

**EFFECT OF AMENDMENT SOURCES TO RECLAIM THE SODIC SOIL
UNDER SUBSURFACE DRAINAGE SYSTEM ON YIELD AND
NUTRIENT UPTAKE OF MAIZE**

by

Mr. Gedam Akash Temdas

(Reg. No. 018/081)

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
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2021**

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MAHARASHTRA, INDIA**

2021

CANDIDATE'S DECLARATION

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

Place: MPKV, Rahuri

Date: / / 2021

(A.T. Gedam)

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CERTIFICATE

This is to certify that the thesis entitled, **“EFFECT OF AMENDMENT SOURCES TO RECLAIM THE SODIC SOIL UNDER SUBSURFACE DRAINAGE SYSTEM ON YIELD AND NUTRIENT UPTAKE OF MAIZE”** submitted to the Faculty of Agriculture, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahmednagar (Maharashtra) 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 **MR. GEDAM AKASH TEMDAS**, under my guidance and supervision and that no part of the thesis has been submitted for any other Degree or Diploma.

The assistance and help received during the course of this investigation have been duly acknowledged.

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Dated : / /2021

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Place : MPKV, Rahuri

Date : / /2021

(A. T. Gedam)

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LIST OF ABBREVIATIONS

%	: Percent
&	: And
@	: At the rate of
□	: Similarly
<	: Less than
>	: Greater than
CD	: Critical Difference
CEC	: Cation exchange capacity
cm	: Centimeter
cm hr ⁻¹	: Centimeter per hour
cmole (p ⁺) kg ⁻¹	: Centimol positive charge per kg of soil
DAS	: Days After Sowing
dS m ⁻¹	: 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
g	: gram
GR	: Gypsum requirement
ha	: Hectare
hr	: Hours
i.e.	: Id est (That is)
J.	: Journal
Kg	: Kilogram(s)
Kg ha ⁻¹	: Kilogram (s) per hectare
m	: Meter
M	: Molar
Meq L ⁻¹	: Miliequivalent per litre
Mg m ⁻³	: Milligram per meter cube
MOP	: Murate of potash

MT	: Million tonnes
No.	: Number
NS	: Non-significant
°C	: Degree celcius
pH	: Negative logarithm of hydrogen ion activity
pHs	: pH of soil saturated paste
ppm	: Parts per million
PVC	: Polyvinyl chloride
qha ⁻¹	: Quintal per hectare
RBD	: Randomized block design
RDF	: Recommended dose of fertilizer
S.E	: Standard error
SAR	: Sodium absorption ratio
SSD	: Subsurface drainage
SSP	: Single super phosphate
<i>Viz.</i>	: Videlicent (namely)

ABSTRACT

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Research Guide : Dr. S.R. Shelke
Department : Soil Science and Agricultural Chemistry

The present investigation was undertaken to study the effect of amendment sources to reclaim the sodic soil under subsurface drainage system on yield and nutrient uptake of maize on soil classified as a fine montmorillonite hyperthermic family of Sodic *Calciustert*. The field experiment was conducted at Post Graduate Institute, Research Farm, Department of Soil Science and Agril. Chemistry, M.P.K.V., Rahuri, during *Kharif* 2019. Experimental soil showed strongly alkaline reaction, normal electrical conductivity, medium organic carbon content and moderately calcareous. Soil fertility was low in available nitrogen, low in available phosphorous and very high in available potassium content with deficient in available Zn and sufficient in available Fe, Mn and Cu.

The experiment was laid out in a randomized block design with three replication and twelve treatments. The treatment comprised of T₁: Absolute control, T₂: Gypsum as per 100% GR, T₃: Elemental sulphur as per 1/5th of GR, T₄: Zeolite @ 600 kg ha⁻¹, T₅: Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹, T₆: Gypsum as per 50% GR + zeolite @ 600 kg ha⁻¹, T₇: Gypsum as per 100% GR + zeolite @ 300 kg ha⁻¹, T₈: Gypsum as per 50% GR + zeolite @ 300 kg ha⁻¹, T₉: Elemental sulphur as per 1/5th of GR + zeolite @ 600 kg ha⁻¹, T₁₀: Elemental sulphur as per 50% of 1/5th GR + zeolite @ 600 kg ha⁻¹, T₁₁: Elemental sulphur as per 1/5th of GR + zeolite @ 300 kg ha⁻¹ and T₁₂: Elemental sulphur as per 50% of 1/5th GR + zeolite @ 300 kg ha⁻¹.

The results of investigation revealed that, the amendments applications in sodic soil under SSD system was influenced the soil physical and chemical characteristics. Significant results were found in reclamation of sodic soil, yield of maize and nutrient uptake.

The physical properties of soil i.e. hydraulic conductivity and bulk density of sodic soil in SSD field was significantly improved by treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ at harvest of maize.

ESP and exchangeable cations i.e. Ca²⁺, Na⁺ and K⁺ content of sodic soils in SSD field after harvest of maize was significantly influenced by treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ except exchangeable Mg²⁺ which shows non-significant effect.

Soil organic carbon, calcium carbonate and cation exchange capacity of sodic soils in SSD field are influenced by the inorganic amendments after harvest of maize. The organic carbon content of sodic soils in SSD field was significantly higher in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹, the Elemental sulphur as per 1/5th of GR + zeolite @ 600 kg ha⁻¹

was found significantly lower values of CaCO_3 and the cation exchange capacity was significantly increased by the Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹.

The SAR, pHs, ECe, cations (Ca^{2+} , Mg^{2+} , Na^+ and K^+) and anions i.e. bicarbonate and chloride in saturation paste extract of sodic soil in SSD system was significantly influenced by treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ after harvest of maize. Whereas, sulphate content was non-significant and carbonates was in trace amount.

The result in respect of soil available nutrients and micronutrients as significantly influenced by treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ in SSD field at harvest of maize.

The biomass production in maize crop grown on sodic soils under SSD field in terms of their fresh and dry matter yield mainly depends on uptake of nutrient and micronutrient by maize crop. Total uptake of nitrogen, phosphorus and potassium by maize crop were found to be higher (132.77, 27.14 and 134.46 kg ha⁻¹, respectively) in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹. Total uptake of iron, zinc, manganese and copper were found to be significantly higher (2034, 1134, 1443 and 805 g ha⁻¹, respectively) in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹. The grain and stover yield of maize was significantly highest recorded in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ (53.8 and 62.44 q ha⁻¹).

In order to study the leaching behaviour of sodic soil in SSD field with application of different amendments. The application of Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ showed significantly maximum leaching of sodium and soluble salt that leached down and removed by SSD system installed at field.

Therefore, based on above findings, application of Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ along with the FYM and general recommended dose of nutrients (10 t ha⁻¹ FYM + 120:60:40, N:P₂O₅:K₂O kg ha⁻¹) to maize in SSD field was found beneficial for reclamation of sodic soil, increase in availability of nutrients in soil, total uptake of macro and micronutrients and higher grain and stover yield of maize grown in sodic soil under SSD system.

1. INTRODUCTION

In India, agriculture is a backbone of its economy in food production and employment point of view, 54.6% of the total workforce is engaged in agricultural and allied sector activities and accounts for 17.1% of the country's Gross Value Added (GVA) for the year 2017-18 at current price (Annual Report 2018-19). India is self-sufficient in food production mainly due to better crop productivity from the irrigated crops. However, no one has concentrated on the ill effects of irrigation. Due to improper drainage facilities in irrigated command areas, water table has increased drastically, in addition, high evaporation and low precipitation leads to accumulation of more salts on the soil surface, which leads to salinity and alkalinity in these command areas. Because of this fertile soils have become barren leading to low crop yields there by reducing the economic development of the farmer's. However, if these salts are in excess, the growth, yield and quality of most crops is adversely affected.

In India, salt affected soils currently constitute 6.74 million ha in different agro-ecological regions, the area is likely to increase to 16.2 million ha by Vision 2050 (CSSIR, 2015). Sodic soils cover >50% (3.77 M ha) of the total salt-affected area (6.74 M ha) of India, and in Maharashtra 0.42 M ha of the total salt-affected area (0.60 M ha). According to one estimate (Mandal *et al.*, 2010) an area of 6.74 M ha in India suffers from salt accumulation out of which 3.78 M ha (~56 per cent) are sodic while, 2.96 M ha (44 Per cent) are saline soils and in Maharashtra total area under salt affected soil is 0.60 M ha out of which saline soil contain 0.18 M ha and sodic soil having 0.42 M ha. In Maharashtra highest sodicity affected area is in Ahmednagar district (26,500,0 ha) followed by Nashik (40,000 ha), Aurangabad (31,000 ha), Pune (26,000 ha) and Solapur (20,000 ha) Singh *et al.*, (2010). After green revolution major emphasis was given on four elements of agriculture namely, improved quality seeds, fertilizers, pesticides and irrigation. The role of irrigation can be judged from the fact that, except in rare and limited areas, there has been no green revolution in India on un-irrigated land. As a result area under major and minor irrigation increased from 9.70 million ha during pre-plan to 42.77 million ha at the end of ninth plan. Area under minor irrigation also increased from 12.90 million ha in pre-plan period to 67.32 million ha at the end of annual plan 2000-01 (Chahar and Vadodaria, 2008). Due to excess irrigation most of the area under irrigation is affected by the problem of soil salinity; and it became a major limiting factor for agricultural crop production (Kapourchal *et al.*, 2013).

Sodic soils are those which have an exchangeable sodium percentage (ESP) of more than 15, pHs values will be more than > 8.5, and ECe will be < 4 dSm⁻¹. Excess exchangeable sodium has an adverse effect on the physical and nutritional properties of the soil (Richards, 1968) with consequent reduction in crop growth, significantly or entirely. Contrary to the saline soils having

excessive levels of chlorides and sulphates of Na^+ , Ca^{2+} , and Mg^{2+} , sodic soils contain high amounts of CO_3^{2-} and HCO_3^- salts (Sharma *et al.*, 2016b). Soil sodicity is characterized by high pH, high water soluble and exchangeable sodium, low biological activity, poor physical properties and deficiency of many essential nutrients. Exchangeable sodium and pH decrease soil permeability, available water capacity and infiltration rates through swelling and dispersion of clays as well as slaking of soil aggregates (Lauchli and Epstein, 1990). The increase in exchangeable sodium percentage (ESP) adversely affects soil physical properties, including infiltration and aeration. In the early stages of sodic irrigation, large amounts of divalent cations are released into the soil solution from exchange sites. In a monsoonal climate, alternating irrigation with sodic water and rainwater induces cycles of precipitation and dissolution of salts. Several field observations have shown that, although steady-state conditions are never reached in a monsoonal climate, a quasi-stable salt balance is reached within 4-5 years of sustained sodic irrigation, while a further rise in pH and ESP is very low (Minhas and Tyagi, 1998).

Basically, reclamation or improvement of sodic soils requires the removal of part or most of the exchangeable sodium and its replacement by the more favourable calcium ions in the root zone (Tanji and Deveral, 1985). For reasonably quick results cropping must be preceded by the application of soil amendments gypsum, followed by leaching for removal of salts derived from the reaction of the amendment with the sodic soil, that leachate are drain out by installation of subsurface drainage system in soil (Goel and Tiwari, 2015). In contrast to leaching of saline soils, reclamation of saline-sodic and sodic soils requires consideration of chemical factors as well as water flow. The traditional approach has been to calculate the amendment requirement based on the amount of Ca needed to reduce the exchangeable sodium percentage (ESP) in the soil to a specific level, typically to below 10 (US Salinity Laboratory Staff, 1954). Several products have been used as soil amendments for reclamation and improvement of saline and alkaline soils such as CaCl_2 , H_2SO_4 and CaSO_4 and elemental sulphur (S) (Hilal and Abd-Elfattah, 1987). In chemical reclamation strategies include application of elemental sulphur or sulfuric acid, which solubilize native calcite and provide the required Ca^{2+} to offset Na^+ on the exchange sites (Amezqueta *et al.*, 2005). Zeolites are crystalline, hydrated aluminosilicate of alkali and alkaline earth cations possessing an infinite, open three-dimensional structure. Zeolite has a sheet-like organization where each sheet contains open rings that bind together (from sheet to sheet) to form channels. The cationic exchange capacity (CEC) of natural zeolites ranges from 2 to 4 meq g^{-1} , The natural zeolite has the ability, by ion exchange, to take those salts present in sodic soils (Noori *et al.*, 2007). Based on their high ion-exchange capacity and water retention, zeolites have been used extensively in Japan and Taiwan as amendments for soils (Hsu *et al.*, 1967).

In improvement of salt affected soils drainage plays an important role. Among the different types of drainages open drains and sub-surface drains are important. In open drains nearly 10-12 per cent cultivated land is wasted and in addition maintenance is required for removal of silt quite often, otherwise they will not be effective. Subsurface drainage is considered as a most suitable approach for groundwater balance and land and water management practices containing the groundwater table at a suitable level (Luthin 1978; Gates and Grismer, 1989). In recent years corrugated and perforated plastic pipes are used for sub surface drainage. These pipes will perform efficiently for several years there by helps in improving the fertility status of the soil which in turn improve the crop productivity. Hence, a study is taken at subsurface drains installed area to see the changes in water logged and salt affected soils, amount of salts removed and changes in the crop yield and nutrient uptake. If sodium is present, amendments like gypsum, Elemental sulphur and zeolite (Ramesh *et al.*, 2011) should be used to leach out sodium to desired level from the exchange sites to reclaim the salt affected soils (Kuligod *et al.*, 2002).

A subsurface drainage system consists of an underground network of corrugated perforated lateral and collector drain pipes wrapped with synthetic filters installed at designed depth and spacing below the ground surface to remove excess water and salts from the affected fields. The outlets are either pumped outlet comprising of a small pumping station or gravity outlet. The pipes slope towards the outlet or the collector which remove excess water and salts from the fields (Bundela *et al.*, 2016). If the natural drainage is insufficient to wash excess water and salts away from an area without raising the ground water table. It may be necessary to install an artificial drainage system for leaching of excess salts. Drainage system may be surface and sub-surface. Surface drainage is draining off excessive surface ponding where sub-surface is lowering the root zone accumulation and the water table. Out of various methods of drainage systems sub-surface drainage system will be most effective. Sub-surface drainage performed by fixing perforated PVC or clay tiles underground in a grade and draining an accumulated salt along with water to common outlet and then out of the field (Padalkar *et al.*, 2012). Manjari drainage scheme in Maharashtra state is located in Khadakwasala irrigation project near Pune, in the command of distributory No. 5 and 6 of old Mutha right bank canal. The drainage scheme for 30 ha was designed for reclamation of waterlogged black cotton soils of Mahatma Phule Krishi Vidyapeeth Rahuri 1981. The main causes of waterlogging were seepage from Mula right bank canal, excess irrigation on the upper part of field and percolation tank on the upper boundary of the field. In India about 66,084 ha area has been reclaimed using SSD. Out of 66,084 ha, 26,500 ha area is in Karnataka, 6,500 ha area is in Maharashtra, 1,300 ha area in Gujarat and 950 ha in Madhya Pradesh and 500 ha area in Andhrapradesh and Telangana. To go for drainage installation, a drainage planning is very much essential (Chinchmalatpure and Vibhute, 2017).

Maize is medium salt tolerant crops, leafy stalk whose kernels have seeds inside. Maize belongs to the tribe *Maydeae* of the grass family *Poaceae*. “*Zea*” was derived from an old Greek name for a food grass. The genus *Zea* consists of four species of which *Zea mays* L. is economically important. The other *Zea sp.*, referred to as teosinte, is largely wild grass native to Mexico and Central America. The number of chromosomes in *Zea mays* is $2n = 20$.

Maize is called the ‘Queen of Cereals’, also known as corn, is a cereal grain that was first grown by people in Central America. It is now the third most important cereal crop in the world. Maize is cultivated globally being one of the most important cereal crops worldwide. Globally, it is cultivated on nearly 150 m ha in about 160 countries having wider diversity of soil, climate, biodiversity and management practices that contributes 36 per cent (782 MT) in the global grain production. The United States of America (USA) is the largest producer of maize contributes nearly 35 per cent of the total production in the world and maize is the driver of the US economy. The USA has the highest productivity ($> 9.6 \text{ t ha}^{-1}$) which is double than the global average (4.92 t ha^{-1}). Whereas, the average productivity in India is 2.43 t ha^{-1} (Murdia *et al.*, 2016)

In India maize containing area, production and yield in 2016-17 is 9.63 million hectare, 25.90 million tonnes and 2689 kg ha^{-1} respectively. In Maharashtra maize containing area, production and yield in 2016-17 is 1.15 million hectare, 3.45 million tonnes and 3009 kg ha^{-1} respectively. (Anonymous, 2019). India produces about 2% the world’s maize produce. Karnataka is the leading producer of maize in India producing around 16% of India’s total Maize production. Karnataka is followed by Telangana & Bihar which together contribute 20% to India’s maize production basket. Maharashtra, Madhya Pradesh, Tamil Nadu, Andhra Pradesh, Rajasthan and Uttar Pradesh are other maize producing states of India (Kumar *et al.*, 2014). About 71% of maize in India is produced in the *Kharif* season. Karnataka, Madhya Pradesh, Tamil Nadu, Maharashtra, Telangana, UP & Rajasthan produce *Kharif* Maize, with Karnataka being the leader. Bihar, Andhra Pradesh & Tamil Nadu are states which produce *rabi* maize crop. *Rabi* is the primary crop of Bihar and Andhra Pradesh. Tamil Nadu produces 40% crop in *rabi*.

In addition to staple food for human being and quality feed for poultry and animals, it serves as a basic raw material for the industry for production of starch for textile, pharmaceutical, cosmetic industries, high quality corn oil, protein, alcoholic beverages, food sweeteners etc. The current maize utilization pattern in India shows that for food only 24%, for poultry, livestock, fish, pig, mithun, goats *etc.* 63%, for starch and brewery 12%, and for seed 1% are utilized. Feed requirement of maize by the various sectors in the world is at par with India but, higher percentage (22%) of its industrial use in the world is due to bio-fuel extraction

in USA. It is also grown as several other types *viz.* quality protein maize (QPM), sweet corn, baby corn, popcorn, waxy corn, high oil corn etc (Kumar *et al.*, 2013).

In view of the above considerations, the present research work on “Effect of amendment sources to reclaim the sodic soil under subsurface drainage system on yield and nutrient uptake of maize”, planned and field experiment was conducted during *kharif* 2019 at Post Graduate Institute Research Farm, M.P.K.V., Rahuri with following objectives,

1. To study the effects of amendment sources and their combination on reclamation of sodic soils under subsurface drainage system.
2. To study the effects of amendment sources under subsurface drainage system on yield and nutrient uptake of maize.

2. REVIEW OF LITERATURE

The literature on effect of subsurface drainage system and different sources of amendments on reclamation of sodic soil, nutrient uptake and yield of crop has been reviewed under appropriate headings in this chapter.

- 2.1 Characteristics of sodic soil
- 2.2 Effect of subsurface drainage system on salt affected soil and yield of crop
 - 2.2.1 Effect of subsurface drainage system on salt affected soil
 - 2.2.2 Effect of subsurface drainage system on yield of crop
- 2.3 Effect of application of different sources of amendments (Gypsum, Elemental sulfur and Zeolite) on salt affected soil and yield of crop
 - 2.3.1 Effect of Gypsum
 - 2.3.2 Effect of Elemental Sulfur
 - 2.3.3 Effect of Zeolite

2.1 Characteristics of Sodic Soil

According to Richards (1968) sodic soils characterized as ESP > 15 and dominated with carbonate and bicarbonate salts of sodium and lack of neutral salts. E_c of soil were < 4 dSm⁻¹, pHe > 8.5. The dark colour of sodic soil was due to dispersion of clay and dissolution and coating of organic matter. Generally surface of these soil were dry and hard at field condition.

Joshi and Jha (1992) studied soil alkalinity and waterlogging in Sharada Sahayak Irrigation Project. Results on productivity and profitability of crop production indicated that yields of paddy and wheat declined 50 per cent in about eight year times due to increasing soil degradation. Paddy and wheat yields went down by more than 51 per cent and 56 percent, respectively. Net income of HYV paddy declined by 54 per cent in waterlogged and 87 per cent in saline soils.

Durgude (1999) carried out high intensity detailed soil survey to characterized salt affected soils of Central Campus Farm, MPKV, Rahuri and revealed that 8.6 (120.76 ha) percent soils of potential cultivated area are sodic and pHs of sodic soil ranged from 8.50 to 8.90, EC from 0.46 to 2.45 dsm⁻¹ and ESP varied from 15.0 to 24.8 and high bulk density with poor physical conditions.

Somwanshi *et al.* (1999) reported that GR of the soils in Sangamner area is found to be high. This is possibly due to high order of K and Mg present in the soils. This is because GR does not distinguish between exchangeable sodium percentage of the soils from the area (Deshmukh, 2012).

Sagare *et al.* (2001) reported that, the lower extent of increase in hydraulic conductivity of sodic *Vertisols* from 0.41 to 1.05 cm h⁻¹ due to gypsum @ 100 per cent gypsum requirement.

They also reported that, highest increase in hydraulic conductivity was observed due to combined use of gypsum and press mud.

Sen (2003) reported that the distinguishing characteristics of sodic soils are high exchangeable sodium per cent ($ESP > 15$), $E_{c_e} < 4 \text{ dSm}^{-1}$, $pH > 8.2$ and presence of higher amount of carbonates and bicarbonates of Na^+ . Due to high ESP, sodic soil possess poor physical and chemical properties. The high exchangeable 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 CO_3^{2-} and 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.

Bhalerao and Pharande (2003) reported the chemical properties of soils of Central Research Farm, MPKV, Rahuri. The pHs was strongly alkaline (8.5) in sodic soil. The EC was lowest in sodic soil (1.1 dSm^{-1}). However ESP was higher in sodic soil.

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 ($E_{c_e} 0.6$ to 2.66 dS m^{-1}). Cationic concentration showed decreasing trend in order of $\text{SO}_4^{2-} > \text{Cl}^- > \text{HCO}_3^- > \text{CO}_3^{2-}$.

Kharche *et al.* (2004) studied the soils of Mula canal command area Minor no. 3 at Umbre, Sade and Kukudhwedhe village and reported the area under salt affected soils was sodic was to the tune of 65 percent out of which 36 percent area was sodic and 29 percent saline sodic. The sodic soil had pHs ranging from 8.5 to 9.3, E_{c_e} from 1.02 to 2.65 dsm^{-1} and ESP from 15.0 to 23.1.

Kharche and Pharande (2010) reported that, the particle size distribution majority of the soils had fairly high amount of clay. The clay content in different horizons varied from 36.2 to 57.2 per cent. Basalt, being the parent material of these soils is known to produce higher amount of clay. The bulk density of surface soils varied from 1.32 to 1.65 Mg m^{-3} due to relatively higher amount of organic matter and plant root concentration. Increase in bulk density with depth in these swell-shrink soils are attributed to the high content of expanding type of clay minerals present and the over-burden pressure causing compaction in the sub-surface horizons.

Deshmukh (2012) understand the chemical characteristics of the soils pH of the soils ranges from 8 to 9.7 reflecting alkaline nature. The EC values ranges from 0.1 to 46.8 dsm^{-1} . Higher Concentration of CaCO_3 content in the soils varies from 5.2 to 20.2%. Higher concentration among the soluble cations, higher concentration of Na^+ followed by Ca^{2+} and Mg^{2+} indicating the alkalization process in the shrink-swell types of soils. As far as anions are considered chloride is predominant followed by sulphate and bicarbonate in the soils.

Wang *et al.* (2012) studied the typical characteristics of sodic soil, that is high pH (9.15) and exchangeable sodium percentage (42.85%), low hydraulic conductivity (2.51×10^{-5} cm min⁻¹), EC is less than 4 (2.15) and Bulk density is 1.48 g cm⁻³.

Somani (2013) reported that, excessive sodicity, high pH and poor physical condition are chief factors responsible to sodic soils.

Deshmukh (2014) reported the sodic soils have low to very low content of nitrogen and phosphorus and high to very high content of available potassium.

Sharma *et al.* (2016a) observed that, sodic soils are characterized by variable electrical conductivity of soil saturation paste (ECe mostly <4 dS m⁻¹), high pHs (>8.2) and high exchangeable sodium percentage (ESP) (>15). Contrary to the saline soils having excessive levels of chlorides and sulphates of Na⁺, Ca²⁺ and Mg²⁺, sodic soils contain high amounts of CO₃²⁻ and HCO₃⁻ salts.

Ashim *et al.* (2017) reported that, soil pH_{1:2} ranged from 9.12 to 10.4 the highest and lowest were observed at 140-160 and 0-20 cm soil depth, respectively. Soil pHs of saturation paste varied between 8.54 to 9.64, the highest (9.64) and lowest (8.54) pHs were observed at 160-180 and 0-20 cm soil depth, respectively. The highest EC 1:2 (2.74 dS m⁻¹) and ECe (3.05 dS m⁻¹) were observed at 120-140 and 0-20 cm soil depth, respectively. With depth increment, sodium adsorption ratio (SAR_e) increased significantly and the highest (40.8) was observed at 180-200 cm soil depth. The lowest SAR_e (14.52) was observed at 0-20 cm soil depth. This finding claimed an increment of alkalinity along depth.

2.2 Effect of Subsurface Drainage System on Salt Affected Soil and Yield of Crop

2.2.1 Effect of Subsurface Drainage System on Salt Affected Soil

Doddamani *et al.* (1995) conducted an experiment to study the effect of sub-surface drainage and gypsum application on physico-chemical condition of a sodic vertisol. It was observed that decrease in soluble cations and anions and reduced in pH.

Supekar *et al.* (2000) conducted an experiment to know the response of salt affected soil for drainage system and gypsum application. They observed that the decreased in soil pH (from 8.90 to 8.10) and ESP, where the treatment had sub-surface drains installed at 15 m apart with gypsum application about half of the gypsum requirement.

Thatte and Kulkarni (2000) reported that the subsurface drainage has been found to be the only solution for providing land reclamation on a long-term basis when salts are present in the soil and groundwater. Comprehensive reclamation programs involving provision of subsurface drainage in irrigated areas have been embarked in a big way in Pakistan over the past 50 years, while these started much earlier in India during late 1920s.

Bharambe *et al.* (2001) observed that the pH of the salt affected soil was 8.26 and it was reduced to 8.22, 8.23 and 8.24 for the 25, 50 and 75 m spaced sub-surface drainage system

respectively. They studied the management of salt affected *Vertisols* with subsurface drainage and crop residue incorporation under soybean-wheat cropping system on sodic *Vertisols* and revealed that the salinity (ECe) and sodicity (ESP) of soil reduced considerably below critical limit of salinity hazards with incorporation of crop residue such as sugarcane trash @ 5 t ha⁻¹ or green manuring with dhaincha over period of four years.

Srinivasulu *et al.* (2005) studied the impact of sub surface drainage system in combating problems of waterlogging and salinity in Nagarjuna Sagar Project Right Canal Command. Subsurface pipe drain was installed in eight ha area at Konanki village in farmers' fields with drain spacing of 30 and 60 meter. The initial water table depth before drainage ranged between 0 and 3.75 meter with salinity levels ranging between 1.3 and 18.6 dsm⁻¹. The results revealed that the drainage system was functioning effectively by discharging drain water at a higher rate which contributed in lowering the water table by 0.2 to 0.35 meter.

Datta *et al.* (2004) studied the average electrical conductivity levels in subsurface drainage project and control area during rabi of 1999-2000 were 4.6 and 9.2 dsm⁻¹, respectively whereas the average electrical conductivity of the (control) undrained area during rabi season of 1995-96 was 7.1 dsm⁻¹, indicating a decrease in salt content of 35 percent after subsurface drainage. Block-wise drainage area also showed a similar picture. In some of the subsurface drainage blocks, the decrease in soil electrical conductivity ranged from 9.7 to 66.3 per cent. On the other hand, the electrical conductivity level in the undrained area increased from 9.0 dsm⁻¹ (1995-96) to 9.2 dsm⁻¹ (1999-2000), indicating an increase of 2.2 per cent within two years.

Tewari *et al.* (2004) reported that the Indian Council of Agricultural Research has given priority to control and manage salinity problems that have developed in north-west India. Multi-disciplinary taskforces have recommended installation of subsurface drainage for salinity control, based on design and management techniques developed by the Central Soil Salinity Research Institute (CSSRI), to rehabilitate lands with excess soil salinity. After small-scale studies, large-scale pilot projects were launched to install subsurface drainage in problem areas.

Kamble *et al.* (2006) studied pH, ECe, SAR and ESP of soil in SSD with synthetic envelope, coarse sand filter and synthetic envelope+coarse sand filter were decreased in monsoon and winter season but slightly increased during the summer season. This indicates the improvement in salt affected soils due to subsurface drainage and gypsum application within a period of one year.

Kulkarni (2007) studied that, irrigation induced land degradation and its reclamation in upper krishna project command area and reported that the average affected area to the total holding increased substantially. Only 15 per cent of the farmers had less than 0.80 hectare area affected, whereas, 57.78 per cent of the farmers had affected area ranging between 0.80 ha and 2.40 ha. Farmers perceived that inadequate natural drains, irrigation return flow and seepage

losses, flooding methods of irrigation, growing of paddy in the upstream areas were some of the prime factors inducing degradation. Soil degradation due to water logging and soil salinity led to shifting resources to other fertile lands possessed by the farmers.

Babu *et al.* (2008) studied adoption of Sub surface drainage technology is probably one of the best ways to increase resource use efficiency in order to increase crop production and sustain natural resources like soil and water in severely water logged saline soils. So there is a great demand for the research and developmental efforts to reclaim all the salt affected and water logged soils by providing drainage and bring them back to non-saline productive soils. Soil, land and water are essential resources for the sustained quality of human life and foundation of agricultural development.

Chahar and Vadodaria (2008) studied, the drainage maintains the productive capacity of soil by removing excess water, improving the soil moisture, improving the air circulation and reducing salt content and erosion.

Ritzema and Schultz (2011) reported that the subsurface drainage technology has proved to be a technically feasible and cost-effective tool to combat the twin problems of waterlogging and soil salinity.

Azhar and Latif (2011) analysed the crop yield data revealed that the objectives of drainage systems installation have been achieved in terms of improving the crop yields at all four study sites. Subsurface drainage water quality of different drainage projects should also be investigated because shallow water quality plays an important role in crop production and physiochemical properties of the soils.

Padalkar *et al.* (2012) reported the sub-surface drainage can be one of the most effective treatments for reclamation of saline soil if the water used for drainage purpose is of good quality. In the experiment sub surface drainage treatment carried out in salt affected area along with the water and soil analysis, it is observed that the treatment is quite effective and it shows satisfactory results. Leaching of salts in the form of ions is good to reduce soil salinity.

Shao *et al.* (2012) explained a well-designed subsurface drainage system with reasonable drain space and depth contributes to large ratio of desalination and high crop yield.

Bundela *et al.* (2016) reported that the subsurface drainage is a technically and financial viable technology for reclaiming waterlogged saline lands in the country. The SSD cost varies considerably from north-western states to southern states based on soil texture, drain depth and spacing, and outlet conditions in different agro-climatic, water table, soil salinity and soil texture and outlet regimes.

Chinchmalatpure and Vibhute (2017) concluded that the black cotton soils (Vertisols) are heavy textured soils with low permeability and are more prone to waterlogging and soil salinity

if irrigated without proper drainage. These soils can be reclaimed by installing subsurface drainage system with proper design specifications.

Birru *et al.* (2019) showed that the chemical amendments were not effective at promoting Na^+ leaching and ability to wash the salts out of the soil profile was reduced by bypass flow, A common restoration treatment for saline-sodic soils involves improving soil drainage, applying soil amendments (e.g., CaSO_4 , CaCl_2 , or elemental S) and leaching with water that has a relatively low electrical conductivity.

2.2.2 Effect of Subsurface Drainage System on Yield of Crop

Sharma *et al.* (1991) conducted, the study to evaluate the effect of three subsurface drain spacing (25, 50 and 75m) on soil salinity, cotton growth and yield behaviour in a sandy loam saline soil. Increasing sub-surface drain spacing (25, 50 and 75m) decreased many of the plant characteristics and seed cotton yield. Root penetrated upto 95 cm depth in the 25 m drain spacing but the high salinity at low depth in 75 m drain spacing restricted the root penetration only to 60 cm depth. Mansoon rains decreased the soil salinity appreciably but decrease was more in 25 m drain spacing than in 50 and 75 m drain spacing.

Sharma *et al.* (1992) founded the decrease in soil salinity more in 25 m drain spacing than in 75 m spacing, Grain and straw decreased with increasing drain spacing. Grain yield was higher near the drains and decreased as the distanced from the drains increased.

Datta *et al.* (2004) concluded that, monitoring of soil and crop improvement in a drainage area provides a convenient way for impact assessment of subsurface drainage system in waterlogged saline lands. To assess the impact of subsurface drainage system on soil and crop, the samples of soil and crop were collected from several locations after the harvesting of rabi crops using the grid pattern.

Ritzema *et al.* (2007) monitored the programmes, which continued 2 or 3 years after the installation of the subsurface drainage systems, clearly show that the installation of subsurface drainage systems resulted in higher crop yields although there were differences between the various areas. Overall, the yield increased from 2.5 to 4.3 t ha⁻¹ for rice, from 0.7 to 1.2 t ha⁻¹ for cotton, from 66 to 101 t ha⁻¹ for sugarcane and from 1.4 to 2.8 t ha⁻¹ for wheat. To assess how much of the increase in yield can be attributed to drainage, yields from fields with different drain depth/spacing combinations were compared with non-drained (control) areas. The yield increases in the drained fields were significantly higher than the increases in the non-drained fields. These higher crops yields are the result of the two direct effects of drainage, i.e. in the deeper and the soil salinity decreased with 50%.

Kolekar *et al.* (2011) studied the provision of subsurface drainage system in waterlogged saline-alkali soil increased the germination percentage, plant height, leaf length, leaf width and leaf area index of maize crop, due to removal of a large amount of soluble salts, waterlogging

free condition and increased nutrient availability in drained field, favored the plant growth and development.

Goel and Tiwari (2015) reported that impact of subsurface drainage project studies on salinity management in developing countries. Discussed the old to current state of art in subsurface drainage system, positive effects of drainage on crop production and also what the future hold for this technical approach. Decide the drain depth, spacing, types of subsurface drainage and type of outlets.

Kamra and Sharma (2015) discussed about Sub Surface Drainage in Haryana and Maharashtra, This technology in different states has resulted in about 40% improvement in cropping intensity and yields of different crops resulting in 3 fold increase in farmers' income. It has been implemented in about 10,000 ha in Haryana and about 3,500 ha in Maharashtra as a major activity under RKVY and other development schemes. The design features and outfall conditions, implementation agencies, drainage machinery and socio-economic impacts and dimensions of SSD projects, quite different in Haryana and Maharashtra.

Patil *et al.* (2016) reported that the impact of subsurface drainage system on soil chemical properties and crop yield in upper krishna command. ESP was observed to be reduced in smaller amount as compared to pre sowing conditions, as the soil was found to be sodic in nature, there is need of application of gypsum in requires amount in order to turn the soil from sodicity to saline or non-saline soils. The crop yield was observed to be increased by 51.21 per cent as compare to pre drainage conditions.

Talukolae *et al.* (2016) studied the subsurface drainage improves the productivity of poorly-drained soils by lowering the water table, creating a deeper aerobic zone, enabling faster soil drying and improving the root zone soil layer condition to activate functions of pants roots.

Basavaraja *et al.* (2016) studied the installation of sub surface drainage in water logged/saline/alkali soils and application of gypsum in alkali soils based on the soil test and stagnating with good quality water to leach out salts and application of sufficient quantity of organic manures and required quantity of NPK nutrients will helps to get better yield of crop in problematic soils.

Arumugam *et al.* (2019) concluded that provision of the subsurface drainage system, readily leach the soluble salts from the soil layer through drainage water, which is a limiting factor for proper growth and development of plants in salt-affected soil. The overall improvement in the soil physicochemical condition, increase in germination percentage, plant height, leaf length, leaf width and leaf area index of maize crop was observed, due to removal of a large amount of soluble salts, waterlogging free condition and increased nutrient availability in drained field, which favored the plant growth and development.

2.3 Effect of Application of Different Sources of Amendments (Gypsum, Elemental Sulfur and Zeolite) on Salt Affected Soil and Yield of Crop

2.3.1 Effect of Gypsum

Richards (1954) studied the reclamation of sodic soils involves the replacement of exchangeable sodium with a favourable cation like calcium. Calcium can be supplied through the addition of amendments containing calcium such as gypsum or through the release of native calcium by the addition of acid formers to a calcareous alkali soils.

Sharma *et al.* (2001) reported that gypsum and organic amendments application were most effective in removing CO_3^{2-} and HCO_3^- , respectively. The significant reduction in bicarbonate in soluble phase due to sesbania leaves (*dhaincha*) and gypsum application has been reported. As regards to Cl^- and SO_4^{2-} they are also reduced significantly due to organic matter incorporation and gypsum application. This may be due to increasing leachability of soluble and exchangeable Na^+ throughout the soil profile.

Suarez (2001) studied the reclamation of sodic soils has traditionally been undertaken using calculation of gypsum or Ca requirement assuming 100% exchange efficiency and neglect of the contribution of calcium carbonate in the profile. The UNSATCHEM model is reviewed and then evaluated for its ability to predict field reclamation of a sodic saline soil.

Rathod *et al.* (2003) conducted experiment on efficiency of gypsum in reclaiming sodic Vertisol when used in association with FYM followed by irrigation with alkali water. They concluded that, integration of gypsum and FYM with NPK reduced deleterious effect of alkaline water applied to sodic Vertisols and there was decrease in sodicity of soil.

Hanay *et al.* (2004) and Wong *et al.* (2009) showed the 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 effects of high sodium content in soil due to it is high solubility and low cost.

Makoi *et al.* (2007) reported that the incorporation of FYM (25 t ha^{-1}) with gypsum (12.5 t ha^{-1}) improved the pHs, ECe, ESP, infiltration rate, osmotic potential and available water capacity of sodic soils and increased the maize yield.

Kharche *et al.* (2010) studied integrated use of gypsum and organic amendments and bio-inoculant for reclamation of sodic swell-shrink soils of Mula command area and reported that integrated as well as combined use of gypsum and organic amendments increased soluble Ca^{2+} , Mg^{2+} and Na^+ concentration in saturation paste extract.

Singh *et al.* (2011) carried out extensive study on impact of sodic soil reclamation technology at Pallia, Haripura, Jugalpura and Banasthali of Newai panchayat samite of Tonk district on selected farmers field on sandy loam (sodic soil) and found that deep tillage coupled with the application of gypsum 50% GR with green manuring (*Dhaincha*) practice decreased pH value by 0.66 units, EC and ESP to 0.12 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 CaCO_3 . The calcium thus released displaced 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.

Ahmed *et al.* (2017) suggested that in salt affected soils, S @ 125 & 100% of SGR are as efficient as gypsum @ 100% of SGR, however, with respect to benefit cost ratio gypsum is the most economical amendment with second-best treatment of S @ 100% of SGR which could also be an effective, suitable but slightly expensive alternative amendment for improving the different qualities of salt affected soils and rice-wheat yield.

Muhammad *et al.* (2018) studied the effect of compost and gypsum on soil physical properties and concluded that, most effective treatment was gypsum @ 50 per cent gypsum requirement (GR) + compost @ 20 t ha⁻¹. The decrease in soil pH and SAR decreased soil dispersion, increase soil porosity and resultant net reduction in bulk density was recorded. Hydraulic conductivity was increased manifold during two years with a maximum of 0.878 cm hr⁻¹ when gypsum @ 50 per cent gypsum requirement (GR) + compost 20 t ha⁻¹ were applied in combination. It might be due to reduction in SAR which resultantly decrease soil dispersion and encouraged coagulation of soil particles.

2.3.2 Effect of Elemental Sulfur

Balbaa (1995) and Wei *et al.* (2006) studied the sulfur may also be added, which is microbiologically oxidized to sulfuric acid, which reacts with the native calcium carbonate to form gypsum.

Sing (1999) reported that the application of Sulphur increased the uptake of various macro and micro nutrients in groundnut. Sulphur had synergistic effect on the yield and nutrients uptake.

Schueneman (2001) reported that elemental sulfur as soil amendment is recommended when soil pH exceeds 6.6 for the purpose of reducing pH and changes in soil pH can mobilize nutrients from unavailable phases to available pools therefore increasing P and micronutrient availability.

Wei *et al.* (2006) and Rice *et al.*, (2006) studied the elemental sulfur as soil amendment is recommended when soil pH exceeds 6.6 for the purpose of reducing pH and changes in soil pH can mobilize nutrients from unavailable phases to available pools therefore increasing P and micronutrient availability.

Badr *et al.* (2002) conducted experiment of sulfur fertilization in salt affected soils has definite impact on plant establishment as it increased nutrient use efficiency N, P, K and Zn in the plant due to its synergistic effect as well as it improves K^+/Na^+ selectivity and helps Na^+ exclusion of plant roots exposed to saline conditions.

Mohamed *et al.* (2007) reported that the oxidation of elemental sulphur and producing sulphuric acid which dissolved the CaCO_3 and release Ca ions, thereby, enhancing the

replacement of Na^+ from the exchange site and improve soil structure, water movement and thus help to leach the salts more easily and effectively. Elemental sulphur was used in a series of field and laboratory experiments in different countries to study its effect as a source of this element for plant and as a soil amendment to improve chemical and physical properties of alkali and calcareous soils.

Kubenkulov *et al.* (2013) reported the effects of the application of various doses of elemental sulphur and duration of their incubation to the soda-saline soil recorded that, without application of sulphur (control) result over time to gradual decrease in concentration of ions of HCO_3^- and Na^+ , at without essential changes of concentration of other ions and the total of salts result to gradual decrease pH from 10.5 to 9.1.

Mutowal *et al.* (2013) showed that, sulphur significantly affected to the soil EC, pH and organic matter (OM) in both soil depths ($p < 0.01$), except the soil OM in 0-15 cm soil depth with $p < 0.05$. Increasing the doses of sulphur decreased the soil EC. The results indicated that, 6 t ha^{-1} sulphur dose significantly decreased EC (57.54% and 51.51%) and pH (4.67% and 2.83%) in (0-15) and (15-30) cm soil depth, respectively compared with the control. Organic matter (OM) of the soil increased (3.99% and 7.60%) in (0-15) and (15-30) cm soil depth.

Ahmed *et al.* (2017) studied varying levels of sulphur and gypsum @ 100 per cent soil gypsum requirement (SGR) considerably improved the soil chemical properties i.e. pHs, ECe, sodium adsorption ratio (SAR) and SO_4^- - S contents. Among all the treatments sulphur (S) @ 125 per cent of soil gypsum requirement (SGR) dropped pHs value by 6.94 per cent followed by gypsum @ 100 per cent SGR lowering pHs value by 6.84 per cent, whereas with control decreased in pHs was only 3.36 per cent of their respective initial values. Similarly, gypsum @ 100 per cent SGR appreciably lowered the ECe and sodium adsorption ratio (SAR) by 44.26 per cent and 48.64 per cent, respectively and sulphur @ 125 per cent of SGR and sulphur @ 100 per cent of SGR lowered the ECe and SAR by 44.59 per cent, 43.44 per cent and 49.60 per cent, 45.83 per cent, respectively. Maximum addition in soil sulphur contents (90.14 mg kg^{-1}) were noted in sulphur @ 125 per cent of SGR followed by sulphur @ 100 per cent of SGR (80.91 mg kg^{-1}) and gypsum @ 100 per cent SGR (76.25 mg kg^{-1}) whereas, in control (no amendment used) sulphur content decreased to (14.6 mg kg^{-1}).

2.3.3 Effect of Zeolite

Huang and Petrovic (1994) studied the zeolite contain large vacant spaces (cages) that can accommodate cations (Na^+ , K^+ , Ba^{2+} , Ca^{2+}), as well as large molecules and cation groups (H_2O , NH_4^+). The cations are mobile throughout the structure and play a charge balancing role with the AlO_4^- tetrahedral.

Polat *et al.* (2004) reported that the high ion-exchange and retention ability of zeolites as wells as their large adsorptive affinity for water has contributed to their successful applications in soil amendment.

Elliot and Zhang (2005) studied that, in zeolite charge balancing cations (Na^+ , K^+ , Ba^{2+} , Ca^{2+}) can be exchanged with other cations in aqueous solution, without affecting the aluminosilicate framework.

Noori *et al.* (2007) studied that there were statistically significant differences in yield obtained by using natural clinoptilolite (Natural Zeolite) which improved soil quality and increased quantification and quality of the crop. Clinoptilolite (NZ) adsorbs Na^+ and Cl^- which enter into the cavities and consequently NZ improves the soil properties. NZ improves crop “yields”, growth in poor, sandy and porous soils. The application of Natural Zeolite in *Raphanus sativus* cultivation seems to increase the final product by retention of salt and the inability to pass through the roots to the plants. In this study, it is clear that using Natural Zeolite in salinity soil increased growth and weight in plants, especially the aerial section by reduction of uptake of these salts.

Ramesh *et al.* (2011) studied the zeolite is also used as a nutrient in agriculture because of its ion exchange ability. More than 50 different kinds of this element have been identified, among which the natural zeolite of clinoptilolite is the most frequent. The conducted studies on this kind of zeolite have indicated effects of moderating soil and conserving nitrogen in soil, high exchange ability, increasing phosphorus uptake, increase yield and reducing pollution load of this element.

Majid *et al.* (2013a) founded that application of soil amendments such as zeolite with composted manure to improved soil properties such as soil cation exchange capacity.

Susana *et al.* (2015) studied the zeolite amendments in agriculture and 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 draught 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.

Latifah *et al.* (2016) carried out a pot study using maize (*Zea mays* L.) as a test crop was to determine the effects of amending inorganic fertilizers with compost and clinoptilolite zeolite on: (i) selected soil chemical properties, and (ii) N, P, and K uptake and use efficiency in maize cultivation. They found that amending inorganic fertilizers with compost and clinoptilolite zeolite increased soil total N, exchangeable Ca, Mg, K, and available P. Furthermore, P and K uptake and use efficiency of maize were significantly improved upon amending inorganic fertilizers with compost and clinoptilolite zeolite. Soil chemical properties and productivity of maize on acid soils can be improved through co-application of compost and clinoptilolite zeolite.

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.

3. MATERIAL AND METHODS

In order to study the “Effect of amendment sources to reclaim the sodic soil under subsurface drainage system on yield and nutrient uptake of maize” was conducted on PGI research farm, Department of Soil Science and Agricultural Chemistry, Mahatma Phule Krishi Vidyapeeth, Rahuri, during *kharif* 2019. The material used and methods adopted are discussed in this chapter.

3.1 Materials

3.1.1 Experimental Site and Location

The experiment was laid out during *kharif*, 2019, at Post Graduate Institute Research Farm of Department of Soil Science and Agricultural Chemistry, M.P.K.V., Rahuri, Dist. Ahmednagar, Maharashtra (India).

The location of the experimental farm lies between 19° 47' N to 19° 57' N latitude and 74° 18' E to 74° 19' E longitude. The elevation above mean sea level ranged from 435 to 495 m. The tract lies on the eastern side of western ghat and falls under scarcity zone.

3.1.2 Soils

Field experiment was conducted on salt affected soils in which sodic soils. The soil of the experimental site is classified as a fine montmorillonite hyperthermic family of Sodic *Calciustert*. The soil sample were collected and analyzed at the start of the experiment and presented in Table 3.1.

Textural class was clayey, bulk density of experimental soil was 1.58 Mg m⁻³ and hydraulic conductivity was slow (0.20 cm h⁻¹). The chemical properties of experimental soil showed strongly alkaline in reaction (pHs 8.48) with total soluble salts content (ECe) was 3.12 dSm⁻¹. The soil was medium in organic carbon content (0.49%) whereas calcium carbonate was 8.90 per cent. Soil fertility was low in available nitrogen (143.24 kg ha⁻¹), low in available phosphorous (9.15 kg ha⁻¹) and very high in available potassium (457.82 kg ha⁻¹) content. The initial soil micronutrients *viz.* Fe, Mn, Zn and Cu status were sufficient in range 4.53, 5.07, 0.42 and 2.58 mg kg⁻¹, respectively. The exchangeable Ca, Mg, Na and K were 35.80, 6.08, 8.75 and 0.98 c mol (p⁺) kg⁻¹, respectively. The exchangeable sodium percentage (ESP) and sodium adsorption ratio (SAR) of soil were 16.62 and 12.54, respectively. The cation exchange capacity (CEC) was 52.64 c mol (p⁺) kg⁻¹. In case of saturation paste extract, the analysed cations *viz.* Ca²⁺, Mg²⁺, K⁺ and Na⁺ were 3.15, 5.92, 0.18 and 26.70 me L⁻¹, respectively and anions *viz.* HCO³⁻, Cl⁻ and SO₄²⁻ were 16.35, 10.35 and 7.80 me L⁻¹, respectively.

Table 3.1 Initial soil properties of experimental site

Sr. No.	Parameters	Value
I.	Soil analysis	
1.	pH (1:2.5)	8.56
2.	EC (dSm ⁻¹)	1.23
3.	Organic carbon (%)	0.49
4.	Calcium carbonate (%)	8.90
5.	Available N (kg ha ⁻¹)	143.24
6.	Available P (kg ha ⁻¹)	9.15
7.	Available K (kg ha ⁻¹)	457.82
8.	Available Fe (mg kg ⁻¹)	4.53
9.	Available Zn (mg kg ⁻¹)	0.42
10.	Available Mn (mg kg ⁻¹)	5.07
11.	Available Cu (mg kg ⁻¹)	2.58
12.	Exchangeable Ca ²⁺ (cmol (p ⁺) kg ⁻¹)	35.80
13.	Exchangeable Mg ²⁺ (cmol (p ⁺) kg ⁻¹)	6.08
14.	Exchangeable K ⁺ (cmol (p ⁺) kg ⁻¹)	0.98
15.	Exchangeable Na ⁺ (cmol (p ⁺) kg ⁻¹)	8.75
16.	CEC (cmol (p ⁺) kg ⁻¹)	52.64
17.	ESP	16.62
18.	Bulk density (Mg m ⁻³)	1.58
19.	Hydraulic Conductivity (cmh ⁻¹)	0.20
II.	Saturation Paste extract Analysis	
1.	pHs	8.48
2.	ECe (dS m ⁻¹)	3.12
3.	Ca ²⁺ (me L ⁻¹)	3.15
4.	Mg ²⁺ (me L ⁻¹)	5.92
5.	Na ⁺ (me L ⁻¹)	26.70
6.	K ⁺ (me L ⁻¹)	0.18
7.	CO ₃ ²⁻ (me L ⁻¹)	Trace
8.	HCO ₃ ⁻ (me L ⁻¹)	16.35
9.	Cl ⁻ (me L ⁻¹)	10.35
10.	SO ₄ ²⁻ (me L ⁻¹)	7.80
11.	SAR	12.54

3.1.4 Climate

Climatically the area belongs to semiarid zone, characterized by hot summer (March to May) and general dryness in other months except in rainy months (June to September). The average annual normal rainfall of study area is 693.6 mm. The rainfall received during the experimental period was 25.8 mm in 23 rainy days. The maximum and minimum temperature was ranged between 32.5 °C and 21.3 °C during the maize crop growth period.

In order to get clear idea about the prevailing climatic conditions during the period of experimentation, the weekly weather data was obtained from the Department of Meteorology, PGI, Rahuri and presented in Table 3.2. The data presented in table revealed that the weekly meteorological data with parameters are Temperature, humidity, sunshine, wind velocity, rainfall and rainy days.

Table 3.2 Weekly meteorological data during the experimental period

Met. Week	Date	Temperature (°C)		Humidity (%)		Sunshine (hr.)	Wind velocity (km hr ⁻¹)	Rainfall (mm)	Rainy days
		Max.	Min.	Morn.	Even.				
July, 2019									
27	02-08	30.6	23.5	79	63	1.3	2.0	5.3	3
28	09-15	32.0	23.6	76	56.57	4.7	7.4	0.5	1
29	16-22	33.8	23.2	71.42	51.28	7.8	6.4	4.6	2
30	23-29	30.5	23.6	78.42	68.14	2.3	4.1	2.6	4
31	30-05	27.0	22.9	87	77.42	0.2	4.8	6.8	6
August, 2019									
32	06-12	28.0	23.3	80.57	68.14	2.0	8.2	0.5	3
33	13-19	31.0	22.5	75.14	59.6	4.3	7.0	0.2	1
34	20-26	32.5	21.3	72.42	47.57	7.9	4.1	0.0	0
35	27-02	32.0	23.0	75.14	55.71	5.9	4.1	12.6	4
September, 2019									
36	03-09	30.0	23.3	77.57	70.57	1.9	3.6	0.4	2
37	10-16	28.8	22.5	78.57	68.42	1.4	4.6	2.7	3
38	17-23	29.8	21.7	83.57	71	4.2	1.6	12.0	4
39	24-30	30.2	21.9	83.42	66.85	5.0	0.8	5.2	3
October, 2019									
40	01-07	31.1	21.1	80.57	58.71	6.1	1.1	1.1	4
41	08-14	31.7	21.1	77	50.28	7.1	0.8	0.4	2
42	15-21	28.3	18.6	81.57	67.71	5.0	1.4	7.5	3
43	22-28	25.7	20.8	87.14	79.57	2.4	1.4	20.3	6
44	29-04	30.4	21.0	84	58.57	6.1	1.1	0.6	2
November, 2019									
45	05-11	31.1	18.4	76.14	46.14	9.0	0.6	3.3	2
46	12-18	29.7	16.7	73	48	7.5	0.9	0.0	0

3.1.5 Laying of Subsurface Drainage System

The subsurface drainage system was already installed at PGI research farm of M.P.K.V., Rahuri, with laterals spacing of 30 m apart and the experiment was laid on the same site. PVC, corrugated perforated pipe is used, perforation size is 20 × 15 mm, diameter is 80 mm OD and slope given to the drain pipe is 0.2 per cent.

3.1.6 Collection of Leachate Samples

In order to assess the effect of subsurface drainage, leachate collected from field by piezometer was installed plot wise at depth of 60 cm to collect leachate.

3.1.7 Fertilizers

Commercial grade urea, single super phosphate and muriate of potash were used to supply N, P, and K respectively, obtained from Rahuri market.

3.1.8 Amendment Sources

Three amendments sources *viz.* Gypsum, zeolite and elemental Sulphur were obtained from private agro agencies situated in the local market.

Table 3.3 Characteristics of different amendments

Sr. No.	Amendments	Parameter	Value
1.	Zeolite	pH (1:2.5)	D.W.: 7.62 KCl : 6.63
		EC (1:2.5) (dS m ⁻¹)	0.07
		CEC (cmol p ⁽⁺⁾ kg ⁻¹)	160
		NH ₄ ⁺ - N (%)	0.06
		NO ₃ ⁻ - N (%)	0.021
		Fe (ppm)	580.8
		Mn (ppm)	121.2
		Zn (ppm)	9.660
		Cu (ppm)	0.560
2.	Gypsum	Ca (%)	23.15
		S (%)	18.10
3.	Elemental Sulphur	S (%)	90.8

3.1.9 Seeds

Healthy maize seeds of *pinnacle* variety obtained from Rahuri market.

3.2.10 Collection of Plant Sample

For studying the uptake of nutrient by maize crop plant sample (leaves and stalk) were collected after harvest of maize crop from field, crushed and weighted 250 gm in paper bag. After processed, samples analysed it for N, P, K, Fe, Mn, Zn and Cu content.

3.2 Details of Field Experiment

3.2.1 Layout and Experimental Design

A field experiment on sodic soil was conducted during *kharif* 2019 with maize as a test crop. The experiment was laid out in a randomized block design with 12 treatments and 3 replications. The gross plot size was 4.5 m x 3.0 m i.e. 13.5 m² and net plot size was 3.0 m x 2.6 m i.e. 7.8 m². The recommended spacing of 75 cm x 20 cm was adopted for dibbling of maize. The general recommended dose of nutrients (120:60:40 kg ha⁻¹ N, P₂O₅ and K₂O, respectively) were given to maize as per treatment details except T₁ at the time of dibbling of maize.

3.2.2 I. Experimental Details

1. Location	PGI Research Farm, Department of Soil Science and Agril. Chemistry, M.P.K.V., Rahuri.
2. Crop	Maize
3. Soil type	Sodic soil
4. Season	<i>Kharif</i> 2019
5. Variety	<i>Pinnacle</i>
6. Treatments	12
7. Replications	3
8. Design	RBD
9. Spacing	75 x 20 cm
10. Plot size	Gross : 4.5 m x 3.0 m Net : 3.0 m x 2.6 m

II. Treatments Details

T ₁ :	Absolute control
T ₂ :	Gypsum as per 100% GR
T ₃ :	Elemental sulphur as per 1/5 th of GR
T ₄ :	Zeolite @ 600 kg ha ⁻¹
T ₅ :	Gypsum as per 100% GR + zeolite @ 600 kg ha ⁻¹
T ₆ :	Gypsum as per 50% GR + zeolite @ 600 kg ha ⁻¹
T ₇ :	Gypsum as per 100% GR + zeolite @ 300 kg ha ⁻¹
T ₈ :	Gypsum as per 50% GR + zeolite @ 300 kg ha ⁻¹
T ₉ :	Elemental sulphur as per 1/5 th of GR + zeolite @ 600 kg ha ⁻¹
T ₁₀ :	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 600 kg ha ⁻¹
T ₁₁ :	Elemental sulphur as per 1/5 th of GR + zeolite @ 300 kg ha ⁻¹
T ₁₂ :	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 300 kg ha ⁻¹

Note: i) ZnSO₄ @ 20 kg ha⁻¹ was applied at basal in all treatments except T₁.
ii) GRDF were common in all the treatment except T₁.
iii) Amendments were applied one month before of sowing.

3.3 Details of Field Operations

3.3.1 Application of Amendments

Amendments (Gypsum, Elemental sulphur and Zeolite) applied as per treatment with farm yard manure @ 10 t ha⁻¹ to all treatment plots except T₁.

3.3.2 Fertilizers

The recommended doses of nutrients were 120:60:40 kg ha⁻¹ N, P₂O₅ and K₂O and given through urea, single superphosphate and muriate of potash, respectively. Urea applied in three doses i.e. Basal dose, 30 DAS and 45 DAS.

3.3.3 Sowing

The maize seeds were dibbled on July 25, 2019 in ridges and furrow with the spacing of 75 cm x 20 cm.

3.3.4 Gap filing

The gaps observed in experimental plots were filled after 7 DAS.

3.3.5 Irrigation

Field capacity of soil moisture was maintained by irrigating the field. Two irrigations were given during the crop growth period as per requirement considering rainfall and crop growth stages.

3.3.6 Plant Protection

The incidence of fall armyworms were observed during the course of investigation, was controlled by spraying insecticide three times, 1st spray of Thiamethaxan 12%, 2nd spray of Chlorantraniliprole 18.5% and 3rd effective spray of Emamectin Benzoate 5% SG. Fall army worms were finally controlled by 3rd spray of insecticide.

3.3.7 Harvesting

The maize plants in net plots after full maturity were harvested carefully for grain and stover yield and samples were taken for nutrients uptake studies.

3.4 Details of Laboratory Analysis

3.4.1 Laboratory Material

3.4.1.1 Glassware

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

3.4.1.2 Equipment

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

Table 3.4 Calendar of the field operations

Sr. No.	Field operations	Frequency	Date
A.	Preparatory tillage		
1.	Initial soil sampling	1	25-06-19
2.	Ploughing	1	03-07-19
3.	Rotavator	1	05-07-19
4.	Preparation of layout	1	08-07-19
5.	Application of amendments with FYM	1	10-07-19
B.	Piezometer		
1.	Installation	1	20-07-19
C.	Sowing		
1.	Fertilizer application, SSP and MOP	1	25-07-19
2.	Fertilizer application, Urea	3	25-07-19 26-08-19 09-09-19
2.	Sowing of seeds	1	25-07-19
3.	Gap filing	1	02-08-19
C.	Inter cultivation		
1.	Weeding	3	19-08-19 17-09-19 15-10-19
2.	Irrigation	2	18-08-19 30-08-19
E.	Plant protection		
1.	Spraying	3	16-08-19 28-08-19 05-09-19
F.	Harvesting		
		1	15-09-19

3.4.1.3 Chemicals

High purity (AR grade) chemicals were used *viz.* sulphuric acid, sodium hydroxide, hydrogen peroxide, hydrochloric acid, potassium permanganate, potassium chloride, silver nitrate, barium chloride, potassium Ferro cyanide, ammonium acetate, ammonium chloride, ammonium hydroxide, boric acid, ethanol, methanol, triethanolamine, phenolphthalein, methyl red, calcon, bromocresol green etc.

3.4.2 Methods

3.4.2.1 Soil analysis

In order to study the physical and chemical properties of soil, a representative composite soil sample were collected 0-30 cm depth from experimental field. Surface soil samples were drawn before sowing and after harvest of the maize crop. The soil samples were collected in cloth bags and then air dried in the shade for processing. The samples were then pounded thoroughly in wooden mortar with pestle and sieved through 2 mm sieve for analysis of physical and chemical properties of the soil, soil fertility and saturation paste extract analysis by using the standard analytical methods as indicated in Table 3.6. The soil samples were analyzed at initial and at harvest of maize.

3.4.2.2 Leachate analysis

Leachate samples were collected from each piezometer was installed in each plot to assess the effect of subsurface drainage system. From leachate sample pH, EC and exchangeable cations and anions were analyzed by adopting standard method given in Table 3.6.

3.4.2.3 Plant analysis

The plant and grain samples were collected at harvest of maize. The samples were air dried in shade and then dried in oven at 70°C till constant weight. The whole plant sample of each treatment was ground through a stainless steel Willey mill after oven drying. Digestion of plant and grain sample was done and used for estimation of nutrient concentration *viz.* N, P, K and micronutrients Fe, Zn, Mn and Cu by using standard methods as per table 3.6.

3.5 Uptake of Nutrient

The uptake of major and minor nutrient were worked out by multiplying dry matter accumulation to N, P, K, Fe, Mn, Zn and Cu concentration at harvest by using the following formula.

$$\text{Uptake of nutrients (kg ha}^{-1}\text{)} = \frac{\text{Total dry matter (kg ha}^{-1}\text{)} \times \text{Concentration of element (\%)}}{100}$$

$$\text{Uptake of micronutrient (g ha}^{-1}\text{)} = \frac{\text{Total dry matter (kg ha}^{-1}\text{)} \times \text{Concentration of element (mg kg}^{-1}\text{)}}{100}$$

3.6 Biometric Observation

The dry matter yield of stover and grain per net plot of maize in q ha⁻¹ was recorded.

3.7 Statistical Analysis

The field experiment was conducted by using randomized block design. The data obtained was analysed as per the methods described by Panse and Sukhatme (1985).

Table 3.5 Standard methods for analysis of soil and plant sample

Sr. No.	Parameter	Method	Reference
a)	Soil analysis		
	Physical properties		
1.	Bulk density	Clod method	Blake and Hartage (1986)
2.	Hydraulic conductivity	Constant head	Klute and Dirkson (1986)
	Chemical properties		
1.	pH (1:2.5)	Potentiometric	Jackson (1973)
2.	EC (1:2.5)	Conductometric	Jackson (1973)
3.	CaCO ₃	Acid neutralization	Alison and Moodier (1965)
4.	Organic carbon	Walkely and Black, Wet Oxidation	Nelson and Sommers (1982)
5.	Available N	Alkaline Potassium permanganate	Subbiah and Asija (1956)
6.	Available P	0.5 M NaHCO ₃ (pH 8.5)	Watanabe and Olsen (1965)
7.	Available K	Neutral N NH ₄ OAc	Knudsen and Peterson (1982)
8.	Micronutrients (DTPA -Fe, Mn, Zn & Cu)	DTPA extractant Atomic Absorption Spectrophotometry	Lindsay and Norvell (1978)
9.	Exchangeable cations	Flame photometry	Page <i>et al.</i> (1982)
10.	Cation exchange capacity	Flame photometry NaOAC method pH 7.0	Page <i>et al.</i> (1982)
	Saturation paste extract analysis		
1.	pHs	Potentiometry	Richards (1968)
2.	EC _e	Conductivity bridge	Richards (1968)
3.	Ca ²⁺	Versenate	Richards (1968)
4.	Mg ²⁺	Versenate	Richards (1968)
5.	Na ⁺	Flamephotometry	Richards (1968)
6.	K ⁺	Flamephotometry	Richards (1968)
7.	CO ₃ ²⁻	Titration	Richards (1968)
8.	HCO ₃ ⁻	Titration	Richards (1968)
9.	Cl ⁻	Titration	Richards (1968)
10.	SO ₄ ²⁻	Turbidimetric	Jackson (1973)
b)	Plant analysis		
1.	Total N	Micro-Kjeldahl (1:1 H ₂ O ₂ :H ₂ SO ₄)	Parkinson and Allen (1975)
2.	Total P	Vanadomolybdate yellow colour method in nitric acid (9:4 HNO ₃ :HClO ₄)	Jackson (1973)
3.	Total K	Flame photometry	Chapman and Pratt (1961)
4.	Total micronutrients (Fe, Mn, Zn and Cu)	Atomic absorption Spectrophotometry	Zososki and Burau (1977)
c)	Leachate analysis		
1.	pH	Potentiometry	Richards (1968)
2.	EC	Conductivity bridge	Richards (1968)
3.	Ca ²⁺	Versenate	Richards (1968)
4.	Mg ²⁺	Versenate	Richards (1968)
5.	Na ⁺	Flamephotometry	Richards (1968)
6.	K ⁺	Flamephotometry	Richards (1968)
7.	CO ₃ ²⁻	Titration	Richards (1968)
8.	HCO ₃ ⁻	Titration	Richards (1968)
9.	Cl ⁻	Titration	Richards (1968)
10.	SO ₄ ²⁻	Turbidimetric	Jackson (1973)
d)	Derived parameters		
1.	ESP	$\frac{Ex. Na}{CEC} \times 100$	Richards (1968)
3.	SAR	$\frac{Na}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$	Richards (1968)

4. RESULTS AND DISCUSSION

Soil degradation due to natural process, human intervention, agricultural practices, excess and injudicious use of irrigation water in command areas led to irrigation induced salinity and sodicity as well as arid salinity. These reasons causing a serious decline in soil physical, chemical and biological properties. The agricultural sustainability in degraded soils is challenging and needs urgent. Soil degradation resulting from salinity and/or sodicity is a major impediment to optimal utilization of these land resources (Maji *et al.*, 2010). Degraded soils either by salinity or sodicity needs a amelioration with organics, inorganics, bioremediation or an integration of these amelioration has paramount importance for their improvement and enhancing the crop productivity.

A field experiment was conducted at Post Graduate Institute, Research Farm, Department of Soil Science and Agricultural Chemistry, MPKV, Rahuri during *kharif* 2019 with a view to study the “Effect of amendment sources to reclaim the sodic soil under subsurface drainage system on yield and nutrient uptake of maize”. The results obtained in this respect to improvement in soil properties and yield of maize in subsurface drainage field are discussed in this chapter.

4.1 Effect of Amendments in Subsurface Drainage Field on Properties of Sodic Soils

Organic amendments are consist of green manuring, crop residue management, trash management, FYM, vermicompost, compost, pressmud compost, post biomethanated spent wash etc. The inorganic/chemical amendments consist of gypsum, phosphogypsum, elemental sulphur, iron pyrite. Application of organic amendments enhances the reclamation action by improving physical and chemical properties of soil and markedly decreasing soil pH and ESP. Compost, pressmud compost, compost, vermicompost, FYM improves aggregation and lead to better aeration and water relationship. Amelioration of sodic soils needs gypsum, phosphogypsum as a source of calcium (Ca^{++}) that replaces the excess Na^+ from exchange complex and makes the root zone of soil congenial for absorption of water and nutrient by crop plants. The organic amendments vary in their reclamation ability due to decomposition and C:N ratio, hence, reclamation of sodic soils due to organic amendments will be dependent on the nature of organic material. An integration of organic and inorganic amendments are most useful for reclamation of sodic soils with their synergistic effect for improvement in physical condition by organics and chemical improvement by organic/chemical amendment rather than they use in alone.

Basically, reclamation or improvement of sodic soils requires the removal of part or most of the exchangeable sodium and its replacement by the more favourable calcium ions in the root zone. For reasonably quick results, cropping must be preceded by the application of soil

amendments i.e. gypsum, followed by leaching for removal of salts derived from the reaction of the amendment with the sodic soil.

In improvement of salt affected soils drainage plays an important role. Among the different types of drainages open drains and sub-surface drains are important. In open drains nearly 10-12 per cent cultivated land is wasted and in addition maintenance is required for removal of silt quite often, otherwise they will not be effective. Subsurface drainage is considered as a most suitable approach for groundwater balance and land and water management practices containing the groundwater table at a suitable level that leachate are drain out by installation of subsurface drainage system in soil

Zeolite contain large vacant spaces (cages) that can accommodate cations (Na^+ , K^+ , Ba^{2+} , Ca^{2+}), as well as large molecules and cation groups (H_2O , NH_4^+). The cations are mobile throughout the structure and play a charge balancing role with the AlO_4^- tetrahedral. The high ion exchange and retention ability of zeolites as well as their large adsorptive affinity for water has contributed to their successful applications in soil amendment. In zeolite charge balancing cations (Na^+ , K^+ , Ba^{2+} , Ca^{2+}) can be exchanged with other cations in aqueous solution, without affecting the aluminosilicate framework. Considering this, the present study was conducted to compare the sources of amendment to reclaim the sodic soil under subsurface drainage field.

4.1.1 Effect of Amendments on Physical Properties in Subsurface Drainage Field at Harvest of Maize

The hydraulic conductivity and bulk density of sodic soil in SSD field at harvest of maize as influenced by inorganic amendments are presented in Table 4.1.

The bulk density of sodic soil was significantly less in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ at harvest of maize (1.50 Mg m⁻³) which was at par with treatment Gypsum as per 100% GR + zeolite @ 300 kg ha⁻¹ (1.51 Mg m⁻³). The decreased bulk density might be because of addition of gypsum with zeolite, adds sufficient calcium in soil and zeolite increases the CEC of soil. The added calcium replaced the adsorbed sodium from clay complex and leached out through SSD system from soil as soluble form of salt *viz.* sodium sulphate or sodium chloride. The removal of sodium helps to improve the soil physical condition by inhibiting flocculation, dispersion and disintegration of soil particles. As results, increased pore space, aeration and development of capillaries in soil, which in turn decreased the soil bulk density. This might be because of added amendments did provide the calcium in required quantity to replace the sodium from clay complex. This might be due to the removal of sodium which reduced the dispersion of soil particles. Similar results were reported by Bharambe *et al.* (2001).

Table 4.1 Effect of amendments on physical properties in subsurface drainage field at harvest of maize

Sr. No.	Treatment	Bulk density (Mg m ⁻³)	Hydraulic conductivity (cm h ⁻¹)
T ₁	Absolute control	1.58	0.23
T ₂	Gypsum as per 100% GR	1.54	0.32
T ₃	Elemental sulphur 1/5 th of GR	1.56	0.29
T ₄	Zeolite @ 600 kg ha ⁻¹	1.57	0.26
T ₅	Gypsum as per 100% GR + zeolite @ 600 kg ha ⁻¹	1.50	0.34
T ₆	Gypsum as per 50% GR + zeolite @ 600 kg ha ⁻¹	1.53	0.32
T ₇	Gypsum as per 100% GR + zeolite @ 300 kg ha ⁻¹	1.51	0.33
T ₈	Gypsum as per 50% GR + zeolite @ 300 kg ha ⁻¹	1.54	0.31
T ₉	Elemental sulphur as per 1/5 th of GR + zeolite @ 600 kg ha ⁻¹	1.55	0.30
T ₁₀	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 600 kg ha ⁻¹	1.56	0.29
T ₁₁	Elemental sulphur as per 1/5 th of GR + zeolite @ 300 kg ha ⁻¹	1.55	0.30
T ₁₂	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 300 kg ha ⁻¹	1.56	0.28
	SEm(±)	0.009	0.008
	CD at 5%	0.027	0.024
	Initial	1.58	0.20

The hydraulic conductivity at harvest of maize was significantly higher in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ (0.34 cm h⁻¹) and statistically at par with treatments T₂, T₆, T₇ and T₈ (0.32, 0.32, 0.33 and 0.31 cm h⁻¹, respectively). The remaining treatments i.e. T₃, T₄, T₉, T₁₀, T₁₁ and T₁₂ were at par with each other for hydraulic conductivity after harvest of maize (0.29, 0.26, 0.30, 0.29, 0.30 and 0.28 cm hr⁻¹, respectively). The higher hydraulic conductivity after harvest of maize in SSD field might be because of decreased bulk density increased the porosity in soil and reflected in increased hydraulic conductivity of soil (Suarez *et al.*, 1984).

Thus, chemical amendments for sodic soils in SSD field are more beneficial for hydraulic conductivity and bulk density after harvest of maize.

4.1.2 Effect of Amendments on Exchangeable Cations in Subsurface Drainage Field at Harvest of Maize

The exchangeable cations content of sodic soils in SSD field at harvest of maize as influenced by the inorganic amendments are presented in Table 4.2.

Table 4.2 Effect of amendments on exchangeable cations in subsurface drainage field at harvest of maize

Sr. No.	Treatment	Cations [cmol (p ⁺) kg ⁻¹]			
		Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺
T ₁	Absolute control	35.63	7.90	8.21	1.04
T ₂	Gypsum as per 100% GR	47.80	8.57	7.23	1.16
T ₃	Elemental sulphur 1/5 th of GR	38.00	8.57	7.70	1.13
T ₄	Zeolite @ 600 kg ha ⁻¹	35.70	8.07	8.03	1.12
T ₅	Gypsum as per 100% GR + zeolite @ 600 kg ha ⁻¹	49.67	9.03	6.82	1.18
T ₆	Gypsum as per 50% GR + zeolite @ 600 kg ha ⁻¹	47.57	8.67	7.16	1.17
T ₇	Gypsum as per 100% GR + zeolite @ 300 kg ha ⁻¹	48.53	8.90	6.98	1.17
T ₈	Gypsum as per 50% GR + zeolite @ 300 kg ha ⁻¹	46.77	8.43	7.33	1.16
T ₉	Elemental sulphur as per 1/5 th of GR + zeolite @ 600 kg ha ⁻¹	39.63	8.37	7.36	1.16
T ₁₀	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 600 kg ha ⁻¹	37.06	8.63	7.56	1.14
T ₁₁	Elemental sulphur as per 1/5 th of GR + zeolite @ 300 kg ha ⁻¹	39.87	8.60	7.42	1.15
T ₁₂	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 300 kg ha ⁻¹	35.57	8.33	7.66	1.13
	SEm(±)	0.405	0.501	0.067	0.009
	CD at 5%	1.187	NS	0.198	0.065
	Initial	35.80	6.08	8.75	0.98

The exchangeable calcium content after harvest of maize was significantly highest in the treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ (49.67 cmol (p⁺) kg⁻¹ soil) and statistically at par with the treatment Gypsum as per 100% GR + zeolite @ 300 kg ha⁻¹ (48.53 cmol (p⁺) kg⁻¹ soil). Similarly treatments T₂, T₆ and T₈ (47.80, 47.57 and 46.77 cmol (p⁺) kg⁻¹ soil, respectively) were found statistically at par with each other for their exchangeable calcium content at harvest of maize. The addition of gypsum and zeolite contains the calcium which was used as an amendment in sodic soil in SSD field. The calcium has an ability to replace the other cation adsorbed on clay surface. In sodic soils the sodium is the predominant cations adsorbed on clay surface. The adsorbed sodium on clay surface was easily replaced by the calcium, as calcium is divalent cation and sodium is monovalent cation. The replaced sodium by the calcium of gypsum (CaSO₄.5H₂O) was immediately combined with sulphate (SO₄²⁻) of gypsum and forms sodium sulphate (Na₂SO₄). The sodium sulphate is soluble salts which can be easily

leached out from sodic soil through SSD system and calcium remains adsorbed on surface of clay mycelli. This might be the reason for more amount of exchangeable calcium in gypsum amended sodic soils in maize crop field. Similarly, gypsum promote leaching and create conducive environment for ionic reactions at soil exchange complex. The addition of gypsum in salt affected soil can removes the excess of Na^+ from soil profile by leaching process and also improvement of chemical soil properties such as electrical conductivity and sodium adsorption ratio (Amezketta *et al.*, 2005).

The treatments of elemental sulphur also recorded considerably high content of exchangeable calcium in sodic soil, treatments T₉ and T₁₁ were found statistically at par with each other for their exchangeable calcium content after harvest of maize (39.63 and 39.87 $\text{cmol}(\text{p}^+) \text{kg}^{-1}$ soil, respectively). Elemental sulphur which on oxidation in soil forms sulphurous acid (H_2SO_3). These sulphurous acid neutralize the calcium carbonate and release the calcium in soil (Abdelhamid *et al.*, 2013).

The treatment T₄ of zeolite clay mineral are next to elemental sulphur as an amendment for sodic soil for exchangeable calcium content in soil (35.70 $\text{cmol}(\text{p}^+) \text{kg}^{-1}$ soil). The zeolite clay mineral has comb like structure in which the cations like Ca^{2+} and NH_4^+ are catch hold and release in soil slowly. Clinoptilolite adsorbs Na^+ and Cl^- which enter into the cavities and consequently improves the soil properties (Noori *et al.*, 2007)

The exchangeable magnesium content in sodic soil was found nonsignificant by various amendments under SSD system. Numerically, it was the highest in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha^{-1} (9.03 $\text{cmol}(\text{p}^+) \text{kg}^{-1}$ soil) followed by elemental sulphur and zeolite. The nonsignificant results of exchangeable magnesium might be due to the magnesium in sodic soil in the form of insoluble salts like magnesium carbonate and magnesium biocarbonate.

The exchangeable sodium content in sodic soils in SSD field was found significantly lower in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha^{-1} (6.82 $\text{cmol}(\text{p}^+) \text{kg}^{-1}$ soil) was statistically at par with treatment Gypsum as per 100% GR + zeolite @ 300 kg ha^{-1} (6.98 $\text{cmol}(\text{p}^+) \text{kg}^{-1}$ soil). Similarly the treatments T₂, T₆ and T₈ were at par with each other for exchangeable sodium content. (7.23, 7.16 and 7.33 $\text{cmol}(\text{p}^+) \text{kg}^{-1}$ soil, respectively). High calcium releases from the gypsum amendments preferentially replace the sodium from clay particles and facilitated it to leached out through SSD system. The treatments of elemental Sulphur i.e. T₉ and T₁₁ was at par with each other by exchangeable sodium content (7.36 and 7.42 $\text{cmol}(\text{p}^+) \text{kg}^{-1}$ soil, respectively).

The exchangeable potassium content in sodic soils in SSD field was found significantly highest in treatment of Gypsum as per 100% GR + zeolite @ 600 kg ha^{-1} (1.18 $\text{cmol}(\text{p}^+) \text{kg}^{-1}$ soil) and it was statistically at par with all the treatments except T₁ (Absolute control).

Numerically the values are more or less similar. This might be associated with the potassium is always remain in soil in an equilibrium condition as exchangeable, nonexchangeable, water soluble and total potassium. Similarly, drying and wetting cycle of soil governs the potassium content in soil.

In general, the chemical amendments like gypsum, elemental Sulphur with zeolite in SSD field are the best amendments for exchangeable Ca^{2+} , Mg^{2+} , Na^+ and K^+ content in sodic soil after harvest of maize.

4.1.3 Effect of Amendments on Derived Parameters in Subsurface Drainage Field at Harvest of Maize

The exchangeable sodium percentage (ESP) and sodium adsorption ratio (SAR) at harvest of maize as influenced by the inorganic amendments are presented in Table 4.3.

Table 4.3 Effect of amendments on derived parameters in subsurface drainage field at harvest of maize

Sr. No.	Treatment	Exchangeable Sodium Percentage (ESP)	Sodium Adsorption Ratio (SAR)
T ₁	Absolute control	15.40	11.41
T ₂	Gypsum as per 100% GR	12.08	8.31
T ₃	Elemental sulphur 1/5 th of GR	14.01	10.14
T ₄	Zeolite @ 600 kg ha ⁻¹	14.84	11.02
T ₅	Gypsum as per 100% GR + zeolite @ 600 kg ha ⁻¹	10.42	6.62
T ₆	Gypsum as per 50% GR + zeolite @ 600 kg ha ⁻¹	11.53	7.65
T ₇	Gypsum as per 100% GR + zeolite @ 300 kg ha ⁻¹	10.77	7.15
T ₈	Gypsum as per 50% GR + zeolite @ 300 kg ha ⁻¹	11.92	8.17
T ₉	Elemental sulphur as per 1/5 th of GR + zeolite @ 600 kg ha ⁻¹	12.25	9.05
T ₁₀	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 600 kg ha ⁻¹	13.60	9.91
T ₁₁	Elemental sulphur as per 1/5 th of GR + zeolite @ 300 kg ha ⁻¹	12.86	9.72
T ₁₂	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 300 kg ha ⁻¹	13.89	10.27
	SEm(±)	0.23	0.23
	CD at 5%	0.701	0.680
	Initial	16.62	12.54

The exchangeable sodium percentage was significantly less in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ (10.42) and statistically at par with treatment Gypsum as per 100% GR + zeolite @ 300 kg ha⁻¹ (10.77). Similarly treatments T₂, T₆ and T₈ were at par with

each other (12.08, 11.53 and 11.92, respectively). This might be associated with addition of calcium through gypsum, replaced the other adsorbed cations from clay particles, as sodium, magnesium, potassium and ammonium etc. This phenomenon decreased the exchangeable sodium percentage in sodic soils. Similarly, the amelioration of sodic soils with gypsum reduced the Na^+ ion concentration in the exchange complex and thereby, reduced the ESP significantly, This results indicated that, addition of gypsum and as per 100 per cent gypsum requirement in sodic soil is provides higher quantity of calcium for replacement of sodium from the soil complex and resulting in reduction of sodium and exchangeable sodium percentage (ESP). The decrease in soil ESP with increasing rates of amendments may be attributed to increase Ca in soil solution as a result of addition gypsum and organic amendments which promoted Na displacement and removed by leaching process (Gharaibeh *et al.*, 2009)

The sodium adsorption ratio was significantly influenced by the amelioration of sodic soils with inorganic amendments in SSD field. Significantly the lowest sodium adsorption ratio was recorded in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ (6.62) and statistically at par with treatment Gypsum as per 100% GR + zeolite @ 300 kg ha⁻¹ (7.15). The elemental Sulphur containing treatments Elemental sulphur as per 1/5th of GR + zeolite @ 600 kg ha⁻¹ and Elemental sulphur as per 1/5th GR + zeolite @ 300 kg ha⁻¹ were found statistically at par with each other (9.05 and 9.72, respectively). This might be associated with the higher exchange of sodium by the calcium applied through 100 % gypsum with zeolite on clay complex in sodic soils. The decreased SAR by amendments in sodic soil might be associated with improvement in soil physical conditions subjected to replacement of exchangeable sodium from clay complex and leached out from soil and decreased the concentration of sodium in sodic soils (Sagare *et al.* 2001).

4.1.4 Effect of Amendments on pHs, ECe and Cations of Saturation Paste Extract in Subsurface Drainage Field At Harvest of Maize

The pHs, ECe and cations of saturation paste extract of sodic soils in SSD field at harvest of maize as influenced by the inorganic amendments are presented in Table 4.4.

The pHs of saturation paste extract after harvest of maize was found significantly lower in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ (8.02) which was statistically at par with treatment Gypsum as per 100% GR + zeolite @ 300 kg ha⁻¹ (8.06). Similarly, treatments T₂, T₆ and T₈ were found statistically at par with each other (8.14, 8.09 and 8.13, respectively). The pHs of elemental Sulphur containing treatments Elemental sulphur as per 1/5th of GR + zeolite @ 600 kg ha⁻¹ (8.15) and Elemental sulphur as per 1/5th of GR + zeolite @ 300 kg ha⁻¹ (8.18) were statistically at par with each other. The reduction in pHs of sodic soil might be associated with the replacement of sodium from clay complex by calcium from amendments and replaced sodium reacted with sulphate and forms sodium sulphate as soluble salts, easily

leached out through SSD system. Yadav and Chippa (2007) also reported similar results on reduction of pHs with application of gypsum.

Table 4.4 Effect of amendments on pHs, ECe and cations of saturation paste extract in subsurface drainage field at harvest of maize

Sr. No.	Treatment	pHs	ECe (dSm ⁻¹)	Cations (me L ⁻¹)			
				Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺
T ₁	Absolute control	8.29	3.04	3.20	6.04	24.53	0.21
T ₂	Gypsum as per 100% GR	8.14	2.84	6.06	6.46	20.78	0.32
T ₃	Elemental sulphur 1/5 th of GR	8.22	2.92	4.22	6.19	23.14	0.25
T ₄	Zeolite @ 600 kg ha ⁻¹	8.24	2.97	3.52	6.13	24.20	0.23
T ₅	Gypsum as per 100% GR + zeolite @ 600 kg ha ⁻¹	8.02	2.71	6.88	6.85	17.34	0.38
T ₆	Gypsum as per 50% GR + zeolite @ 600 kg ha ⁻¹	8.09	2.79	5.64	6.65	18.96	0.34
T ₇	Gypsum as per 100% GR + zeolite @ 300 kg ha ⁻¹	8.06	2.73	6.33	6.67	18.22	0.36
T ₈	Gypsum as per 50% GR + zeolite @ 300 kg ha ⁻¹	8.13	2.82	5.29	6.49	19.83	0.33
T ₉	Elemental sulphur as per 1/5 th of GR + zeolite @ 600 kg ha ⁻¹	8.15	2.85	4.58	6.33	21.14	0.29
T ₁₀	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 600 kg ha ⁻¹	8.21	2.91	4.29	6.24	22.73	0.27
T ₁₁	Elemental sulphur as per 1/5 th of GR + zeolite @ 300 kg ha ⁻¹	8.18	2.88	4.45	6.29	22.53	0.28
T ₁₂	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 300 kg ha ⁻¹	8.21	2.91	4.03	6.16	23.19	0.26
	SEm(±)	0.020	0.015	0.338	0.249	0.48	0.010
	CD at 5%	0.059	0.050	1.03	0.740	1.469	0.029
	Initial	8.48	3.12	3.15	5.92	26.70	0.18

The electrical conductivity of saturation paste extract of sodic soils was significantly influenced by the inorganic amendments with SSD system. The treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ recorded significantly lower values of ECe (2.71 dSm⁻¹) and was statistically at par with treatment Gypsum as per 100% GR + zeolite @ 300 kg ha⁻¹ (2.73 dSm⁻¹). Similarly the ECe values of other gypsum applied treatments i.e. T₂, T₆, and T₈ were at par with each other (2.84, 2.79 and 2.82 dSm⁻¹, respectively). The lower values of ECe by these

amendments might be because of exchange of sodium from clay complex by calcium applied through gypsum. The exchanged sodium immediately forms salts of Na_2SO_4 and NaCl , which leached out through SSD system from field. Electrical conductivity of saturation paste extract in surface soils can rapidly decrease as percolating water removes soluble cations and anions (Carlson *et al.*, 2016). The E_{Ce} values of elemental Sulphur applied treatments Elemental sulphur as per 1/5th of GR + zeolite @ 600 kg ha⁻¹ and Elemental sulphur as per 1/5th of GR + zeolite @ 300 kg ha⁻¹ were at par with each other (2.85 and 2.88 dSm⁻¹, respectively). The sulphur application as amendment in sodic soils released the SO_4^{2-} ion on their oxidation. The released SO_4^{2-} may react with exchanged sodium and forms the soluble salts like Na_2SO_4 . Similarly, the oxidation of sulphur in soil may leads to formation of sulphurous acid and neutralize the exchangeable sodium as well as native CaCO_3 . This may solubilize the insoluble salts into soluble salts. That soluble salts removed through SSD system installed at field cause reduced in E_{Ce}. The management guidelines generally recommend drainage along with the application of an appropriate soil amendments (Carlson *et al.*, 2016).

The cations *viz.* calcium, magnesium, sodium and potassium in saturation paste extract of sodic soils were significantly influenced by inorganic amendments under SSD system. The treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ recorded the highest value of calcium cation in saturation paste extract (6.88 meq L⁻¹) and was statistically at par with treatment Gypsum as per 100% GR + zeolite @ 300 kg ha⁻¹ (6.33 meq L⁻¹). Similarly other gypsum containing treatments i.e. T₂, T₆, and T₈ were statistically at par with each other (6.06, 5.64 and 5.29 meq L⁻¹, respectively). The increased calcium in saturation paste extract might be because of the calcium content of amendments has an ability to adsorb on clay complex of sodic soils by exchanging the adsorbed sodium from clay complex (Kharche *et al.*, 2010)

The magnesium content in sodic soils in SSD field was found significantly highest in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ (6.85 meq L⁻¹) and it was statistically at par with all the treatments except T₁ (Absolute control).

The sodium content in saturation paste extract of sodic soil in SSD field after harvest of maize was found significantly lower in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ (17.34 meq L⁻¹) was statistically at par with treatment Gypsum as per 100% GR + zeolite @ 300 kg ha⁻¹ (18.22 meq L⁻¹). Sodium content in rest of gypsum applied treatments i.e. T₂, T₆, and T₈ were at par with each other (20.78, 18.96 and 19.83 meq L⁻¹, respectively). The high calcium release from the gypsum amendments preferentially replace the sodium from clay particles and facilitated it to leached out through SSD system. Similarly sodium content in elemental sulphur containing treatments Elemental sulphur as per 1/5th of GR + zeolite @ 600 kg ha⁻¹ (21.14 meq L⁻¹) and Elemental sulphur as per 1/5th of GR + zeolite @ 300 kg ha⁻¹ (22.53

meq L⁻¹) were at par with each other. Elemental Sulphur oxidized to form SO₄²⁻ ion which fix sodium and removed by leaching through SSD system.

The potassium content in saturation paste extract was significantly higher in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ (0.38 meq L⁻¹) and at par with treatment Gypsum as per 100% GR + zeolite @ 300 kg ha⁻¹ (0.36 meq L⁻¹). The rest of gypsum applied treatments i.e. T₂, T₆ and T₈ were at par with each other (0.32, 0.34 and 0.33 meq L⁻¹, respectively). In general, the potassium content in saturation paste extract of sodic soils might be because of calcium would have occupied the exchange site of potassium in soil during the reclamation process.

4.1.5 Effect of Amendments on Anions of Saturation Paste Extract in Subsurface Drainage Field At Harvest of Maize

The anions *viz.* bicarbonate, chloride and sulphate content in saturation paste extract of sodic soil in SSD field at harvest of maize as influenced by inorganic amendments, whereas carbonates was in trace amount are presented in Table 4.5.

The bicarbonate content in saturation paste extract of sodic soils in SSD field were found significantly less in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ (14.85 meq L⁻¹) was statistically at par with treatment Gypsum as per 100% GR + zeolite @ 300 kg ha⁻¹ (14.88 meq L⁻¹). Similarly, treatments T₂, T₆ and T₈ (15.15, 15.05 and 15.12 meq L⁻¹, respectively) were at par with each other. This might be due to leaching of bicarbonate with sodium as sodium bicarbonate through drainage water. Carbonate contents in saturation paste extract was in trace amount in sodic soil by the inorganic amendments after harvest of maize. The considerable reduction in bicarbonate has been achieved by reduction through the use of amendments (Singh, 1997).

The chloride content in saturation paste extract of sodic soils in SSD field was found significantly less in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ (6.82 meq L⁻¹) which was at par with treatment Gypsum as per 100% GR + zeolite @ 300 kg ha⁻¹ (7.15 meq L⁻¹). Similarly, treatments T₂, T₆ and T₈ (7.75, 7.48 and 7.55 meq L⁻¹, respectively) were at par with each other. The chloride removed under drainage condition during leaching. Similar finding have been reported by Shehata *et al.* (1983).

The sulphate content in saturation paste extract of sodic soil in SSD field after harvest of maize was found nonsignificant by the amelioration of sodic soils with inorganic amendments. However, it was numerically less in Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ (5.74 me L⁻¹) and closely followed by Gypsum as per 100% GR + zeolite @ 300 kg ha⁻¹ (6.59 me L⁻¹). The rest of the treatments were numerically similar with small difference. The non significant results of SO₄²⁻ content in saturation paste extract of sodic soils in SSD field after harvest maize might be because of during reclamation processes of sodic soils by various amendments

exchanged the sodium from clay complex. The exchanged sodium reacted with sulphate and forms the sodium sulphate. The sodium sulphate are soluble salt which can be easily leached out through SSD system from soil.

Table 4.5 Effect of amendments on anions of saturation paste extract in subsurface drainage field at harvest of maize

Sr. No.	Treatment	Anions (me L ⁻¹)			
		CO ₃ ²⁻	HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻
T ₁	Absolute control	Trace	16.18	9.75	7.75
T ₂	Gypsum as per 100% GR	Trace	15.15	7.75	6.77
T ₃	Elemental sulphur 1/5 th of GR	Trace	15.38	8.65	7.16
T ₄	Zeolite @ 600 kg ha ⁻¹	Trace	15.58	8.92	7.68
T ₅	Gypsum as per 100% GR + zeolite @ 600 kg ha ⁻¹	Trace	14.85	6.82	5.74
T ₆	Gypsum as per 50% GR + zeolite @ 600 kg ha ⁻¹	Trace	15.05	7.48	6.73
T ₇	Gypsum as per 100% GR + zeolite @ 300 kg ha ⁻¹	Trace	14.88	7.15	6.59
T ₈	Gypsum as per 50% GR + zeolite @ 300 kg ha ⁻¹	Trace	15.12	7.55	6.80
T ₉	Elemental sulphur as per 1/5 th of GR + zeolite @ 600 kg ha ⁻¹	Trace	15.25	8.02	6.83
T ₁₀	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 600 kg ha ⁻¹	Trace	15.32	8.48	7.15
T ₁₁	Elemental sulphur as per 1/5 th of GR + zeolite @ 300 kg ha ⁻¹	Trace	15.18	8.18	6.89
T ₁₂	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 300 kg ha ⁻¹	Trace	15.35	8.58	7.57
	SEm(±)	-	0.052	0.142	0.058
	CD at 5%	-	0.159	0.422	NS
	Initial	Trace	16.35	10.35	7.80

Thus, addition of gypsum as per 100 per cent gypsum requirement with zeolite as an amendment in sodic soils are beneficial for regulating anions *viz.* HCO₃⁻, Cl⁻ and SO₄²⁻ in sodic soils under SSD system after harvest of maize.

4.1.6 Effect of Amendments on Soil Properties in Subsurface Drainage Field At Harvest of Maize

The soil organic carbon, calcium carbonate and cation exchange capacity of sodic soils in SSD field at harvest of maize as influenced by inorganic amendments are presented in Table 4.6.

Table 4.6 Effect of amendments on soil properties in subsurface drainage field at harvest of maize

Sr. No.	Treatment	Organic Carbon (%)	Calcium Carbonate (%)	CEC (cmol (p⁺) kg⁻¹ soil)
T ₁	Absolute control	0.49	8.86	53.31
T ₂	Gypsum as per 100% GR	0.53	8.51	59.86
T ₃	Elemental sulphur 1/5 th of GR	0.52	7.40	54.98
T ₄	Zeolite @ 600 kg ha ⁻¹	0.51	8.72	54.11
T ₅	Gypsum as per 100% GR + zeolite @ 600 kg ha ⁻¹	0.56	7.95	65.47
T ₆	Gypsum as per 50% GR + zeolite @ 600 kg ha ⁻¹	0.54	8.26	62.11
T ₇	Gypsum as per 100% GR + zeolite @ 300 kg ha ⁻¹	0.55	8.12	64.83
T ₈	Gypsum as per 50% GR + zeolite @ 300 kg ha ⁻¹	0.54	8.45	61.48
T ₉	Elemental sulphur as per 1/5 th of GR + zeolite @ 600 kg ha ⁻¹	0.53	7.17	60.10
T ₁₀	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 600 kg ha ⁻¹	0.52	7.54	55.57
T ₁₁	Elemental sulphur as per 1/5 th of GR + zeolite @ 300 kg ha ⁻¹	0.53	7.25	57.71
T ₁₂	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 300 kg ha ⁻¹	0.52	7.72	55.16
	SEm(±)	0.02	0.24	1.74
	CD at 5%	0.06	0.75	5.26
	Initial	0.49	8.90	52.64

The organic carbon content of sodic soils in SSD field was significantly higher in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ (0.56) and at par with all the treatments except T₁ (Absolute Control). The increases organic carbon content in SSD field due to normal growth of the maize, thus crop residues have been contributed to the organic carbon content of SSD field. It may also be due to decomposition and degradation of organic matter, addition of FYM and increased in root biomass which contributed to the organic carbon content of soil.

The lower values of organic carbon in sodic soils in SSD plots by ameliorating with gypsum, elemental sulphur and zeolite might be because of exchanged sodium from clay particles by calcium of these amendments degrade the organic matter and leached down from soil during reclamation process.

The calcium carbonate content of sodic soil after harvest of maize was significantly influenced by the inorganic amendments. The application of Elemental sulphur as per 1/5th of GR + zeolite @ 600 kg ha⁻¹ was found to record the significantly lower values of CaCO₃ (7.17%) and was statistically at par with treatments T₃, T₁₀, T₁₁ and T₁₂ (7.40, 7.54, 7.25 and 7.72%, respectively). The decrease in CaCO₃ in sodic soils in SSD field at sulphur treatments was due to the solubilization of CaCO₃ by the release of acid (H₂CO₃). The sulphur application produced the sulphurous acid on their oxidation, which solubilize the CaCO₃ in sodic soil (Abdelhamid *et al.*, 2013).

The cation exchange capacity of sodic soil in SSD field was significantly increased by the treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ after harvest of maize (65.47 cmol (p⁺) kg⁻¹ soil) and was statistically at par with other gypsum containing treatments i.e. T₂, T₆, T₇, and T₈ (59.86, 62.11, 64.83 and 61.48 cmol (p⁺) kg⁻¹ soil, respectively). The sulphur containing treatments were statistically on par with each other for their cation exchange capacity after harvest of maize. The gypsum provides mainly the calcium which can exchange the cations from exchange site of clay complex. The increases in CEC might be due to more removal of soluble salts through leaching. Similar results were recorded by Bharambe *et al.* (1990).

4.2 Effect of Amendments on Availability of Nutrients in Subsurface Drainage Field At Harvest of Maize

The data in respect of soil available nutrients *viz.* N, P and K in SSD field at harvest of maize as influenced by inorganic amendments are presented in Table 4.7.

The available nitrogen content in soil at harvest was significantly increased in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ (146.48 kg ha⁻¹) and was at par with treatment Gypsum as per 100% GR + zeolite @ 300 kg ha⁻¹ (143.35 kg ha⁻¹). Similarly rest of gypsum applied treatments i.e. T₂, T₆ and T₈ were at par with each other (135.29, 140.05 and 136.74 kg ha⁻¹, respectively), thus followed by elemental sulphur and zeolite treatments. The lowest available nitrogen (124.24 kg ha⁻¹) was in treatment T₁ (Absolute control). Organic matter in soil is the ultimate source of nutrients for plant and soil microbial activity. It decides the fate of soil structure, water holding capacity, infiltration rate, aeration and porosity. This was increase in available nitrogen might be due to stimulation of microorganism and/or neutralization of toxic salts thereby creation of favorable habitat for them and it increases N mineralization in soil.

Table 4.7 Effect of amendments on availability of nutrients in subsurface drainage field at harvest of maize

Sr. No.	Treatment	Soil available nutrient (kg ha ⁻¹)		
		Available N	Available P	Available K
T ₁	Absolute control	120.24	7.38	335.57
T ₂	Gypsum as per 100% GR	135.29	8.79	415.09
T ₃	Elemental sulphur 1/5 th of GR	128.03	8.15	346.35
T ₄	Zeolite @ 600 kg ha ⁻¹	126.38	7.86	340.03
T ₅	Gypsum as per 100% GR + zeolite @ 600 kg ha ⁻¹	146.48	9.54	445.69
T ₆	Gypsum as per 50% GR + zeolite @ 600 kg ha ⁻¹	140.05	9.03	420.12
T ₇	Gypsum as per 100% GR + zeolite @ 300 kg ha ⁻¹	143.35	9.18	435.84
T ₈	Gypsum as per 50% GR + zeolite @ 300 kg ha ⁻¹	136.74	8.96	418.97
T ₉	Elemental sulphur as per 1/5 th of GR + zeolite @ 600 kg ha ⁻¹	133.81	8.44	388.98
T ₁₀	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 600 kg ha ⁻¹	129.75	8.35	362.67
T ₁₁	Elemental sulphur as per 1/5 th of GR + zeolite @ 300 kg ha ⁻¹	131.84	8.41	373.77
T ₁₂	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 300 kg ha ⁻¹	128.48	8.27	358.13
	SEm(±)	1.86	0.14	7.75
	CD at 5%	5.89	0.45	23.57
	Initial	143.24	9.15	457.82

The available phosphorus in soil was significantly increased at harvest of maize in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ (9.54 kg ha⁻¹) which was statistically at par with treatment Gypsum as per 100% GR + zeolite @ 300 kg ha⁻¹ (9.18 kg ha⁻¹). Similarly rest of gypsum applied treatments i.e. T₂, T₆ and T₈ were found at par with each other (8.79, 9.03 and 8.96 kg ha⁻¹, respectively). Thus lowest value (7.98 kg ha⁻¹) was observed in treatment T₁ (Absolute control). Gypsum is a useful for soil reclamation, have potential to improve soil fertility. The P availability is the most dynamic in the soil and besides other factors, its availability is controlled by soil pH, clay content, calcareousness and soil organic matter. The application organic source of nutrition breaks the bond between phosphorus compound and CaCO₃ keeping it as at higher amounts in available form.

The available potassium in soil after harvest of maize recorded highest in the treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ (445.69 kg ha⁻¹) and which was statistically at par with treatment Gypsum as per 100% GR + zeolite @ 300 kg ha⁻¹ (435.84 kg ha⁻¹). Similarly rest of gypsum applied treatments i.e. T₂, T₆ and T₈ were found at par with each other (415.09, 420.12 and 418.97 kg ha⁻¹, respectively). The significant increase in available potassium status due to application of gypsum may be attributed to the fact that addition of gypsum brought about remarkable improvement in physical and chemical properties of soil. The FYM application with amendments influenced the soil potassium availability. The effect is positive resulting in more availability of K⁺ to plants. The hydrogen ions released from organic material are exchange with K on exchange site or set free from the fixed site of the clay micelle.

4.3 Effect of Amendments on Availability of Micronutrients in Subsurface Drainage Field At Harvest of Maize

The data in respect of residual soil available micronutrient *viz.*, Fe, Mn, Zn and Cu in SSD field at harvest of maize as influenced by the application inorganic amendments are presented in Table 4.8.

Among the treatments, application of Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ registered significantly higher content of available Fe (4.46 µg g⁻¹) it was at par with treatment Gypsum as per 100% GR + zeolite @ 300 kg ha⁻¹ (4.43 µg g⁻¹). The lowest Fe was observed in control treatment (4.06 µg g⁻¹). In general, it was noted that the available iron significantly increased with the addition of FYM, gypsum, elemental sulphur and zeolite in SSD field.

The application of Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ registered significantly higher content of available zinc (0.42 µg g⁻¹) it was at par with treatments T₂, T₆, T₇ and T₈ (0.38, 0.39, 0.40 and 0.38 µg g⁻¹, respectively), whereas rest of the treatments was at par with each other except T₁ (Absolute control). The lowest (0.30 µg g⁻¹) Zn content was observed in control treatment. The data revealed that the zinc content in soil was significantly increased by the application of FYM, from these observations it is concluded that the available Zn content was increased by the application of amendments than control treatment.

The treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ registered significantly higher (4.83 µg g⁻¹) content of available manganese and it was at par with treatment Gypsum as per 100% GR + zeolite @ 300 kg ha⁻¹ (4.80 µg g⁻¹). The lowest Mn content was observed in control treatment (4.02 µg g⁻¹). This indicated that the available Mn increased due to reduction in soil pH by removal of sodium by amendments and acidulating effect of sulphur.

Table 4.8 Effect of amendments on availability of micronutrients in subsurface drainage field at harvest of maize

Sr. No.	Treatment	Soil available micronutrient ($\mu\text{g g}^{-1}$)			
		Fe	Zn	Mn	Cu
T ₁	Absolute control	4.06	0.30	4.02	1.86
T ₂	Gypsum as per 100% GR	4.38	0.38	4.77	2.20
T ₃	Elemental sulphur 1/5 th of GR	4.31	0.36	4.60	2.09
T ₄	Zeolite @ 600 kg ha ⁻¹	4.27	0.33	4.45	1.96
T ₅	Gypsum as per 100% GR + zeolite @ 600 kg ha ⁻¹	4.46	0.42	4.83	2.39
T ₆	Gypsum as per 50% GR + zeolite @ 600 kg ha ⁻¹	4.40	0.39	4.75	2.22
T ₇	Gypsum as per 100% GR + zeolite @ 300 kg ha ⁻¹	4.43	0.40	4.80	2.23
T ₈	Gypsum as per 50% GR + zeolite @ 300 kg ha ⁻¹	4.38	0.38	4.72	2.18
T ₉	Elemental sulphur as per 1/5 th of GR + zeolite @ 600 kg ha ⁻¹	4.37	0.37	4.68	2.17
T ₁₀	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 600 kg ha ⁻¹	4.33	0.35	4.64	2.09
T ₁₁	Elemental sulphur as per 1/5 th of GR + zeolite @ 300 kg ha ⁻¹	4.34	0.37	4.65	2.10
T ₁₂	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 300 kg ha ⁻¹	4.30	0.34	4.56	2.08
	SEm(±)	0.012	0.011	0.016	0.012
	CD at 5%	0.036	0.031	0.048	0.034
	Initial	4.53	0.42	5.07	2.58

The application of Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ registered significantly higher content of available copper (2.39 $\mu\text{g g}^{-1}$) and superior over rest of the treatments. The lowest Cu content was observed in the control treatment (1.86 $\mu\text{g g}^{-1}$). This increase might be due to the Cu content in organic sources (FYM).

4.4 Effect of Amendments on Nutrient Uptake in Subsurface Drainage Field At Harvest of Maize

The biomass production in maize crop grown on sodic soils under SSD field in terms of their fresh and dry matter yield mainly depends on nutrient availability, soil reaction, soluble/insoluble salts contents, soil drainability, moisture and soil structure. Sodicity makes the threat to interfere the above properties of soil thus influenced the biomass production of maize. The sodicity also led to interference in plant metabolic activities.

4.4.1 Effect of Amendments on Nutrient Uptake in Subsurface Drainage Field At Harvest of Maize

The total uptake of nutrients *viz.* nitrogen, phosphorus and potassium by maize crop grown on sodic soils in SSD field at harvest of maize as influenced by inorganic amendments are presented in Table 4.9.

Table 4.9 Effect of amendments on nutrient uptake in subsurface drainage field at harvest of maize

Sr. No.	Treatment	Total nutrient uptake (kg ha ⁻¹)		
		N	P	K
T ₁	Absolute control	62.87	7.65	46.7
T ₂	Gypsum as per 100% GR	121.78	19.42	123.82
T ₃	Elemental sulphur 1/5 th of GR	107.37	14.65	103.39
T ₄	Zeolite @ 600 kg ha ⁻¹	96.76	12.93	98.85
T ₅	Gypsum as per 100% GR + zeolite @ 600 kg ha ⁻¹	132.77	27.14	134.46
T ₆	Gypsum as per 50% GR + zeolite @ 600 kg ha ⁻¹	122.12	20.45	124.64
T ₇	Gypsum as per 100% GR + zeolite @ 300 kg ha ⁻¹	125.65	22.72	128.11
T ₈	Gypsum as per 50% GR + zeolite @ 300 kg ha ⁻¹	119.19	18.98	122.89
T ₉	Elemental sulphur as per 1/5 th of GR + zeolite @ 600 kg ha ⁻¹	112.51	16.32	111.87
T ₁₀	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 600 kg ha ⁻¹	106.02	14.86	106.74
T ₁₁	Elemental sulphur as per 1/5 th of GR + zeolite @ 300 kg ha ⁻¹	110.46	15.14	110.92
T ₁₂	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 300 kg ha ⁻¹	100.37	13.39	99.11
	SEm(±)	2.13	1.421	1.866
	CD at 5%	6.561	4.431	5.516

The sodic soil ameliorated with Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ recorded significantly higher uptake of nitrogen, phosphorus and potassium at harvest by maize (132.77, 27.14 and 134.46 kg ha⁻¹ respectively). The increased nutrient uptake by maize on sodic soils by gypsum application might be because of gypsum provides the sufficient amount of calcium in soil and soil solution, these calcium exchange the excesses sodium from exchange site of clay and leached out through SSD system from soil. The replacement of sodium from sodic soil decreased soil pH, electrical conductivity, improves the chemical and physical properties of

soil, as well as workability of soil. These factors make the congenial condition in rhizosphere for nutrient absorption by maize crop. Similar results were observed by Jadhao *et al.* (2003).

The nitrogen uptake by maize was significantly higher (132.77 kg ha⁻¹) in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹, whereas other gypsum containing treatments i.e. T₂, T₆, T₇ and T₈ (121.78, 122.12, 125.65 and 119.19 kg ha⁻¹, respectively) were statistically at par with each other. The less uptake of nitrogen might be because the treatment of ameliorating the sodic soil has less effect of replacing the sodium from exchange site of sodic soils and their less from soil through leaching. The high concentration of sodium chloride inhibit the nitrogen uptake and the excess amount of adsorbed sodium depressed ammonium (NH₄⁺) absorption. Reduction in root permeability and consequent decrease in water and nutrient uptake under high salt concentration. Increase in chloride uptake and accumulation is after accompanied by a decrease in shoot NO₃⁻ of many crops.

The phosphorus uptake by maize was significantly higher in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ (27.14 kg ha⁻¹) and significantly highest over all the treatments, whereas other gypsum containing treatments i.e. T₂, T₆, T₇ and T₈ (19.42, 20.45, 22.72 and 18.98 kg ha⁻¹, respectively) were statistically at par with other.

The potassium uptake by maize in different treatments showed similar trend to that of nitrogen and phosphorus uptakes. The potassium uptake by maize in treatments was significantly higher in Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ (134.46 kg ha⁻¹) were found significantly highest over all the treatments, whereas other gypsum containing treatments i.e. T₂, T₆, T₇ and T₈ (123.82, 124.64, 128.11 and 122.89 kg ha⁻¹, respectively) were statistically at par with each other. The effect of chemical amendments used in SSD field might be due to reclamation of sodic soils which improve properties of soil for growth of crops.

4.4.2 Effect of Amendments on Micronutrient Uptake in Subsurface Drainage Field At Harvest of Maize

The uptake of micronutrients *viz.*, Fe, Mn, Zn and Cu by maize crop grown on sodic soils in SSD field at harvest of maize as influenced by inorganic amendments are presented in Table 4.10.

The micronutrients *viz.*, Fe, Mn, Zn and Cu uptake was significantly superior in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ in maize (2034, 1443, 1134 and 805 g ha⁻¹). The iron uptake by maize in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ was found significantly highest (2034 g ha⁻¹) over all the treatments, whereas other gypsum applied treatments i.e. T₂, T₆, T₇ and T₈ (1876, 1888, 1907 and 1870 g ha⁻¹, respectively) were statistically at par with each other.

Table 4.10 Effect of amendments on micronutrient uptake in subsurface drainage field at harvest of maize

Sr. No.	Treatment	Total micronutrient uptake (g ha ⁻¹)			
		Fe	Mn	Zn	Cu
T ₁	Absolute control	830	740	487	299
T ₂	Gypsum as per 100% GR	1876	1298	1008	708
T ₃	Elemental sulphur 1/5 th of GR	1696	1143	706	590
T ₄	Zeolite @ 600 kg ha ⁻¹	1587	1020	698	554
T ₅	Gypsum as per 100% GR + zeolite @ 600 kg ha ⁻¹	2034	1443	1134	805
T ₆	Gypsum as per 50% GR + zeolite @ 600 kg ha ⁻¹	1888	1306	1009	716
T ₇	Gypsum as per 100% GR + zeolite @ 300 kg ha ⁻¹	1907	1334	1018	728
T ₈	Gypsum as per 50% GR + zeolite @ 300 kg ha ⁻¹	1870	1267	989	698
T ₉	Elemental sulphur as per 1/5 th of GR + zeolite @ 600 kg ha ⁻¹	1768	1184	765	612
T ₁₀	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 600 kg ha ⁻¹	1716	1154	716	596
T ₁₁	Elemental sulphur as per 1/5 th of GR + zeolite @ 300 kg ha ⁻¹	1732	1176	734	607
T ₁₂	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 300 kg ha ⁻¹	1656	1141	692	584
	SEm(±)	43.124	34.22	39.54	14.51
	CD at 5%	118.3	102.7	100.1	42.49

The manganese uptake by maize in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ was significantly highest (1443 g ha⁻¹) over all the treatments, whereas other gypsum applied treatments i.e. T₂, T₆, T₇ and T₈ (1298, 1306, 1334 and 1267 g ha⁻¹, respectively) were statistically at par with each other.

The zinc uptake by maize in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ was found significantly highest (1134 g ha⁻¹) over all the treatments, whereas other gypsum applied treatments i.e. T₂, T₆, T₇ and T₈ (1008, 1009, 1018 and 989 g ha⁻¹, respectively) statistically at par with each other.

The copper uptake by maize in different treatments showed similar trend to that of other micronutrients uptake. The copper uptake by maize in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ was found significantly highest (805 g ha⁻¹) over all the treatments, whereas other gypsum applied treatments i.e. T₂, T₆, T₇ and T₈ (708, 716, 728 and 698 g ha⁻¹, respectively) statistically at par with each other.

The availability of micronutrients in salt affected soils is mainly controlled by soil pH, concentration of salts in the soil solution, organic matter content and the interaction between crops and micronutrients. Micronutrient availability in salt affected soils is very complex. These constraints of micronutrient availability in sodic soil might be overcome by amending with gypsum as per gypsum requirement. The addition of gypsum in sodic soils provides sufficient amount of calcium, which plays crucial role to replace the predominant Na^+ cation from exchange site. The exchanged Na^+ by Ca^{2+} of gypsum loss from soil leads to decrease the pH, ESP, SAR and increased CEC as well as avoid decomposition of organic matter from sodic soils. Preserving the organic matter in soil by replacing Na^+ by Ca^{2+} improves the soil aggregation, aeration and ultimately increased biodiversity. This might be reasons for the increased micronutrient uptake of maize crop. This result indicated that, none of the chemical amendments are comparable for micronutrient uptake of maize crop to gypsum amendment of sodic soil as per 100 per cent gypsum requirement. Similar results were observed by Jadhao *et al.* (2003).

4.5 Effect of Amendments on Yield of Maize in Subsurface Drainage Field

Sodic soils are soils which contains excess exchangeable sodium which adversely affects the most of crop plants. Adverse effects of sodic soil are the degradation of soil physical properties and nutritional properties with consequent reduction in crop growth significantly or entirely. Sodic soils can be improved by ameliorating with organic or inorganic amendments for their reclamation. The fundamental principle which governed the reclamation of sodic soils was the removal of part or most of exchangeable sodium and its replacement by calcium ions and other preferred cations such as Mg and K in the root zone. This involved the use of soluble calcium salt such as gypsum, calcium chloride, acid or acid forming substances, including elemental sulphur, iron pyrite and some time the use of calcium salt of low solubility like ground limestone. In view of use of chemical amendments were studied to improve the yield of maize grown on sodic soils in SSD field during 2019.

The grain and stover yield of maize on sodic soils in SSD field at harvest of maize as influenced by inorganic amendments are presented in Table 4.11.

The maize grains and stover yield was recorded significantly highest in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ (53.80 and 62.44 q ha⁻¹) over all the treatments. Whereas, treatments T₂ (49.31 and 59.34), T₆ (50.26 and 59.73), T₇ (51.14 and 60.03) and T₈ (49.10 and 58.17) were statistically at par with each other for yield of maize grains and stover. The higher yields in treatment of amendments might be associated directly to the nutritional effect and indirectly through improved soil physical and chemical properties. The results confirm the findings of several researchers who reported increased yield due to integrated use of gypsum. Similarly, the slight decrease in the pH of the soil due to the nitrification and acidification processes stimulated by application of fertilizers as well as by H^+ released by roots.

The addition of amendments (gypsum) had a profound influence on the exchangeable cations at all stages of crop growth. The increase in Ca, Mg and K by gypsum application with organics (FYM) due to dissolution of gypsum by the organic acid formed during decomposition of organics. This was attributed to improvement in sodicity problems by leaching Na through gypsum application which helped in better utilization of applied NPK nutrients there by increased the yields. In addition, installation of sub surface drainage in these soils directly helped in increasing the yield, by reducing water logging and removing the salts in the root zone and create favorable conditions in the root zone to take up more nutrients from the soil for optimum plant growth. The increase in yield mainly due to large quantity of salts which were harmful to crop growth have been removed and soil fertility has been increased to supply sufficient quantity of nutrients for crop growth and productivity (Basavaraja *et al.*, 2016).

Table 4.11 Effect of amendments on yield of maize in subsurface drainage field

Sr. No.	Treatment	Grain (q ha⁻¹)	Stover (q ha⁻¹)
T ₁	Absolute control	33.40	41.47
T ₂	Gypsum as per 100% GR	49.31	59.34
T ₃	Elemental sulphur 1/5 th of GR	44.50	54.57
T ₄	Zeolite @ 600 kg ha ⁻¹	41.95	50.24
T ₅	Gypsum as per 100% GR + zeolite @ 600 kg ha ⁻¹	53.80	62.44
T ₆	Gypsum as per 50% GR + zeolite @ 600 kg ha ⁻¹	50.26	59.73
T ₇	Gypsum as per 100% GR + zeolite @ 300 kg ha ⁻¹	51.14	60.03
T ₈	Gypsum as per 50% GR + zeolite @ 300 kg ha ⁻¹	49.10	58.17
T ₉	Elemental sulphur as per 1/5 th of GR + zeolite @ 600 kg ha ⁻¹	47.25	56.31
T ₁₀	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 600 kg ha ⁻¹	45.78	54.36
T ₁₁	Elemental sulphur as per 1/5 th of GR + zeolite @ 300 kg ha ⁻¹	46.46	55.61
T ₁₂	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 300 kg ha ⁻¹	44.62	53.77
	SEm(±)	0.743	0.677
	CD at 5%	2.178	1.985

4.6 Effect of Amendments on Characteristics of Leachate in Subsurface Drainage Field of Maize

In order to study the leaching behaviour of sodic soil in SSD field with different amendments *viz.* gypsum, elemental sulphur and zeolite. The data regarding the composition of leachate discussed under following heads.

4.6.1 Effect of Amendments on Periodical pH of Leachate in Subsurface Drainage Field of Maize

The pH values of leachate as influenced by inorganic amendments during leaching of sodic soil with water are presented in Table 4.12.

Table 4.12 Effect of amendments on periodical pH of leachate in subsurface drainage field of maize

Sr. No.	Treatment	pH of leachate		
		30 DAS	60 DAS	At harvest
T ₁	Absolute control	9.08	8.82	8.24
T ₂	Gypsum as per 100% GR	9.29	8.86	8.47
T ₃	Elemental sulphur 1/5 th of GR	9.16	8.63	8.46
T ₄	Zeolite @ 600 kg ha ⁻¹	9.10	8.52	8.40
T ₅	Gypsum as per 100% GR + zeolite @ 600 kg ha ⁻¹	9.42	9.17	8.98
T ₆	Gypsum as per 50% GR + zeolite @ 600 kg ha ⁻¹	9.32	9.02	8.64
T ₇	Gypsum as per 100% GR + zeolite @ 300 kg ha ⁻¹	9.38	9.12	8.86
T ₈	Gypsum as per 50% GR + zeolite @ 300 kg ha ⁻¹	9.23	8.92	8.56
T ₉	Elemental sulphur as per 1/5 th of GR + zeolite @ 600 kg ha ⁻¹	9.25	8.96	8.51
T ₁₀	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 600 kg ha ⁻¹	9.17	8.76	8.47
T ₁₁	Elemental sulphur as per 1/5 th of GR + zeolite @ 300 kg ha ⁻¹	9.23	8.80	8.50
T ₁₂	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 300 kg ha ⁻¹	9.14	8.69	8.46
	SEm(±)	0.021	0.032	0.085
	CD at 5%	0.062	0.094	0.249

The pH value of leachate was higher in first 30 DAS in all the treatments and decreasing thereafter 60 DAS and at harvest of maize. The treatments Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ and Gypsum as per 100% GR + zeolite @ 300 kg ha⁻¹ found superior all over the treatments and was at par with each other with pH value at 30 DAS (9.42 and 9.38), 60 DAS (9.17 and 9.12) and at harvest (8.98 and 8.86). The increased in pH values of leachates might be due to the content of more soluble salts in the leachate collected from sodic soil treated with amendments (Moazed and Sepaskha, 1987).

4.6.2 Effect of Amendments on Periodical Electrical Conductivity of Leachate In Subsurface Drainage Field of Maize

The electrical conductivity of leachate as influenced by inorganic amendments during leaching of sodic soil with water is presented in Table 4.13.

Table 4.13 Effect of amendments on periodical electrical conductivity of leachate in subsurface drainage field of maize

Sr. No.	Treatment	EC of leachate (dSm ⁻¹)		
		30 DAS	60 DAS	At harvest
T ₁	Absolute control	1.78	2.20	1.70
T ₂	Gypsum as per 100% GR	2.66	4.06	2.65
T ₃	Elemental sulphur 1/5 th of GR	2.14	3.45	2.35
T ₄	Zeolite @ 600 kg ha ⁻¹	2.10	2.90	1.97
T ₅	Gypsum as per 100% GR + zeolite @ 600 kg ha ⁻¹	3.15	4.37	2.86
T ₆	Gypsum as per 50% GR + zeolite @ 600 kg ha ⁻¹	2.89	4.12	2.67
T ₇	Gypsum as per 100% GR + zeolite @ 300 kg ha ⁻¹	3.08	4.25	2.78
T ₈	Gypsum as per 50% GR + zeolite @ 300 kg ha ⁻¹	2.76	4.08	2.74
T ₉	Elemental sulphur as per 1/5 th of GR + zeolite @ 600 kg ha ⁻¹	2.47	3.77	2.35
T ₁₀	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 600 kg ha ⁻¹	2.22	3.53	2.45
T ₁₁	Elemental sulphur as per 1/5 th of GR + zeolite @ 300 kg ha ⁻¹	2.35	3.69	2.42
T ₁₂	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 300 kg ha ⁻¹	2.18	3.48	2.32
	SEm(±)	0.168	0.123	0.106
	CD at 5%	0.524	0.361	0.312

The electrical conductivity of leachate was lowest in first 30 DAS in all the treatments thereafter increased at 60 DAS and then decreased at harvest of maize. The significantly highest electrical conductivity of leachate was recorded with the application of Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ at 30 DAS, 60 DAS and at harvest of maize (3.15, 4.37 and 2.86 dSm⁻¹, respectively) and was statistically at par with treatments T₂ (2.66, 4.06 and 2.65 dSm⁻¹, respectively), T₆ (2.89, 4.12 and 2.67 dSm⁻¹, respectively), T₇ (3.08, 4.25 and 2.78 dSm⁻¹, respectively) and T₈ (2.76, 4.08 and 2.74 dSm⁻¹, respectively). The increased in electrical conductivity of leachate might be due to the content of more soluble salts in the leachate

collected from sodic soil treated with amendments. Singh *et al.* (1980) is also in close scrutiny that gypsum application significantly reduces the electrical conductivity of soil solution.

4.6.3 Effect of Amendments on Periodical Calcium Content of Leachate in Subsurface Drainage Field of Maize

The calcium contents of leachate as influenced by inorganic amendments during leaching of sodic soil with water are presented in Table 4.14, which clearly indicates that the total calcium content in leachate was less in all the treatments than control.

Table 4.14 Effect of amendments on periodical calcium content of leachate in subsurface drainage field of maize

Sr. No.	Treatment	Ca ²⁺ of leachate (me L ⁻¹)		
		30 DAS	60 DAS	At harvest
T ₁	Absolute control	2.54	2.66	2.33
T ₂	Gypsum as per 100% GR	2.21	2.37	1.94
T ₃	Elemental sulphur 1/5 th of GR	2.41	2.53	2.15
T ₄	Zeolite @ 600 kg ha ⁻¹	2.50	2.60	2.19
T ₅	Gypsum as per 100% GR + zeolite @ 600 kg ha ⁻¹	2.00	2.20	1.75
T ₆	Gypsum as per 50% GR + zeolite @ 600 kg ha ⁻¹	2.18	2.32	1.86
T ₇	Gypsum as per 100% GR + zeolite @ 300 kg ha ⁻¹	2.12	2.25	1.81
T ₈	Gypsum as per 50% GR + zeolite @ 300 kg ha ⁻¹	2.20	2.35	1.89
T ₉	Elemental sulphur as per 1/5 th of GR + zeolite @ 600 kg ha ⁻¹	2.28	2.41	2.03
T ₁₀	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 600 kg ha ⁻¹	2.35	2.48	2.10
T ₁₁	Elemental sulphur as per 1/5 th of GR + zeolite @ 300 kg ha ⁻¹	2.31	2.45	2.08
T ₁₂	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 300 kg ha ⁻¹	2.38	2.53	2.12
	SEm(±)	0.073	0.067	0.070
	CD at 5%	0.225	0.206	0.209

The calcium content of leachate was higher in first 30 DAS in all the treatments and decreasing thereafter 60 DAS and at harvest of maize. The significantly lowest calcium removal was recorded with the application of Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ at 30 DAS, 60 DAS and at harvest of maize (2.00, 2.20 and 1.75 me L⁻¹, respectively) and was statistically at par with treatments T₂ (2.21, 2.37 and 1.94 me L⁻¹, respectively), T₆ (2.18, 2.32 and 1.86 me L⁻¹, respectively), T₇ (2.12, 2.25 and 1.81 me L⁻¹, respectively) and T₈ (2.20, 2.35

and 1.89 me L⁻¹, respectively). The leaching of calcium was less with the application of amendments than control, which indicate that the released calcium might be adsorbed on exchange complex. Hence amendments minimized the calcium losses during leaching (Satyanarayana, 1954).

4.6.4 Effect of Amendments on Periodical Magnesium Content of Leachate in Subsurface Drainage Field of Maize

The magnesium contents of leachate as influenced by inorganic amendments during leaching of sodic soil with water are presented in Table 4.15.

Table 4.15 Effect of amendments on periodical magnesium content of leachate in subsurface drainage field of maize

Sr. No.	Treatment	Mg ²⁺ of leachate (me L ⁻¹)		
		30 DAS	60 DAS	At harvest
T ₁	Absolute control	1.28	1.30	1.05
T ₂	Gypsum as per 100% GR	1.49	1.55	1.20
T ₃	Elemental sulphur 1/5 th of GR	1.38	1.43	1.12
T ₄	Zeolite @ 600 kg ha ⁻¹	1.35	1.38	1.11
T ₅	Gypsum as per 100% GR + zeolite @ 600 kg ha ⁻¹	1.58	1.66	1.29
T ₆	Gypsum as per 50% GR + zeolite @ 600 kg ha ⁻¹	1.53	1.60	1.23
T ₇	Gypsum as per 100% GR + zeolite @ 300 kg ha ⁻¹	1.55	1.63	1.26
T ₈	Gypsum as per 50% GR + zeolite @ 300 kg ha ⁻¹	1.51	1.58	1.22
T ₉	Elemental sulphur as per 1/5 th of GR + zeolite @ 600 kg ha ⁻¹	1.45	1.50	1.18
T ₁₀	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 600 kg ha ⁻¹	1.41	1.45	1.15
T ₁₁	Elemental sulphur as per 1/5 th of GR + zeolite @ 300 kg ha ⁻¹	1.43	1.47	1.16
T ₁₂	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 300 kg ha ⁻¹	1.40	1.44	1.13
	SEm(±)	0.04	0.04	0.32
	CD at 5%	0.12	0.14	0.10

The magnesium content of leachate was higher in first 30 DAS in all the treatments and decreasing thereafter 60 DAS and at harvest of maize. The highest magnesium removal was recorded with the application of Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ at 30 DAS, 60 DAS and at harvest of maize (1.58, 1.66 and 1.29 me L⁻¹, respectively) and was statistically at par with treatments T₂ (1.49, 1.55 and 1.20 me L⁻¹, respectively), T₆ (1.53, 1.60 and 1.23

me L⁻¹, respectively), T₇ (1.55, 1.63 and 1.26 me L⁻¹, respectively) and T₈ (1.51, 1.58 and 1.22 me L⁻¹, respectively). It was revealed that maximum amount of magnesium leached with gypsum amendments followed by elemental sulphur. It might be due to the release of magnesium from soil and removal of magnesium as MgCl₂ through leachate (Jadhao *et al.*, 2008).

4.6.5 Effect of Amendments on Periodical Sodium Content of Leachate in Subsurface Drainage Field of Maize

The sodium contents of leachate as influenced by inorganic amendments during leaching of sodic soil with water are presented in Table 4.16. Initially the leaching of sodium was higher in all treatments but decreased with time.

Table 4.16 Effect of amendments on periodical sodium content of leachate in subsurface drainage field of maize

Sr. No.	Treatment	Na ⁺ of leachate (me L ⁻¹)		
		30 DAS	60 DAS	At harvest
T ₁	Absolute control	7.38	16.38	10.78
T ₂	Gypsum as per 100% GR	18.07	38.07	27.10
T ₃	Elemental sulphur 1/5 th of GR	16.63	36.63	25.41
T ₄	Zeolite @ 600 kg ha ⁻¹	10.9	24.9	12.63
T ₅	Gypsum as per 100% GR + zeolite @ 600 kg ha ⁻¹	19.38	39.78	28.12
T ₆	Gypsum as per 50% GR + zeolite @ 600 kg ha ⁻¹	18.09	38.09	27.05
T ₇	Gypsum as per 100% GR + zeolite @ 300 kg ha ⁻¹	19.25	39.25	28.47
T ₈	Gypsum as per 50% GR + zeolite @ 300 kg ha ⁻¹	17.92	37.91	26.95
T ₉	Elemental sulphur as per 1/5 th of GR + zeolite @ 600 kg ha ⁻¹	17.75	37.65	26.17
T ₁₀	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 600 kg ha ⁻¹	16.97	36.97	25.86
T ₁₁	Elemental sulphur as per 1/5 th of GR + zeolite @ 300 kg ha ⁻¹	17.48	37.48	26.09
T ₁₂	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 300 kg ha ⁻¹	16.47	36.52	24.95
	SEm(±)	0.517	0.646	0.385
	CD at 5%	1.521	1.913	1.231

The sodium content of leachate was lowest in first 30 DAS in all the treatments thereafter increased at 60 DAS and then decreased at harvest of maize. The significantly highest sodium leaching was recorded with the application of Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ at 30 DAS, 60 DAS and at harvest of maize (19.38 , 39.78 and 28.12 me L⁻¹, respectively) and

was statistically at par with treatments T₂ (18.07, 38.07 and 27.10 me L⁻¹, respectively), T₆ (18.09, 38.09 and 27.05 me L⁻¹, respectively), T₇ (19.25, 39.25 and 28.47 me L⁻¹, respectively) and T₈ (17.92, 37.91 and 26.95 me L⁻¹, respectively). The adsorbed sodium on clay surface was easily replaced by the calcium of gypsum. Thus replaced sodium can be easily leached down in the form of soluble salts *viz.*, sodium sulphate or sodium chloride. The sodium content of elemental sulphur containing treatments was at par with each other. This might be due to the reaction between CaCO₃ and formation of H₂SO₃ which improves soil permeability, which allows maximum passage of water and ultimately the removal of sodium (Verma and Abrol, 1981).

4.6.6 Effect of Amendments on Periodical Potassium Content of Leachate in Subsurface Drainage Field of Maize

The potassium contents of leachate as influenced by inorganic amendments during leaching of sodic soil with water are presented in Table 4.17.

Table 4.17 Effect of amendments on periodical potassium content of leachate in subsurface drainage field of maize

Sr. No.	Treatment	K ⁺ of leachate (me L ⁻¹)		
		30 DAS	60 DAS	At harvest
T ₁	Absolute control	0.21	0.12	0.10
T ₂	Gypsum as per 100% GR	0.24	0.18	0.14
T ₃	Elemental sulphur 1/5 th of GR	0.23	0.17	0.12
T ₄	Zeolite @ 600 kg ha ⁻¹	0.22	0.15	0.11
T ₅	Gypsum as per 100% GR + zeolite @ 600 kg ha ⁻¹	0.25	0.20	0.15
T ₆	Gypsum as per 50% GR + zeolite @ 600 kg ha ⁻¹	0.24	0.18	0.14
T ₇	Gypsum as per 100% GR + zeolite @ 300 kg ha ⁻¹	0.24	0.19	0.14
T ₈	Gypsum as per 50% GR + zeolite @ 300 kg ha ⁻¹	0.24	0.16	0.13
T ₉	Elemental sulphur as per 1/5 th of GR + zeolite @ 600 kg ha ⁻¹	0.24	0.19	0.14
T ₁₀	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 600 kg ha ⁻¹	0.23	0.17	0.13
T ₁₁	Elemental sulphur as per 1/5 th of GR + zeolite @ 300 kg ha ⁻¹	0.24	0.18	0.14
T ₁₂	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 300 kg ha ⁻¹	0.23	0.16	0.12
	SEm(±)	0.005	0.003	0.005
	CD at 5%	0.016	0.041	0.024

The potassium content of leachate was higher in first 30 DAS in all the treatments and decreasing thereafter 60 DAS and at harvest of maize. The highest potassium removal was recorded with the application of Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ at 30 DAS, 60 DAS and at harvest of maize (0.25, 0.20 and 0.15 me L⁻¹, respectively) and was statistically at par with all the treatments except T₄ (Zeolite @ 600 kg ha⁻¹) and T₁ (Absolute control). It was observed that the removal of potassium was slightly more under the soil treated with gypsum and elemental sulphur. Replacement of Na⁺ and K⁺ by Ca²⁺ on the exchange site probably led to an increase in soluble Na⁺ and K⁺ (Majid *et al.*, 2013b). There was very little difference in the removal of potassium under the soil treated with amendments.

4.6.7 Effect of Amendments on Periodical Bicarbonate Content of Leachate in Subsurface Drainage Field of Maize

The data pertaining to the bicarbonate content in leachate as influenced by inorganic amendments are presented in Table 4.18, which emanated that there was continuous removal of bicarbonate through leachates but decrease with time.

Table 4.18 Effect of amendments on periodical bicarbonate content of leachate in subsurface drainage field of maize

Sr. No.	Treatment	HCO ₃ ⁻ of leachate (me L ⁻¹)		
		30 DAS	60 DAS	At harvest
T ₁	Absolute control	11.07	10.17	8.40
T ₂	Gypsum as per 100% GR	14.97	13.78	12.55
T ₃	Elemental sulphur 1/5 th of GR	13.17	11.96	10.83
T ₄	Zeolite @ 600 kg ha ⁻¹	12.00	10.35	9.80
T ₅	Gypsum as per 100% GR + zeolite @ 600 kg ha ⁻¹	16.53	14.63	13.47
T ₆	Gypsum as per 50% GR + zeolite @ 600 kg ha ⁻¹	15.40	13.82	12.63
T ₇	Gypsum as per 100% GR + zeolite @ 300 kg ha ⁻¹	15.53	13.96	12.87
T ₈	Gypsum as per 50% GR + zeolite @ 300 kg ha ⁻¹	14.83	12.94	12.20
T ₉	Elemental sulphur as per 1/5 th of GR + zeolite @ 600 kg ha ⁻¹	14.03	12.26	12.03
T ₁₀	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 600 kg ha ⁻¹	13.83	11.64	11.07
T ₁₁	Elemental sulphur as per 1/5 th of GR + zeolite @ 300 kg ha ⁻¹	13.93	12.02	12.00
T ₁₂	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 300 kg ha ⁻¹	12.80	11.96	10.77
	SEm(±)	0.629	0.535	0.477
	CD at 5%	1.882	1.725	1.305

The bicarbonate content of leachate was higher in first 30 DAS in all the treatments and decreasing thereafter 60 DAS and at harvest of maize. The significantly highest bicarbonate content removal was recorded with the application of Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ at 30 DAS, 60 DAS and at harvest of maize (16.53, 14.63 and 13.47 me L⁻¹, respectively) and was statistically at par with treatments T₂ (14.97, 13.78 and 12.55 me L⁻¹, respectively), T₆ (15.40, 13.82 and 12.63 me L⁻¹, respectively), T₇ (15.53, 13.96 and 12.87 me L⁻¹, respectively) and T₈ (14.83, 12.94 and 12.20 me L⁻¹, respectively). The maximum bicarbonate were leached out with gypsum and followed by elemental sulphur. This might be due to improvement in physical condition of soil and governs the enhancing of bicarbonate from soils. Sodium carbonate and sodium bicarbonate are relatively soluble can be removed by leaching (Chi *et al.*, 2012).

4.6.8 Effect of Amendments on Periodical Chloride Content of Leachate in Subsurface Drainage Field of Maize

The data pertaining to the chloride content in leachate as influenced by inorganic amendments are presented in Table 4.19 which revealed that the removal of chloride was more in first leachate in all treatments while it was decrease with time.

Table 4.19 Effect of amendments on periodical chloride content of leachate in subsurface drainage field of maize

Sr. No.	Treatment	Cl ⁻ of leachate (me L ⁻¹)		
		30 DAS	60 DAS	At harvest
T ₁	Absolute control	4.07	7.73	3.47
T ₂	Gypsum as per 100% GR	7.43	12.16	8.43
T ₃	Elemental sulphur 1/5 th of GR	6.03	9.58	6.45
T ₄	Zeolite @ 600 kg ha ⁻¹	5.43	8.77	4.93
T ₅	Gypsum as per 100% GR + zeolite @ 600 kg ha ⁻¹	8.37	13.13	9.37
T ₆	Gypsum as per 50% GR + zeolite @ 600 kg ha ⁻¹	7.83	12.07	8.83
T ₇	Gypsum as per 100% GR + zeolite @ 300 kg ha ⁻¹	8.13	12.42	9.13
T ₈	Gypsum as per 50% GR + zeolite @ 300 kg ha ⁻¹	7.15	11.98	8.10
T ₉	Elemental sulphur as per 1/5 th of GR + zeolite @ 600 kg ha ⁻¹	6.93	10.60	7.82
T ₁₀	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 600 kg ha ⁻¹	6.73	9.85	6.67
T ₁₁	Elemental sulphur as per 1/5 th of GR + zeolite @ 300 kg ha ⁻¹	6.87	10.53	7.73
T ₁₂	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 300 kg ha ⁻¹	6.03	9.68	6.58
	SEm(±)	0.421	0.396	0.487
	CD at 5%	1.234	1.164	1.430

The chloride content of leachate was lowest in first 30 DAS in all the treatments thereafter increased at 60 DAS and then decreased at harvest of maize. The significantly highest chloride content removal was recorded with the application of Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ at 30 DAS, 60 DAS and at harvest of maize (8.37, 13.13, 9.37 me L⁻¹, respectively) and was statistically at par with other gypsum containing treatments T₂ (7.43, 12.16 and 8.43 me L⁻¹, respectively), T₆ (7.83, 12.07 and 8.83 me L⁻¹, respectively), T₇ (8.13, 12.42 and 9.13 me L⁻¹, respectively) and T₈ (7.15, 11.98 and 8.10 me L⁻¹, respectively). The maximum removal of chloride through leachate was under the treatment containing gypsum followed by elemental sulphur. This indicated that the improvement in soil after adding amendments by which maximum amount of leachate were collected (Singh *et al.*, 1980).

4.6.9 Effect of Amendments on Periodical Sulphate Content of Leachate in Subsurface Drainage Field of Maize

The sulphate contents of leachate as influenced by inorganic amendments during leaching of sodic soil with water are presented in Table 4.20.

Table 4.20 Effect of amendments on periodical sulphate content of leachate in subsurface drainage field of maize

Sr. No.	Treatment	SO ₄ ²⁻ of leachate (me L ⁻¹)		
		30 DAS	60 DAS	At harvest
T ₁	Absolute control	2.34	4.17	3.21
T ₂	Gypsum as per 100% GR	6.45	14.98	7.34
T ₃	Elemental sulphur 1/5 th of GR	5.23	14.12	6.62
T ₄	Zeolite @ 600 kg ha ⁻¹	3.66	10.96	5.03
T ₅	Gypsum as per 100% GR + zeolite @ 600 kg ha ⁻¹	7.21	15.45	7.98
T ₆	Gypsum as per 50% GR + zeolite @ 600 kg ha ⁻¹	6.83	15.26	7.61
T ₇	Gypsum as per 100% GR + zeolite @ 300 kg ha ⁻¹	6.94	15.36	7.88
T ₈	Gypsum as per 50% GR + zeolite @ 300 kg ha ⁻¹	6.57	15.15	7.22
T ₉	Elemental sulphur as per 1/5 th of GR + zeolite @ 600 kg ha ⁻¹	6.02	14.38	7.08
T ₁₀	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 600 kg ha ⁻¹	5.65	14.25	6.73
T ₁₁	Elemental sulphur as per 1/5 th of GR + zeolite @ 300 kg ha ⁻¹	5.85	14.34	6.85
T ₁₂	Elemental sulphur as per 50% of 1/5 th GR + zeolite @ 300 kg ha ⁻¹	5.42	14.21	6.67
	SEm(±)	0.351	0.332	0.254
	CD at 5%	1.085	1.012	0.792

The sulphate content of leachate was higher in first 30 DAS in all the treatments thereafter decreased at 60 DAS and then increased at harvest of maize. The significantly highest sulphate content removal was recorded with the application of Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ at 30 DAS, 60 DAS and at harvest of maize (7.21, 15.45 and 7.98 me L⁻¹, respectively) and was statistically at par with other gypsum containing treatments T₂ (6.45, 14.98 and 7.34 me L⁻¹, respectively), T₆ (6.83, 15.26 and 7.61 me L⁻¹, respectively), T₇ (6.94, 15.36 and 7.88 me L⁻¹, respectively) and T₈ (6.57, 15.15 and 7.22 me L⁻¹, respectively). This might be due to sulphate contain in gypsum and removal of sulphate from soil as Na₂SO₄ through leachates. The highest removal of sulphate by amendment gypsum followed by elemental sulphur. Gypsum and elemental sulphur produced sulphate ions in the soil which replaced other anions from the colloidal surface and that is evident from the fact that greater amounts of sulphate in leachate were found in the treatment receiving higher dose of amendment (Yadav and Chippa, 2007).

5. SUMMARY AND CONCLUSIONS

A field experiment entitled, “Effect of amendment sources to reclaim the sodic soil under subsurface drainage system on yield and nutrient uptake of maize” was conducted at Instructional Farm of Post Graduate Institute, MPKV, Rahuri during *kharif* 2019. The results discussed in previous chapter are summarized as below

5.1. Effect of Amendments in SSD Field on Physical Properties of Sodic Soils At Harvest of Maize

The physical properties of soil i.e. bulk density and hydraulic conductivity of sodic soil in SSD field was significantly improved by application of inorganic amendments at harvest of maize. The bulk density of sodic soil was significantly less in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ at harvest of maize (1.50 Mg m⁻³) and was at par with treatment Gypsum as per 100% GR + zeolite @ 300 kg ha⁻¹ (1.51 Mg m⁻³). The hydraulic conductivity at harvest of maize was significantly higher (0.34 cm h⁻¹) in treatment of Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹.

5.2 Effect of Amendments on Chemical Properties of Sodic Soil At Harvest of Maize

5.2.1 Effect of Amendments in SSD Field on Exchangeable Cations of Sodic Soils At Harvest of Maize

The exchangeable calcium content after harvest of maize was significantly highest in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ (49.67 cmol (p⁺) kg⁻¹ soil) and was at par with the treatment Gypsum as per 100% GR + zeolite @ 300 kg ha⁻¹ (48.53 cmol (p⁺) kg⁻¹ soil).

The exchangeable magnesium content in sodic soil was found non significant by various amendments under SSD system. Numerically, it was highest in Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ (9.03 cmol (p⁺) kg⁻¹ soil) followed by elemental sulphur and zeolite.

The exchangeable sodium content in sodic soils in SSD field was found significantly lower in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ (6.82 cmol (p⁺) kg⁻¹ soil) and was statistically at par with treatment Gypsum as per 100% GR + zeolite @ 300 kg ha⁻¹ (6.98 cmol (p⁺) kg⁻¹ soil). The effects of various amendments in sodic soils under SSD system were statistically at par with each other for exchangeable potassium except treatment T₁ (Absolute control).

5.2.2 Effect of Amendments in SSD Field on ESP and SAR of Sodic Soil At Harvest of Maize

The exchangeable sodium percentage was significantly less in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ (10.42) and was statistically at par with Gypsum as per 100% GR + zeolite @ 300 kg ha⁻¹ (10.77). Sodium adsorption ratio was significantly lowest in

treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ (6.62) and was statistically at par with treatment Gypsum as per 100% GR + zeolite @ 300 kg ha⁻¹ (7.15).

5.2.3 Effect of Amendments in SSD Field on pHs, ECe and Cations in Saturation Paste Extract of Sodic Soil At Harvest of Maize

The pHs of saturation paste extract after harvest of maize was found significantly lower in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ (8.02) and was statistically at par with treatment Gypsum as per 100% GR + zeolite @ 300 kg ha⁻¹ (8.06). The electrical conductivity of saturation paste extract was recorded significantly lowest in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ (2.71 dSm⁻¹) and was statistically at par with treatment Gypsum as per 100% GR + zeolite @ 300 kg ha⁻¹ (2.73 dSm⁻¹).

The Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ was recorded significantly highest value of calcium content in saturation paste extract (6.88 meq L⁻¹) and was statistically at par with treatment Gypsum as per 100% GR + zeolite @ 300 kg ha⁻¹ (6.33 meq L⁻¹). The magnesium content in saturation paste extract of sodic soils in SSD field was found significantly highest in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ (6.85 meq L⁻¹) and was statistically at par with all the treatments except T₁ (Absolute control). The sodium content in saturation paste extract of sodic soil in SSD field at harvest of maize was found significantly lower in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ (17.34 meq L⁻¹) and was statistically at par with treatment Gypsum as per 100% GR + zeolite @ 300 kg ha⁻¹ (18.22 meq L⁻¹). The potassium content in saturation paste extract of sodic soil was significantly higher in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ (0.38 meq L⁻¹) and was at par with treatment Gypsum as per 100% GR + zeolite @ 300 kg ha⁻¹ (0.36 meq L⁻¹).

5.2.4 Effect of Amendment in SSD Field on Anion in Saturation Paste Extract of Sodic Soil At Harvest of Maize

The bicarbonate content in saturation paste extract of sodic soils in SSD field was found significantly less in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ (14.85 meq L⁻¹) and was statistically at par with treatment Gypsum as per 100% GR + zeolite @ 300 kg ha⁻¹ (14.88 meq L⁻¹). The chloride content in saturation paste extract of sodic soils in SSD field was found significantly less in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ (6.82 meq L⁻¹) and was statistically at par with treatment Gypsum as per 100% GR + zeolite @ 300 kg ha⁻¹ (7.15 meq L⁻¹). The non significant results of sulphate content in saturation paste extract was numerically less in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ (5.74 mg L⁻¹) and followed by treatment Gypsum as per 100% GR + zeolite @ 300 kg ha⁻¹ (6.59 me L⁻¹).

5.2.5 Effect of Amendment in SSD on Organic Carbon, CaCO₃ and CEC of Sodic Soils At Harvest of Maize

The organic carbon content of sodic soils in SSD field was significantly higher in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ (0.56) and at par with all the treatments except T₁ (Absolute control). The calcium carbonate content of sodic soil after harvest of maize as influenced by treatment elemental sulphur as per 1/5th of GR + zeolite @ 600 kg ha⁻¹ was found to record the significantly lower values of CaCO₃ (7.17%). The cation exchange capacity of sodic soil in SSD field was significantly increased by treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ at harvest of maize (65.47 cmol (p⁺) kg⁻¹ soil).

5.3 Effect of Amendments in SSD Field on Soil Available Nutrients At Harvest of Maize

The available nitrogen content in sodic soil at harvest of maize was significantly increased in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ (146.48 kg ha⁻¹) and was at par with treatment Gypsum as per 100% GR + zeolite @ 300 kg ha⁻¹ (143.35 kg ha⁻¹). The available phosphorus in sodic soil significantly increased at harvest of maize in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ (9.54 kg ha⁻¹) which was statistically at par with treatment Gypsum as per 100% GR + zeolite @ 300 kg ha⁻¹ (9.18 kg ha⁻¹). The available potassium in sodic soil at harvest of maize was recorded highest in the treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ (445.69 kg ha⁻¹) and was statistically at par with treatment Gypsum as per 100% GR + zeolite @ 300 kg ha⁻¹ (435.84 kg ha⁻¹).

5.4 Effect of Amendments in SSD Field on Soil Available Micronutrients At Harvest of Maize

Among the treatments, application of Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ registered significantly higher content of available Fe (4.46 µg g⁻¹) and was at par with treatment Gypsum as per 100% GR + zeolite @ 300 kg ha⁻¹ (4.43 µg g⁻¹). The application of Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ registered significantly higher content of available zinc (0.42 µg g⁻¹) over all the treatments. The treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ registered significantly higher content of available manganese (4.83 µg g⁻¹) and was at par with treatment Gypsum as per 100% GR + zeolite @ 300 kg ha⁻¹ (4.80 µg g⁻¹). The treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ registered significantly higher content of available copper (2.39 µg g⁻¹) and superior over rest of the treatments.

5.5 Effect of Amendments in SSD Field on Nutrient Uptake

5.5.1 Effect of Amendments in SSD Field on Nutrient Uptake of Maize

The sodic soil ameliorated with Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ recorded significantly higher uptake of nitrogen, phosphorus and potassium at harvest by maize (132.77, 27.14 and 134.46 kg ha⁻¹, respectively) and superior over all the treatments.

5.5.2 Effect of Amendments in SSD Field on Micronutrient Uptake of Maize

The uptake of micronutrients *viz.* Fe, Mn, Zn and Cu was significantly superior in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ by maize (2034, 1443, 1134 and 805 g ha⁻¹, respectively) and found significantly highest over all the treatments

5.6 Effect of Amendments in SSD Field on Yield of Maize

The grain and stover yield of maize on sodic soils in SSD field was significantly influenced by use of amendments. The maize grains and stover yield were recorded significantly highest in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ (53.80 and 62.44 q ha⁻¹) over all the rest of treatments.

5.7 Effect of Amendments on Characteristics of Leachate in SSD Field of Maize

5.7.1 Effect of Amendments on Periodical pH of Leachate in SSD Field of Maize

The treatments Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ and Gypsum as per 100% GR + zeolite @ 300 kg ha⁻¹ found superior all over the treatments with pH values at 30 DAS (9.42 and 9.38), 60 DAS (9.17 and 9.12) and at harvest (8.98 and 8.86).

5.7.2 Effect of Amendments on Periodical Electrical Conductivity of Leachate in SSD Field of Maize

The electrical conductivity of leachate was lowest in first 30 DAS in all the treatments thereafter increased at 60 DAS and then decreased at harvest of maize. The electrical conductivity of leachate at 30 DAS, 60 DAS and at harvest of maize significantly higher in treatment Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ (3.15, 4.37 and 2.86 dSm⁻¹, respectively).

5.7.3 Effect of Amendments on Periodical Calcium Content of Leachate in SSD Field of Maize

The calcium content of leachate was higher in first 30 DAS in all the treatments and decreasing thereafter 60 DAS and at harvest of maize. The significantly lowest calcium removal was recorded with the application of Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ at 30 DAS, 60 DAS and at harvest of maize (2.00, 2.20 and 1.75 me L⁻¹, respectively).

5.7.4 Effect of Amendments on Periodical Magnesium Content of Leachate in SSD Field of Maize

The magnesium content of leachate was higher in first 30 DAS in all the treatments and decreasing thereafter 60 DAS and at harvest of maize. The highest magnesium removal was recorded with the application of Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ at 30 DAS, 60 DAS and at harvest of maize (1.58, 1.66 and 1.29 me L⁻¹, respectively).

5.7.5 Effect of Amendments on Periodical Sodium Content of Leachate in SSD Field of Maize

The sodium content of leachate was lowest in first 30 DAS in all the treatments thereafter increased at 60 DAS and then decreased at harvest of maize. The significantly highest sodium removal was recorded with the application of Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ at 30 DAS, 60 DAS and at harvest of maize (19.38, 39.78 and 28.12 me L⁻¹, respectively).

5.7.6 Effect of Amendments on Periodical Potassium Content of Leachate in SSD Field of Maize

The potassium content of leachate was higher in first 30 DAS in all the treatments and decreasing thereafter 60 DAS and at harvest of maize. The highest potassium removal was recorded with the application of Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ at 30 DAS, 60 DAS and at harvest of maize (0.25, 0.20 and 0.15 me L⁻¹, respectively) and was statistically at par with all the treatments except application of Zeolite @ 600 kg ha⁻¹ and Absolute control.

5.7.7 Effect of Amendments on Periodical Bicarbonate Content of Leachate in SSD Field of Maize

The bicarbonate content of leachate was higher in first 30 DAS in all the treatments and decreasing thereafter 60 DAS and at harvest of maize. The significantly highest bicarbonate content removal was recorded with the application of Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ at 30 DAS, 60 DAS and at harvest of maize (16.53, 14.63 and 13.47 me L⁻¹, respectively).

5.7.8 Effect of Amendments on Periodical Chloride Content of Leachate in SSD Field of Maize

The chloride content of leachate was lowest in first 30 DAS in all the treatments thereafter increased at 60 DAS and then decreased at harvest of maize. The highest chloride content removal was recorded with the application of Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ at 30 DAS, 60 DAS and at harvest of maize (8.37, 13.13, 9.37 me L⁻¹, respectively).

5.7.9 Effect of Amendments on Periodical Sulphate Content of Leachate in SSD Field of Maize

The sulphate content of leachate was lowest in first 30 DAS in all the treatments thereafter increased at 60 DAS and then decreased at harvest of maize. The highest sulphate content removal was recorded with the application of Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ at 30 DAS, 60 DAS and at harvest of maize (7.21, 15.45 and 7.98 me L⁻¹, respectively).

5.8 Conclusion

The results discussed in earlier chapter on the basis it can be concluded that application of Gypsum as per 100% GR + zeolite @ 600 kg ha⁻¹ found beneficial for reclamation of sodic soil, nutrient uptake and yield of maize crop in subsurface drainage field. The effect application of amendments with FYM before one month + GRDF of maize grown in sodic soil under

subsurface drainage system are beneficial to harvest the higher yield of maize, nutrient uptake, improvement of soil health *viz.*, physical condition (bulk density and hydraulic conductivity), chemical properties (pH, EC, exchangeable cations, pHs, ECe, soluble cations and anions, organic carbon, CaCO₃, soil available NPK and micronutrients) and maximum soluble salt leached out through sub surface drainage system. The conclusion drawn is on the basis of one year crop experiment and needs confirmation by conducting further more multiplication trials.

6. LETERATURE CITED

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7. VITAE

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IN
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2021

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