} > \text{Cl}^-$ . The organic carbon content in sodic and saline-sodic soils were low and it was medium in normal soil. The normal and saline-sodic soils were medium in calcium carbonate content and it was high in sodic soils. The exchangeable sodium percentage was highest in sodic soils followed by saline sodic and normal soils. The exchangeable  $\text{Mg}^{2+}$  was dominant in sodic soils. The available  $\text{K}^+$  was very high in all the soils. Potassium was very high in all saline-sodic, sodic and normal soils. Positive and significant correlation was observed between nitrogen, organic carbon, CEC,  $\text{Ca}^{2+}$  and  $\text{Cl}^-$ . While phosphorus was positively and significantly correlated with organic carbon and CEC. Potassium was positively and significantly correlated with  $\text{Mg}^{2+}$  and SAR. Exchangeable  $\text{Ca}^{2+}$  showed positive and significant correlation with ECe, organic carbon, CEC,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Cl}^-$ . The exchangeable  $\text{Na}^+$  and  $\text{K}^+$  showed positive and significant correlation with pHs,  $\text{CaCO}_3$ , ESP and SAR.

Sharma *et al.* (2004) reported that sodic soils contain excess of salts capable of alkaline hydrolysis such as sodium carbonate, sodium bicarbonate, sodium silicate and sufficient exchangeable sodium. These soils have saturated paste pHs  $>8.5$  and ESP  $>15$ .

Durgude (1999) stated that sodic soils were classified as Sodic Calcicustert and Typic Natraquert and tentatively identified as Phule 4 and Phule 5 respectively. The extent of sodic soil was 120.76 ha contributing to the 8.6 per cent of total potential cultivated area and localized in D, C and B blocks. Very poor soil physical condition was noted such as very high bulk density, COLE value, dispersion index and very low in hydraulic conductivity. These soils were strongly alkaline, strongly calcareous but low in CEC, organic carbon and available N, P and Zn status. Smectite was dominant clay mineral with chloritization, however, it was of lesser degree than smectite of the saline-sodic soil. The associated clay minerals were kaolinite, mica and chlorite. Soils containing measurable quantities of  $\text{Na}_2\text{CO}_3$ , have a pH of more than 8.2; the pH increases with increasing amounts of  $\text{Na}_2\text{CO}_3$ , and may be as high as 10.0 to 10.5. This is due to the higher solubility of  $\text{Na}_2\text{CO}_3$  and therefore the greater potential for hydrolysis. Exchangeable sodium and  $\text{CaCO}_3$  react in low  $\text{CO}_2$  low neutral salt to produce high pH and appreciable concentrations of  $\text{Na}_2\text{CO}_3$ .

Kawde *et al.* (2005) studied the soils from Keliveli village (Akola dist. of Maharashtra) in Purna valley of Vidharbha and found that the saturation extract analysis denotes cations in order:  $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+$ . The soluble sodium percentage ranged from 47.90 to 89.79

per cent and sodium adsorption ratio varied from 1.78 to 21.85, which showed an increasing trend with depth denoting that soils are developing salinity.

Padole *et al.* (1998) reported that the bulk density of these soils ranged from 1.28 to 1.88  $\text{Mg m}^{-3}$ , typically low hydraulic conductivity which ranged from 5.2 to 1.7  $\text{mm hr}^{-1}$ , low to moderate organic carbon, high CEC (more than 42.3  $\text{cmol (p}^+) \text{ kg}^{-1}$ ) and high base saturation.  $\text{Ca}^{2+}$  was dominant followed by  $\text{Mg}^{2+}$  and  $\text{Na}^+$ . The pHs, ECe, ESP of soil ranged between 7.3 to 9.6, 0.90 to 5.74  $\text{dS m}^{-1}$  and 2.57 to 33.78 respectively. Problem of saline and alkali soils in Maharashtra has assumed a greater importance with the introduction of new irrigation projects. With increasing irrigation potential, the danger of soil deterioration has also increased. Most of the salt stresses in nature are mainly due to sodium, particularly, NaCl. The major cationic constituents of the soluble salts in saline soils are  $\text{Na}^+$ ,  $\text{Mg}^{2+}$  and  $\text{Ca}^{2+}$  and the major anionic constituents are sulphates, chloride, carbonates and bicarbonates. The presence of high amount of salts in soil profile adversely affect the availability and uptake of mineral nutrients and consequently the crop growth and its quality.

Sagare *et al.* (1991) stated that characterized sodic soils of Purna Valley of Vidarbha which had soil pH in the range of 8.4 to 8.9, EC 0.91 to 1.2  $\text{dS m}^{-1}$  and ESP 15.25 to 51.23 whereas the pHs was in the range of 7.98 to 9.20, ECe 1.00 to 5.54  $\text{dS m}^{-1}$  and ESP 7.91 to 29.14

Abrol *et al.* (1988) showed that relationship between the pH of the saturated soil paste and the exchangeable sodium percentage of the soils studied by them. Since pH can be relatively easily determined, these workers suggested that pH could be used as an approximate measure of the exchangeable sodium percentage.

Nimkar *et al.* (1992) reported that soils had mild alkalinity (pH 8.5 to 8.9), very low exchangeable sodium percentage (ESP) and ECe in the sub soil horizon. Despite uniform clay content and non-sodic nature of the soils the saturated hydraulic conductivity decreased sharply with depth (5.5 to 0.3  $\text{mm hr}^{-1}$ ) and layed drainage of the soil could be severely impaired due to incomplete leaching of salts.

Balpande *et al.* (1996) reported that the soil degradation problems in these soils especially in the sub soil sodicity is mainly due to semi-arid climate with annual rainfall of about 875 mm and tropical ustic moisture regime. All these factors are responsible for starting the pedogenic process which result in the depletion of  $\text{Ca}^{2+}$  ions from soil solution in the form of  $\text{CaCO}_3$  and also in the simultaneous increase of both SAR and ESP with pedon depths in Vertisols of the Purna Valley.

Kadu *et al.* (2003) studied the Vertisols of Nagpur, Amravati and Akola districts of Maharashtra and reported that the soils were clayey and pH values generally increased as the rainfall decreases from Nagpur to Akola. The soils were impoverished with respect to organic

carbon and  $\text{Ca}^{2+}$  was dominant exchangeable cations followed by  $\text{Mg}^{2+}$ ,  $\text{Na}^+$  and  $\text{K}^+$  in almost all the soils.

### 2.3 Zeolite as Soil Amendment Used for Improvement of Sodic Soil

Noori *et al.* (2006) reported that the zeolite used as amendment for sandy clay poor soil. Natural zeolite has ability by ion exchange to take this salt. Thus, zeolite used as fertilizer, stabilizer, chelator. Natural clinoptilolite which improve soil quality and increase soil qualification and quality of crops.

Ahmed *et al.* (2008) studied the synthetic zeolite is beneficial soil amendment because it enhances absorption and retention of plant nutrient and water and supplement nutrient. Soil amendment with zeolite effectively ameliorate salinity stress and improve nutrient balance in sandy soil.

Gharaibeh *et al.* (2011) reported that some amendment provides a source of calcium ( $\text{Ca}^{2+}$ ) to replace excessive  $\text{Na}^+$  from cation exchange site. If gypsum added in soil, subsequent leaching of replaced  $\text{Na}^+$ . Effect of treatment on soil, result in the decrease in ECe and pH at depth of 8-16 cm. However, after reclamation, slightly increase in pH.

Polat *et al.* (2004) reported that zeolite as soil amendment does not break down over but remain in the soil to improve nutrient retention. Its addition to soil will significantly reduce water and fertilizer costs by retaining beneficial nutrient in root zone. The porous structure of natural zeolite helps to keep the soil aerated and moist as well as active for a long time. Zeolite use with fertilizer can help buffer soil pH levels.

Al-Busaide *et al.* (2007), Andry *et al.* (2007) and Yamada *et al.* (2007) studied that zeolite has the ability to enhance the soil aggregate stability and it can be used as soil amendment to reclaim sodic soil.

Moritani *et al.* (2010) found that incorporation of 10% artificial zeolite in sodic soil has resulted in improved wet aggregate stability which ranged 22.4% and 59.4% in two different soils.

Meharkure *et al.* (2018) reported that zeolites a natural aluminosilicate was studied extensively as soil amendment as it increases the soil-nutrient surface area and extend the magnitude of nutrient use efficiency in farming systems.

Butorac *et al.* (2002) studied that zeolite amendments enhance ion exchange in the soil and their activation at a considerably lower pH than it is the case after liming.

### 2.4 Zeolite

Mumpton (1999) studied that zeolites are natural minerals first discovered in 1756 by Swedish mineralogist, who named the porous minerals from the Greek words meaning “boiling stone”. Clinoptilolites are one kind of zeolites which are one of the most useful zeolites.

Extensive deposits clinoptilolite are found in Western United State, Bulgaria, Hungary, Japan, Australia and Iran.

Dwairi (1998) reported that the unique physical and chemical properties of natural zeolites in sedimentary deposits and in rocks derived from volcanic parent materials.

Kaduk and Faber (1995) reported that zeolites are composed of pores and corner sharing aluminosilicate ( $\text{AlO}_4$  and  $\text{SiO}_4$ ) tetrahedrons, joined into 3-dimensional frame works. The pore structure is characterized by cages approximately 12 Å in diameter, which are interlinked through channels about 8 Å in diameter, composed of rings of 12 linked tetrahedrons. The pores are interconnected and form long wide channels of varying sizes depending on the mineral.

Barbarick and Pirela (1984) reported that there are about 50 different species of zeolites, each having a different chemical composition and structure. While most zeolites are beneficial in improving animal and plant growth, it has been demonstrated that certain zeolites with sodium as the main exchangeable cation can actually decrease rather than increase plant growth and yield.

Perez Caballero *et al.* (2008) stated that zeolites are hydrated aluminosilicate minerals made from inter linked tetrahedra of alumina ( $\text{AlO}_4$ ) and silica ( $\text{SiO}_4$ ). They are solids with a relatively open, three-dimensional crystal structure built from the element aluminium, oxygen, and silicon, with alkali or alkaline earth metals (such as sodium, potassium, and magnesium) plus water molecules trapped in the gaps between them. Zeolites are crystalline structure which have large open pores (cavities) in a very regular arrangement and roughly the same size as small molecules.

Bhattacharyya *et al.* (2015) stated that Ca-rich zeolitic soils are found to occupy an area of 2.8 m ha in India

Enkeleida *et al.* (2008) studied the use of zeolite, pure or in combination with manure application increased significantly the fertility of soil resulting in faster growth, higher yield and better plant quality. The best performance of zeolite was the treatment with 600 kg ha<sup>-1</sup> (101.50%) zeolite and treatment 600 kg ha<sup>-1</sup> + NPK (127.43%).

## 2.5 Type of Zeolite

Several type of zeolite such as Analcime, Chabazite, Clinoptilolite, Erionite, Heulandite, Mordenite, Philipsite, stilbite etc. Clinoptilolite zeolite used in agriculture.

Sarioglu (2005) stated that 1000 different type of zeolite minerals have been reported from sedimented rocks of volcanic origin. Zeolite deposits exist in all over the world, huge natural zeolite reserves are found in japan, USA, Russia, Hungary, Croatia, Serbia and Turkey.

Vaughan (1978) observed that zeolites are a naturally occurring mineral group consisting of about 50 mineral types. They have a rigid three-dimensional crystal structure with voids and channels of molecular size and a high cation exchange capacity (CEC).

Lewis *et al.* (2004) showed that out of the many zeolites i.e. Zeolite A, Mordenite, Faujasite, Zeolite X, Zeolite P. Zeolite A has the highest capacity to bind heavy metals such as cadmium and zinc. Zeolite A has the highest binding capacity between pH 5 and 6.5 and was stable pH > 5.5.

## 2.6 Properties of Zeolite

Polat *et al.* (2004) reported that zeolite can absorb CO<sub>2</sub>, SO<sub>2</sub>, H<sub>2</sub>S, NH<sub>3</sub>, HCHO (formaldehyde), O<sub>2</sub>, N<sub>2</sub>, H<sub>2</sub>O, CH<sub>3</sub>OH and many more gases.

Auerback *et al.* (2003) and Bhattacharyya *et al.* (2015) reported chemical and physical properties include: high void volume (50%), low density (2.1–2.2 g cm<sup>-3</sup>), excellent molecular sieve properties and high cation exchange capacity (CEC) of 150–250 cmol (p<sup>+</sup>) kg<sup>-1</sup> cation selectivity, specifically for cations like ammonium, potassium, calcium, etc.

Torkashvand and Shadparvar (2013) observed that zeolite maintain maximum percentage of field capacity and delay in PWP in sandy clay loam soil.

Xiubin and Zhanbin (2001) studied soil treated with zeolite could increase infiltration by 7-30% on gentle slope land and more than 50% on steep slope land. In extreme drought condition, zeolite treated soil could increase soil moisture by 0.4-1.8% as compared to increase in soil moisture by 5-15% in general situation.

Sprynskyy *et al.* (2005) and Zabochnicka-Swiatek (2007) stated that zeolite has permanent negative charge on their surface due to which they have high adsorption capacity for cations (ions of potassium, ammonia calcium, sodium, magnesium).

### 2.6.1 Effect of Zeolite on Ion Exchange of Sodic Soil

Mumpton (1999) stated that zeolite with a negative charge provides an ideal trap for positive cations such as sodium, potassium, barium and calcium and positively charged groups such as water and ammonia. Both carbonate and nitrate ions are attracted by the negative charge within zeolites. Therefore, alkali and soil alkali metallic cations are attracted in the same way and water can be absorbed by zeolites. Absorbed cations are relatively mobile due to their weak attraction and can be replaced using the standard ion exchange techniques making zeolites good ion exchangers.

### 2.6.2 Effect of Zeolite on Cation Exchange Capacity (CEC) of Sodic Soil

Mumpton (1999) revealed that clinoptilolite has a theoretical CEC of 216 cmol (p<sup>+</sup>) kg<sup>-1</sup> while the still unexploited Zambian zeolite (laumontite) has a theoretical CEC of 425 cmol (p<sup>+</sup>) kg<sup>-1</sup> and laumontite has greater potential as a soil conditioner than clinoptilolite.

DeSutter and Pierzynski (2005) studied the CEC of soil may be increased by using zeolite as soil amendments.

Girijaveni *et al.* (2018) observed that zeolite has permanent negative charge on their surface due to which they have high adsorption capacity for cations such as the ions of potassium, ammonia, calcium, sodium and magnesium and many other.

## 2.7 Effect of Application of Gypsum on Sodic Soil

Oster (1982) and Shainberg *et al.* (1989) reported that gypsum provide a source of calcium ( $\text{Ca}^{2+}$ ) to replace excessive  $\text{Na}^+$  from the cation exchange sites.

Koo *et al.* (1990) and Qadir *et al.* (1996) stated that the increased displacement of exchangeable  $\text{Na}^+$  by  $\text{Ca}^{2+}$  was from the added gypsum and/or dissociation of  $\text{CaCO}_3$  and subsequent leaching of replaced  $\text{Na}^+$

Shainberg *et al.* (1980) observed that due to application of gypsum, effluent SAR was at maximum during initial leachate collection in column study experiment, indicating that most of the exchange reactions had taken place. Gypsum i.e. G100 treatments had greater SAR profiles compared with other treatments. At the early stages of reclamation, sodium was exchanged and as effluent SAR decreased, the efficiency of  $\text{Na}^+$  and  $\text{Ca}^{2+}$  exchange decreased. This was due to decreased probability of exchange reactions between adsorbed  $\text{Na}^+$  and soluble  $\text{Ca}^{2+}$

Oster and Frenkel (1980) reported that dissolution of gypsum depends on many factors such as composition of irrigation water, contact time between gypsum and soil water, hydraulic conductivity and soil sodicity. Longer contact time between gypsum and water is the result of lower hydraulic conductivity and increased gypsum dissolution. Similarly, high soil sodicity increases gypsum dissolution rate because exchangeable  $\text{Na}^+$  acts a sink to soluble  $\text{Ca}^{2+}$  (exchange reaction) and more gypsum ( $\text{CaCO}_3$ ) dissolved. Therefore, higher soil sodicity accelerates gypsum dissolution.

Aharoni *et al.* (1991) stated that long water residence time in soil favors gypsum dissolution and Ca/Na exchange reaction. In this reaction, adsorbed  $\text{Na}^+$  migrate from inside of the aggregate into the solution. Simultaneously,  $\text{Ca}^{2+}$  ion in the solution must go the other way and be adsorbed on the clay. The exchange rate is determined by the diffusion process and the exchange reaction.

Sagare *et al.* (2001) reported that significantly highest reduction in pHs, ECe, SAR and ESP was noticed due to application of gypsum @ 100% GR. Gypsum application reducing ECe, ESP and SAR was significant. The significant increase in HC of sodic Vertisol was observed due to gypsum @ 100% GR over gypsum @ 25% GR.

Keren and O'Connor (1982) and Nadler *et al.* (1996) reported that the exchange reaction is a fast process and the diffusion process control the exchange reaction rate. In stable aggregates, inter-aggregate diffusion process controls the rate of exchange reaction. Thus, in this soil, the exchange reaction is a slow process and low flow velocity increases the efficiency of desodification. As  $\text{Ca}^{2+}$  carrying solution flow is slow, there is more opportunity time for  $\text{Ca}^{2+}$  to

penetrate into aggregates and replace exchangeable  $\text{Na}^+$ . In well controlled laboratory studies, the effectiveness of gypsum or lime in reclamation of sodic soils was found to be dependent on the flow rate of the percolating solution; increasing the water flow rate, decrease the gypsum or lime dissolution and the slower the soil water flow, higher the efficiency of replacing  $\text{Na}^+$  by  $\text{Ca}^{2+}$ .

Shainberg and Letey (1984), Oster (1982), Qadir *et al.* (2001), Qadir *et al.* (2002), Qadir and Oster (2002), Gharaibeh *et al.* (2009) and Mahmoodabadi *et al.* (2012) reported that some amendments such as gypsum supply  $\text{Ca}^{2+}$  directly to the soil to replace excess  $\text{Na}^+$  from the exchange site or out of the soil profile by leaching irrigation process with a good quality water.

Mohmoodabadi *et al.* (2012) Stated that reduction in soluble  $\text{K}^+$  when applied irrigation water and gypsum to saline sodic soil may be due to the leaching and gypsum application rates which release  $\text{Ca}^{2+}$  and replacement of  $\text{Na}^+$  and  $\text{K}^+$  on the site exchangeable.

Maurya *et al.* (2009) studied that impact of amendments on properties of sodic soil constitute of two sources of inorganic amendments *viz.*, pyrite gypsum and organic amendment. Use of gypsum found to be more effective in reducing pH, EC, exchangeable  $\text{Na}^+$  and ESP over other rest of the treatments and significantly improve the exchangeable  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{K}^+$  and CEC, organic carbon and water holding capacity of soil.

Hanay *et al.* (2004) and Wong *et al.* (2009) studied that gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ) is the most common amendments used for the amelioration of salts affected soil and reducing the harmful effect of high sodium content in soil due to it is high solubility and low cost.

Amezketta *et al.* (2005) suggested that the addition of gypsum rates in salt affected soil can remove the excess of  $\text{Na}^+$  from soil profile by leaching process and also improvement chemical soil properties such as electrical conductivity and sodium adsorption ratio.

Yaduvanshi (2008) reported that gypsum is the most commonly applied product for the reclamation of saline–sodic soils and can improve physical and chemical soil properties primarily by maintaining a favorable electrolyte concentration in soil solution. As adsorbed  $\text{Na}^+$  on exchangeable sites of clay particles are considered to be responsible for soil dispersion. Gypsum can prevent it by maintaining high  $\text{Ca}^{2+}/\text{Na}^+$  ratios and thus promoting clay flocculation and structure stability.

Abdel Fattah (2012) studied that application of gypsum is helpful to improve the soil physical structure and helps in leaching of salts from the saline and sodic soil.

María Alcívar *et al.* (2018) observed that amendment application improved chemical properties of soil (decreases soil salinity) and influenced by effective salt leaching from soil profile. In experiment, most of amended soil decreases the soil ECe compared to control soil and suggesting that these amendments have a strong efficiency in reducing soil ECe.

Tejada *et al.* (2006) and Gupta *et al.* (2016) reported that soil EC was significantly lower when organic amendments and Gypsum were applied to reclaim salt-affected soils compared to the control. Application of chemical and organic amendments increases the concentration of  $\text{Ca}^{2+}$  and promotes the displacement of adsorbed  $\text{Na}^+$  and found that SAR and ESP values reduced significantly in all amended soils.

Negim (2015) reported that soil pH, ECe and ESP were considerable decreased with increasing gypsum. Soil pH value was reduced from 8.33 to 7.78 and also reducing the EC of soil as compared with control. Regarding of soluble  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$ , they were increased in all soil treatments.

Nan *et al.* (2016) reported that application of Gypsum and HS in a sodic soil were improved the structural stability and a reduction of ESP from soil colloids. In this sense, salts could be leached down to deeper layers.

## **2.8 Effect of Application of Gypsum on Chemical Properties of Sodic Soil**

### **2.8.1 Soil pH**

Richards (1954) reported that, 0-8 cm soil depth, gypsum treatments depicted non-significant differences for any change in pH. At lower depths (8-16 cm), the lowest pH was observed with cropped treatments. However, after reclamation, a slight increase in soil pH (7.67) was observed in all treatments and this may be attributed to leaching of neutral salts that tends to lower the pH by moderating the alkalinizing reactions.

Negim (2015) indicated that the application of amendments reduced soil pH of all soil treatments compared with control treatment. It was noticed that the soil pH value decreased from 8.33 to 7.78.

Abdel Fattah (2012) reported that application of gypsum combined with compost enhanced reclamation process and caused more decreases in sodicity.

Kharche *et al.* (2010) reported that application of gypsum and spent-wash press-mud compost along with bioinoculants in sodic soil on research farm, MPKV, Rahuri during 2004-05 and 2005-06 and reported that @ 25 per cent GR significantly reduced the soil pHs from 8.65 to 8.14, ECe from 2.93 to 2.30  $\text{dS m}^{-1}$  and ESP from 18 to 11.4. The integrated use of amendments was also found beneficial for improvement in physical properties of soils *viz.*, bulk density (from 1.40 to 1.23  $\text{Mg m}^{-3}$ ) and hydraulic conductivity (0.45 to 0.81  $\text{cm h}^{-1}$ ).

### **2.8.2 Electrical Conductivity (ECe)**

Sampaio and Ruiz (1996) reported that soils in PVC columns with gypsum and subjected to six successive leaching with solutions of  $\text{CaCl}_2$  and  $\text{MgCl}_2$  at 50 per cent the pore volume. Electrical conductivity of the leachate decreased with successive leaching and calcium and magnesium were absorbed on the exchange complex. During the final leaching, the pronounce decreased in soluble salts concentration promoted gypsum dissolution.

Oster (1982) reported that the decrease in E<sub>Ce</sub> could be attributed to flocculation of soil particles as a result of increased Ca<sup>2+</sup> which in turn increases soil permeability and hence the leaching of soluble salts.

Negim (2015) studied that effect of soil amendments on soil electrical conductivity is revealed that the gypsum treatment reduced significantly the E<sub>Ce</sub> (0.82 dS m<sup>-1</sup>) of the soil as compared to initial value (48.5 dS m<sup>-1</sup>) after leaching experiment.

Robbins (1986) reported that soil E<sub>Ce</sub> decreased significantly in all treatments as compared with the control. Gypsum i.e G50 was the most efficient. Surface E<sub>Ce</sub> decreased to 3.1, 3.9 dS m<sup>-1</sup> in CrG50, G100 treatments, respectively). All depths were efficient at lowering EC as compared to the control. Increasing E<sub>Ce</sub> with depth could be attributed to the accumulation of salts in the lower depths.

Mohite and Shingte (1984) found that the electrical conductivity of the first leachate was the highest and it continuously decreased in the subsequent effluent waters of the successive dilutions in all the treatments. Further, they also observed that sodium content in the first leachate under each treatment was the highest which decreased gradually.

### **2.8.3 Exchangeable Sodium Percentage (ESP)**

Robbins (1986) reported that gypsum treatments significantly decreased soil ESP compared to the control. G100 and CrG50 were the most efficient. The ESP of the upper 8 cm of soil was significantly decreased compared to the lower layers. Treatments containing gypsum (CrG50 and G100) significantly decreased ESP compared to treatments without gypsum application (Cr and C). Moreover, ESP increased with depth in all treatments and this may be attributed to the accumulation of sodium in the lower layers. The decrease in ESP in G100, CrG50 treatments may be attributed to increased Ca<sup>2+</sup> in soil solution as a result of gypsum addition, which promoted Na<sup>+</sup> displacement and removal by leaching simple leaching (control) decreased ESP.

Suarez (2001) reported salt removal in the control decreased more steeply in later collection. This may be attributed to supplement of available Ca<sup>2+</sup> in soil solution which coming from gypsum treatment, replacement of exchangeable Na<sup>+</sup>, leaching of exchanged Na<sup>+</sup> and subsequent increase in electrolyte concentration. Salt concentration due to depletion of gypsum by time.

Negim (2015) reported that application of gypsum reduces ESP in all treatments compared to control soil. ESP at the end of leaching ranged from 6.55% to 13.43% as compared with initial value of 22.14%, thus exhibiting a decrease in value between 70 to 40%.

Choudhary *et al.* (2004) found that the addition of organic matter with gypsum decreased the ESP of the sodic and sodic saline soil.

Gharaibeh *et al.* (2011) reported that the decrease in soil ESP with increasing rates of amendments may be attributed to increase  $\text{Ca}^{2+}$  in soil solution as a result of addition gypsum and organic amendments which promoted  $\text{Na}^+$  displacement and removed by leaching process.

Shehata *et al.* (1983) reported that sodium was the main soluble and exchangeable cation to be leached, a first leaching resulted in the removal of more than 60 per cent of total soluble salts, 70 % of chloride and 38 % of  $\text{SO}_4^{2-}$  ions. ESP of the soil was decreased from 63.6 and pH from 9.4 to 8.5.

#### 2.8.4 Sodium

Robbins (1986) reported that analysis of leachate showed the gypsum treatment removed most of the  $\text{Na}^+$  during initial collections, leaving little amounts to be displaced and leached in later collections. The maximum removal of  $\text{Na}^+$  was observed in / achieved with CrG50 and G100 treatments (80 and 73%) respectively. A Similar finding was reported by Qadir *et al.* (1996), where the  $\text{Na}^+$  leached from each treatment revealed a superiority of the highest application over other treatments.

Banerjee (1957) reported that various studies on the percolation of water through soils. He showed that all the cations can be in the largest amount in the first leachate. The amount fell very sharply in the successive leachate but continued to come even in the 18<sup>th</sup> leachate. All the replaceable sodium was removed in the 3 or 4 leachates.

Murthy (1960) studied that laboratory leaching trials on saline alkali soil by treating it with FYM, paddy straw and green leaves, then three successive leaching were carried out, he found that the presence of more chloride ions than sodium ions in first leachate. It indicated that some chloride ion was in combination with other cations and sodium was found mostly in the first and second leachate.

Satyanarayan (1954) studied that the gypsiferous saline soils and observed that chloride ion content was more than the sodium ion showing that some chloride ions were in combination with other cations especially magnesium and potassium in the first leachate. Chloride and sodium were removed earlier and sulphate ions predominates in the latter leachates. Magnesium and potassium ions continued to come out in solution when the sodium and chloride ions were absent. In the latter leachate calcium and sulphate ions remained steady and divalent cations calcium and magnesium were in excess of monovalent ions.

Singh *et al.* (2011) reported that application of gypsum 50% GR with green manuring decreased the pH value by 0.66 units, EC and ESP to  $0.12 \text{ dS m}^{-1}$  and 13.1 respectively. This might be due to application of gypsum and green manure have enhanced the availability of soluble calcium directly and indirectly through dissolution of native  $\text{CaCO}_3$ . The calcium thus released displaced  $\text{Na}^+$  from exchange complex and removal of Na with anions through leaching reduced the pH of soil and improved the physico-chemical properties of soil.

## 2.9 Effect of Different Levels Zeolite Application on Soil Available Nutrients

Ahmed *et al.* (2008) reported that the soil treated with calcium type zeolite @ 1 and 5% and irrigated every alternate day dilute to EC level of 3 and 16 dS m<sup>-1</sup>. Application of zeolite enhances water and salt holding capacity of soil. Post-harvest analysis showed high concentration of Ca<sup>2+</sup>, Mg<sup>2+</sup>, Na<sup>+</sup> and K<sup>+</sup> in upper soil layer but concentration was lower in soil treated with zeolite. Calcium plays a vital nutritional and physiological role in plant, restricted plant growth due to effect of specific ion or Na<sup>+</sup>/Ca<sup>+</sup> imbalance may ameliorate using Ca type zeolite.

Noori *et al.* (2006) studied that different sources of amendments for reclamation of salt affected soils and reported that the zeolite (0.06 kgm<sup>-2</sup> i.e. 600 kg ha<sup>-1</sup>). Natural clinoptilolite absorbed Na<sup>+</sup> and Cl<sup>-</sup> which enter into cavities and consequently natural zeolite improves soil property. Generally, it has been used to improve soil fertility, to develop soil release fertilizer enriched with ammonium and affect buffer capacity of soil. In fact natural clinoptilolite is alkaline and used with fertilizer may help buffer soil pH level. Thus, reducing need for lime application. It improves crop yield and growth in poor, sandy and porous soil.

Allen *et al.* (1993) studied that zeolites can enhance the efficiency on nutrient use by increasing the accessibility of P from phosphate rocks, and the consumption of NH<sub>4</sub>, N and NO<sub>3</sub>, reduce loss by leaching of K<sup>+</sup> and also act as a slow release fertilizer without harming the environment. The use of zeolites could be beneficial for retention of nutrient in soil and their use efficiency. Zeolite as soil amendment reduced significantly the total chromium in plants (Molla *et al.*, 2015).

Latifah *et al.* (2017) reported that zeolite has permanent negative charge on their surface due to which they have high adsorption capacity for cations such as the ions of potassium, ammonia, calcium, sodium and magnesium and many other.

Mazloomi and Jalali (2016) reported that the adsorption capacity of these ions onto zeolite was determined by isotherms and kinetics by several researchers and this property is used for various purposes such as waste water treatment etc. There are number of factors such as mass, particle size, initial concentration of ammonium ions of model solution, contact time, temperature and pH that affect adsorption efficiency of these zeolites.

Campana and Moraes (2015) observed the zeolites also improve the efficiency of nutrient use by increasing the availability of P from phosphate rock, the utilization of NH<sub>4</sub>-N and NO<sub>3</sub>-N and reduce losses by leaching of exchangeable cations.

Butorac *et al.* (2002) and Ramesh *et al.* (2010) stated that nutrients use efficiency can also be achieved through the use of clinoptilolite zeolite because of the unique physical and chemical properties of clinoptilolite zeolite coupled with their abundance in sedimentary deposits

and in rocks derived from volcanic parent materials have made them useful in many agricultural applications.

Dakovic *et al.* (2007) Clinoptilolite zeolite is a hydrated alumino silicate of alkali and alkaline earth metals consist of infinite three-dimensional crystal structure, a polyedric shape, and a great open cavity. Clinoptilolite zeolite is widely used in cultivating different crops such as cereals, forage, vegetables, vine and fruit crops due to their exceptionally high ion-exchange.

## **2.10 Effect of Zeolite Application on Soil Properties**

### **2.10.1 Effect of Zeolite Application on Physical Properties of Soil**

MacKown and Tucker (1985) concluded that natural zeolite enriched soils, increased water holding capacity by (18-19%) and CEC by 30-40% whereas the synthetic zeolite enriched soils increased water-holding capacity by 25-30% and CEC by 40-50%. Ion exchange plays an important role in introducing  $\text{NH}_4^+$  into the framework by exchanging for cations present in the zeolite framework.

Xiliang *et al.* (1991) stated that zeolite also promoted the formation of soil aggregate that increase in soil porosity and decreasing soil bulk density and improving the output of crops.

Kralova *et al.* (1992) studied that zeolites are widely used as soil conditioners to improve soil physio-chemical properties. The increase in soil pH and exchangeable K on adding clinoptilolite to soils is significant, and has no influence on soil humus content and soil chemical composition. Addition of zeolite to soil helps to control soil pH and improves ammonium retention.

He and Huang (2001) studied that soil treated with zeolite compared with the normal soil, could increase infiltration by 7–30% on gentle slope land and more than 50% on steep slope land. In addition, the treated soil could increase soil moisture by 0.4–1.8% in the extreme drought condition, and 5–15% in general situation.

Al-Busaidi *et al.* (2008) reported that soil treated with zeolite could increase infiltration by 7–30% on gentle slope land and more than 50% on steep slope land.

Moritani *et al.* (2010) found that incorporation of 10% artificial zeolite in sodic soil has resulted in improved wet aggregate stability which ranged 22.4% and 59.4% in two different soils. It was concluded in that study that zeolites might be used as amendments for sodic saline alkaline soils. Some of the soil properties which can be improved by incorporating zeolites as part of organic fertilizers are soil quality by improving soil structure, ion exchange capacity of soils and moisture and nutrient retention. The nutrient loss to the environment can also be inhibited by application of zeolites to soil.

Xiliang *et al.* (1991) observed that the ideal bulk density for optimum crop growth varies from  $1.2 \text{ g cm}^{-3}$  for clay soil and  $1.4 \text{ g cm}^{-3}$  for a sandy soil. Bulk density of the zeolite and sand mixture ranged from 1.37 to  $1.42 \text{ g cm}^{-3}$  which is significantly lower than unamended sand

(Huang and Petrovic, 1994). Zeolite also promoted the formation of soil aggregate that increase in soil porosity and decreasing soil bulk and improving the output of crops.

Bernardi *et al.* (2013) reported that treating light-textured soils with soil amendments such as zeolites can improve their WHC. Generally, zeolite can decrease the bulk density and increase total porosity which consequently increase soil water content. Its application changes the inter-particle porosity of soil. Zeolite is a porous medium with open pore network channels into its structure which can also play an important role in water retention.

Susana *et al.* (2015) reported that assessment of zeolite amendment in agriculture. They concluded that zeolites are considered to be molecular sieves and a successful unconventional amendment. Further, they revealed that application of zeolite improves significantly soil fertility, physical and chemical properties and is very useful in drought conditions because it absorbs a high quantity of water in its pores. Zeolite can retain soil nutrients in the root zone to be used by plants when required.

Kavvadias *et al.* (2019) reported that zeolite and compost have positive impact on soil properties as well on crop yield parameter.

Pirzad *et al.* (2014) reported that effect of different rates of zeolite and drought stress on the protein and mineral nutrients (nitrogen, phosphorus and potassium) of *Lathyrus sativus*. In general, zeolite as a soil amendment that improved water retention capacity, soil cation exchangeable capacity led to higher yield under drought stress conditions and then it can be suggested for these lands in arid and semi-arid regions.

Filcheva and Chakalov (2002) reported that zeolite can improve the soil capacity for carbon sequestration.

## **2.10.2 Effect of Zeolite Application on Chemical Properties of Soil**

### **2.10.2.1 Soil pH**

Mumpton (1999) reported that zeolite is not acidic but marginally alkaline and its use with fertilizers can help buffer the soil pH, thus reducing the need for lime application. Thus, the increase in soil pH because of zeolites may contribute to nutrient availability in soils. The leaching of cations such as  $\text{Na}^+$ ,  $\text{Mg}^{2+}$  and  $\text{Ca}^{2+}$  from  $T_5$  partly explains the lower pH of the soil without zeolite.

Noori *et al.* (2006) reported that addition of zeolite usually increases soil pH. Zeolites are known for not being acidic but marginally alkaline and this is one of the reasons why when they are used with fertilizer. They help to buffer soil pH, thus reducing the need for liming.

Ramesh *et al.* (2015) studied that effect of zeolites on soil quality, plant growth and nutrient uptake efficiency in Sweet Potato (*Ipomoea batatas*) at ICAR-Central Tuber Crops Research Institute, Thiruvananthapuram, Kerala. The study has shown the pH buffering effect

and beneficial action of fly ash base zeolites in maintaining a near neutral pH condition for successful cultivation of sweet potato in soils.

#### **2.10.2.2 Soil EC**

Ming and Boettinger (1989) reported that the application of zeolite to soils increases their EC and as a result, it increases nutrient retention capacity. This increase in the electrical conductivity may be attributed to the increase in the total soluble salts.

Hadi and Ali (2008) reported that zeolites can change soil solution compositions due to having high capacity of adsorption as well as water holding capacity. Zeolite are able to decrease fertilizer losses and their leaching from the soil. The result showed that electrical conductivity of filtered solution was lower in mixtures containing zeolite compared to soil. The electrical conductivity of the filtered solutions was considerably lower in  $\text{NO}_3^{2-}$  solutions compared to  $\text{Cl}^-$ . It concluded that zeolite could probably reduce the electrical conductivity of soil solutions by adsorption of ions from the primary solutions and it seems that zeolite would tend to adsorb more  $\text{NO}_3^-$  ions compared to  $\text{Cl}^-$  ions from the solutions resulting lower electrical conductivity of  $\text{NO}_3^-$  containing compared to  $\text{Cl}^-$  containing solutions.

#### **2.10.2.3 Soil CEC**

Sumalatha *et al.* (2010) stated that the treatment with zeolite ( $T_6$ ) resulted in significantly higher soil CEC compared with the treatment without zeolite. Increase in soil CEC relates to the amount of channels in the zeolite as these channels are responsible for selective cation exchange in zeolites.

Girijaveni *et al.* (2018) observed that zeolite has permanent negative charge on their surface due to which they have high adsorption capacity for cations such as the ions of potassium, ammonia, calcium, sodium and magnesium and many other.

Ahmed *et al.* (2010) studied that pot study using zeolites with different combinations of fertilizers in Maize. They found the increase in soil pH, CEC, total N, available P, exchangeable  $\text{K}^+$ ,  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  after harvest with successive increasing levels of zeolite.

He *et al.* (2002) showed that natural zeolite clinoptilolite amended soil, increases soil surface area and cation exchange capacity.

Ramesh *et al.* (2015) stated that ion exchange properties of zeolites can be utilized in agriculture because of their large porosity and high cation exchange capacity. They can be used both as carriers of nutrients and as a medium to free nutrients. Among the natural zeolite clinoptilolite is most commonly used in agriculture.

#### **2.10.2.4 Soil salts**

Morkou *et al.* (2015) observed that the application of zeolite also enhanced water and salt holding capacity of soil. Post-harvest soil analysis showed high concentrations of calcium ( $\text{Ca}^{2+}$ ),

magnesium ( $Mg^{2+}$ ), sodium ( $Na^+$ ) and potassium ( $K^+$ ) due to saline water especially in the upper soil layer but concentrations were lower in soil treated with zeolite

Mass *et al.* (1972) observed that the zeolite application at 5% increased  $Ca^{2+}$  concentration in salt stressed plants; concentrations of trace elements were also increased by 19% for iron ( $Fe^{2+}$ ) and 10% for manganese ( $Mn^{2+}$ ). The overall results indicated that soil amendment with zeolite could effectively ameliorate salinity stress and improve nutrient balance in a sandy soil.

Ahmed *et al.* (2010) studied that the use of zeolite in maize (*Zea mays*) cultivation on nitrogen, potassium and phosphorus uptake and use efficiency at University Putra, Malaysia. They concluded that zeolite improved P, K and Ca concentrations in soil because the zeolite also has the ability to absorb these nutrients from the fertilizers used as well as leaching in the soil.

### **2.11 Effect of Zeolite Application on Water Use Efficiency**

Abdi *et al.* (2006) reported that application of zeolite at 3 kg to soil increased water use efficiency (WUE) as compared to unamended treatment.

Sepaskhah *et al.* (2010) reported that zeolite application rates of 8 t  $ha^{-1}$  and N application rate of 80 kg  $ha^{-1}$  could obtain the highest water use efficiency (WUE).

Kocakusak *et al.* (2001) reported that zeolite may hold water up to 60% of their weight to a high porosity of the crystalline structure. Water molecule in the pores could be easily evaporated or reabsorbed without damage to such structure.

Pisarovic *et al.* (2003) reported that zeolites can absorb up to 55% water, later this water is used by the plants for their metabolic activities.

### **2.12 Effect of Zeolite Application for Reclamation of Sodic Soil**

El-Enany (2005) observed that the salinity and the presence of harmful salts in the soil is one of the most serious problems in agricultural production. The natural zeolite has the ability to take those salts by ion exchange. Thus, zeolite can be used as amendment fertilizer, stabilizer and chelator.

Al-Busaide *et al.* (2007), Andry *et al.* (2007) and Yamada *et al.* (2007) reported that zeolite has the ability to enhance the soil aggregate stability and it can be used as soil amendment to reclaim sodic soil.

### **2.13 Optimum Level of Zeolite for Improvement of Sodic Soil**

Enkeleida *et al.* (2008) reported that Ca was decreased in treatment V2 (NPK) and V5 (Z-600 kg  $ha^{-1}$  + NPK). CEC shows a light increase from treatment V3 (Z-600 kg  $ha^{-1}$ ) through V4 (Z-1200 kg  $ha^{-1}$ ) to treatment V5 (Z-600 kg  $ha^{-1}$  + NPK) and a more evident decrease towards the treatment V6 (Z-1200 kg  $ha^{-1}$ ), V7 (Z-5% of soil weight). Content of micro nutrient in soil (pH-8.5) show a significant decrease at the end of experiment. The best performance of

zeolite application was treatment with 600 kg ha<sup>-1</sup> zeolite and treatment 600 kg ha<sup>-1</sup> zeolite +NPK).

#### **2.14 Effect of Application of Zeolite Periodical Release and Movement of Salt in Soil Column**

Ackley and Yang (1991) reported that zeolite was saturated with cations and anions such as Na<sup>+</sup>, Ca<sup>2+</sup>, Cl<sup>-</sup> which existed in influent upon first leachate applications. Exchangeable ions such as Na<sup>+</sup>, K<sup>+</sup>, Ca<sup>2+</sup> and Mg<sup>2+</sup> commonly occupy clinoptilolite.

Ahmed *et al.* (2010) reported that pot study using zeolites with different combinations of fertilizers in Maize. They found the increase in soil pH, CEC, total N, available P, exchangeable K<sup>+</sup>, Ca<sup>2+</sup> and Mg<sup>2+</sup> after harvest with successive increasing levels of zeolite.

Filcheva and Chakalov (2002) reported that zeolite can improve the soil capacity for carbon sequestration.

#### **2.15 Effect of Application of Gypsum Periodical Release and Movement of Salt in Soil Column**

Mohmoodabadi *et al.* (2012) reported that reduction in soluble K<sup>+</sup> when applied irrigation water and G-amended to saline sodic soil may be due to the leaching and gypsum application rates which release Ca<sup>2+</sup> and replacement of Na<sup>+</sup> and K<sup>+</sup> on the site exchangeable.

Gharaibeh *et al.* (2009) reported that the decrease in soil ESP with increasing rates of amendments may be attributed to increase Ca<sup>2+</sup> in soil solution as a result of addition gypsum and organic amendments which promoted Na displacement and removed by leaching process.

Gharaibeh *et al.* (2011) reported that analysis of leachate showed that all treatments removed most of the Na<sup>+</sup> during initial collections, leaving little amounts to be displaced and leached in later collections. The maximum removal of Na<sup>+</sup> was observed in / achieved with CrG50 and G100 treatments (80 and 73%) respectively.

Koo *et al.* (1990) reported that the increased displacement of exchangeable Na<sup>+</sup> by Ca<sup>2+</sup> was from the added gypsum and/or dissociation of CaCO<sub>3</sub>, and subsequent leaching of replaced Na<sup>+</sup>.

Singh *et al.* (1980) studied that laboratory experiment on alkali soils to study the effect of the application of gypsum and pyrites on the leachate composition and they reported that in the leachate collected from amended soils, Na<sup>+</sup>, K<sup>+</sup>, Ca<sup>2+</sup>, CO<sub>3</sub><sup>2-</sup>, HCO<sub>3</sub><sup>-</sup> and SO<sub>4</sub><sup>2-</sup> were increased with the levels of applied gypsum and pyrites.

Verma and Abrol (1981) reported that the application of gypsum and pyrites amendments on the surface of sodic soil removed the greater amount of soluble and exchangeable sodium from the soil than the leaching of soils without any amendments.

Sanjeev Kumar *et al.* (2004) revealed that progressive decline in pHs, ECe and ESP levels found under gypsum and FYM. Maximum reduction in pH, ECe and ESP recorded in treatments

with FYM @ 400 q ha<sup>-1</sup>, FYM @ 200 q ha<sup>-1</sup>, gypsum @ 25 GR and FYM @ 100 q ha<sup>-1</sup>. Improvement in infiltration rate and hydraulic conductivity was also due to application of FYM @ 400 q ha<sup>-1</sup> and FYM @ 200 q ha<sup>-1</sup> treated plots.

### **2.16 Effect of Zeolite Application Depthwise Movement and Concentration of Different Salt**

Turan (2008) studied that natural zeolite absorb salinity ions which enter cavities of the material and consequently, the salinity levels of the effluent are decreased.

Hatt *et al.* (2007) reported that when zeolite applied in soil, salts are accumulated in soil. Due to accumulation of salts in the soil during first weeks and leaching these elements at the end of study.

Ackley and Yang (1991) reported that zeolite was saturated with cations and anions such as Na<sup>+</sup>, Ca<sup>2+</sup>, Cl<sup>-</sup>, which existed in influent upon first leachate application. Exchangeable ions such as Na<sup>+</sup>, K<sup>+</sup>, Ca<sup>2+</sup> and Mg<sup>2+</sup> commonly occupy clinoptilolite.

Verma and Gupta (1989) reported the effect of continuous and intermittent application of water of varying depth in the leaching behaviour of salts. Before the commencement of leaching the maximum salts concentration were in the surface 10 cm of the soil. The salinity level decreased markedly and observed E<sub>Ce</sub> < 2 dS m<sup>-1</sup> in top layer with initial E<sub>Ce</sub> of > 8.2 dS m<sup>-1</sup>. There was about 80 per cent reduction in initial salt concentration upto depth of 0-10, 0-20, 0-40 cm with application of 15, 30 and 60 cm water, respectively.

### 3. MATERIAL AND METHODS

The present investigation entitled, “Effect of different levels of zeolite for improvement of sodic soil” was carried out at Instructional Farm, Post Graduate Institute, Department of Soil Science and Agricultural Chemistry, Mahatma Phule Krishi Vidyapeeth, Rahuri during 2019. The soil of experimental field was sodic. The details of the material used and method adopted during the conduct of this investigation are described in this chapter.

#### 3.1 Material

##### 3.1.1 Location

Geographically, Central Campus of MPKV, Rahuri is situated between  $19^{\circ} 47'$  to  $19^{\circ} 57'$  North latitude and  $74^{\circ} 19'$  to  $74^{\circ} 42'$  East Longitude with elevation of 525 m above the mean sea level Mahatma Phule Krishi Vidyapeeth is situated on Ahmednagar-Manmad state highway, about 33 km North to Ahmednagar town. The unlined Mula right bank canal passes West from South side of study area.

##### 3.1.2 Soils

The soils of study area are slight to severally salt affected, nearly leveled to very gentle slopping midlands of low lying area of lower and upper piedmont plains (basin shape topography).

Soils are derived from the igneous rocks *viz.*, Basalt (Deccan trap) which is basic in nature containing mainly feldspars (Plasioclase), augite and small amount of titaniferous mineral like zeolite and quartz. The free lime reserve is fairly high (6.9 to 20.8%) and at places excessive quantity of lime nodule are precipitated in the weathered basaltic material of the soil profile.

##### 3.1.3 Climate

Climatically, this area falls in semi-arid, subtropical zone, with annual rainfall varying from 307 mm to 619 mm. The average annual rainfall is 475 mm. Most of the rainfall is being received through South-West monsoon. The annual mean maximum and minimum temperatures was  $34.50^{\circ}\text{C}$  and  $18.30^{\circ}\text{C}$  respectively.

##### 3.1.4 Sources of Amendment

Zeolite is highly fine powdered was purchased from Rudra Zeochem Pvt. Ltd. Nashik. A product named Agripower- A-Z was a potential enriched zeolite. The zeolite powder procured from Rudra Zeochem and characterized for different chemical properties by using standard methods of analysis. Gypsum procured from Rahuri Market. The chemical properties of zeolite and gypsum are given in table 3.2.

**Table 3.1 Initial Properties of Sodic Soil**

<b>Sr. No.</b>	<b>Parameters</b>	<b>Value</b>
<b>I</b>	<b>Physical Properties</b>	
1.	Bulk density ( $\text{Mg m}^{-3}$ )	1.52
2.	Hydraulic conductivity ( $\text{cm h}^{-1}$ )	0.34
3.	Particle size distribution	
	i) Coarse sand	5.87
	ii) Fine sand	12.94
	iii) Silt	22.90
	iv) Clay	58.23
3.	Texture class	Clayey
<b>II</b>	<b>A) Chemical Properties</b>	
1.	pH (1:2.5)	8.54
2.	EC ( $\text{dS m}^{-1}$ )	1.24
3.	Organic carbon (%)	0.45
4.	Calcium carbonate (%)	9.0
8.	Exchangeable $\text{Na}^+$ ( $\text{cmol (p}^+) \text{ kg}^{-1}$ )	9.52
9.	CEC ( $\text{cmol (p}^+) \text{ kg}^{-1}$ )	56.84
10.	Sodium Adsorption Ratio (SAR)	14.26
11.	Exchangeable Sodium Percentage (ESP)	16.75
12.	Available N ( $\text{kg ha}^{-1}$ )	144.21
13.	Available P ( $\text{kg ha}^{-1}$ )	8.15
14.	Available K ( $\text{kg ha}^{-1}$ )	448.52
15.	Available Fe ( $\text{mg kg}^{-1}$ )	4.49
16.	Available Zn ( $\text{mg kg}^{-1}$ )	0.43
17.	Available Mn ( $\text{mg kg}^{-1}$ )	3.40
18.	Available Cu ( $\text{mg kg}^{-1}$ )	2.80
<b>III</b>	<b>A) Saturation Paste Analysis</b>	
	a) PHs	8.51
	b) ECe	3.71
	<b>B) Cations</b>	
	a) Calcium ( $\text{me L}^{-1}$ )	3.16
	b) Magnesium ( $\text{me L}^{-1}$ )	2.02
	c) Sodium ( $\text{me L}^{-1}$ )	29.95
	d) Potassium ( $\text{me L}^{-1}$ )	0.29
	<b>C) Anions</b>	
	a) Carbonate ( $\text{me L}^{-1}$ )	Trace
	b) Bicarbonate ( $\text{me L}^{-1}$ )	9.29
	c) Chloride ( $\text{me L}^{-1}$ )	10.48
	d) Sulphate ( $\text{me L}^{-1}$ )	18.32

**Table 3.2 Characterization of Amendment**

Sr. No.	Amendment	Parameter	Value
1	Zeolite	pH	D.W: 7.62 KCL: 6.67
		EC (dS m <sup>-1</sup> )	0.09
		CEC (cmol (p <sup>+</sup> ) kg <sup>-1</sup> )	160
		Fe (ppm)	580.8
		Mn (ppm)	121.2
		Zn (ppm)	9.660
		Cu (ppm)	0.557
2	Gypsum	Ca (%)	23.15
		S (%)	18.10

**3.1.5 PVC Pipe Procurement**

PVC pipe were procured from Rahuri Market.

**3.2 Method****3.2.1 Experimental Details**

The experiment was laid out in Completely Randomized Design (CRD) with three replications having nine treatments including one control. The details of present investigation conducted during the year 2019 were as below

1. **Location** : Department of Soil Science and Agril. Chemistry, PGI, M.P.K.V., Rahuri.
2. **Soil** : Sodic Soil
3. **Design** : Completely Randomized Design (CRD)
4. **Replication** : Three
5. **Treatments** : Nine
6. **Date of Experiment** : 08 / 08 / 2019
7. **No. of Column** : 27

**Table 3.3 Treatment Details**

Sr. No.	Treatments
1.	Absolute Control
2.	Application of gypsum as per gypsum requirement
3.	Application of Zeolite @ 400 kg ha <sup>-1</sup>
4.	Application of Zeolite @ 600 kg ha <sup>-1</sup>
5.	Application of Zeolite @ 800 kg ha <sup>-1</sup>
6.	Application of Zeolite @ 1000 kg ha <sup>-1</sup>
7.	Application of Zeolite @ 1200 kg ha <sup>-1</sup>
8.	Application of Zeolite @ 1400 kg ha <sup>-1</sup>
9.	Application of Zeolite @ 600 kg ha <sup>-1</sup> + application of 100% gypsum as per gypsum requirement

**NOTE:**

- 1) FYM was mixed in treatments as per 10 t ha<sup>-1</sup> except T<sub>1</sub>
- 2) Gypsum, zeolite and FYM (Farm yard manure) were mixed thorough with weighed quantity of soil as per treatment and filled the column.

### 3.2.2 Preparation of Soil Column

The sodic soils was collected from Post Graduate Instructions Farm. The collected soil was ponded in wooden mortar and pestle and sieved. The known quantity of processed soil was taken (26 kg per column). The soil was thoroughly mixed with gypsum and zeolite as per treatment. This mixed soil was filled poly vinyl chloride (PVC) pipe of 100 cm height and 15 cm diameter. The bottom end of PVC pipe was tied with porous nylon net and on which the filter was placed and above that 5 cm layer of inert acid washed quartz sand to facilitate the leaching process. The PVC pipe was filled with mixed soil as per treatment upto 90 cm height. The 90 cm height was in between the top surface of soil layer in column to interface of soil and quartz sand layer. It was marked from top surface of soil in column as 0-30, 30-60 and 60-90 cm. Then there PVC pipe was hold with help of iron stand. Below the PVC column a big size funnel was kept to collect the leachate in bowl. The collected leachate was measured in measuring cylinder and thereafter used to analyze for pHs, ECe, cations and anions. The PVC column was cut at 120 DOL at 0-30, 30-60 and 60-90 cm marking. The soil was taken out from cutted portion of PVC column, dried in diffuse sunlight then ponded, sieved and used for analyzing the chemical properties in all the column filled as per treatments.

**Table 3.4 Observations recorded in experiment**

Sr. No.	Parameters	
<b>A)</b>	<b>Soil analysis</b>	
<b>Physical properties</b>	1. Bulk density	Initial
	2. Hydraulic conductivity	Initial
	3. Mechanical analysis for sand, silt, clay	Initial
<b>Chemical properties</b>	1. pH (1:2.5)	Initial
	2. EC	
	3. Organic carbon	
	4. Calcium carbonate	
	5. Cation exchange capacity (CEC)	
	6. Available N, P, K	
	7. Micro nutrients (Fe, Mn, Zn, Cu)	
<b>Saturation paste extract analysis</b>	1. pHs, ECe	Initial (Saturation paste extract analysis for characterization of soil for sodicity appraisal)
	2. $\text{Ca}^{2+}$ , $\text{Mg}^{2+}$ , $\text{Na}^+$ , $\text{K}^+$ (cations)	
	3. $\text{CO}_3^{2-}$ , $\text{HCO}_3^-$ , $\text{Cl}^-$ , $\text{SO}_4^{2-}$ (Anions)	
<b>B)</b>	<b>Leachate analysis of salts from 0 to 15 days, 15 to 30 days, 30 to 45 days, 45 to 60 days, 60 to 75 days, 75 to 90 days, 90 to 105 days, 105 to 120 days</b>	
	1. pHs	At periodical leachate analysis
	2. Ece	
	3. cations ( $\text{Ca}^{2+}$ , $\text{Mg}^{2+}$ , $\text{Na}^+$ , $\text{K}^+$ )	
	4. Anions ( $\text{CO}_3^{2-}$ , $\text{HCO}_3^-$ , $\text{Cl}^-$ , $\text{SO}_4^{2-}$ )	
<b>C)</b>	<b>Post leaching soil analysis</b>	
	1. pHs	At final (The soil sample at 30, 60 and 90 cm depth was analyzed for saturation paste extract analysis.
	2. Ece	
	3. cations ( $\text{Ca}^{2+}$ , $\text{Mg}^{2+}$ , $\text{Na}^+$ , $\text{K}^+$ )	
	4. Anions ( $\text{CO}_3^{2-}$ , $\text{HCO}_3^-$ , $\text{Cl}^-$ , $\text{SO}_4^{2-}$ )	

### 3.3 Details of Laboratory Analysis

#### 3.3.1 Laboratory Material

##### 3.3.1.1 Glasswares

The glassware *viz.*, beaker, conical flask, volumetric flask, pipette, glass rod, burette, funnel, measuring cylinder, etc. were used for analytical work.

**Table 3.5 Standard methods for analysis of soils and zeolite sample**

Sr. No.	Parameter	Method	Reference
<b>A) Initial Soil Analysis</b>			
<b>a) Physical Properties</b>			
1.	Bulk density	Clod method	Blake and Hartage (1986)
2.	Hydraulic conductivity	Constant head method	Klute and Drikson (1986)
3.	Texture	International pipette method	Piper (1966)
<b>b) Chemical Properties</b>			
1.	pH	Potentiometric	Jackson (1973)
2.	EC	Conductometric	Jackson (1973)
3.	CEC	NH <sub>4</sub> OAc	Page <i>et al.</i> (1982)
4.	Organic carbon	Wet oxidation-Walkley and Black (1934)	Nelson and Somner (1982)
5.	Calcium carbonate	Rapid titration method	Jackson (1973)
6.	Available N	Modified alkaline permanganate	Subbiah and Asija (1956)
7.	Available P	0.5 M NaHCO <sub>3</sub> (pH 8.5)	Olsen <i>et al.</i> (1954)
8.	Available K	Neutral MNH <sub>4</sub> OAc	Knudsen <i>et al.</i> (1982)
9.	Micronutrients (Fe, Mn, Zn, Cu)	Atomic absorption spectrophotometer	Lindsay and Norvell (1978)
<b>B) 1. Saturation Paste Extract Analysis 2. Leachate Analysis for every 15 days interval up to 120 days 3. Post Leaching Soil Analysis</b>			
1.	PHs	Potentiometry	Richards (1968)
2.	E <sub>Ce</sub>	Conductivity bridge	Richards (1968)
3.	Ca <sup>2+</sup> , Mg <sup>2+</sup>	Versenate titration	Richards (1968)
4.	Na <sup>+</sup> , K <sup>+</sup>	Flame Photometer	Richards (1968)
5.	Cl <sup>-</sup> , CO <sub>3</sub> <sup>2-</sup> , HCO <sub>3</sub> <sup>-</sup>	Volumetric	Richards (1968)
6.	SO <sub>4</sub> <sup>2-</sup>	Turbidimetry	Jackson (1973)
<b>C) Analysis of Zeolite</b>			
1.	pH	KCL	Wolf and Synder (2003)
2.	EC	KCL	Wolf and Synder (2003)
3.	CEC	NH <sub>4</sub> OAc	Page <i>et al.</i> (1982)
4.	Micronutrients (Fe, Mn, Zn & Cu)	Inductively coupled plasma-optical emission spectrometry	Spivey and Neubauer (2016)
<b>D) Derived Parameter</b>			
1.	ESP	$\frac{Ex. Na^+}{CEC} \times 100$	Richards (1968)
2.	SAR	$\frac{Na^+}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}}$	Richards (1968)

### 3.3.1.2 Equipments

The equipments *viz.*, pH meter, conductivity meter, distillation unit, hot air oven, weighing balance, mechanical shaker, spectrophotometer, flame photometer and atomic absorption spectrophotometer etc. were used during the laboratory analysis.

### 3.3.1.3 Chemicals

The high purity (AR grade) chemicals such as sulphuric acid, silver nitrate, potassium chromate, sodium hydroxide, hydrochloric acid, potassium ferricyanide, sodium chloride, glycerol, ethyl alcohol, barium chloride, EDTA and boric acids. The indicated used are calcon, EBT, phenolphthalein and methyl orange.

## 3.3.2 Laboratory Methods

### 3.3.2.1 Soil analysis

Composite soil sample (0-15 cm) were collected, processed and analysed for pH, EC, CaCO<sub>3</sub>, CEC, soil organic carbon and pHs, E<sub>Ce</sub>, cations (Ca<sup>2+</sup>, Mg<sup>2+</sup>, Na<sup>+</sup> and K<sup>+</sup>) and anions (CO<sub>3</sub><sup>-</sup>, HCO<sub>3</sub><sup>-</sup>, Cl<sup>-</sup>, SO<sub>4</sub><sup>2-</sup>) from saturation paste extract before installing column study experiment and after harvest according to standard methods are mentioned in Table 3.5.

## 3.4 Statistical Analysis

The data recorded for each observation was analysed statistically as per the procedure described by Panse and Sukhatme (1985). The standard error and critical difference for each observation was determined.

## 4. RESULTS AND DISCUSSION

Soil salinization and sodification are two major threats to soil productivity in arable croplands. Soils having high amount of soluble salts (saline soils) or exchangeable sodium (sodic soils) or both (saline-sodic) adversely affect the growth of most of crop plants and are collectively called salt affected soils. Salt affected soils are wide spread in arid and semiarid regions of Asia, Australia, Africa and South America, is likely to be expand worldwide in future due to poor management of land and water resources and unprecedented regional and global climate change and variability.

Salt affected soils may be saline, saline sodic or sodic. However, from the management and reclamation point of view, salt affected soils are grouped into two classes only saline and saline-sodic and sodic soils. Excessive concentration of soluble salts and/ or exchangeable sodium ( $\text{Na}^+$ ) on cation exchange sites in soil cause poor and patch crop stands with uneven and stunted growth thus, reducing yield. Salt affected soils can be used successfully for crop production following measures aimed at removal of soluble salts and/ or exchangeable  $\text{Na}^+$  (reclamation of salt affected soils) or minimizing the adverse impact of salts on plants (management of salt affected soils).

Saline soils easy to reclaim because the problem lies with the excessive amount of soluble salts that can be removed from the soil profile, providing good quality water is available and there is no hindrance to movement of water from the soil. For reclamation of saline-sodic and sodic soils there is a need to remove excessive amount of sodium from the cation exchange sites using other cations such as calcium followed by leaching the replaced sodium from the soil profile.

Application of organic amendments to saline-sodic and/or sodic soils could produce beneficial impact on plant growth by improving soil properties especially physico-chemical one. Inorganic/ chemical amendments could replace the excessive sodium from soil and improves the soil properties. An integration of organic and inorganic amendments used to reclaim the saline-sodic or sodic soils till the best for improvement of soil properties. In view of this the present investigation was planned to find out the effect of graded levels of zeolite and gypsum on sodic soils by laboratory column study and field experiments. The results emerged from present investigation are presented in this chapter.

### 4. Column Study

The column study was conducted in the laboratory under ambient condition. The column of PVC pipe of 100 cm length and 6 inches diameter. The bottom end was tied with fine mesh net on which three layers filter paper. Sand was kept on filter paper to facilitate the filtration. The column was filled with processed sodic soils collected from field in which the field experiment conducted, gently tap the column for uniform filling. The height of soil column was 90 cm and

empty portion was 10 cm. The PVC column was marked from top of soil surface as 0-30, 30-60 and 60-90 cm respectively (Soils filled on column was mixed with zeolite and gypsum as per treatment thoroughly). This soil filled column were hold with stand in vertical position on tripods and with funnel in such way that the column circumference was fit in to filter. Then column was saturated with canal irrigation water. Allow the column to leach out by putting the irrigation water at top 10 cm height.

The leachate collected periodically *viz.*, 15, 30, 45, 60, 75, 90, 105 and 120 days. At every period of leachate collection was analyzed for their pH, EC, cations and anions.

The experiment on “Effect of different levels of zeolite for improvement of sodic soil” was carried out in Department of Soil Science and Agricultural Chemistry, MPKV, Rahuri and the results obtained during this investigation are presented and discussed in this chapter under the following heads.

4.1 Effect of amendment on leaching behaviour of soil.

4.2 Effect of amendments on characteristics of leachates.

4.3 Effect of leaching on chemical properties of soil.

4.4 Effect of leaching on physical properties of soil.

#### 4.1 Effect of Amendment on Leaching Behaviour of Soil

**Table 4.1 Effect of Amendment on Leaching Behaviour of Soil**

Tr. No.	Treatment	Leachate (litre)							Total
		15 DOL	30 DOL	45 DOL	60 DOL	75 DOL	90 DOL	105 DOL	
T <sub>1</sub>	Absolute control	220.0	88.0	12.5	4.5	1.55	0.40	0.20	327.15
T <sub>2</sub>	Gypsum as per GR	341.5	95.4	10.7	6.0	1.80	0.75	0.71	456.86
T <sub>3</sub>	Zeolite @ 400 kg ha <sup>-1</sup>	295.9	73.2	9.5	7.6	1.66	0.57	0.53	388.96
T <sub>4</sub>	Zeolite @ 600 kg ha <sup>-1</sup>	305.2	81.4	7.6	6.5	1.88	0.41	0.38	403.37
T <sub>5</sub>	Zeolite @ 800 kg ha <sup>-1</sup>	310.0	80.5	4.5	4.8	1.20	0.33	0.30	401.63
T <sub>6</sub>	Zeolite @ 1000 kg ha <sup>-1</sup>	321.3	75.7	6.6	5.8	1.95	0.61	0.58	412.54
T <sub>7</sub>	Zeolite @ 1200 kg ha <sup>-1</sup>	320.0	53.8	6.1	6.4	2.20	0.41	0.40	389.31
T <sub>8</sub>	Zeolite @ 1400 kg ha <sup>-1</sup>	312.5	40.5	8.1	6.3	1.60	0.30	0.30	369.6
T <sub>9</sub>	Zeolite @ 600 kg ha <sup>-1</sup> + 100% gypsum as per GR	345.8	95.4	13.1	7.6	2.35	0.15	0.10	464.5

In order to study the leaching behaviour of sodic soils, the column study was conducted for 120 days with different amendments *viz.*, zeolite, gypsum and their combinations with FYM. Irrigation water was allowed to pass through the soil column and collected it for measurement of quantity.

From Table 4.1, it was observed that the highest amount of leachate was collected in T<sub>9</sub> treatment i.e. 464.5 litre, whereas the least amount of leachate was collected with treatment T<sub>1</sub> i.e. 327.15 litre. The amount of water passed through a soil column was more in first 15 days in all the treatments and decreases thereafter. This also reported that the addition of water with gypsum enhanced leaching (Banerjee, 1957).

## 4.2 Effect of Amendment on Characteristics of Leachate

### 4.2.1 Effect of Graded Levels of Zeolite on Periodical pHs Leachate in Sodic Soils

The data with respect to the pHs of leachate as influenced by FYM, Zeolite, Gypsum and their combinations are presented in Table 4.2

**Table 4.2 Effect of Graded Levels of Zeolite on Periodical pHs Leachate in Sodic Soils**

Tr. No	Treatment	pHs							
		15 DOL	30 DOL	45 DOL	60 DOL	75 DOL	90 DOL	105 DOL	120 DOL
T <sub>1</sub>	Absolute control	8.79	8.76	8.72	8.69	8.65	8.63	8.60	8.57
T <sub>2</sub>	Gypsum as per GR	8.54	8.48	8.38	8.30	8.26	8.24	8.20	8.18
T <sub>3</sub>	Zeolite @ 400 kgha <sup>-1</sup>	8.76	8.70	8.68	8.65	8.63	8.60	8.57	8.52
T <sub>4</sub>	Zeolite @ 600 kgha <sup>-1</sup>	8.72	8.68	8.65	8.61	8.57	8.54	8.52	8.50
T <sub>5</sub>	Zeolite @ 800 kgha <sup>-1</sup>	8.69	8.63	8.59	8.56	8.54	8.52	8.50	8.46
T <sub>6</sub>	Zeolite @ 1000 kgha <sup>-1</sup>	8.65	8.62	8.58	8.55	8.52	8.49	8.45	8.43
T <sub>7</sub>	Zeolite @ 1200 kgha <sup>-1</sup>	8.62	8.58	8.55	8.51	8.47	8.45	8.41	8.39
T <sub>8</sub>	Zeolite @ 1400 kgha <sup>-1</sup>	8.58	8.52	8.49	8.47	8.41	8.34	8.35	8.32
T <sub>9</sub>	Zeolite @ 600 kgha <sup>-1</sup> + 100% gypsum as per GR	8.51	8.40	8.32	8.29	8.23	8.20	8.16	8.11
	<b>SEm±</b>	0.05	0.04	0.06	0.07	0.06	0.04	0.03	0.08
	<b>CD at 5%</b>	0.15	0.12	0.18	0.21	0.18	0.14	0.11	0.24

The periodical pHs of leachate of sodic soil was significantly influenced by gypsum and graded levels of zeolite (Table 4.2). The pHs of leachate of sodic soil was significantly decrease with increase the levels of zeolite application in all the period of study. It was also decreased with increased period of leachate collection. The treatment zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per gypsum requirement recorded significantly lower values of pHs of leachate from 15 DOL to 120 DOL with an interval of 15 days viz., 15, 30, 45, 60, 75, 90, 105 and 120 DOL (8.51, 8.40, 8.32, 8.29, 8.23, 8.20, 8.16 and 8.11 respectively). The pHs of leachate was reduced averagely by 1 unit at 30 DOL by the graded levels of zeolite application at 30 DOL as compared to pHs of leachate at 15 DOL. However, in further, period the pHs was reduced in fraction values but decreased with increased period of leachate collection.

The increased the levels of zeolite decreased the pHs of leachate might be associated with honey comb structure of zeolite in which most of the cation are trapped. The trapped sodium cation by zeolite was not allowed to leached the water from column. Similarly, over a period of column study more amount of cation might be trapped by zeolite and restricted their leaching in the column. Hence, the pHs of leachate was decreased with increased period of column study.

The treatment zeolite @ 600 kg ha<sup>-1</sup> + gypsum application as per 100% gypsum requirement was recorded significantly lower value of pHs of leachate from 15 DOL to 120 DOL. This might be because of Ca<sup>++</sup> of gypsum replaced the Na<sup>+</sup> from exchange site of clay complex and also replaced the trapped Na<sup>+</sup> from comb like structure by Ca<sup>++</sup>. The replaced the

$\text{Na}^+$  might be combined with  $\text{SO}_4^-$  of gypsum and forms  $\text{Na}_2\text{SO}_4^-$  salt. This salt is soluble in water and easily leached from column by irrigation water (Sunitha *et al.*, 2010).

#### 4.2.2 Effect of Graded Levels of Zeolite on Periodical Electrical Conductivity of Leachate in Sodic Soils

The data with respect to electrical conductivity of leachate as influenced by FYM, Zeolite, Gypsum and their combinations are presented in Table 4.3

**Table 4.3 Effect of graded levels of zeolite on periodical electrical conductivity of leachate in sodic soils**

Tr. No.	Treatment	ECe (dS m <sup>-1</sup> )							
		15 DOL	30 DOL	45 DOL	60 DOL	75 DOL	90 DOL	105 DOL	120 DOL
T <sub>1</sub>	Absolute control	2.52	2.64	2.71	2.86	2.84	2.81	2.78	2.74
T <sub>2</sub>	Gypsum as per GR	3.29	4.02	4.78	5.52	5.41	5.27	5.12	5.01
T <sub>3</sub>	Zeolite @ 400 kg ha <sup>-1</sup>	2.59	3.11	3.32	3.61	3.58	3.52	3.48	3.39
T <sub>4</sub>	Zeolite @ 600 kg ha <sup>-1</sup>	2.63	3.25	3.36	3.68	3.62	3.57	3.51	3.47
T <sub>5</sub>	Zeolite @ 800 kg ha <sup>-1</sup>	2.71	3.32	3.53	3.77	3.73	3.70	3.64	3.59
T <sub>6</sub>	Zeolite @ 1000 kg ha <sup>-1</sup>	2.78	3.42	3.56	3.88	3.85	3.78	3.69	3.67
T <sub>7</sub>	Zeolite @ 1200 kg ha <sup>-1</sup>	2.81	3.61	3.72	3.98	3.95	3.91	3.87	3.73
T <sub>8</sub>	Zeolite @ 1400 kg ha <sup>-1</sup>	2.87	3.71	3.83	4.14	4.05	3.97	3.93	3.85
T <sub>9</sub>	Zeolite @ 600 kg ha <sup>-1</sup> + 100% gypsum as per GR	3.35	4.42	4.92	5.73	5.54	5.48	5.39	5.22
	<b>SEm<sub>±</sub></b>	0.18	0.24	0.45	0.53	0.51	0.58	0.52	0.51
	<b>CD at 5%</b>	0.54	0.73	1.34	1.59	1.53	1.74	1.57	1.54

The application of graded levels of zeolite @ 600 kg ha<sup>-1</sup> with 100% gypsum requirement significantly influenced the periodical electrical conductivity of leachate in sodic soils (Table 4.3). It was significantly the highest in treatment zeolite application @ 600 kg ha<sup>-1</sup> + gypsum application as per 100% gypsum requirement at all the period of column study *viz.*, 15, 30, 45, 60, 75, 90, 105 and 120 DOL (3.35, 4.42, 4.92, 5.73, 5.54, 5.48, 5.39 and 5.22 dSm<sup>-1</sup> respectively). This might be because of calcium of gypsum replaced the  $\text{Na}^+$  from exchange site of clay surface and forms soluble salt  $\text{Na}_2\text{SO}_4^-$  which can easily be leached from column while illuting with irrigation water along with that there might be formation of  $\text{NaCl}^-$  salt. The  $\text{Na}_2\text{SO}_4^-$  and  $\text{NaCl}^-$  both salts of sodium easily soluble in water and leached from column to leachate. This was reflected in increased electrical conductivity of periodical leachate of column.

The graded levels of zeolite *viz.*, 400, 600, 800, 1000, 1200 and 1400 kg ha<sup>-1</sup> respectively increases the electrical conductivity of leachate of sodic soils. This might be because of trapping of  $\text{Ca}^{++}$  in comb like structure of zeolite and replacing the  $\text{Na}^+$  from structure of zeolite and exchange site complex. The replaced  $\text{Na}^+$  combines with either  $\text{SO}_4^-$  or  $\text{Cl}^-$  and forms soluble salts as  $\text{Na}_2\text{SO}_4^-$  or  $\text{NaCl}^-$  which can each leached out and come into the leachate and increase the electrical conductivity of leachate irrespective of period of column study. Similarly, electrical

conductivity increases from 15 DOL to 60 DOL and then the increased period of column study i.e. from 75 DOL to 120 DOL decreased the electrical conductivity irrespective of graded levels of zeolite application.

The periodical electrical conductivity increases with increasing the days of leachate. This might be associated with an early period of column leachate more illution of soluble salts and later on it was decreased. Hence, the increased period of column study decreased the electrical conductivity of leachate of sodic soils (Kharche *et al.*, 2010 and Robbins, 1986).

#### 4.2.3 Effect of Graded Levels of Zeolite on Periodical Calcium Content of Leachate in Sodic Soils

Calcium content in leachate as influenced by FYM, Zeolite, Gypsum and their combinations are presented in Table 4.4, which clearly indicates that the total calcium content in leachate was less in all the treatments than control.

**Table 4.4 Effect of graded levels of zeolite on periodical calcium content of leachate in sodic soil**

Tr. No.	Treatment	Periodical Ca <sup>2+</sup> (me L <sup>-1</sup> )							
		15 DOL	30 DOL	45 DOL	60 DOL	75 DOL	90 DOL	105 DOL	120 DOL
T <sub>1</sub>	Absolute control	2.66	2.52	2.49	2.31	2.29	2.26	2.23	2.18
T <sub>2</sub>	Gypsum as per GR	2.26	2.09	2.08	1.89	1.85	1.82	1.81	1.73
T <sub>3</sub>	Zeolite @ 400 kg ha <sup>-1</sup>	2.50	2.36	2.33	2.25	2.19	2.14	2.11	2.06
T <sub>4</sub>	Zeolite @ 600 kg ha <sup>-1</sup>	2.44	2.30	2.27	2.18	2.16	2.13	2.08	2.03
T <sub>5</sub>	Zeolite @ 800 kg ha <sup>-1</sup>	2.41	2.27	2.24	2.10	2.08	2.06	2.03	1.98
T <sub>6</sub>	Zeolite @ 1000 kg ha <sup>-1</sup>	2.38	2.24	2.21	2.08	2.06	2.02	2.01	1.96
T <sub>7</sub>	Zeolite @ 1200 kg ha <sup>-1</sup>	2.35	2.20	2.18	2.03	2.01	1.98	1.95	1.90
T <sub>8</sub>	Zeolite @ 1400 kg ha <sup>-1</sup>	2.31	2.19	2.15	1.98	1.95	1.90	1.87	1.82
T <sub>9</sub>	Zeolite @ 600 kg ha <sup>-1</sup> + 100% gypsum as per GR	2.20	2.06	2.03	1.85	1.83	1.78	1.75	1.70
	<b>SEm<sub>±</sub></b>	0.05	0.06	0.04	0.05	0.06	0.07	0.05	0.04
	<b>CD at 5%</b>	0.15	0.18	0.12	0.15	0.18	0.21	0.15	0.12

The calcium were recorded with the application of Zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR i.e. 2.20, 2.06, 2.03, 1.85, 1.83, 1.78, 1.75 and 1.70 me L<sup>-1</sup> at 15, 30, 45, 60, 75, 90, 105 and 120 days respectively, which was statistically lower over other treatments. The removal of calcium was low in T<sub>9</sub> (2.20 me L<sup>-1</sup>) over all other treatment on the 15 DOL of the experiment and at par with T<sub>2</sub> (2.26 me L<sup>-1</sup>), T<sub>7</sub> (2.35 me L<sup>-1</sup>), T<sub>8</sub> (2.31 me L<sup>-1</sup>). Whereas after 30<sup>th</sup> DOL, the removal of calcium was 2.06 me L<sup>-1</sup> in the same treatment which was lower as compared to the 15<sup>th</sup> DOL and at par with treatment T<sub>2</sub> (2.09 me L<sup>-1</sup>), T<sub>6</sub> (2.24 me L<sup>-1</sup>), T<sub>7</sub> (2.20 me L<sup>-1</sup>) and T<sub>8</sub> (2.19 me L<sup>-1</sup>). The Ca<sup>++</sup> of leachate of sodic soil was significantly decreased with increased levels of zeolite application in all the period of study. It was also decreased with increased period of leachate collection.

On 45 DOL, it was found low in T<sub>9</sub> i.e. (2.03 me L<sup>-1</sup>) which was significantly lower over the all treatments and at par with treatment T<sub>2</sub> (2.08 me L<sup>-1</sup>) and T<sub>8</sub> (2.15 me L<sup>-1</sup>). However on 60<sup>th</sup> DOL, it was minimum with the application of Zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR (1.85 me L<sup>-1</sup>) which was significantly lower and at par with T<sub>2</sub> (1.89 me L<sup>-1</sup>) and T<sub>8</sub> (1.98 me L<sup>-1</sup>). On 75<sup>th</sup> DOL, it was low in same treatment i.e. in T<sub>9</sub> (1.83 me L<sup>-1</sup>) and at par with T<sub>2</sub> (1.85 me L<sup>-1</sup>), T<sub>7</sub> (2.01 me L<sup>-1</sup>) and T<sub>8</sub> (1.95 me L<sup>-1</sup>). On 90 DOL, calcium content was 1.78 me L<sup>-1</sup> which was lower over the all treatment and at par with T<sub>2</sub> (1.82 me L<sup>-1</sup>), T<sub>7</sub> (1.98 me L<sup>-1</sup>) and T<sub>8</sub> (1.90 me L<sup>-1</sup>). Calcium content was low in T<sub>9</sub> (1.75 me L<sup>-1</sup>) and at par with T<sub>2</sub> (1.81 me L<sup>-1</sup>) and T<sub>8</sub> (1.87 me L<sup>-1</sup>) on 105 DOL whereas on 120 DOL, it was recorded low in T<sub>9</sub> (1.70 me L<sup>-1</sup>) which was lower and at par with T<sub>2</sub> (1.73 me L<sup>-1</sup>) and T<sub>8</sub> (1.82 me L<sup>-1</sup>).

The calcium of leachate was higher at initial stage. The calcium was lower with the application of amendment than control, which indicates that the released calcium of gypsum might be replaced on exchange complex. Hence amendments minimized the calcium losses during leaching (Mumpton, 1999 and Ahroni *et al.*, 1991).

#### 4.2.4 Effect of Graded Levels of Zeolite on Periodical Magnesium Content of Leachate in Sodic Soil

The data with respect to the magnesium content in leachate as influenced by FYM, Zeolite, Gypsum and their combinations are presented in Table 4.5.

**Table 4.5 Effect of graded levels of zeolite on periodical magnesium content of leachate in sodic soil**

Tr. No.	Treatment	Periodical Mg <sup>2+</sup> (me L <sup>-1</sup> )							
		15 DOL	30 DOL	45 DOL	60 DOL	75 DOL	90 DOL	105 DOL	120 DOL
T <sub>1</sub>	Absolute control	1.37	1.33	1.21	1.17	1.16	1.12	1.05	1.01
T <sub>2</sub>	Gypsum as per GR	1.62	1.54	1.50	1.46	1.40	1.32	1.26	1.26
T <sub>3</sub>	Zeolite @ 400 kg ha <sup>-1</sup>	1.39	1.31	1.28	1.20	1.14	1.10	1.09	1.04
T <sub>4</sub>	Zeolite @ 600 kg ha <sup>-1</sup>	1.43	1.36	1.32	1.22	1.18	1.14	1.11	1.09
T <sub>5</sub>	Zeolite @ 800 kg ha <sup>-1</sup>	1.47	1.39	1.36	1.29	1.23	1.18	1.17	1.12
T <sub>6</sub>	Zeolite @ 1000 kg ha <sup>-1</sup>	1.51	1.45	1.42	1.31	1.28	1.21	1.20	1.16
T <sub>7</sub>	Zeolite @ 1200 kg ha <sup>-1</sup>	1.54	1.49	1.45	1.38	1.31	1.24	1.21	1.20
T <sub>8</sub>	Zeolite @ 1400 kg ha <sup>-1</sup>	1.59	1.53	1.49	1.42	1.38	1.28	1.24	1.22
T <sub>9</sub>	Zeolite @ 600 kg ha <sup>-1</sup> + 100% gypsum as per GR	1.66	1.58	1.54	1.49	1.43	1.35	1.31	1.29
	<b>SEm±</b>	0.04	0.01	0.01	0.01	0.01	0.01	0.02	0.02
	<b>CD at 5%</b>	0.12	0.05	0.05	0.03	0.05	0.03	0.05	0.07

The periodical Mg<sup>++</sup> of leachate of sodic soil was significantly influenced by gypsum and graded levels of zeolite (Table 4.5). The magnesium was higher with the application of Zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum requirement which was significantly recorded superior value of Mg<sup>++</sup> of leachate from 15 DOL to 120 DOL (1.66, 1.58, 1.54, 1.49, 1.43, 1.35, 1.31, 1.29 me L<sup>-1</sup>

respectively). The removal of magnesium was significantly higher in T<sub>9</sub> (1.66 me L<sup>-1</sup>) over all other treatment on the 15 DOL of the experiment and at par with T<sub>2</sub> (1.62 me L<sup>-1</sup>), T<sub>7</sub> (1.54 me L<sup>-1</sup>), T<sub>8</sub> (1.59 me L<sup>-1</sup>). Whereas after 30 DOL, the removal of magnesium was 1.58 me L<sup>-1</sup> in the same treatment which was lower as compared to the 15 DOL but significantly higher over the all treatments and at par with treatment T<sub>2</sub> (1.54 me L<sup>-1</sup>) and T<sub>8</sub> (1.53 me L<sup>-1</sup>). The Mg<sup>++</sup> of leachate of sodic soil was significantly increased with increased levels of zeolite application in all the period of study. It was also decreased with increased period of leachate collection.

On 45 DOL, it was found more in T<sub>9</sub> i.e. (1.54 me L<sup>-1</sup>) which was higher over the all treatment and at par with treatment T<sub>2</sub> (1.50 me L<sup>-1</sup>) and T<sub>8</sub> (1.49 me L<sup>-1</sup>). However on 60 DOL, it was maximum with the application of Zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR (1.49 me L<sup>-1</sup>) which was significantly higher followed by T<sub>2</sub> (1.46 me L<sup>-1</sup>) On 75 DOL, it was maximum in same treatment i.e. in T<sub>9</sub> (1.43 me L<sup>-1</sup>) and at par with T<sub>2</sub> (1.40 me L<sup>-1</sup>) and T<sub>8</sub> (1.38 me L<sup>-1</sup>). On 90 and 105 DOL, magnesium content was 1.35 me L<sup>-1</sup> and 1.31 me L<sup>-1</sup> respectively which highly superior over all treatment followed by gypsum as per GR. Magnesium content was maximum in T<sub>9</sub> (1.29 me L<sup>-1</sup>) and at par with T<sub>2</sub> (1.26 me L<sup>-1</sup>) and T<sub>8</sub> (1.22 me L<sup>-1</sup>) on 120 DOL. It might be due to the release of magnesium from the soil and from honey comb structure of zeolite which removal of magnesium and form magnesium complex as MgCl<sub>2</sub> through leachate (Satyanarayan, 1954).

#### 4.2.5 Effect of Graded Levels of Zeolite on Periodical Sodium Content of Leachate in Sodic Soil

The data brought forth to the sodium content in leachate as influenced by organic and inorganic amendments are given in Table 4.6 and depicted in Fig. 4.5 Initially the removal of sodium was higher in all treatments but decreased with time.

**Table 4.6 Effect of graded levels of zeolite on periodical sodium content of leachate in sodic soil**

Tr. No.	Treatment	Periodical Na <sup>+</sup> (me L <sup>-1</sup> )							
		15 DOL	30 DOL	45 DOL	60 DOL	75 DOL	90 DOL	105 DOL	120 DOL
T <sub>1</sub>	Absolute control	23.22	25.20	27.42	28.27	28.12	27.97	27.79	27.67
T <sub>2</sub>	Gypsum as per GR	27.19	36.76	48.28	53.23	53.04	52.86	52.68	52.56
T <sub>3</sub>	Zeolite @ 400 kg ha <sup>-1</sup>	24.28	29.78	32.01	32.85	32.83	32.65	32.47	32.35
T <sub>4</sub>	Zeolite @ 600 kg ha <sup>-1</sup>	24.35	29.85	32.07	32.92	32.86	32.76	32.56	32.41
T <sub>5</sub>	Zeolite @ 800 kg ha <sup>-1</sup>	24.39	29.89	32.11	32.96	32.94	32.80	32.59	32.46
T <sub>6</sub>	Zeolite @ 1000 kg ha <sup>-1</sup>	24.43	29.93	32.15	33.23	33.13	33.03	32.63	32.52
T <sub>7</sub>	Zeolite @ 1200 kg ha <sup>-1</sup>	24.84	30.34	32.56	33.41	33.37	33.22	33.04	32.92
T <sub>8</sub>	Zeolite @ 1400 kg ha <sup>-1</sup>	25.02	30.57	32.74	33.59	33.54	33.39	33.21	33.09
T <sub>9</sub>	Zeolite @ 600 kg ha <sup>-1</sup> + 100% gypsum as per GR	27.49	36.99	48.51	53.46	53.39	53.24	53.06	52.94
	<b>SEM<sub>+</sub></b>	0.91	2.15	5.43	6.68	6.61	0.14	6.71	6.63
	<b>CD at 5%</b>	2.72	6.45	16.3	20.05	19.85	0.42	20.12	19.89

The periodical  $\text{Na}^{++}$  of leachate of sodic soil was significantly influenced by gypsum and graded levels of zeolite (Table 4.6). Sodium was maximum in treatment i.e. zeolite @ 600 kg  $\text{ha}^{-1}$  with 100% gypsum requirement) which was significantly recorded superior value of  $\text{Na}^{++}$  of leachate from 15 DOL to 120 DOL (27.49, 36.99, 48.51, 53.46, 53.39, 53.24, 53.06 and 52.94  $\text{me L}^{-1}$  respectively).

On 15 DOL, sodium was 27.49  $\text{me L}^{-1}$  with the application of Zeolite @ 600 kg  $\text{ha}^{-1}$  + 100% gypsum as per GR which was significantly higher over the all treatments and at par with  $T_2$  (27.19  $\text{me L}^{-1}$ ),  $T_7$  (24.84  $\text{me L}^{-1}$ ) and  $T_8$  (25.02  $\text{me L}^{-1}$ ); whereas at 30 DOL, it was found maximum with treatment  $T_9$  (36.99  $\text{me L}^{-1}$ ) i.e. Zeolite @ 600 kg  $\text{ha}^{-1}$  + 100% gypsum as per GR which was significantly higher over the all treatments and at par with  $T_2$  (36.76  $\text{me L}^{-1}$ ) and  $T_8$  (30.57  $\text{me L}^{-1}$ ). On 45 DOL of the experiment, the maximum sodium were leached out with the application of Zeolite @ 600 kg  $\text{ha}^{-1}$  + 100% gypsum as per GR and found at par with treatment  $T_2$  (48.28  $\text{me L}^{-1}$ ),  $T_7$  (32.56  $\text{me L}^{-1}$ ) and  $T_8$  (32.74  $\text{me L}^{-1}$ ); whereas on 60 DOL, the maximum removal of sodium was found with treatment  $T_9$  i.e. (53.46  $\text{me L}^{-1}$ ) and found higher over the all treatments and however treatment  $T_9$  was at par with  $T_2$  (53.23  $\text{me L}^{-1}$ ),  $T_7$  (33.41  $\text{me L}^{-1}$ ) and  $T_8$  (33.59  $\text{me L}^{-1}$ ).

On 75 DOL, sodium was found more in  $T_9$  i.e. (53.39  $\text{me L}^{-1}$ ) which was superior over the all treatments and at par with  $T_2$  (53.04  $\text{me L}^{-1}$ ) and  $T_8$  (33.54  $\text{me L}^{-1}$ ). However on 90 DOL, it was maximum with the application of Zeolite @ 600 kg  $\text{ha}^{-1}$  + 100% gypsum as per GR (53.24  $\text{me L}^{-1}$ ) which was significantly higher over the all other treatments followed by  $T_2$  (52.86  $\text{me L}^{-1}$ ). Maximum sodium was leached out at 105 DOL with  $T_9$  (53.06  $\text{me L}^{-1}$ ) which was higher over the all treatments and at par with  $T_2$  (52.68  $\text{me L}^{-1}$ ),  $T_7$  (33.04  $\text{me L}^{-1}$ ) and  $T_8$  (33.21  $\text{me L}^{-1}$ ). On 120 DOL, it was also maximum in same treatment i.e. in  $T_9$  (52.94  $\text{me L}^{-1}$ ) over all treatments and at par with  $T_2$  (52.56  $\text{me L}^{-1}$ ),  $T_8$  (33.09  $\text{me L}^{-1}$ ). The  $\text{Na}^+$  of leachate of sodic soil was significantly increase with increasing levels of zeolite application in all the period of study. Similarly, sodium was increased from 15 DOL to 60 DOL and then it was decreased from 75 DOL to 120 DOL irrespective of graded levels of zeolite application.

From the data it was investigated that treatment  $T_9$  was found effective for removal of sodium which might be due to the reaction between  $\text{CaSO}_4$  and  $\text{Na}^+$  ion in soil. This might be because of trapping of  $\text{Ca}^{++}$  in comb like structure of zeolite and replacing the  $\text{Na}^+$  on exchange site complex. The replaced  $\text{Na}^+$  combines with either  $\text{SO}_4^-$  or  $\text{Cl}^-$  and forms soluble salts as  $\text{Na}_2\text{SO}_4^-$  or  $\text{NaCl}^-$  which can each leached out and come into the leachate and increased  $\text{Na}^+$  of leachate (Suarez, 2001; Gharaibeh *et al.*, 2011).

#### 4.2.6 Effect of Graded Levels of Zeolite on Periodical Potassium Content of Leachate in Sodic Soil

The potassium content in leachate was influenced by the application of FYM, zeolite, Gypsum and their combinations in sodic soil is given in Table 4.7.

**Table 4.7 Effect of graded levels of zeolite on periodical potassium content of leachate in sodic soil**

Tr. No.	Treatment	Periodical K <sup>+</sup> (me L <sup>-1</sup> )							
		15 DOL	30 DOL	45 DOL	60 DOL	75 DOL	90 DOL	105 DOL	120 DOL
T <sub>1</sub>	Absolute control	0.49	0.47	0.44	0.37	0.36	0.35	0.33	0.30
T <sub>2</sub>	Gypsum as per GR	0.63	0.61	0.59	0.55	0.54	0.53	0.51	0.48
T <sub>3</sub>	Zeolite @ 400 kg ha <sup>-1</sup>	0.51	0.46	0.44	0.39	0.36	0.35	0.33	0.30
T <sub>4</sub>	Zeolite @ 600 kg ha <sup>-1</sup>	0.53	0.48	0.46	0.41	0.38	0.37	0.35	0.32
T <sub>5</sub>	Zeolite @ 800 kg ha <sup>-1</sup>	0.55	0.52	0.46	0.43	0.41	0.40	0.38	0.35
T <sub>6</sub>	Zeolite @ 1000 kg ha <sup>-1</sup>	0.57	0.52	0.48	0.44	0.42	0.41	0.39	0.36
T <sub>7</sub>	Zeolite @ 1200 kg ha <sup>-1</sup>	0.61	0.53	0.52	0.48	0.47	0.45	0.44	0.41
T <sub>8</sub>	Zeolite @ 1400 kg ha <sup>-1</sup>	0.62	0.55	0.53	0.50	0.49	0.46	0.48	0.45
T <sub>9</sub>	Zeolite @ 600 kg ha <sup>-1</sup> + 100% gypsum as per GR	0.64	0.63	0.60	0.58	0.57	0.56	0.54	0.51
	<b>SEm<sub>±</sub></b>	0.02	0.02	0.03	0.03	0.02	0.01	0.02	0.02
	<b>CD at 5%</b>	0.07	0.08	0.09	0.10	0.08	0.04	0.06	0.07

The periodical K<sup>+</sup> of leachate of sodic soil was significantly influenced by gypsum and graded levels of zeolite (Table 4.7). The potassium was high with application of Zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum requirement which was significantly recorded superior value of K<sup>+</sup> of leachate from 15 DOL to 120 DOL (0.64, 0.63, 0.60, 0.58, 0.57, 0.56, 0.54, 0.51 me L<sup>-1</sup> respectively). On 15 DOL, treatment T<sub>9</sub> (0.64 me L<sup>-1</sup>) was found effective in the removal of potassium whereas treatment T<sub>2</sub> (0.63 me L<sup>-1</sup>), T<sub>6</sub> (0.57 me L<sup>-1</sup>), T<sub>7</sub> (0.61 me L<sup>-1</sup>) and T<sub>8</sub> (0.62 me L<sup>-1</sup>) were at par with treatment T<sub>9</sub> (0.64 me L<sup>-1</sup>). Whereas on 30 DOL of experiment, the removal of potassium found effective with the application of Zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR (0.63 me L<sup>-1</sup>) which was significantly higher over the all treatments and at par with treatment T<sub>2</sub> (0.61 me L<sup>-1</sup>) and T<sub>8</sub> (0.55 me L<sup>-1</sup>) whereas on 45 DOL of experiment, removal of potassium i.e. (0.60 me L<sup>-1</sup>) was recorded highest which was observed with the application of Zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR and found significantly superior over control and at par with treatment T<sub>2</sub> (0.59 me L<sup>-1</sup>), T<sub>7</sub> (0.52 me L<sup>-1</sup>) and T<sub>8</sub> (0.53 me L<sup>-1</sup>). Whereas on 60 DOL, maximum removal of potassium was observed in T<sub>9</sub> (0.58 me L<sup>-1</sup>) which was significantly higher over the all treatments and at par with the treatment T<sub>2</sub> (0.55 me L<sup>-1</sup>), T<sub>7</sub> (0.48 me L<sup>-1</sup>) and T<sub>8</sub> (0.50 me L<sup>-1</sup>).

The removal of potassium was significantly higher in T<sub>9</sub> (0.57 me L<sup>-1</sup>) which statistically on par with T<sub>2</sub> (0.54 me L<sup>-1</sup>) and T<sub>8</sub> (0.49 me L<sup>-1</sup>) on the 75 DOL of the experiment. Whereas

after 90 DOL, the removal of potassium was  $0.56 \text{ me L}^{-1}$  in the same treatment which was lower as compared to 75 DOL but significantly higher followed by treatment  $T_2$  ( $0.53 \text{ me L}^{-1}$ ). The periodical  $K^+$  of leachate of sodic soil was significantly influenced by gypsum and graded levels of zeolite. The  $K^+$  of leachate of sodic soil was significantly increased with increased levels of zeolite application in all the period of study. It was also decreased with increased period of leachate collection. Potassium content was also more in same treatment i.e. in  $T_9$  ( $0.54 \text{ me L}^{-1}$ ) and at par with  $T_2$  ( $0.51 \text{ me L}^{-1}$ ) and  $T_8$  ( $0.48 \text{ me L}^{-1}$ ) at 105 DOL. On 120 DOL, it was  $0.51 \text{ me L}^{-1}$  in  $T_9$  which was higher and at par with  $T_2$  ( $0.48 \text{ me L}^{-1}$ ) and  $T_8$  ( $0.45 \text{ me L}^{-1}$ ). This might be due to Organic and inorganic amendments in sodic soil and  $K^+$  is remain in water as a soluble form (Satyanarayan, 1954).

#### 4.2.7 Effect of Graded Levels of Zeolite on Periodical Bicarbonate Content of Leachate in Sodic Soil

The data pertaining to the bicarbonate content in leachate as influenced by FYM, Gypsum, Zeolite and their combinations are presented in Table 4.8. There were continuous removals of bicarbonate through leachates but decreased with time.

**Table 4.8 Effect of graded levels of zeolite on periodical bicarbonate content of leachate in sodic soil**

Tr. No.	Treatment	Periodical $\text{HCO}_3^-$ (me $\text{L}^{-1}$ )							
		15 DOL	30 DOL	45 DOL	60 DOL	75 DOL	90 DOL	105 DOL	120 DOL
T <sub>1</sub>	Absolute control	5.04	4.89	4.78	4.71	4.63	4.47	4.40	4.28
T <sub>2</sub>	Gypsum as per GR	7.74	7.67	7.23	7.17	7.08	6.95	6.71	6.65
T <sub>3</sub>	Zeolite @ $400 \text{ kg ha}^{-1}$	5.20	5.05	4.94	4.79	4.70	4.63	4.56	4.44
T <sub>4</sub>	Zeolite @ $600 \text{ kg ha}^{-1}$	5.39	5.31	5.09	4.98	4.81	4.75	4.58	4.46
T <sub>5</sub>	Zeolite @ $800 \text{ kg ha}^{-1}$	5.55	5.43	5.27	5.11	5.07	4.98	4.84	4.79
T <sub>6</sub>	Zeolite @ $1000 \text{ kg ha}^{-1}$	6.95	6.84	6.76	6.61	6.34	6.29	6.21	6.15
T <sub>7</sub>	Zeolite @ $1200 \text{ kg ha}^{-1}$	7.43	7.29	6.98	6.73	6.47	6.35	6.28	6.22
T <sub>8</sub>	Zeolite @ $1400 \text{ kg ha}^{-1}$	7.59	7.42	7.09	6.91	6.88	6.64	6.53	6.44
T <sub>9</sub>	Zeolite @ $600 \text{ kg ha}^{-1}$ + 100% gypsum as per GR	8.51	8.32	8.28	8.23	8.17	7.88	7.84	7.71
	<b>SEm<sub>±</sub></b>	0.32	0.34	0.41	0.54	0.45	0.51	0.46	0.49
	<b>CD at 5%</b>	0.95	1.05	1.23	1.62	1.35	1.53	1.39	1.46

The bicarbonate of leachate of sodic soil was significantly influenced by gypsum and graded levels of zeolite (Table 4.8). On 15 DOL of experiment, higher value of bicarbonate was recorded ( $8.51 \text{ me L}^{-1}$ ) with the application of Zeolite @  $600 \text{ kg ha}^{-1}$  + 100% gypsum as per GR which was significantly higher over the all treatments and at par with treatment  $T_2$  ( $7.74 \text{ me L}^{-1}$ ) and  $T_8$  ( $7.59 \text{ me L}^{-1}$ ). Bicarbonate was maximum with application of Zeolite @  $600 \text{ kg ha}^{-1}$  with 100% gypsum as per GR which was significantly recorded higher value was  $8.32 \text{ me L}^{-1}$  at 30 DOL and  $T_2$  ( $7.67 \text{ me L}^{-1}$ ),  $T_7$  ( $7.29 \text{ me L}^{-1}$ ) and  $T_8$  ( $7.42 \text{ me L}^{-1}$ ) are at par with  $T_9$ . Whereas on

45 DOL, treatment T<sub>9</sub> (8.28 me L<sup>-1</sup>) was found effective in the removal of bicarbonate over control and at par with treatment T<sub>2</sub> (7.23 me L<sup>-1</sup>) and T<sub>8</sub> (7.09 me L<sup>-1</sup>). On 60 DOL, maximum bicarbonate reduced in T<sub>9</sub> (8.23 me L<sup>-1</sup>) which was higher and treatment T<sub>2</sub> (7.17 me L<sup>-1</sup>), T<sub>6</sub> (6.61 me L<sup>-1</sup>), T<sub>7</sub> (6.73 me L<sup>-1</sup>) and T<sub>8</sub> (6.91 me L<sup>-1</sup>) are at par with T<sub>9</sub>. On 75 DOL, bicarbonate was found more in T<sub>9</sub> i.e. (8.17 me L<sup>-1</sup>) which was significantly higher over the all treatments and at par with T<sub>2</sub> (7.08 me L<sup>-1</sup>) and T<sub>8</sub> (6.88 me L<sup>-1</sup>). However on 90 DOL, it was maximum with the application of Zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR (7.88 me L<sup>-1</sup>) which was significantly higher over all other treatments and at par with T<sub>2</sub> (6.95 me L<sup>-1</sup>), T<sub>7</sub> (6.35 me L<sup>-1</sup>) and T<sub>8</sub> (6.64 me L<sup>-1</sup>). Maximum bicarbonate was leached out at 105 DOL with T<sub>9</sub> (7.84 me L<sup>-1</sup>) which was higher over the all other treatments and at par with T<sub>2</sub> (6.71 me L<sup>-1</sup>) and T<sub>8</sub> (6.53 me L<sup>-1</sup>). On 120 DOL, it was also maximum in same treatment i.e. in T<sub>9</sub> (7.71 me L<sup>-1</sup>). HCO<sub>3</sub><sup>-</sup> was significantly increased with increased levels of zeolite application in all the period of study. It was also decreased with increased period of leachate collection. Maximum bicarbonate was leached out with the increased levels of zeolite and gypsum.

#### 4.2.8 Effect of Graded Levels of Zeolite on Periodical Chloride Content of Leachate in Sodic Soil

The data pertaining to the chloride content in leachate as influenced by FYM, Zeolite, Gypsum and their combination in Table 4.9 which reveals that the removal of chloride was more in first leachate in all the treatments while it was decreased with time.

**Table 4.9 Effect of graded levels of zeolite on periodical chloride content of leachate in sodic soil**

Tr. No.	Treatment	Periodical Cl <sup>-</sup> (me L <sup>-1</sup> )							
		15 DOL	30 DOL	45 DOL	60 DOL	75 DOL	90 DOL	105 DOL	120 DOL
T <sub>1</sub>	Absolute control	10.70	11.02	11.35	11.46	11.53	11.79	11.82	11.95
T <sub>2</sub>	Gypsum as per GR	11.29	13.37	15.23	15.94	16.11	16.32	16.45	16.78
T <sub>3</sub>	Zeolite @ 400 kg ha <sup>-1</sup>	10.88	13.11	14.06	14.15	14.24	14.26	14.29	14.41
T <sub>4</sub>	Zeolite @ 600 kg ha <sup>-1</sup>	10.90	13.14	14.09	14.21	14.26	14.29	14.31	14.44
T <sub>5</sub>	Zeolite @ 800 kg ha <sup>-1</sup>	10.92	13.19	14.12	14.24	14.31	14.37	14.43	14.46
T <sub>6</sub>	Zeolite @ 1000 kg ha <sup>-1</sup>	10.97	13.23	14.15	14.26	14.33	14.45	14.48	14.51
T <sub>7</sub>	Zeolite @ 1200 kg ha <sup>-1</sup>	11.01	13.27	14.21	14.32	14.37	14.49	14.57	14.63
T <sub>8</sub>	Zeolite @ 1400 kg ha <sup>-1</sup>	11.09	13.29	14.28	14.45	14.49	14.54	14.59	14.71
T <sub>9</sub>	Zeolite @ 600 kg ha <sup>-1</sup> + 100% gypsum as per GR	11.52	13.50	15.55	16.26	16.43	17.28	17.71	18.54
	<b>SEm<sub>±</sub></b>	0.19	0.08	0.43	0.63	0.65	0.95	1.04	1.34
	<b>CD at 5%</b>	0.57	0.24	1.29	1.89	1.95	2.85	3.12	4.02

Removal of chloride was low in first leachate in all the treatments while it was increase with increase the period of leachate. The maximum removal of chloride was observed in T<sub>9</sub> (application of Zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum (11.52 me L<sup>-1</sup>) which was significantly

higher over the all treatments and at par with the treatment T<sub>2</sub> (11.29 me L<sup>-1</sup>), T<sub>6</sub> (10.97 me L<sup>-1</sup>), T<sub>7</sub> (11.01 me L<sup>-1</sup>) and T<sub>8</sub> (11.09 me L<sup>-1</sup>). Whereas on 30 DOL, it was observed that removal of chloride was more with the treatment T<sub>9</sub> (13.50 me L<sup>-1</sup>) and treatment T<sub>2</sub> (13.37 me L<sup>-1</sup>), T<sub>7</sub> (13.27 me L<sup>-1</sup>) and T<sub>8</sub> (13.29 me L<sup>-1</sup>) were at par value with the treatment T<sub>9</sub>. Chloride content was more in T<sub>9</sub> among all treatment which was significantly higher over the all treatments at 45, 60 and 75 DOL which were 15.55, 16.26 and 16.43 me L<sup>-1</sup> respectively and at par with T<sub>2</sub> and T<sub>8</sub> at 45, 60 and 75 DOL. However on 90 DOL, treatment T<sub>9</sub> (17.28 me L<sup>-1</sup>) was found effectively for removal of chloride through leachate which was significantly higher and at par with the treatment T<sub>2</sub> (16.32 me L<sup>-1</sup>), T<sub>6</sub> (14.45 me L<sup>-1</sup>) T<sub>7</sub> (14.49 me L<sup>-1</sup>) and T<sub>8</sub> (14.54 me L<sup>-1</sup>). Chloride of leachate of sodic soil was significantly influenced by gypsum and graded levels of zeolite in T<sub>9</sub> (17.71 me L<sup>-1</sup>) and at par with T<sub>2</sub> and T<sub>8</sub> on 105 DOL of experiment. Maximum removal of chloride was recorded in same treatment i.e. in T<sub>9</sub> (18.54 me L<sup>-1</sup>) which higher among all and at par with T<sub>2</sub> (16.78 me L<sup>-1</sup>), T<sub>7</sub> (14.63 me L<sup>-1</sup>) and T<sub>8</sub> (14.71 me L<sup>-1</sup>). This indicates that the addition of gypsum improves soil properties which result into more removal of chloride (Murthy, 1960).

#### 4.2.9 Effect of Graded Levels of Zeolite on Periodical Sulphate Content of Leachate in Sodic Soil

The data pertaining to the sulphate content in leachate as a function of FYM, Zeolite, Gypsum and their combinations are presented in Table 4.10.

**Table 4.10 Effect of graded levels of zeolite on periodical sulphate content of leachate in sodic soil**

Tr. No.	Treatment	Periodical SO <sub>4</sub> <sup>2-</sup> (me L <sup>-1</sup> )							
		15 DOL	30 DOL	45 DOL	60 DOL	75 DOL	90 DOL	105 DOL	120 DOL
T <sub>1</sub>	Absolute control	9.65	9.99	10.36	10.78	11.14	11.69	11.88	12.12
T <sub>2</sub>	Gypsum as per GR	16.20	21.54	23.23	24.85	25.71	26.66	27.05	28.89
T <sub>3</sub>	Zeolite @ 400 kg ha <sup>-1</sup>	10.42	13.57	15.46	15.86	16.27	16.77	17.16	17.20
T <sub>4</sub>	Zeolite @ 600 kg ha <sup>-1</sup>	10.54	13.69	15.56	15.98	16.47	16.89	17.29	17.32
T <sub>5</sub>	Zeolite @ 800 kg ha <sup>-1</sup>	10.83	13.97	15.82	16.28	16.62	17.17	17.36	17.60
T <sub>6</sub>	Zeolite @ 1000 kg ha <sup>-1</sup>	10.89	14.04	15.91	16.33	16.69	17.20	17.44	17.67
T <sub>7</sub>	Zeolite @ 1200 kg ha <sup>-1</sup>	11.04	14.19	16.06	16.48	16.84	17.39	17.58	17.83
T <sub>8</sub>	Zeolite @ 1400 kg ha <sup>-1</sup>	11.12	14.27	16.14	16.56	16.92	17.47	17.66	17.90
T <sub>9</sub>	Zeolite @ 600 kg ha <sup>-1</sup> + 100% gypsum as per GR	16.34	21.68	23.35	25.07	26.93	27.86	28.77	30.31
	<b>SEM<sub>±</sub></b>	1.74	2.49	2.40	2.83	3.35	3.46	3.71	4.13
	<b>CD at 5%</b>	5.22	7.49	7.21	8.51	10.09	10.39	11.11	12.40

On 15 DOL, removal of sulphate (16.34 me L<sup>-1</sup>) was recorded with the application of Zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR which was higher among all treatment and at par with T<sub>2</sub> (16.20 me L<sup>-1</sup>) and T<sub>8</sub> (11.12 me L<sup>-1</sup>). Whereas on 30 DOL, treatment T<sub>9</sub> was superior in

the removal of sulphate i.e. (21.68 me L<sup>-1</sup>) and found at par with the treatment T<sub>2</sub> (21.54 me L<sup>-1</sup>), T<sub>7</sub> (14.19 me L<sup>-1</sup>) and T<sub>8</sub> (14.27 me L<sup>-1</sup>) where amendment was applied.

On 45 DOL, treatment T<sub>9</sub> was significantly higher over the all treatments i.e. 23.35 me L<sup>-1</sup> which was at par with the treatment T<sub>2</sub> (23.23 me L<sup>-1</sup>), T<sub>8</sub> (16.14 me L<sup>-1</sup>) and on 60 DOL, it was increased over 15 DOL with the treatment T<sub>9</sub> (25.07 me L<sup>-1</sup>) which was significantly higher and found at par with the treatment T<sub>2</sub> (24.85 me L<sup>-1</sup>) and T<sub>8</sub> (16.56 me L<sup>-1</sup>). Sulphate was significantly increased with increased levels of zeolite application in all the period of study. It was also increased with increased period of leachate collection. On 75 DOL, sulphate content in leachate was more in Zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR which was 26.93 me L<sup>-1</sup> and at par with T<sub>2</sub> (25.71 me L<sup>-1</sup>), T<sub>7</sub> (16.84 me L<sup>-1</sup>) and T<sub>8</sub> (16.92 me L<sup>-1</sup>). Sulphate content was recorded more in T<sub>9</sub> (27.86 me L<sup>-1</sup>) which was higher over the all treatment and at par with T<sub>2</sub> (26.66 me L<sup>-1</sup>) and T<sub>8</sub> (17.47 me L<sup>-1</sup>) at 90 DOL. On 105 DOL, it was found more i.e. 28.77 me L<sup>-1</sup> which was higher and at par with T<sub>2</sub> (27.05 me L<sup>-1</sup>) and T<sub>8</sub> (17.66 me L<sup>-1</sup>). On 120 DOL, highest sulphate content recorded in T<sub>9</sub> (30.31 me L<sup>-1</sup>) which was higher among all treatment and at with T<sub>2</sub> (28.89 me L<sup>-1</sup>) and T<sub>8</sub> (17.90 me L<sup>-1</sup>). This might be due to sulphate contain in gypsum which react with Na<sup>+</sup> and removal of sulphate from soil as Na<sub>2</sub>SO<sub>4</sub><sup>-</sup> through leachates.

Gypsum produced sulphate ions in the soil which replaced other anions from the colloidal surface and greater amounts of sulphate in leachate was found in the treatment T<sub>9</sub> (Satyanarayan, 1954).

### 4.3 Impact of Amendment on Chemical Properties of Soil

After 120 day of leaching the soil column were cut at 0-30, 30-60 and 60-90 cm depth and analyzed it for various parameter and the results obtained before and after leaching are discussed as under.

#### 4.3.1 Effect of Graded Levels of Zeolite on Depth wise pHs in Column of Sodic Soil

The data regarding to the pHs of sodic soil as influenced by leaching with FYM, Zeolite, Gypsum and their combinations after 120 days of leaching is presented in Table 4.11.

**Table 4.11 Effect of graded levels of zeolite on depth wise pHs in column of sodic soil**

Tr. No.	Treatment	pHs		
		0-30 cm	30-60 cm	60-90 cm
T <sub>1</sub>	Absolute control	8.51	8.58	8.65
T <sub>2</sub>	Gypsum as per GR	8.16	8.22	8.34
T <sub>3</sub>	Zeolite @ 400 kg ha <sup>-1</sup>	8.47	8.53	8.57
T <sub>4</sub>	Zeolite @ 600 kg ha <sup>-1</sup>	8.41	8.49	8.53
T <sub>5</sub>	Zeolite @ 800 kg ha <sup>-1</sup>	8.36	8.42	8.48
T <sub>6</sub>	Zeolite @ 1000 kg ha <sup>-1</sup>	8.30	8.37	8.43
T <sub>7</sub>	Zeolite @ 1200 kg ha <sup>-1</sup>	8.27	8.34	8.35
T <sub>8</sub>	Zeolite @ 1400 kg ha <sup>-1</sup>	8.21	8.20	8.29
T <sub>9</sub>	Zeolite @ 600 kg ha <sup>-1</sup> + 100% gypsum as per GR	8.10	8.15	8.21
	<b>SEm±</b>	<b>0.03</b>	<b>0.08</b>	<b>0.06</b>
	<b>CD at 5%</b>	<b>0.10</b>	<b>0.26</b>	<b>0.20</b>

The data showed that the pHs of sodic soil decreased in all treatments at all three depth as compared to initial value. The pHs with the application of Zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR which was lower over all other treatments, the increased in pHs was 8.10, 8.15 and 8.21 at 0-30, 30-60 and 60-90 cm depths respectively. pHs of treatment T<sub>9</sub> (8.10) was significantly lower and at par with the treatment T<sub>2</sub> (8.16) and T<sub>8</sub> (8.21) at 0-30 cm. Similarly, pHs of treatment T<sub>9</sub> (8.15) was found lower and treatment T<sub>2</sub> (7.73), T<sub>6</sub> (8.37), T<sub>7</sub> (8.34) and T<sub>8</sub> (8.20) were at par at 30-60 cm. At 60-90 cm, pHs of treatment T<sub>9</sub> (8.21) was lower over the all other treatments whereas treatment T<sub>2</sub> (8.34), T<sub>7</sub> (8.35) and T<sub>8</sub> (8.29) were at par with T<sub>9</sub>.

The reduction in pHs with application of gypsum @ 25 GR + 10 Mg SWPMC ha<sup>-1</sup> + bi inoculants which oxidized sulphur from residual gypsum might have produce H<sub>2</sub>SO<sub>4</sub> and resulted in lowering pHs of soil by combined effects in the integrated treatments. The decline in pHs is ascribed to removal of sodium by the calcium from Gypsum (Negim, 2015).

#### 4.3.2 Effect of Graded Levels of Zeolite on Depth wise Electrical Conductivity in Column of Sodic Soil

The data regarding to the ECe of sodic soil as influenced by leaching with FYM, Zeolite, Gypsum and their combinations after 120 days of leaching are presented in Table 4.12.

**Table 4.12 Effect of graded levels of zeolite on depth wise electrical conductivity in column of sodic soil**

Tr. No.	Treatments	ECe (dS m <sup>-1</sup> )		
		0-30 cm	30-60 cm	60-90 cm
T <sub>1</sub>	Absolute control	3.77	3.81	3.86
T <sub>2</sub>	Gypsum as per GR	4.58	4.63	4.78
T <sub>3</sub>	Zeolite @ 400 kg ha <sup>-1</sup>	4.23	4.28	4.33
T <sub>4</sub>	Zeolite @ 600 kg ha <sup>-1</sup>	4.29	4.33	4.37
T <sub>5</sub>	Zeolite @ 800 kg ha <sup>-1</sup>	4.35	4.38	4.40
T <sub>6</sub>	Zeolite @ 1000 kg ha <sup>-1</sup>	4.38	4.42	4.46
T <sub>7</sub>	Zeolite @ 1200 kg ha <sup>-1</sup>	4.42	4.47	4.52
T <sub>8</sub>	Zeolite @ 1400 kg ha <sup>-1</sup>	4.45	4.51	4.55
T <sub>9</sub>	Zeolite @ 600 kg ha <sup>-1</sup> + 100% gypsum as per GR	4.82	4.96	5.03
	<b>SEm<sub>±</sub></b>	<b>0.13</b>	<b>0.15</b>	<b>0.17</b>
	<b>CD at 5%</b>	<b>0.40</b>	<b>0.46</b>	<b>0.51</b>

The data investigated that after the leaching process the electrical conductivity of saturation paste extract increased in all the treatments than initial values at all the three depths. ECe was recorded with the application of Zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR and it increased to 4.82, 4.96 and 5.03 dS m<sup>-1</sup> at 0-30, 30-60 and 60-90 cm depths respectively. Highest ECe to be recorded in T<sub>9</sub> treatment. ECe of treatment T<sub>9</sub> (4.82 dS m<sup>-1</sup>) was significantly higher over the all other treatments and at par with the treatment T<sub>2</sub> (4.58 dS m<sup>-1</sup>), T<sub>7</sub> (4.42 dS m<sup>-1</sup>) and T<sub>8</sub> (4.45 dS m<sup>-1</sup>) at 0-30 cm. Similarly, ECe of T<sub>9</sub> (4.96 dS m<sup>-1</sup>) was found higher and treatment T<sub>2</sub> (4.63 dS m<sup>-1</sup>) and T<sub>8</sub> (4.51 dSm<sup>-1</sup>) were at par at 30-60 cm. At 60-90 cm, ECe of

treatment T<sub>9</sub> (5.03 dS m<sup>-1</sup>) was significantly higher over the all treatments whereas treatment T<sub>2</sub> (4.78 dS m<sup>-1</sup>), T<sub>7</sub> (4.52 dS m<sup>-1</sup>) and T<sub>8</sub> (4.55 dS m<sup>-1</sup>) were at par with T<sub>9</sub>. The increase in ECe might be due to the removal of more salts and zeolite has high ion exchange capacity. Treatment T<sub>9</sub> was found effective in increasing ECe followed by treatment T<sub>2</sub> over initial value (María Alcívar *et al.*, 2018).

### 4.3.3 Effect of Graded Levels of Zeolite on Depthwise Calcium Content in Column of Sodic Soil

The data in respect of calcium content in saturation paste extract of soil after the leaching of soil with FYM, Zeolite, Gypsum and their combination is given in Table 4.13.

**Table 4.13 Effect of graded levels of zeolite on depthwise calcium content in column of sodic soil**

Tr. No.	Treatment	Ca <sup>2+</sup> (me L <sup>-1</sup> )		
		0-30 cm	30-60 cm	60-90 cm
T <sub>1</sub>	Absolute control	9.31	9.36	9.58
T <sub>2</sub>	Gypsum as per GR	10.82	10.96	11.21
T <sub>3</sub>	Zeolite @ 400 kg ha <sup>-1</sup>	9.28	9.41	9.62
T <sub>4</sub>	Zeolite @ 600 kg ha <sup>-1</sup>	9.33	9.47	9.64
T <sub>5</sub>	Zeolite @ 800 kg ha <sup>-1</sup>	9.35	9.54	9.67
T <sub>6</sub>	Zeolite @ 1000 kg ha <sup>-1</sup>	9.39	9.59	9.71
T <sub>7</sub>	Zeolite @ 1200 kg ha <sup>-1</sup>	9.41	9.62	9.77
T <sub>8</sub>	Zeolite @ 1400 kg ha <sup>-1</sup>	9.46	9.66	9.84
T <sub>9</sub>	Zeolite @ 600 kg ha <sup>-1</sup> + 100% gypsum as per GR	10.85	10.99	11.24
	<b>SEm<sub>±</sub></b>	<b>0.46</b>	<b>0.44</b>	<b>0.49</b>
	<b>CD at 5%</b>	<b>1.39</b>	<b>1.34</b>	<b>1.47</b>

The calcium content was influenced by the application of Gypsum, Zeolite, FYM over initial value. Calcium was recorded with the application of Zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR and it was 10.85 me L<sup>-1</sup>, 10.99 me L<sup>-1</sup> and 11.24 me L<sup>-1</sup> at 0-30, 30-60 and 60-90 cm depth respectively, which was significantly higher over the all treatments and at par with T<sub>2</sub> (10.82 me L<sup>-1</sup>) and T<sub>8</sub> (9.46 me L<sup>-1</sup>) at 0-30. Similarly calcium content of treatment T<sub>9</sub> (10.99 me L<sup>-1</sup>) was found higher and treatment T<sub>2</sub> (10.96 me L<sup>-1</sup>) and T<sub>8</sub> (9.66 me L<sup>-1</sup>) were at par at 30-60. At 60-90 cm, calcium content of treatment T<sub>9</sub> (11.24 me L<sup>-1</sup>) was higher whereas treatment T<sub>2</sub> (11.21 me L<sup>-1</sup>), T<sub>7</sub> (9.77 me L<sup>-1</sup>) and treatment T<sub>8</sub> (9.84 me L<sup>-1</sup>) were at par with the treatment T<sub>9</sub>. Which shows that the leaching of sodic soil with Zeolite @ 600 kg ha<sup>-1</sup>+ 100% gypsum as per GR was more effective in the removal of soluble salts. The significant increase in Ca<sup>2+</sup> in saturation paste extract can be attributed to application of gypsum and zeolite. Ca<sup>2+</sup> content more in T<sub>9</sub> treatment with increasing depth due to trapped of calcium in comb structure of zeolite (Mumpton, 1999).

#### 4.3.4 Effect of Graded Levels of Zeolite on Depth wise Magnesium Content in Column of Sodic Soil

The data pertaining to the magnesium content in saturation paste extract of sodic soil upto 120 days after leaching as influenced by FYM, Zeolite, Gypsum and their combination is given in Table 4.14.

**Table 4.14 Effect of graded levels of zeolite on depth wise magnesium content in column of sodic soil**

Tr. No.	Treatment	Mg <sup>2+</sup> (me L <sup>-1</sup> )		
		0-30 cm	30-60 cm	60-90 cm
T <sub>1</sub>	Absolute control	1.61	1.68	1.75
T <sub>2</sub>	Gypsum as per GR	1.32	1.36	1.39
T <sub>3</sub>	Zeolite @ 400 kg ha <sup>-1</sup>	1.52	1.56	1.64
T <sub>4</sub>	Zeolite @ 600 kg ha <sup>-1</sup>	1.49	1.51	1.61
T <sub>5</sub>	Zeolite @ 800 kg ha <sup>-1</sup>	1.44	1.47	1.54
T <sub>6</sub>	Zeolite @ 1000 kg ha <sup>-1</sup>	1.42	1.45	1.51
T <sub>7</sub>	Zeolite @ 1200 kg ha <sup>-1</sup>	1.36	1.38	1.47
T <sub>8</sub>	Zeolite @ 1400 kg ha <sup>-1</sup>	1.34	1.36	1.43
T <sub>9</sub>	Zeolite @ 600 kg ha <sup>-1</sup> + 100% gypsum as per GR	1.27	1.32	1.36
	<b>SEm<sub>±</sub></b>	<b>0.04</b>	<b>0.05</b>	<b>0.07</b>
	<b>CD at 5%</b>	<b>0.13</b>	<b>0.16</b>	<b>NS</b>

The magnesium content was decreased in all the treatments over initial value. The maximum decrease in magnesium content in saturation paste extract was recorded with the application of Zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR i.e. 1.27 me L<sup>-1</sup> over initial value. Whereas treatment T<sub>2</sub> (1.32 me L<sup>-1</sup>), T<sub>7</sub> (1.36 me L<sup>-1</sup>) and T<sub>8</sub> (1.34 me L<sup>-1</sup>) were at par with treatment T<sub>9</sub> at 0-30 cm depth. At 30-60 cm, it was 1.32 me L<sup>-1</sup> and treatment T<sub>2</sub> (1.36 me L<sup>-1</sup>), T<sub>5</sub> (1.47 me L<sup>-1</sup>), T<sub>6</sub> (1.45 me L<sup>-1</sup>), T<sub>7</sub> (1.38 me L<sup>-1</sup>) and T<sub>8</sub> (1.36 me L<sup>-1</sup>) were statistically at par with T<sub>9</sub>. At 60-90 cm, maximum reduction in magnesium content was recorded in T<sub>9</sub> (1.36 me L<sup>-1</sup>). This might be due to more accumulation of salts at lower depth.

#### 4.3.5 Effect of Graded Levels of Zeolite on Depth wise Sodium Content in Column of Sodic Soil

The data with respect to the sodium content in saturation paste extract of sodic soil as a function of leaching the soil with FYM, Zeolite, Gypsum and their combinations is given in Table 4.15.

The sodium content in saturation paste extract of soil reduced in all treatment (Table 4.15) but maximum decrease in sodium content were observed with the application of Zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR and the reduction was 27.66 me L<sup>-1</sup> (T<sub>9</sub>) which was significantly lower over the all other treatments and at par with the treatment T<sub>2</sub> (27.74 me L<sup>-1</sup>) and T<sub>8</sub> (28.40 me L<sup>-1</sup>) at first layer of soil i.e. 30-60 cm. At 30-60 cm, the reduction of sodium content was 27.73 me L<sup>-1</sup> (treatment T<sub>9</sub>) which was at par with treatment T<sub>2</sub> (27.81 me L<sup>-1</sup>) and

T<sub>8</sub> (28.47 me L<sup>-1</sup>). At 60-90 cm, the sodium content was reduced when the soil was amended with Zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR, reduction was 28.18 me L<sup>-1</sup>. Treatment T<sub>2</sub> (28.26 me L<sup>-1</sup>) and T<sub>8</sub> (28.63 me L<sup>-1</sup>) were at par with T<sub>9</sub>.

**Table 4.15 Effect of graded levels of zeolite on depth wise sodium content in column of sodic soil**

Tr. No.	Treatment	Na <sup>+</sup> (me L <sup>-1</sup> )		
		0-30 cm	30-60 cm	60-90 cm
T <sub>1</sub>	Absolute control	29.11	29.18	29.63
T <sub>2</sub>	Gypsum as per GR	27.74	27.81	28.26
T <sub>3</sub>	Zeolite @ 400 kg ha <sup>-1</sup>	28.63	28.70	29.11
T <sub>4</sub>	Zeolite @ 600 kg ha <sup>-1</sup>	28.59	28.64	29.02
T <sub>5</sub>	Zeolite @ 800 kg ha <sup>-1</sup>	28.52	28.62	28.84
T <sub>6</sub>	Zeolite @ 1000 kg ha <sup>-1</sup>	28.46	28.59	28.76
T <sub>7</sub>	Zeolite @ 1200 kg ha <sup>-1</sup>	28.44	28.51	28.69
T <sub>8</sub>	Zeolite @ 1400 kg ha <sup>-1</sup>	28.40	28.47	28.63
T <sub>9</sub>	Zeolite @ 600 kg ha <sup>-1</sup> + 100% gypsum as per GR	27.66	27.73	28.18
	<b>SEm<sub>±</sub></b>	<b>0.24</b>	<b>0.24</b>	<b>0.15</b>
	<b>CD at 5%</b>	<b>0.73</b>	<b>0.74</b>	<b>0.45</b>

This might be due to improvement in soil permeability by the addition of gypsum and zeolite which allows maximum passage of water which concurrently remove more water-soluble sodium. By using of CaSO<sub>4</sub> (Koo *et al.*, 1990; Qadir *et al.*, 1996).

#### 4.3.6 Effect of Graded Levels of Zeolite on Depth wise Potassium Content in Column of Sodic Soil

The data regarding the potassium content in saturation paste extract of sodic soil as a influenced by FYM, Zeolite, Gypsum and their combinations are presented in Table 4.16.

**Table 4.16 Effect of graded levels of zeolite on depthwise potassium content in column of sodic soil**

Tr. No.	Treatment	K <sup>+</sup> (me L <sup>-1</sup> )		
		0-30 cm	30-60 cm	60-90 cm
T <sub>1</sub>	Absolute control	0.27	0.31	0.33
T <sub>2</sub>	Gypsum as per GR	0.16	0.20	0.22
T <sub>3</sub>	Zeolite @ 400 kg ha <sup>-1</sup>	0.25	0.29	0.31
T <sub>4</sub>	Zeolite @ 600 kg ha <sup>-1</sup>	0.25	0.28	0.30
T <sub>5</sub>	Zeolite @ 800 kg ha <sup>-1</sup>	0.23	0.28	0.29
T <sub>6</sub>	Zeolite @ 1000 kg ha <sup>-1</sup>	0.23	0.27	0.29
T <sub>7</sub>	Zeolite @ 1200 kg ha <sup>-1</sup>	0.22	0.26	0.28
T <sub>8</sub>	Zeolite @ 1400 kg ha <sup>-1</sup>	0.19	0.23	0.25
T <sub>9</sub>	Zeolite @ 600 kg ha <sup>-1</sup> + 100% gypsum as per GR	0.13	0.17	0.19
	<b>SEm<sub>±</sub></b>	<b>0.02</b>	<b>0.03</b>	<b>0.02</b>
	<b>CD at 5%</b>	<b>0.06</b>	<b>0.09</b>	<b>0.07</b>

The data regarding the potassium content in saturation paste extract of sodic soil was presented in Table 4.15, which reflects that the potassium content was reduced over initial value at upper layer of soil, and reduction was  $0.13 \text{ me L}^{-1}$  by the application of Zeolite @  $600 \text{ kg ha}^{-1}$  + 100% gypsum as per GR and at par with T<sub>2</sub> ( $0.16 \text{ me L}^{-1}$ ) and T<sub>8</sub> ( $0.19 \text{ me L}^{-1}$ ). Whereas at lower depth i.e. 30-60 cm, the reduction of potassium content was  $0.17 \text{ me L}^{-1}$  and at par with T<sub>2</sub> ( $0.20 \text{ me L}^{-1}$ ), T<sub>7</sub> ( $0.23 \text{ me L}^{-1}$ ), T<sub>8</sub> ( $0.26 \text{ me L}^{-1}$ ). At 60-90 cm it was reduced to  $0.19 \text{ me L}^{-1}$  by the application of Zeolite @  $600 \text{ kg ha}^{-1}$  + 100% gypsum as per GR and at par with T<sub>2</sub> ( $0.22 \text{ me L}^{-1}$ ) and T<sub>8</sub> ( $0.25 \text{ me L}^{-1}$ ). There is significant change in the potassium content of saturation paste extract as potassium is least leachable cation (Satyanarayan, 1954).

#### 4.3.7 Effect of Graded Levels of Zeolite on Depth wise Bicarbonate Content in Column of Sodic Soil

The data pertaining to the bicarbonate content in saturation paste extract of sodic soil as a function of different amendment is shown in Table 4.17. Which reveals that the bicarbonate content in saturation paste extract of soil reduced with amendments.

**Table 4.17 Effect of graded levels of zeolite on depthwise bicarbonate content in column of sodic soil**

Tr. No.	Treatment	HCO <sub>3</sub> <sup>-</sup> (me L <sup>-1</sup> )		
		0-30 cm	30-60 cm	60-90 cm
T <sub>1</sub>	Absolute control	9.24	9.27	9.49
T <sub>2</sub>	Gypsum as per GR	10.07	10.20	10.45
T <sub>3</sub>	Zeolite @ $400 \text{ kg ha}^{-1}$	9.81	9.84	10.09
T <sub>4</sub>	Zeolite @ $600 \text{ kg ha}^{-1}$	9.83	9.86	10.01
T <sub>5</sub>	Zeolite @ $800 \text{ kg ha}^{-1}$	9.89	9.92	10.07
T <sub>6</sub>	Zeolite @ $1000 \text{ kg ha}^{-1}$	9.90	9.93	10.08
T <sub>7</sub>	Zeolite @ $1200 \text{ kg ha}^{-1}$	9.93	9.96	10.14
T <sub>8</sub>	Zeolite @ $1400 \text{ kg ha}^{-1}$	9.97	10.03	10.19
T <sub>9</sub>	Zeolite @ $600 \text{ kg ha}^{-1}$ + 100% gypsum as per GR	10.11	10.29	10.44
	<b>SEm±</b>	<b>0.05</b>	<b>0.09</b>	<b>0.08</b>
	<b>CD at 5%</b>	<b>0.15</b>	<b>0.27</b>	<b>0.25</b>

The higher value of bicarbonate was recorded with application of Zeolite @  $600 \text{ kg ha}^{-1}$  + 100% gypsum as per GR and HCO<sub>3</sub><sup>-</sup> was  $10.11 \text{ me L}^{-1}$  and at par with T<sub>2</sub> ( $10.07 \text{ me L}^{-1}$ ), T<sub>8</sub> ( $9.97 \text{ me L}^{-1}$ ) at 0-30 cm depth. AT 30-60 cm, it was  $10.29 \text{ me L}^{-1}$  and at par with T<sub>2</sub> ( $10.20 \text{ me L}^{-1}$ ), T<sub>8</sub> ( $10.03 \text{ me L}^{-1}$ ) and at 60-90 cm, it was  $10.44 \text{ me L}^{-1}$  and at par with T<sub>2</sub> ( $10.45 \text{ me L}^{-1}$ ), T<sub>8</sub> ( $10.19 \text{ me L}^{-1}$ ) which was significantly higher over control. The considerable reduction in bicarbonate has been achieved by the use of amendments.

### 4.3.8 Effect of Graded Levels of Zeolite on Depth wise Sulphate Content in Column of Sodic Soil

The data in respect of sulphate content in saturation paste extract of sodic soil when the soil was amended with FYM, Zeolite, Gypsum and their combinations are presented in Table 4.18.

Sulphate content in saturation paste extract of sodic soil was increased to 20.64 me L<sup>-1</sup> by the application of Zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR it which might be due to sulphate present in gypsum and sulphate present in irrigation water at 0-30 cm depth and at par with T<sub>2</sub> (20.61 me L<sup>-1</sup>), T<sub>6</sub> (20.54 me L<sup>-1</sup>), T<sub>7</sub> (20.55 me L<sup>-1</sup>), T<sub>8</sub> (20.58 me L<sup>-1</sup>). Whereas at 30-60 cm, there was increase in sulphate content with the application of Zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR was increased to 20.81 and at par with T<sub>2</sub> (20.79 me L<sup>-1</sup>), T<sub>4</sub> (20.70 me L<sup>-1</sup>), T<sub>5</sub> (20.70 me L<sup>-1</sup>), T<sub>6</sub> (20.72 me L<sup>-1</sup>), T<sub>7</sub> (20.75 me L<sup>-1</sup>) and T<sub>8</sub> (20.76 me L<sup>-1</sup>). At lower depth i.e. 60-90 cm, it was increased to 20.89 me L<sup>-1</sup> and at par with T<sub>2</sub> (20.83 me L<sup>-1</sup>), T<sub>5</sub> (20.76 me L<sup>-1</sup>), T<sub>6</sub> (20.77 me L<sup>-1</sup>), T<sub>7</sub> (20.79 me L<sup>-1</sup>) and T<sub>8</sub> (20.81 me L<sup>-1</sup>). It might be due to more accumulation of soluble salt at lower depth and sulphur present in the gypsum.

**Table 4.18 Effect of graded levels of zeolite on depth wise sulphate content in column of sodic soil**

Tr. No.	Treatment	SO <sub>4</sub> <sup>2-</sup> (me L <sup>-1</sup> )		
		0-30 cm	30-60 cm	60-90 cm
T <sub>1</sub>	Absolute control	18.60	18.85	18.91
T <sub>2</sub>	Gypsum as per GR	20.61	20.79	20.83
T <sub>3</sub>	Zeolite @ 400 kg ha <sup>-1</sup>	20.43	20.67	20.72
T <sub>4</sub>	Zeolite @ 600 kg ha <sup>-1</sup>	20.46	20.70	20.74
T <sub>5</sub>	Zeolite @ 800 kg ha <sup>-1</sup>	20.51	20.70	20.76
T <sub>6</sub>	Zeolite @ 1000 kg ha <sup>-1</sup>	20.54	20.72	20.77
T <sub>7</sub>	Zeolite @ 1200 kg ha <sup>-1</sup>	20.55	20.75	20.79
T <sub>8</sub>	Zeolite @ 1400 kg ha <sup>-1</sup>	20.58	20.76	20.81
T <sub>9</sub>	Zeolite @ 600 kg ha <sup>-1</sup> + 100% gypsum as per GR	20.64	20.81	20.89
	<b>SEm±</b>	<b>0.04</b>	<b>0.05</b>	<b>0.04</b>
	<b>CD at 5%</b>	<b>0.12</b>	<b>0.15</b>	<b>0.14</b>

The lower concentration of sulphate in the upper part of the soil which was due to its slower mobility and lower solubilities of calcium and magnesium sulphate (Satyanarayan, 1954).

### 4.3.9 Effect of Graded Levels of Zeolite on Depth wise chloride Content in Column of Sodic Soil

The data pertaining to the chloride content in saturation paste extract of sodic soil as a function of different amendments are shown in Table 4.19 which indicates the increase in chloride content with soil depth.

**Table 4.19 Effect of graded levels of zeolite on depth wise chloride content in column of sodic soil**

Tr. No.	Treatment	Cl <sup>-</sup> (me L <sup>-1</sup> )		
		0-30 cm	30-60 cm	60-90 cm
T <sub>1</sub>	Absolute control	9.94	10.16	10.25
T <sub>2</sub>	Gypsum as per GR	10.26	10.48	10.58
T <sub>3</sub>	Zeolite @ 400 kg ha <sup>-1</sup>	10.07	10.31	10.40
T <sub>4</sub>	Zeolite @ 600 kg ha <sup>-1</sup>	10.10	10.32	10.43
T <sub>5</sub>	Zeolite @ 800 kg ha <sup>-1</sup>	10.13	10.35	10.44
T <sub>6</sub>	Zeolite @ 1000 kg ha <sup>-1</sup>	10.15	11.37	11.47
T <sub>7</sub>	Zeolite @ 1200 kg ha <sup>-1</sup>	10.19	10.40	10.50
T <sub>8</sub>	Zeolite @ 1400 kg ha <sup>-1</sup>	10.21	10.43	10.55
T <sub>9</sub>	Zeolite @ 600 kg ha <sup>-1</sup> + 100% gypsum as per GR	10.30	10.67	10.76
	<b>SEm<sub>±</sub></b>	<b>0.03</b>	<b>0.08</b>	<b>0.09</b>
	<b>CD at 5%</b>	<b>0.09</b>	<b>0.24</b>	<b>0.27</b>

Chloride content was observed with the application of Zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR, it was 10.30 me L<sup>-1</sup> which was significantly higher over the all treatments and at par with the treatment T<sub>2</sub> (10.26 me L<sup>-1</sup>), T<sub>8</sub> (10.21 me L<sup>-1</sup>) at the upper layer of soil. Whereas at 30-60 cm, it was 10.67 me L<sup>-1</sup> and at par with treatment T<sub>2</sub> (10.48 me L<sup>-1</sup>), T<sub>8</sub> (10.43 me L<sup>-1</sup>). At the lower depth i.e. 60-90 cm, chloride was 10.76 me L<sup>-1</sup> with the application of Zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR which was significantly higher over the all treatments and at par with the treatment T<sub>2</sub> (10.58 me L<sup>-1</sup>), T<sub>7</sub> (10.50 me L<sup>-1</sup>) and T<sub>8</sub> (10.55 me L<sup>-1</sup>) (Murthy, 1960).

#### 4.3.10 Effect of Graded Levels of Zeolite on Depth wise Cation Exchange Capacity in Column of Sodic Soil

The data in relation to CEC of sodic soil when the soil was amended with FYM, Zeolite, Gypsum and their combinations are presented in Table 4.20.

**Table 4.20 Effect of graded levels of zeolite on depthwise cation exchange capacity in column of sodic soil**

Tr. No.	Treatment	CEC (cmol (p <sup>+</sup> ) kg <sup>-1</sup> )		
		0-30 cm	30-60 cm	60-90 cm
T <sub>1</sub>	Absolute control	56.64	56.85	57.11
T <sub>2</sub>	Gypsum as per GR	55.23	55.44	55.70
T <sub>3</sub>	Zeolite @ 400 kg ha <sup>-1</sup>	55.98	56.19	56.45
T <sub>4</sub>	Zeolite @ 600 kg ha <sup>-1</sup>	55.95	56.16	56.42
T <sub>5</sub>	Zeolite @ 800 kg ha <sup>-1</sup>	55.87	56.08	56.34
T <sub>6</sub>	Zeolite @ 1000 kg ha <sup>-1</sup>	55.82	56.03	56.29
T <sub>7</sub>	Zeolite @ 1200 kg ha <sup>-1</sup>	55.79	56.01	56.27
T <sub>8</sub>	Zeolite @ 1400 kg ha <sup>-1</sup>	55.75	55.96	56.22
T <sub>9</sub>	Zeolite @ 600 kg ha <sup>-1</sup> + 100% gypsum as per GR	55.19	55.40	55.66
	<b>SEm<sub>±</sub></b>	<b>0.19</b>	<b>0.18</b>	<b>0.11</b>
	<b>CD at 5%</b>	<b>0.57</b>	<b>0.56</b>	<b>0.32</b>

There was a decrease in cation exchange capacity of soil over initial value. The maximum reduction was observed with the application of Zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR which was reduced to 55.19 cmol (p<sup>+</sup>) kg<sup>-1</sup> of soil at the upper layer of soil which was significantly lower among all other treatment and at par with T<sub>2</sub> (55.23 cmol (p<sup>+</sup>) kg<sup>-1</sup>) and T<sub>8</sub> (55.75 cmol (p<sup>+</sup>) kg<sup>-1</sup>). Whereas at 30-60 cm cation exchange capacity was 55.40 cmol (p<sup>+</sup>) kg<sup>-1</sup> which was significantly lower and at par with T<sub>2</sub> (55.44 cmol (p<sup>+</sup>) kg<sup>-1</sup>) and T<sub>8</sub> (55.96 cmol (p<sup>+</sup>) kg<sup>-1</sup>). At lower depth of soil i.e. 60-90 cm, the cation exchange capacity of soil was 55.66 cmol (p<sup>+</sup>) kg<sup>-1</sup> which was significantly lower among all other treatment and at par with T<sub>2</sub> (55.70 cmol (p<sup>+</sup>) kg<sup>-1</sup>). As per increases levels of zeolite, CEC also decrease but it increases in depth wise. The reduction in CEC might be due to application of zeolite and gypsum which help in removal of soluble and exchangeable salts through leaching. (MacKown and Tucker, 1985).

#### 4.3.11 Effect of Graded Levels of Zeolite on Depth wise Sodium Adsorption Ratio in Column of Sodic Soil

The data regarding the sodium adsorption ratio of the saturation paste extract of sodic soil as a function of leaching are presented in Table 4.21

**Table 4.21 Effect of graded levels of zeolite on sodium adsorption ratio in column of sodic soil**

Tr. No.	Treatment	SAR		
		0-30 cm	30-60 cm	60-90 cm
T <sub>1</sub>	Absolute control	12.53	12.55	12.60
T <sub>2</sub>	Gypsum as per GR	11.22	11.26	11.28
T <sub>3</sub>	Zeolite @ 400 kg ha <sup>-1</sup>	12.31	12.34	12.37
T <sub>4</sub>	Zeolite @ 600 kg ha <sup>-1</sup>	12.29	12.31	12.36
T <sub>5</sub>	Zeolite @ 800 kg ha <sup>-1</sup>	12.27	12.29	12.34
T <sub>6</sub>	Zeolite @ 1000 kg ha <sup>-1</sup>	12.23	12.25	12.30
T <sub>7</sub>	Zeolite @ 1200 kg ha <sup>-1</sup>	12.21	12.23	12.28
T <sub>8</sub>	Zeolite @ 1400 kg ha <sup>-1</sup>	12.18	12.20	12.24
T <sub>9</sub>	Zeolite @ 600 kg ha <sup>-1</sup> + 100% gypsum as per GR	11.19	11.23	11.24
	<b>SEM<sub>±</sub></b>	<b>0.33</b>	<b>0.33</b>	<b>0.34</b>
	<b>CD at 5%</b>	<b>0.99</b>	<b>0.99</b>	<b>1.02</b>

The results showed that Sodium adsorption ratio of saturation paste extract decrease after leaching over initial value in all treatment. SAR was lower with application of Zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR among all other treatment at all three depths. SAR was 11.19 mmol<sup>1/2</sup> L<sup>-1/2</sup> at first layer of soil and at par with T<sub>2</sub> (11.22 mmol<sup>1/2</sup> L<sup>-1/2</sup>) and T<sub>8</sub> (12.18 mmol<sup>1/2</sup> L<sup>-1/2</sup>). Whereas at 30-60 cm depth, it was 11.23 mmol<sup>1/2</sup> L<sup>-1/2</sup> and at par with T<sub>2</sub> (11.26 mmol<sup>1/2</sup> L<sup>-1/2</sup>) and T<sub>8</sub> (12.20 mmol<sup>1/2</sup> L<sup>-1/2</sup>). At 60-90 cm depth, SAR was 11.24 mmol<sup>1/2</sup> L<sup>-1/2</sup> with the application of Zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR at par with T<sub>2</sub> (11.28 mmol<sup>1/2</sup> L<sup>-1/2</sup>) and T<sub>8</sub> (12.24 mmol<sup>1/2</sup> L<sup>-1/2</sup>). As per increase the levels of zeolite, SAR decreases. This reduction in SAR might be due to the removal of sodium from exchange phase and leaching. (Sagare *et al.*, 2001; Kharche *et al.*, 2010).

#### 4.3.12 Effect of Graded Levels of Zeolite on Depth wise Exchangeable Sodium Percentage in Column of Sodic Soil

The data regarding the exchangeable sodium percentage of the saturation paste extract of sodic soil as a function of leaching are presented in Table 4.22.

The exchangeable sodium percentage was decrease after leaching over initial value in all treatment. The exchangeable sodium percentage was observed with the application of Zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR i.e. 12.05 at first layer i.e. 0-30 cm. Whereas at second layer i.e. 30-60 cm, it was reduced to 12.33 and at par with treatment T<sub>2</sub> (12.42). At third layer i.e. 60-90 cm, it was reduced to 12.52. Reduction in ESP might be due to the removal of sodium from exchange phase and leaching. (Sagare *et al.*, 2001; Tejada *et al.*, 2006)

**Table 4.22 Effect of graded levels of zeolite on depth wise exchangeable sodium percentage in column of sodic soil**

Tr. No.	Treatment	ESP		
		0-30 cm	30-60 cm	60-90 cm
T <sub>1</sub>	Absolute control	14.43	14.68	14.86
T <sub>2</sub>	Gypsum as per GR	12.14	12.42	12.62
T <sub>3</sub>	Zeolite @ 400 kg ha <sup>-1</sup>	13.29	13.56	13.74
T <sub>4</sub>	Zeolite @ 600 kg ha <sup>-1</sup>	13.24	13.51	13.70
T <sub>5</sub>	Zeolite @ 800 kg ha <sup>-1</sup>	13.22	13.49	13.67
T <sub>6</sub>	Zeolite @ 1000 kg ha <sup>-1</sup>	13.21	13.48	13.66
T <sub>7</sub>	Zeolite @ 1200 kg ha <sup>-1</sup>	13.15	13.43	13.61
T <sub>8</sub>	Zeolite @ 1400 kg ha <sup>-1</sup>	13.07	13.35	13.53
T <sub>9</sub>	Zeolite @ 600 kg ha <sup>-1</sup> + 100% gypsum as per GR	12.05	12.33	12.52
	<b>SEm<sub>±</sub></b>	<b>0.03</b>	<b>0.03</b>	<b>0.03</b>
	<b>CD at 5%</b>	<b>0.09</b>	<b>0.10</b>	<b>0.10</b>

#### 4.4 Impact of Amendment on Physical Properties of Soil

After 120 days to soil leaching the soil column were cut at 0-30, 30-60 and 60-90 cm depth and analyzed for physical properties and the results obtained after leaching are discussed as under.

##### 4.4.1 Effect of Graded Levels of Zeolite on Depth wise Bulk Density in Column of Sodic Soil

The results with respect to the bulk density of soil after leaching when amended with soil is presented in Table 4.23.

Result reveals that bulk density was influenced by the application Zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR which was 1.41 Mg m<sup>-3</sup> at upper layer of soil. Bulk density was increased with depth and at par with T<sub>2</sub> (1.42 Mg m<sup>-3</sup>), T<sub>7</sub> (1.43 Mg m<sup>-3</sup>), T<sub>8</sub> (1.42 Mg m<sup>-3</sup>). At 30-60 cm soil depth, initial bulk density of soil was 1.52 Mg m<sup>-3</sup> which was reduced to 1.43 Mg m<sup>-3</sup> i.e. T<sub>9</sub> and at par with treatment T<sub>2</sub> (1.43 Mg m<sup>-3</sup>), T<sub>6</sub> (1.46 Mg m<sup>-3</sup>), T<sub>7</sub> (1.44 Mg m<sup>-3</sup>) and T<sub>8</sub> (1.44 Mg m<sup>-3</sup>). At 60-90 cm, the bulk density was reduced to 1.46 Mg m<sup>-3</sup> and at par with T<sub>2</sub> (1.46 Mg m<sup>-3</sup>), T<sub>6</sub> (1.49 Mg m<sup>-3</sup>), T<sub>7</sub> (1.48 Mg m<sup>-3</sup>) and T<sub>8</sub> (1.47 Mg m<sup>-3</sup>).

**Table 4.23 Effect of graded levels of zeolite on depth wise bulk density in column of sodic soil**

Tr. No.	Treatment	Bulk Density		
		0-30 cm	30-60 cm	60-90 cm
T <sub>1</sub>	Absolute control	1.49	1.51	1.52
T <sub>2</sub>	Gypsum as per GR	1.42	1.43	1.46
T <sub>3</sub>	Zeolite @ 400 kg ha <sup>-1</sup>	1.47	1.50	1.51
T <sub>4</sub>	Zeolite @ 600 kg ha <sup>-1</sup>	1.46	1.49	1.50
T <sub>5</sub>	Zeolite @ 800 kg ha <sup>-1</sup>	1.45	1.47	1.50
T <sub>6</sub>	Zeolite @ 1000 kg ha <sup>-1</sup>	1.45	1.46	1.49
T <sub>7</sub>	Zeolite @ 1200 kg ha <sup>-1</sup>	1.43	1.44	1.48
T <sub>8</sub>	Zeolite @ 1400 kg ha <sup>-1</sup>	1.42	1.44	1.47
T <sub>9</sub>	Zeolite @ 600 kg ha <sup>-1</sup> + 100% gypsum as per GR	1.41	1.43	1.46
	<b>SEm<sub>±</sub></b>	<b>0.01</b>	<b>0.01</b>	<b>0.01</b>
	<b>CD at 5%</b>	<b>0.03</b>	<b>0.03</b>	<b>0.03</b>

This result is show that replacement of sodium due to addition of gypsum and zeolite gradually helps in increasing the soil porosity. The reduction in bulk density was also due to regeneration of structure caused by improved aggregation with the addition of organic matter. It suggested that the integration of chemical amendment along with application of FYM was found more beneficial for improving (BD) air water relationship in soil. (Kharche *et.al* 2010; Xiling *et al.*, 1991).

#### **4.4.2 Effect of Graded Levels of Zeolite on Depth wise Hydraulic Conductivity in Column of Sodic Soil**

The data in respect of hydraulic conductivity generated during the experiment is presented in Table 4.24 which indicates that the hydraulic conductivity of soil after leaching was enhanced due to addition of amendments before leaching.

**Table 4.24 Effect of graded levels of zeolite on depth wise hydraulic conductivity in column of sodic soil**

Tr. No.	Treatment	Hydraulic conductivity (cm hr <sup>-1</sup> )		
		0-30 cm	30-60 cm	60-90 cm
T <sub>1</sub>	Absolute control	0.34	0.32	0.31
T <sub>2</sub>	Gypsum as per GR	0.43	0.40	0.38
T <sub>3</sub>	Zeolite @ 400 kg ha <sup>-1</sup>	0.35	0.33	0.32
T <sub>4</sub>	Zeolite @ 600 kg ha <sup>-1</sup>	0.36	0.35	0.33
T <sub>5</sub>	Zeolite @ 800 kg ha <sup>-1</sup>	0.37	0.36	0.34
T <sub>6</sub>	Zeolite @ 1000 kg ha <sup>-1</sup>	0.39	0.36	0.35
T <sub>7</sub>	Zeolite @ 1200 kg ha <sup>-1</sup>	0.40	0.37	0.35
T <sub>8</sub>	Zeolite @ 1400 kg ha <sup>-1</sup>	0.41	0.39	0.37
T <sub>9</sub>	Zeolite @ 600 kg ha <sup>-1</sup> + 100% gypsum as per GR	0.44	0.43	0.39
	<b>SEm<sub>±</sub></b>	<b>0.01</b>	<b>0.02</b>	<b>0.01</b>
	<b>CD at 5%</b>	<b>0.04</b>	<b>0.05</b>	<b>0.03</b>

The hydraulic conductivity was observed with the application of Zeolite @ 600 kg ha<sup>-1</sup>+ 100% gypsum as per GR which was increased to 0.44 cm hr<sup>-1</sup> at 0-30 cm depth and at par with T<sub>2</sub> (0.43 cm hr<sup>-1</sup>), T<sub>7</sub> (0.40 cm hr<sup>-1</sup>), T<sub>8</sub> (0.41 cm hr<sup>-1</sup>). Hydraulic conductivity of the soil was decreased at lower depth. However at 30-60 cm depth, the hydraulic conductivity was higher with the application of Zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR, it was 0.43 cm hr<sup>-1</sup> which was significantly higher over the all treatments and at par with the treatment T<sub>2</sub> (0.40 cm hr<sup>-1</sup>), T<sub>8</sub> (0.39 cm hr<sup>-1</sup>). Whereas at the depth 60-90 cm, the hydraulic conductivity was 0.39 cm hr<sup>-1</sup> with the application of Zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR which was significantly higher among all treatment and at par with T<sub>2</sub> (0.38 cm hr<sup>-1</sup>), T<sub>8</sub> (0.37 cm hr<sup>-1</sup>). This might be due to the dissolution of calcite which might have released more calcium in addition to the calcium from gypsum causing flocculating effect. It low in lower depth due to more compactness in lower depth (Xiubin and Zhanbin, 2001).

The magnitude of increase in hydraulic conductivity due to gypsum is very high in sodic soil of alluvial plains in northern states of India. While the hydraulic conductivity in black swell shrink soil, addition of gypsum is very slow and gradual indicating slow reclamation in sodic black clay soils.

## 5. SUMMARY AND CONCLUSION

The present investigation entitled, “Effect of different levels of zeolite for improvement of sodic soil” was carried out at Department of Soil Science and Agricultural Chemistry, Post Graduate Institute, Mahatma Phule Krishi Vidyapeeth, Rahuri during 2019. The results of the effect of zeolite and gypsum for improvement of sodic soil are summarized and valid conclusions based on the research findings are drawn and presented in this chapter

### 5.1 Effect of Graded Level of Zeolite Application on Chemical Properties of Soil After 120 Day

#### 5.1.1 pHs

pHs of saturation paste extract of soil decreased in all treatments at all three depth as compared to initial value. The pHs considerably decreased with the application of Zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR which was superior over all other treatments, the decrease in pHs were 8.10, 8.15 and 8.21 at 0-30, 30-60 and 60-90 cm depths respectively.

#### 5.1.2 Electrical Conductivity (ECe)

Electrical conductivity of saturation paste extract of soil after continuous leaching with application of Zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR was increased at all three depth i.e. 0-30, 30-60 and 60-90 cm over initial value. The maximum value was recorded with zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR.

#### 5.1.3 Calcium

The calcium content in saturation paste extract of soil increased and maximum calcium was recorded with the application of Zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR and it was increased with increasing depth.

#### 5.1.4 Magnesium

The concentration of magnesium increases as the depth of soil increases. The maximum increase in magnesium was found with application of zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR.

#### 5.1.5 Sodium

Sodium content after leaching in soil was decreased over initial value at all three depth i.e. 0-30, 30-60 and 60-90 cm and maximum sodium was decreased with application of zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR.

#### 5.1.6 Potassium

The potassium content in saturation paste extract of soil was reduced over initial value at all three layers of soil and it was reduced by the application of Zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR followed by gypsum as per GR.

### 5.1.7 Bicarbonate

The bicarbonate content in saturation paste extract of soil after leaching with amendments was maximum recorded at all the depth in T<sub>9</sub> treatment i.e. application of zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR.

### 5.1.8 Chloride

The chloride content in soil were decreased over initial value at all the depth i.e. 0-30, 30-60 and 60-90 cm. the maximum reduction was observed with zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR.

### 5.1.9 Sulphate

Sulphate content in saturation paste extract of sodic soil was increased by the application of Zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR it was might be due to sulphate present in gypsum and in irrigation water at all the depths.

### 5.1.10 Cation Exchange Capacity

The cation exchange capacity of soil decreased in all the treatment and the maximum reduction was observed with zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR.

### 5.1.11 Sodium Adsorption Ratio

The sodium adsorption ratio of saturation paste extract decrease after leaching over initial value in all treatment. The maximum reduction in SAR was recorded in T<sub>9</sub> treatment among all other treatment at all three depths.

### 5.1.12 Exchangeable Sodium Percentage

The ESP value decreased considerably by leaching. The ESP value was decreased in all treatment and the maximum reduction in ESP was recorded with zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR i.e. 1.69, 5.03 and 6.34 % with 0-30, 30-60 and 60-90 cm depth respectively.

## 5.2 Effect of Graded Level of Zeolite Application on Physical Properties of Soil After 120 Day

### 5.2.1 Bulk Density

Bulk density of soil after leaching with zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR was decreased over initial value but increase with increasing depth indicating compactness in sub-surface horizon.

### 5.2.2 Hydraulic Conductivity

Hydraulic conductivity was considerably variable in different horizon and in general, it was increased with the application of zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR but hydraulic conductivity was decreased with increasing depth.

## 5.3 Conclusion

From present investigation it is concluded that the application of zeolite @ 600 kg ha<sup>-1</sup> + 100% gypsum as per GR along with FYM was found beneficial for improvement of physical and chemical properties of sodic soil.

## 6. LITERATURE CITED

- Abdi, M., Khosh-Khm and Eshghi, S. (2006) Effects of natural zeolite on growth and flowering of strawberry (*Fragaria xananassa* Duch.) *Soil Tillage Research* **126**, 193–202.
- Abhange, G.V. (1986). Drainage problems in Maharashtra past experiences and future challenges, *Sinchan* **4**: 50-80.
- Abrol, I. P; J. S. P. Yadav and F. I. Massoud (1988). Salt affected soils and their management, *FAO Soils Bulletin*, (**39**) Italy, Rome, 93 pp.
- Abdel-Fattah, M. K. (2012). Role of gypsum and compost in reclaiming saline-sodic soils. *Journal Agricultural Veterinary Science*, (**1**), 30-38.
- Ackley, M.W and Yang, R.T. (1991) Adsorption characteristics of high exchange clinoptilolite. *Industrial and Engineering Chemistry Research* **30**(12), 2523-2530.
- Aharoni C, Sparks DL, Levinson S, Ravina I. (1991) Kinetics of soil chemical reactions: Relationship between empirical equations and diffusion models. *Soil Science Society of American Journal*. **55**: 1307– 1312.
- Ahmed, O.H., Aminuddin, H., Husni, M.H.A., Anuar, A.R., Nik Muhamad, A.M. (2008) Enhancing the urea-N use efficiency in maize (*Zea mays*) cultivation on acid soils amended with zeolite and TSP. *Science World Journal* **8**, 394-399.
- Ahmed, O., Aminuddin, H. and Husni, M. (2010) Reducing ammonia loss from urea and improving soil exchangeable ammonium retention through mixing triple super-phosphate, humic acid and zeolite. *Soil Use Manage* **22**, 315–319.
- Al-Busaide, A., Yamamoto, T. and Irshad, M. (2007) The ameliorative of artificial zeolite on barley under saline conditions. *Journal of Applied Science* (**7**), 2272-2276.
- Allen, E.R., Hossner, L.R., Ming, D.W. and Henninger, D.L. (1993) Solubility and cation exchange in phosphate rock and saturated clinoptilolite mixtures. *Soil Science Society American Journal* **57**(5), 1368-1374.
- Amezketta, E; R. Aragues and R. Gazol (2005) Efficiency of sulphuric acid, mined gypsum, and two gypsum by-products in soil crusting prevention and sodic soil reclamation. *Agronomy Journal*, (**97**), 983-989
- Andry, H., Yamamoto, T., Rasiyah, V. and Fukada, M. (2007) Improving the resistance of an acid soil to water erosion using artificial zeolite and hydrated lime amendments. *Trans. Jpn Society Irrigation Drainage Rural Eng.*, (**247**), 53-64.
- Anonymous (2004ab) Manufacture of slow release fertilizers and soil amendment zeolites are emerging soil amendments for improving soil physical and chemical properties in agriculture. *Revista Brasileira de Fruticultura* **30**, 794-800.

- Auerback, S.M., Carrado, K.M. and Dutta, P.K. (2003) Handbook of zeolite science and technology. Marcel Dekker, Inc., New York. *Journal Environmental Studies* **20**(6), 1411-1418.
- Balpande, S.S., S.B. Deshpande and D.K. Pal, (1996) Factors and processes of soil degradation in Vertisols of the Purna Valley, Maharashtra, India. *Land Degradation and Rehabilitation*. **7**: 313-324.
- Banerjee, S. 1957. Relative leaching rates of cations from soils. *Journal Indian Society Soil Science*, **(5)** 147.
- Barbarick, K.A. and Pirela, H.J. (1984) Agronomic and horticultural uses of zeolite. In: Pond WG, Mumpton FA, editors. Zeo-agriculture: Use of Natural Zeolites in Agriculture and Aquaculture. Boulder, CO, USA: *Westview Press* **76**, 93–104.
- Bernardi, A.C., Oliviera, P.P.A., De Melo Monte, M.B. and Souza-Barros, F. (2013) Brazilian sedimentary zeolite use in agriculture. *Microporous and Mesoporous Materials* **167**, 16-21.
- Bhattacharyya, R., Ghosh, B.N., Mishra, P.K., Mandal, B., Srinivasarao, C.H., Sarkar, D., Das, K., Anil, K.S., Lalitha, M., Hati, K.M. and Franzluebbbers, A.J. (2015) Soil degradation in India: Challenges and Potential Solutions. *Sustainability* **7**, 3528-3570.
- Burriesci, N., Valente, S., Zipelli, C. and Bart, J. (1984) Studies on zeolites in agriculture: Effect on crop growth of prunus persica and Vifis vinifera. *Zeolite* **4**, 373-376.
- Butorac, C.T., Fillpan, F., Basic, J., Butorac, M. Mesic, I. and Kisic (2002) Crop response to the application of special natural amendments based on zeolite tuff. *Rostlinna Vyroba* **48**(3), 118–124.
- Blake, G.R., and Hartage, K.H. (1986) Bulk density. In Methods of soil analysis, part-I, Klute, A. (Ed.) II edition. *American Society of Agronomy Including and Soil Science Society of America Including Madison*, USA, 363-382.
- Campana, M., Moraes, J.P.G., Santos, E., Herling, V., Barioni Junior, W., Bernardi, A.C.C. and Oliveira, P.P.A. (2015) Ammonia volatilization from exposed soil and Tanzania grass pasture fertilized with urea and zeolite mixture. *Communication in Soil Science and Plant Analysis* **46**, 101-109.
- Choudhary, O. P; A. S. Josan; M. S. Bajwa and L. Kapur (2004). Effect of sustained sodic and saline-sodic irrigation and application of gypsum and farmyard manure on yield and quality of sugarcane under semi-arid conditions. *Field Crops Resource*, **(87)**, 103-116.
- Dakovic, A., Tomasevic-Canovic, M., Rottinghaus, E.G., Matijasevic, S. and Sekulic, Z. (2007) Fumonisin B1 adsorption to octadecyl dimethyl benzyl ammonium-modified clinoptilolite-rich zeolitic tuff. *Microporous and Mesoporous Materials* **105**, 285-290.
- Dana, J.P. (1854) System of Mineralogy, edition 4. Putnam, New York,320.

- DeSutter, T.M. and Pierzynski, G.M. (2005) Evaluation of soils for use as liner materials: A Soil Chemistry Approach. *Journal of Environmental Quality* **34**, 951-962.
- Durgude, A. G. (1999) Morphology, Characterization, Classification and Mapping of Salt Affected Soil of Central Research Farm, MPKV, Rahuri. *Ph.D. Thesis* submitted to the Mahatma Phule Krishi Vidyapeeth, Rahuri (MS) India.
- Durgude, A. G., A. L. Pharande and A. S. Patil, (2004) Characterization and classification of sodic soils of MPKV, Rahuri. *Extended summaries: International conference on sustainable management of sodic lands* **1**:139.
- Dwairi, I.M. (1998) Evaluation of Jordanian zeolite tuff as a controlled slow-release fertilizer for  $\text{NH}_4^+$ . *Environmental Geology* **34**, 1-4.
- El-Enany, A.E. (2005) Proline effect on shoot organogenesis and protein synthesis in salinity-stressed tomato cultures. *Islamic Academic Science* **8**(3), 137–142.
- Enkeleida BEQIRAJ, Fran GJOKA, Fabrice MULLER and Patrick BAILLIF (2008) Use of zeolitic material from munella region (Albania) as fertilizer in the sandy soil of divjaka region (Albania). *Carpath. Journal of Earth and Environmental Science*, **(3)**, pp: 33-47
- Filcheva, E. and Chakalov, K. (2002) Soil fertility management with zeolite amendments. Effect of zeolite on carbon sequestration: A review. In: Agricultural practices and policies for carbon sequestration in soils by kimble. *Journal of Agriculture and Natural Resources Science and Technology* **78**, 223- 236.
- Ford GW, Martin JJ, Rengasamy P, Boucher SC, Ellington A (1993) Soil sodicity in Victoria. *Australian Journal of Soil Research* **31**, 869-909.
- Gaikwad, S.T. and Challa, O. (1996) Soils of Maharashtra, their problems and potentials. *Paper Presented in National Seminar of Indian Society of Soil Science., Akola Chapter, Akola*, pp. 12-13.
- Gharaibeh MA, Eltaif NI, Shunnar O.F (2009) Leaching and reclamation of calcareous saline-sodic soil by moderately saline and moderate-SAR water using gypsum and calcium chloride.
- Gharaibeh, M. A; N. I. Eltaif and A. A. Albalasmeh (2011) Reclamation of highly calcareous saline sodic soil using Atriplex halimus and by-product gypsum. *International Journal Phytoremedies*, **(13)** 873–883.
- Girijaveni, V.K., Reddy, S., Sharma, K.L. and Moulika, G. (2018) Zeolites are emerging soil amendments for improving soil physical and chemical properties in agriculture. *International Journal of Agriculture, Environment and Biotechnology Citation* **11**(6), 841-849.

- Gupta, M.; Srivastava, P.K.; Niranjana, A.; Tewari S.K. (2016) Use of a bioaugmented organic soil amendment in combination with gypsum for *Withania somnifera* growth on sodic soil. *Pedosphere* 2016, **26**, 299–309.
- Hanay, A; B. Fatih; M. K. Fatih and Y. C. Mustafa (2004). Reclamation of saline-sodic soils with gypsum and MSW compost. *Utilization Compost Science*, (**12**) 175–179
- Hadi, G. and Ali, A.B. (2008) International meeting on soil fertility land management and Agro climatology, Turkey. p: 977-985.
- Hatt, BE; Fletcher, TD; Deletic, A (2007) Treatment performance of gravel filter media: implication for design and application of stormwater infiltration systems. *Water Resource* **41**: 2513-2524
- He, Xiubin and Zhanbin, Huang (2001) Zeolite application for enhancing water infiltration and retention in loess soil. *Environmental Health* **34**, 45-52.
- He, Z.L., Calvert, D.V. and Li, A.K. (2002) Clinoptilolite zeolite and cellulose amendments to reduce ammonia volatilization in a calcareous sandy soil. *Plant Soil* **52**, 247-253.
- Huang, Z.T. and Petrovic, A.M. (1994) Physical properties of sand as affected by clinoptilolite zeolite particle size and quantity. *Journal of Turfgrass Management* **1**(1), 1-15.
- Jackson, M.L. (1973) Soil Chemical Analysis. *Prentice Hall of India*, New Delhi.
- Kaduk, J.A. and Faber, J. (1995) Crystal structure of zeolite as a function of ion exchange. *Rigaku Journal* **12**(2), 1434.
- Kadu, P.R, P.H. Vaidya, S.S. Balpande, P.L.A. Satyavathi and D.K. Pal. (2003) Use of hydraulic conductivity to evaluate the suitability of Vertisols for deep-rooted crops in semiarid parts of central India. *Soil Use and Management*, **19**, pp-208-216.
- Kavvadias, V., Ioannou, Z., Katsaris, P., Kardimaki, A., Vavoulidou, E. and Theocharopoulos, S. (2019) Use of zeolites in Agriculture: Effect of addition of natural zeolite and clinoptilolite and compost on soil properties and crop development. *In: Soil amendments for sustainability challenges and perspectives*. Rakshit, A., Sarkar, B. and Abhilash, P. (Eds). CRC press, Taylor and Francis group, Boca Raton.
- Kawde, R. D., N. K. Barade and D. K. Ballal, (2005) Studies on salt affected soils of Keliveli village of Akola district of Maharashtra state. *PKV Resource Journal*. **1**, 51-58.
- Keren R, O'Connor GA. (1982) Gypsum dissolution and sodic soil reclamation as affected by water velocity. *Soil Science Society of American Journal*. **44**, 726–732.
- Kharche, V. K., Pawar, V.S. and Inamdar, P.V. (2004) Characterization and use potential of sodic Vertisols of Mula command area of Maharashtra. *Extended summaries: International conference on sustainable management of sodic lands*, **1**:196-198.

- Kharche, V.K., S.R. Patil, S.V. Belur and N.S. Ghogare. (2010) Integrated use of gypsum, spent-wash press-mud compost and bioinoculants for reclamation of sodic swell shrink soils of Maharashtra. *Journal of Soil Salinity and Water Quality*, **2**(2), pp- 110115.
- Klute, A. and Drikson, C. (1986) Hydraulic conductivity and diffusivity. Laboratory method of soil analysis part-I edition Klute, A. *Agronomy Monograph No. 9*, 687-732.
- Knudsen, D., Peterson, G.A. and Pratt, P.F. (1982) In methods of Soil Analysis Part II Chemical and microbiological properties. *American Society of Agronomy Including Madison, Wisconsin, USA*.
- Kocakusak, S., Savasc, I.O. and Tve Ayok, T. (2001) Dogal Zeolitler ve Uygulama Alanlari. TÜBITAKMAM, Malzeme ve Kimya Tek. Arş. Enst., Rapor *Rostlinna Vyroba*. **42**, 131-41.
- Koo JW, Edling RJ, Taylor V. (1990) A laboratory reclamation study for sodic soils used for rice production. *Agricultural Water Management*.**18**: 243–252.
- Kralova, M., Hrozinkova, A. and Ruzek, P. (1992) Synthetic and natural zeolites affecting the physical-chemical soil properties. *Rostlinna Vyroba* **42**, 131-141.
- Latifah, O., Ahmed, O.H. and Majid, N.M.A. (2017) Short term enhancement of nutrients availability in *Zea mays* L. cultivation on an acid soil using compost and clinoptilolite zeolite. *Compost Science Utilization* **25**(1), 22-35.
- Lewis *et al.* (2004) Optimization of process parameters to obtain NH<sub>4</sub>-clinoptilolite as a supplement to ecological fertilizer. *Clay Minerals* **49**, 735-745.
- Lindsay, W.L. and Norvell, W.A. (1978) Development of DTPA soil test for Zn, Fe, Mn and Cu. *Journal of American Society of Soil Science* **42**, 421-428.
- MacKown, C. and Tucker, T. (1985) Ammonium nitrogen movement in a coarse-textured soil amended with zeolite. *Journal of American Society of Soil Science* **49**, 235-238.
- María Alcívar 1, Andrés Zurita-Silva 2 ID, Marco Sandoval 1, Cristina Muñoz 1 and Mauricio Schoebitz 1. Reclamation of Saline–Sodic Soils with Combined Amendments: Impact on Quinoa Performance and Biological Soil Quality. *Sustainability* 2018, **10**, 3083; doi:10.3390/su10093083
- Mahmoodabadi. M; N. Yazdanpanah; L. Sinobas; E. Pazira and A. Neshat (2012). Reclamation of calcareous saline sodic soil with different amendments (1); Redistribution of soluble cations within the soil profile. *Agricultural Water Management*, (**120**), 30-38.
- Markou, G., Depraetere, O., Vandamme, D. and Muylaert, K. (2015) Cultivation of *Chlorella vulgaris* and *Arthrospira platensis* with recovered phosphorus from wastewater by means of zeolite sorption. *International Journal Molecular Science* **16**(2), 4250-4264.
- Mass, E.V., Ogata, G. and Garber, M.J. (1972) Influence of salinity on Fe, Mn and Zn uptake by plants. *Agronomy Journal* **64**, 793–759.

- Maurya, B.R., H. Ram and S.S. Prasad. (2009) Impact of soil amendments on properties of the salt affected rice soil. *Journal of Indian Society of Soil Science*, **57**(3):385-388.
- Mazloomi, F. and Jalali, M. (2016) Ammonium removal from aqueous solutions by natural Iranian zeolite in the presence of organic acids, cations and anions. *Journal Environmental Chemical Engineering* **4**(1), 240-249.
- Meharkure, M., Thomas, J., Arun, K., Bhople, B.S., Saresh, N.V., Vaid, S.K. and Sanjat, K.S. (2018) Zeolite farming: A sustainable agricultural prospective. *International Journal of Current Microbiology and Applied Sciences* **7**(5), 2319-7706.
- Ming, D.W. and Boettingger, J.L. (1989) "Zeolites in soil environments. Natural Zeolites: Occurrence, Properties, Applications, Reviews in Mineralogy & Geochemistry," *Mineralogical Society of America & Geochemical Society, Washington DC* **45**, 323- 345.
- Mohite, A.V. and A. K. Shingate, 1984. Changes in effluent composition during reclamation of saline-sodic soil by high salt water dilution method. *Journal Maharashtra agricultural University*, **9**(2): 203-205.
- Molla, A., Ioannou, Z., Mollas, S., Skoufogianni E., and Dimirkou A. (2015) Influence of Chromic Ions in Maize Cultivation (ZEA MAYS) after the addition of Natural minerals as Soil Amendments, Proceedings of the 14th International Conference on Environmental Science and Technology Rhodes, Greece, 3-5 September . *Journal of Soil Research* **48**(5), 470-479.
- Moritani, S., Yamamoto, T., Andry, H., Inoue, M., Yuya, A. and Kaneuchi, T. (2010) Effectiveness of artificial zeolite amendment in improving the physicochemical properties of saline-sodic soils characterised by different clay mineralogies. *Australia Journal Soil Resource*, **48**(5), 470-479.
- Mumpton, F.A. (1999) La roca: Uses of Natural zeolites in agriculture and industry. *Geology, Mineralogy and Human Welfare* **96**(7), 346-347.
- Murthy, G. (1960) Leaching trails with a saline alkali soil. A study of the process of leaching out of salts in three successive leaching. *Andhra agriculture Journal* **7**: 199-211.
- Murthy, R.S., L.R. Hirekerur, S.B. Deshpande and B.V. Venkat Rao, (1982) Benchmark Soils of India. *National Bureau of Soil Survey and Land Use Planning (ICAR)*, Nagpur, India, 308p.
- Nadler A, Levy GJ, Keren R, Eisenberg H. (1996) Sodic calcareous soil reclamation as affected by water chemical composition and flow rate. *Soil Science Society American Journal*. **60**: 252–257.
- Nan, J.; Chen, X.; Wang, X.; Lashari, M. S.; Wang, Y.; Guo, Z.; Du, Z. (2016) Effects of applying flue gas desulfurization gypsum and humic acid on soil physicochemical

- properties and rapeseed yield of a saline-sodic cropland in the eastern coastal area of China *Journal Soil Sediment*. 2016, **16**, 38–50.
- Negim O. (2015) Effect of Addition Pressmud and Gypsum by Product to Reclamation of Highly Calcareous Saline Sodic Soil. *AASCIT Journal of Environment*, (**1**), No. 4, 2015, pp. 76-84.
- Nelson, D.W. and Somner, L.E. (1982) Total carbon, organic carbon and organic matter and methods of soil analysis. *American Society of Agronomy Including Soil Science Society of America Including Madison, Wisconsin, USA*, 539-579.
- Noori, M., Zendehtel, M. and Ahmadi, M. (2006) Using natural zeolite for the improvement of soil salinity and crop yield. *Toxicological and Environmental Chemistry*, **88**(1), 77-84.
- Nimkar, A.M., S.B. Deshpande and P.G. Babrekar, 1992. Evaluation of salinity problem in swell-shrink soils of a part of the Purna Valley, Maharashtra, *Agropedology*. **2**: 59-65.
- Olsen, S.R., Col, C.V., Watanabe, F.S. and Dean, L.A. (1954) Estimation of available phosphorous in soils by estimation with  $\text{NaHCO}_3$ . *United State Department of Agronomy Circle 939 (C.A. Black 1965) American Society Including Madison, USA*, 1035.
- Oster, J.D., Frenkel, H. (1980) The chemistry of the reclamation of sodic soil with gypsum and lime 1. *Soil Science Society of America Journal* **44**(1), 41-45, 1980
- Oster J.D. (1982) Gypsum usage in irrigated agriculture: *A review of Fertilizer Resource*. **3**: 73–89.
- Oster J. D; I. Shainberg and I. P. Abrol (1996). Reclamation of salt-affected soil. In: Agassi M (ed) Soil erosion, conservation and rehabilitation. *Marcel Dekker Including New York*, pp 315–352.
- Padole, V.R., R.K. Chaolkar and P.W. Deshmukh. (1998) Characterization of salt affected Vertisols of Vidarbha region, Maharashtra. *PKV Research Journal*. **22**:26-34.
- Page, A.L., Miller, R.H. and Keeney, D.R. (1982) Methods of soil analysis *Agron. Monogs. q. American, Society of Agronomy*, 149-157.
- Panase, V.A. and Sukhatme, P.V. (1985) *Stastical methods for Agricultural Workers*, Revised Edition. ICAR, New Delhi.
- Perez-Caballero, R. Gil, J. Benitez C. Gonzalez, J. L. (2008) The effect of adding zeolite to soils in order to improve the N-K nutrition of olive trees, preliminary results. *American Journal Agriculture Biological Science* **2**(1), 321-324.
- Phadke, A.V. (1984) Natural occurrence of clinoptilolite from western maharashtra, its utilization in refrigeration using solar energy. *Proceedings of Indian National Science Academy* **50A** (5), 479–82.
- Piper, C.S. (1966) *Soil and Plant Analysis*, *Hans Publishers*, Bombay.

- Pirzad, A. and Mohammadzade, S. (2014) Effects of drought stress and zeolites on the protein and mineral nutrients of *Lathyrus sativus*. *International Journal of Biosciences* **4**(7), 241-248.
- Pisarovic, A., Filipan, T. and Tisma, S. (2003) Application of zeolite based special substrates in agriculture: ecological and economical justification. *International Journal of Current Microbiological Applied Science* **7**(5), 2912-2924.
- Polat, E., Karaca, M., Demir, H. and Onus, N.A. (2004) Use of natural zeolite (clinoptilolite) in agriculture. *Journal of Fruit and Ornamental Plant Research* **12**, 183–189.
- Prapagar, K; S. P. Indraratne and P. Premanandharajah (2012). Effect of Soil Amendments on Reclamation of Saline-Sodic Soil. *Tropical Agricultural Resource*, (**23**), 168–176.
- Qadir M, Qureshi RH, Ahmad N (1996) Reclamation of a saline-sodic soil by gypsum and *Leptochloa fusca*. *Geoderma*. **74**: 207–217.
- Qadir M, Schubert S. (2002) Degradation processes and nutrient constraints in sodic soils. *Land Degrad Dev*. **13**: 275–294.
- Ramesh K., Biswas, A.K., Somasundaram, J. and Subbarao, A. (2010) Nano porous zeolites in farming: current status and issues ahead. *Current Science* **99**(6), 760-764.
- Ramesh, K., Reddy, K.S., Rashmi, I. and Pankaj, U. (2015) Nanoporous zeolites as soil urease adsorbers: An opportunity for increasing nitrogen use efficiency. *Advances in Agronomy* **99**(6), 760-765.
- Richards L. (1954) Diagnosis and improvement of saline and alkali soils. *Handbook No. 60. Washington (DC): US Department of Agriculture*. p. 98.
- Richard, L. A. (1968) Pressure plate membrane apparatus. *Soil Science Society of America Proceeding*, 456-459.
- Robbins CW (1986) Sodic calcareous soil reclamation as affected by different amendment sand crops. *Agronomy Journal*. **78**: 916–920.
- Sagare, B. N., R. L. Kalane and Y. S. Guhe, (1991) characterization of salt affected Vertisols of Purna valley tract in Vidarbha region. *Journal Mah. Agriculture University*, **16**(3),310-312.
- Sagare, B.N., S.S. Rewatkar and V.P. Babhulkar. (2001) Effect of land configuration and gypsum levels on dynamics of soil properties and productivity of cotton grown in sodic Vertisols. *Journal of Indian Society of Soil Science*, **49**(2), 377-379.
- Sampio, R.A and H. A. Ruiz, (1996) Characteristics of solutions drained from saline sodic soils after partial leaching. *Revista, Brasileira-deciencia-dosolo*. **20**(1), 13-20.
- Sanjeev Kumar, M.M. Agarwal and A. Kumar, (2004) Utilization of sodic water in sandy loam textured soil. *Extended Summeries, International Conference on sustainable Management of Sodic Lands*. Feb 9-14, 2004, Lucknow, India

- Sarioglu, M. (2005) Removal ammonium from municipal wastewater using natural Turkish (Dogantepe) zeolite. *Sep. Purif. Technology*, **(41)**, 1–11.
- Satyanarayan, K.V.S. (1954) Soils of Kutch and Rann and their better utilization. *Bull. National Institute of Science India*. **3**: 89-94.
- Sen, H.S. (2003) Problem soils in india and their management. Prospect and Retrospect. *Journal of Indian Society of Soil Science.*, **51**(4):388-408.
- Sepaskhah, A.R. and Barzegar, M (2010) Yield, water and nitrogen-use response of rice to zeolite and nitrogen fertilization in a semi-arid environment. *Agriculture Water Management* **98**(1), 38-44.
- Shainberg I, Prather RJ (1980) Effect of low electrolyte concentration on clay dispersion and hydraulic conductivity of a sodic soil. *Soil Science Society American Journal*. **45**: 273–277.
- Shainberg, I and J. Letey (1984). Response of soils to sodic and saline conditions. *Hilgardia*, **(52)**, 1–57.
- Shainberg I, Sumner ME, Miller WP, Farina MPW, Pavan MA, Fey MV. 1989. *Use of gypsum on soils: A review. Advantage of Soil Science*. **9**: 1–111.
- Sharma, R. C., A. K. Mandal, R. K. Saxena and K. S. Verma, (2004) Characteristics, formation and reclaimability of sodic soils under different geomorphic plains of Ganga basin. *Extended summaries: International conference on sustainable management of sodic lands* **1**: 168-170.
- Shehata, A.A., M. A. Hamdy, and D. D. El-Badry, (1983) Gypsum application for leaching of saline-alkali soils in El-Beheira Governorate. *Egyptian Journal of Soil Science*, **23**(1), 63-73.
- Singh D. P., D. C. Sharma, and S. N. Prasad, (1980) The effect of different soil ammendments on physical properties of sodic soil and yield of wheat. *Current Agriculture* **4**(1-2): 47-58.
- Singh, Y.P., S.V.S. Chauhan, H.C. Singh and Sudhir Singh. (2011) Impact of sodic soils reclamation technology: An assessment of on farm trials. *Indian Research Journal External Education*, **11**(1).
- Spivey, N. and Neubauer, K. (2016) Micronutrients analysis from soil to food: *Determination by ICP-OES* **31**, 8-17.
- Sprynskyy, M., Lebedynets, M., Terzyk, A.P., Kowalczyk, P., Namieśnik, J. and Buszewski. B. (2005) Ammonium sorption from aqueous solutions by the natural zeolite Transcarpathian clinoptilolite studied under dynamic conditions. *Journal Colloid Interface Science*, **284**(2), 408-415.

- Subbiah, B.V. and Asijia, G.L. (1956) A rapid procedure for the estimation of available nitrogen in soils. *Current Science* **25**, 259-260.
- Sukheswala, R.N., Avasia, R.K. and Gangopadhyay, M. (1974) Zeolites and associated secondary minerals in the Deccan Traps of Western India. *Mineralogical Magazine* **39**, 658-671.
- Sumalatha, G., Ahmed, O.H. and Nik Muhammad, A.M. (2010) Use of zeolite in maize (*Zea mays*) cultivation on nitrogen, potassium, and phosphorus uptake and use efficiency. *International Journal of the Physical Sciences* **5**(15), 2393- 2401.
- Sunitha N., P.K. Basavaraja, B.N. Dhananjaya, P.N. Narasimhareddy and K. Suddhir. (2010) Characterization of salt affected soils of Dodda Seebi tank command area. *Karnataka Journal Agricultural Science*, **23**(2),354-357.
- Susana, S. (2015) Researches influence of zeolite on productivity elements and microbiological activity on spring barley, soybeans and maize. *Journal of Tropical Soils* **16**, 99-106.
- Suarez DL. (2001) Sodic soil reclamation: Modeling and field study. *Aust J Soil Res.* **39**: 1225–1246.
- Tanji KK. (1990) Nature and extent of agricultural salinity. In: *Agriculture Salinity Assessment and Management*. American Society of Civil Engineers Manuals and Reports on Engineering Practice No. 71. New York (NY): *American Society of Civil Engineers (ASCE)*. p. 1–17.
- Tejada, M.; Garcia, C.; Gonzalez, J.L.; Hernandez, M.T. (2006) Use of organic amendment as a strategy for saline soil remediation: influence on the physical, chemical and biological properties of soil. *Soil Biology Biochemistry* 2006, **38**, 1413–1421.
- Todmal, S. (2011) Characterization and Nutrient Status in Different Saline Sodic and Sodic Soil of Rahuri Tahsil Of Ahmednagar District. *Msc. Thesis* submitted to the Mahatma Phule Krishi Vidyapeeth, Rahuri (MS) India.
- Torkashvand, A.M. and Shadparvar, V. (2013) Effect of some organic waste and zeolite on water holding capacity and PWP delay of soil. *Current Biotication*, **6**(4), 459-465.
- Torma, S., Vilcek, J., Adamisin, P., Huttmanova, E. and Hronec, O. (2014) Influence of natural zeolite on nitrogen dynamics in soil. *Turkish Journal of Agriculture and Forestry* **38**, 739-744.
- Turan, NG (2008) The effects of natural zeolite on salinity level of poultry litter compost. *Bioresour Technol* **99**(7):2097-2101
- Varade, S.B., M.S. Palaskar and S.D. More. (1985) Characteristics and reclamation of salt affected Vertisols in canal commands. *Journal of Maharashtra agricultural University*, **10**(2):115-120.

- Vaughan, D. (1978) Properties of natural zeolites. In: Sand, L., Mumpton, F. (Eds.), *Natural Zeolites: Occurrence, Properties, Use. Pergamon Press, New York*, pp. 353–372.
- Verma, K.S. and I.P. Abrol, (1981) A laboratory study of relative effectiveness of pyrites and gypsum in sodic soil reclamation. *Indian Journal Agricultural Science*. **51**(6), 431-436.
- Verma, S.K., R.K. Gupta, and S.K. Dubey, (1985) Comparative effectiveness of some chemical amendments in reclaims sodic Vertisols. *Journal of the Indian Society of Soil Science* **33**: 948-950.
- Verma, S.K. and Gupta, R.K. (1989) Leaching behaviour of saline clay soil under two modes of water application. *Journal of Indian Society of Soil Science*. **32**(4): 803-808.
- Wong, V. N. L; R. C. Dalal and R. S. B. Greene (2009) Carbon dynamics of sodic and saline soils following gypsum and organic material additions: A laboratory incubation. *Appl Soil Ecol.*, (**41**), 29–40.
- Wolf, B. and Synder, G. H. (2003) Sustainable soil: The place of organic matter in sustainable soils and their productivity. *Food Products Press, New York, USA*.
- Xiliang, H., Enxiang, Z., and Chun, D. (1991) A research of zeolite improving the structural property of soils. *Journal of Hebei Agricultural* **34**(1), 45-52.
- Xiubin, H. and Zhanbin, H. (2001) Zeolite application for enhancing water infiltration and retention in loess soil. *Resource Conservation Recycling*, **34**(1) 45-52.
- Yaduvanshi, N.P.S.; Sharma, D.R. (2008) Tillage and residual organic manures/chemical amendment effects on soil organic matter and yield of wheat under sodic water irrigation. *Soil Tillage Resource* 2008, **98**, 11–16.
- Yamada, M., Fujiyama, H., Endo, T., Uehira, M. and Yamamoto, T. (2007) Effect of K-type and Ca-type artificial zeolites applied to high sodic soil on the growth of plants different in salt tolerance. *Soil Science Plant Nutrition*, **53**, 471-479.
- Zabochnicka-Swiatek, M. (2007) Factors Affecting Adsorption Capacity and Ion Exchange Selectivity of Clinoptilolite towards heavy metal cations. *Inzynieria I Ochrona Srodowiska*, **10**(1), 27.

## 8. VITAE

---

**MISS ABHANG KOYAL PRASHANT**

A candidate for the degree

of

**MASTER OF SCIENCE (AGRICULTURE)**

in

**SOIL SCIENCE & AGRICULTURAL CHEMISTRY**

**2021**

---

<b>Title of thesis</b>		:	Effect of different levels of zeolite for improvement of sodic soil
<b>Major discipline</b>		:	Soil Science and Agricultural Chemistry
<b>Biographical information</b>		:	
<b>Personal</b>	<b>Date of Birth</b>	:	19 <sup>th</sup> May, 1995
	<b>Place of Birth</b>	:	Chakan (Pune)
	<b>Father's Name</b>	:	Mr. Abhang Prahant Vitthal
	<b>Mother's Name</b>	:	Mrs Abhang Nirmala Prashant
<b>Educational</b>	<b>Bachelor Degree Obtained</b>	:	Dadasaheb Mokashi College of Agriculture, Rajmachi, Karad
	<b>Class</b>	:	First class
	<b>Name of the University</b>	:	Mahatma Phule Krishi Vidyapeeth, Rahuri
<b>Address</b>		:	A/p- Rajgurunagar, Tal-Khed, Dist- Pune
	<b>Email- id</b>	:	<a href="mailto:koyalabhang19@gmail.com">koyalabhang19@gmail.com</a>
	<b>Contact No.</b>	:	9890534011