

**SPATIAL AND TEMPORAL DISTRIBUTION OF  
SALTS IN THE SOILS OF VINEYARD AT  
BAGALKOT**

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**DEPARTMENT OF SOIL SCIENCE AND  
AGRICULTURAL CHEMISTRY  
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UNIVERSITY OF HORTICULTURAL SCIENCES  
BAGALKOT- 587 104**

**2019**

**SPATIAL AND TEMPORAL DISTRIBUTION OF  
SALTS IN THE SOILS OF VINEYARD AT  
BAGALKOT**

*Thesis submitted to the  
University of Horticultural Sciences, Bagalkot  
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**Master of Science (Horticulture)**

In

**SOIL SCIENCE AND AGRICULTURAL CHEMISTRY**

*By*

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COLLEGE OF HORTICULTURE, BAGALKOT  
DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL  
CHEMISTRY**

**CERTIFICATE**

This is to certify that the thesis entitled “**SPATIAL AND TEMPORAL DISTRIBUTION OF SALTS IN THE SOILS OF VINEYARDS AT BAGALKOT**” submitted by **MISS PALLAVI C N, ID No. UHS17PGM928** for the Degree of **MASTER OF SCIENCE (HORTICULTURE)** in **SOIL SCIENCE AND AGRICULTURAL CHEMISTRY** to the University of Horticultural Sciences, Bagalkot is a record of bonafide research work carried out by her during the period of her study at University of Horticultural Sciences, Bagalkot under my guidance, supervision and the thesis has not previously been formed the basis for the award of any other degree, diploma, associateship, fellowship or similar titles.

**Place: Bagalkot**

**Date: August, 2019**

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*Affectionately Dedicated*

*to*

*My Beloved Parents*

*Smt. Lakshmi*

*Sri. Narayana*

*and*

*My sister*

*Pavithra*



## CONTENTS

Sl. No.	Particulars	Page No.
	CERTIFICATE	iii
	ACKNOWLEDGEMENT	iv-v
	LIST OF TABLES	ix-x
	LIST OF FIGURES	xi-xii
<b>1.</b>	<b>INTRODUCTION</b>	<b>1-3</b>
<b>2.</b>	<b>REVIEW OF LITERATURE</b>	<b>4-19</b>
	2.1 Formation of saline soils	4-6
	2.2 Electrochemical properties	6-10
	2.3 Water soluble ions	10-12
	2.4 Spatial and temporal distribution of salts in soil	12-17
	2.5 Soil salinity effects on grapevine	17-19
<b>3.</b>	<b>MATERIAL AND METHODS</b>	<b>20-23</b>
	3.1 General description of the study area	20
	3.2 Survey based soil salinity assessment	20
	3.3 Irrigation water quality assessment	21
	3.4 Detailed study on salinity parameters of a grape vineyard	21
	3.5 Analysis of soil and water samples for salinity parameters	21
	3.6 Statistical analysis	23

<b>Sl. No.</b>	<b>Particulars</b>	<b>Page No.</b>
<b>4.</b>	<b>EXPERIMENTAL RESULTS</b>	<b>24-62</b>
	4.1 Survey based soil salinity assessment	24-26
	4.2 Irrigation water quality assessment	26-29
	4.3 Soil reaction (pH)	29
	4.4 Electrical conductivity (EC <sub>1:2</sub> )	29-35
	4.5 Water soluble cations	35-50
	4.6 Water soluble anions	50-62
<b>5.</b>	<b>DISCUSSION</b>	<b>63-77</b>
	5.1 Assessment of vineyard soils and ground water samples for salinity	63-64
	5.2 Soil reaction (pH)	64-65
	5.3 Electrical Conductivity (EC <sub>2.5</sub> )	65-66
	5.4 Water soluble cations	67-72
	5.5 Water soluble anions	72-77
<b>6.</b>	<b>SUMMARY AND CONCLUSION</b>	<b>78-85</b>
<b>7.</b>	<b>REFERENCES</b>	<b>86-99</b>

## LIST OF TABLES

Table No.	Title	Page No.
1	Soil salinity parameters of 69 vineyards surveyed in and around Bagalkot	25
2	Salinity parameters of 20 groundwater samples surveyed in and around Bagalkot	27
3	a. pH of surface soils (0-20cm) of vineyard at different elevations, distances and seasons	30
	b. pH of subsurface soils (20-40cm) of vineyard at different elevations, distances and seasons	31
4	a. Electrical conductivity ( $\text{dS m}^{-1}$ ) of surface soils (0-20cm) of vineyard at different elevations, distances and seasons	32
	b. Electrical conductivity ( $\text{dS m}^{-1}$ ) subsurface soils (20-40cm) of vineyard at different elevations, distances and seasons	33
5	a. Water soluble $-\text{Ca}^{2+}$ ( $\text{me l}^{-1}$ ) in surface soils (0-20cm) of grape vineyard at different elevations, distances and seasons	36
	b. Water soluble $-\text{Ca}^{2+}$ ( $\text{me l}^{-1}$ ) in subsurface soils (20-40cm) of vineyard at different elevations, distances and seasons	37
6	a. Water soluble $-\text{Mg}^{2+}$ ( $\text{me l}^{-1}$ ) in surface soils (0-20cm) of grape vineyard at different elevations, distances and seasons	39
	b. Water soluble $-\text{Mg}^{2+}$ ( $\text{me l}^{-1}$ ) in subsurface soils (20-40cm) of vineyard at different elevations, distances and seasons	40
7	a. Water soluble $-\text{Na}^{+}$ ( $\text{me l}^{-1}$ ) in surface soils (0-20cm) of grape vineyard at different elevations, distances and seasons	42
	b. Water soluble $-\text{Na}^{+}$ ( $\text{me l}^{-1}$ ) in subsurface soils (20-40cm) of vineyard at different elevations, distances and seasons	43
8	a. Water soluble $-\text{K}^{+}$ ( $\text{me l}^{-1}$ ) in surface soils (0-20cm) of grape vineyard at different elevations, distances and seasons	45
	b. Water soluble $-\text{K}^{+}$ ( $\text{me l}^{-1}$ ) in subsurface soils (20-40cm) of vineyard at different elevations, distances and seasons	46

<b>Table No.</b>	<b>Title</b>	<b>Page No.</b>
9	a. Water soluble total cations ( $\text{me l}^{-1}$ ) in surface soils (0-20cm) of grape vineyard at different elevations, distances and seasons	48
	b. Water soluble total cations in subsurface soils (20-40cm) of vineyard at different elevations, distances and seasons	49
10	a. Water soluble total carbonates ( $\text{me l}^{-1}$ ) in surface soils (0-20cm) of grape vineyard at different elevations, distances and seasons	52
	b. Water soluble total carbonates ( $\text{me l}^{-1}$ ) in subsurface soils (20-40cm) of vineyard at different elevations, distances and seasons	53
11	a. Water soluble – $\text{SO}_4^{2-}$ ( $\text{me l}^{-1}$ ) in surface soils (0-20cm) of grape vineyard at different elevations, distances and seasons	55
	b. Water soluble – $\text{SO}_4^{2-}$ ( $\text{me l}^{-1}$ ) in subsurface soils (20-40cm) of vineyard at different elevations, distances and seasons	56
12	a. Water soluble – $\text{Cl}^-$ ( $\text{me l}^{-1}$ ) in surface soils (0-20cm) of grape vineyard at different elevations, distances and seasons	57
	b. Water soluble - $\text{Cl}^-$ ( $\text{me l}^{-1}$ ) in subsurface soils (20-40cm) of vineyard at different elevations, distances and seasons	58
13	a. Water soluble total anions ( $\text{me l}^{-1}$ ) in surface soils (0-20cm) of grape vineyard at different elevations, distances and seasons	60
	b. Water soluble total anions in subsurface soils (20-40cm) of vineyard at different elevations, distances and seasons	61

## LIST OF FIGURES

Figure No.	Title	Between pages
1	Depiction of the study area in Karnataka and weather data of the experimental site	21-22
2	a. Aerial image of experimental site	21-22
	b. Contour map of experimental site	21-22
3	Pictorial representation of spatial distribution of grape plants, drip points, moisture fringe and soil sampling points	21-22
4	Soil salinity parameters of 69 vineyards surveyed in and around Bagalkot	64-65
5	Salinity parameters of 20 groundwater samples surveyed in and around Bagalkot	64-65
6	a. pH of surface soils (0-20cm) of vineyard at different elevations, distances and seasons	64-65
	b. pH of subsurface soils (20-40cm) of vineyard at different elevations, distances and seasons	64-65
7	a. Electrical conductivity ( $\text{dS m}^{-1}$ ) of surface soils (0-20cm) of vineyard at different elevations, distances and seasons	66-67
	b. Electrical conductivity ( $\text{dS m}^{-1}$ ) subsurface soils (20-40cm) of vineyard at different elevations, distances and seasons	66-67
8	a. Water soluble $-\text{Ca}^{2+}$ ( $\text{me l}^{-1}$ ) in surface soils (0-20cm) of grape vineyard at different elevations, distances and seasons	68-69
	b. Water soluble $-\text{Ca}^{2+}$ ( $\text{me l}^{-1}$ ) in subsurface soils (20-40cm) of vineyard at different elevations, distances and seasons	68-69
9	a. Water soluble $-\text{Mg}^{2+}$ ( $\text{me l}^{-1}$ ) in surface soils (0-20cm) of grape vineyard at different elevations, distances and seasons	68-69
	b. Water soluble $-\text{Mg}^{2+}$ ( $\text{me l}^{-1}$ ) in subsurface soils (20-40cm) of vineyard at different elevations, distances and seasons	68-69
10	a. Water soluble $-\text{Na}^{+}$ ( $\text{me l}^{-1}$ ) in surface soils (0-20cm) of grape vineyard at different elevations, distances and seasons	70-71
	b. Water soluble $-\text{Na}^{+}$ ( $\text{me l}^{-1}$ ) in subsurface soils (20-40cm) of vineyard at different elevations, distances and seasons	70-71
11	a. Water soluble $-\text{K}^{+}$ ( $\text{me l}^{-1}$ ) in surface soils (0-20cm) of grape vineyard at different elevations, distances and seasons	70-71
	b. Water soluble $-\text{K}^{+}$ ( $\text{me l}^{-1}$ ) in subsurface soils (20-40cm) of vineyard at different elevations, distances and seasons	70-71

<b>Figure No.</b>	<b>Title</b>	<b>Between pages</b>
12	a. Water soluble total cations ( $\text{me l}^{-1}$ ) in surface soils (0-20cm) of grape vineyard at different elevations, distances and seasons	72-73
	b. Water soluble total cations in subsurface soils (20-40cm) of vineyard at different elevations, distances and seasons	72-73
13	a. Water soluble total carbonates ( $\text{me l}^{-1}$ ) in surface soils (0-20cm) of grape vineyard at different elevations, distances and seasons	74-75
	b. Water soluble total carbonates ( $\text{me l}^{-1}$ ) in subsurface soils (20-40cm) of vineyard at different elevations, distances and seasons	74-75
14	a. Water soluble – $\text{SO}_4^{2-}$ ( $\text{me l}^{-1}$ ) in surface soils (0-20cm) of grape vineyard at different elevations, distances and seasons	74-75
	b. Water soluble – $\text{SO}_4^{2-}$ ( $\text{me l}^{-1}$ ) in subsurface soils (20-40cm) of vineyard at different elevations, distances and seasons	74-75
15	a. Water soluble – $\text{Cl}^-$ ( $\text{me l}^{-1}$ ) in surface soils (0-20cm) of grape vineyard at different elevations, distances and seasons	76-77
	a. Water soluble - $\text{Cl}^-$ ( $\text{me l}^{-1}$ ) in subsurface soils (20-40cm) of vineyard at different elevations, distances and seasons	76-77
16	a. Water soluble total anions ( $\text{me l}^{-1}$ ) in surface soils (0-20cm) of grape vineyard at different elevations, distances and seasons	76-77
	b. Water soluble total anions in subsurface soils (20-40cm) of vineyard at different elevations, distances and seasons	76-77

## I. INTRODUCTION

Grape (*Vitis vinifera* L.) is one of the most important fruit crop of India and contribute high economic returns. Grape cultivation is believed to have originated in Armenia near the Caspian sea in Russia. Later, it appears to have spread westward to Europe and eastward to Iran and Afghanistan during 1300 AD. It is an important fruit crop in peninsular India. The area under grape is estimated at 1.2 lakh ha (Anonymous, 2015) with an annual production of 28.22 lakh tonnes and productivity of 21.1 t ha<sup>-1</sup>. It is commercially grown in Maharashtra, Karnataka, Tamil Nadu, Andhra Pradesh, Punjab and Haryana states. In India, Maharashtra occupies the largest area (90,000 ha) followed by Karnataka (20,500 ha). In Karnataka, Vijayapura and Bagalkot are the major grape growing areas of Krishna valley. Monitoring and management of water and nutrients in soil and vines are the most important aspects in grape cultivation. Perennial fruit crops are heavy nutrient feeders and high yields can only be sustained through balanced nutrition (Vinod *et al.*, 2017).

In Krishna valley, salt affected soils represent a major limiting factor. Grape appears to be one of the most sensitive crops for soil salinity especially for toxicities of Na<sup>+</sup> and Cl<sup>-</sup>. The inhibition of grapevine growth and CO<sub>2</sub> assimilation by water deficit or salinity has been related to changes in stomatal conductance, electron transport rate, leaf water potential, chlorophyll fluorescence, osmotic potential and leaf ion concentrations (Walker *et al.*, 1997). Salinity inhibits plant growth in two phases- firstly, by limiting water uptake through an osmotic or water deficit effect arising from relatively high solute concentrations in the soil and secondly by ion uptake where it injures cells through ionic stress effects. However, grapevine response to salinity depends on several factors, such as rootstock-scion combination, irrigation system, soil type and climate. Hence, grafting on selected rootstocks is being practiced now all over the world. Which are tolerant to saline or calcareous soils.

Ever increasing demand for water due to expansion of irrigation agriculture, declining rainfall trends and increased portioning of water for ecosystem servicing have led to unsustainable levels of water consumption in many parts of the world. Thus, it is necessary to look for alternative water sources. Furthermore, the salt content of these recycled waters and the concentrations of specific salt ions (Na<sup>+</sup>, K<sup>+</sup>) is of paramount importance in relation to soil structure, vine performance and berry and wine

composition. Rising salinization of soil could pose a serious threat to grape growing because most irrigated vineyards, especially those deficit-irrigated are at risk due to dissolved salts in irrigation water. The deleterious effects of salinity on plant growth are caused by an osmotic effect in which the increase in soluble salt concentration of the soil solution imposes an osmotic drought on the plant and a toxic effect in which the tissue concentrations of the micronutrient chloride and the beneficial element sodium increase to toxic levels.

Soils are derived from chemical and physical weathering of rocks and other geological and organic materials. Thus, they always contain some soluble inorganic and organic compounds. Rain and irrigation practices can alter the salt balance and redistribute the salts to new areas and new levels. Application of soluble fertilizers, soil amendments, use of poor quality irrigation water and capillary rise of shallow saline groundwater can all contribute to the salinization of the soil layers. Plants also determine where salts accumulate in the vertical horizon of the soil profile (Rengasamy, 2010).

Crop growth responds to salinity in two phases: a continuous osmotic phase that inhibits the water uptake by plants due to osmotic pressure of saline soil solution lowering its potential energy (water always moving from a higher to lower potential energy levels); and a slower ionic phase when the accumulation of specific ions in the plant over a period of time leads to ion toxicity or ion imbalance. However, the interactions between root-zone environments and plant responses to increased osmotic pressure or specific ion concentrations in the field are complicated by many soil processes such as soil water dynamics, soil structural stability, solubility of compounds in relation to pH and pE (electron concentration related to redox potential) and nutrient and water movement in soil.

The topography influences the movement of salts from higher elevation to lower elevation only when there is enough water to carry the salts from higher topographical region to lower topographical region through surface and also surface flow of water. However, in few conditions when there is no surface flow of water and due to capillary rise the salts are deposited and salts are likely to be higher in case of higher elevation when compared to lower elevation. This is in contrast to the actual situation.

The drip irrigation has some proven advantages over other irrigation methods like conservation of water through reduced evaporation, deep percolation and runoff losses. As such, drip irrigation helps to achieve high production and productivity in most field trials (Peacock *et al*, 1977). It is mainly due to the ability of this technique to result in no or minimal matric stress that blunts the adverse effect of osmotic stress. In spite of this, researchers have engaged themselves to minimize the adverse effect of osmotic stress in drip irrigation. The additional advantage of this technique emerges from the fact that when either land or water or both resources are of poor quality, the system has functioned well with minimum adverse impact on crop production.

In spite of short-term advantages of drip irrigation, possible long term salt accumulation along the crop rows resulting from the inherent limitations in the leaching pattern of trickles is a cause of concern especially in arid zones with low rainfall. Drip irrigation can remove the salts from the active rootzone but not from the soils away from the root zone. Hence, salts tend to accumulate closer to the root zone horizontally, vertically and also at the wetting front close to the soil surface (Karlberg and Vries, 2004).

Soluble salts in the root-zone cause a decrease in the osmotic potential of the soil solution leading to water stress in the plant and excess of some specific ions can lead to nutritional imbalance for the plant. Accumulation of specific ions (mainly  $\text{Cl}^-$ ) in plant tissue can also lead to direct toxicity (Pasternak, 1987).

Considering the points regarding horizontal and vertical salt distribution in the drip irrigated vineyard across different elevations and seasons, a research topic entitled, 'Spatial and temporal distribution of salts in the soils of vineyard at Bagalkot' was undertaken with the following objectives:

1. Characterization of root zone soil salinity and irrigation water quality of different vineyards
2. To assess spatial and temporal variations in soil salinity of selected vineyards
3. To assess the influence of micro-topographic features on soil salinity

## 2. REVIEW OF LITERATURE

Salinity is the accumulation of salts which includes chlorides and sulphates of calcium, magnesium, sodium and potassium etc. in soil and water that impact on human and natural resources (e.g. plants, animals, aquatic ecosystems, water supplies, and agriculture). Saline soil is defined as having a high concentration of soluble salts especially chlorides and sulphates of Na, Ca, Mg and K. The electrical conductivity (EC) of the soil saturation extract of a saline soil is more than  $4 \text{ dS m}^{-1}$  at  $25^{\circ}\text{C}$ , exchangeable sodium percentage is less than 15 and pH is not more than 8.5 (Richards, 1954).

Saline soils have the presence of excessive concentration of natural soluble salts, primarily  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{CO}_3^{3-}$  sometimes  $\text{NO}_3^{3-}$  of  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$  and EC is  $> 4 \text{ dS m}^{-1}$ , but ESP and pH are  $<15 \text{ Cmolkg}^{-1}$  and 8.5 respectively. Soil Survey Division Staff (1995) grouped into five categories of saline soils; non-saline ( $\text{ECe} < 2 \text{ dS m}^{-1}$ ), very slightly saline ( $\text{ECe} 2 \text{ to } 4 \text{ dS m}^{-1}$ ), slightly saline ( $\text{ECe} 4 \text{ to } 8 \text{ dS m}^{-1}$ ) moderately saline ( $\text{ECe} 8 \text{ to } 16 \text{ dS m}^{-1}$ ) and strongly saline ( $\text{ECe} > 16 \text{ dS m}^{-1}$ ).

### 2.1 Formation of saline soils

Soils are considered as integral part of the landscape and their characteristics is governed by the landforms on which they are formed. Topography, an important soil forming factor, was first identified by Jenny (1941) based on its important role in the gains and losses of matter and energy.

The soil is a dynamic, structured, heterogeneous, discontinuous system that exists as organic and inorganic matrices formed by the biotic and abiotic processes. The physical and chemical weathering of minerals gradually releases the soluble connate salts which eventually form part of the soil profile and leads to accumulation of salt over time in the soils once physical phenomenon such as drainage and leaching fails.

Majority of the salt affected soils occur in lower valleys as the salts are transported from ridge areas along with flowing water. Topography influences local and regional microclimates by changing the pattern of precipitation, temperature, solar radiation and relative humidity which in turn determines the salinity. Thus, the type and amounts of salts, its cations/anions, plays an important role in determining the soil chemical and physical properties (Lal and Steward, 1990; Ghassemi *et al*, 1995). The

literature available on the formation, classification, causes, features, management etc are reviewed under different subheadings and presented in this section.

During the physical and chemical weathering process, salts are released from rocks and minerals of the earth crust. In humid areas, soluble salts are carried down through the soil profile percolating rainwater and ultimately transported to the sea. In arid regions, leaching is very limited. Therefore, salts tend to accumulate (Abrol and Fireman, 1977; Abrol and Bhumbla, 1978).

Sharma *et al.* (1987) reported that the aridity of the climate, basic parent material and topographical situations resulting in poor drainage were responsible for the formation of contemporary salt affected soils. High clay content and poor hydraulic conductivity were the other factors apart from the genetic factors responsible for secondary salinization in the soils irrigated by canals.

Rainfall may contain as high as 50 to 200 mg l<sup>-1</sup> of salts near the seacoast. This amount decreases rapidly as rain moves towards inland. Rain water is high in Na, Cl and Mg near the seacoast, whereas inland precipitation is dominated by calcium and magnesium sulphate (Szabolcs, 1989).

In another study on the influence of climatic factors in the salinization of Indian soils (Sen, 1958). Rainfall and annual temperature appear to have greater effect on soil salinization. Soluble salts will accumulate if evaporation exceeds total precipitation, either alone or in combination with irrigation. The origin of salinity directly or indirectly comes from water logging problems (Szabolcs, 1989). The intensity of salinity also depends on the soil type, hydrogeology, climatic condition, and irrigation practices.

Rao *et al.* (1995) found that the major source of environmental degradation in rural areas is the misapplication of yield increasing inputs like water, chemical fertilizers, and pesticides causing waterlogging, salinity and pollution of drinking water and loss of fish etc.

Salinization and alkalisation are time and space dynamic soil degradation processes that reduce the productivity of agricultural lands. Alkalisation results from the concentration and precipitation of water soluble salts such as chlorides, sulphates

and carbonates of sodium, magnesium or calcium on the soil surface in the subsoil and ground water (Metternicht, 2001).

Chandio *et al.* (2013) revealed that ground water depth and its quality play an important role in salinization and alkalization of soils in arid and semi-arid areas. Soil salinity occurs when the salt in soil profile is brought to the surface by rising water tables. They further stated that flood irrigation, improper irrigation management and inadequate drainage facilities will aggravate the problem of soil alkalization.

According to Chhabra (1996), accumulation of salts in soil takes place by following process: (a) Delta cycles pertaining to estuaries of rivers, (b) marine cycles, (c) continental cycles (d) Arterian cycles like volcanic eruption, and (d) Anthropogenic cycle related to the activities of man.

## **2.2 Electrochemical properties**

### **Soil reaction (Soil pH)**

pH is a measure of the acidity or alkalinity of a substance. The range of pH for most soils is from 4 to 10. Soil pH is considered the single most important chemical property of soil because it effects the availability of essential plant nutrients. Many researchers have reported the alkali or sodic soils are often associated with very high pH values ( $> 8.5$  and in some case, as high as 10).

Saline soils generally have a pH less than 8.5. Bear (1964) attributed such low pH in saline soils to the presence of electrolytes and negative adsorption of anions responsible for decrease in the thickness of the double layer and suppression of hydrolysis of adsorbed Na to same extent. As a result, the hydroxyl ion concentration goes down, leading to reduced pH.

Kamil and shainberg (1968) observed a higher pH in the absence of salts and attributed it to the production of more Al ions on the clay surface as a result of increased dehydroxylation of Al complex. These Al ions caused more Na ions to hydrolyse into solution, leading to a higher soil Ph. However, Nakayama (1970) reported that the high pH values is caused under field condition by Na bicarbonate-carbonate minerals present in alkali soils, which precipitate Ca and Mg carbonate during evaporation. In contrast, Gupta (1973) attributed the higher values of pH in a saturated paste (pHs) of alkali soils to the nature of electrolytes. The alkali soils contain

predominantly sodium carbonate and sodium bicarbonates which are weak electrolytes. On hydrolysis, the pH of weak electrolytes increased sharply. The higher concentration of sodium carbonate in alkali soils, which is the cause of high pH, was suggested to be originating by the reaction of exchangeable Na and  $\text{CaCO}_3$  in low  $\text{CO}_2$  and low salt system (Cruz-Romero and Coleman, 1975).

A study was carried out to characterize salt affected soils of Kaira district of Gujarat state. The values of ESP and pH were comparatively higher in lower layers of salt affected areas. Similarly calcium carbonates and soluble boron were also noted to be in salt affected areas. The salinity was mainly  $\text{Cl-SO}_4$  (Pathak and Patel, 1980).

Sunita *et al.* (2010) studied the characteristics of salt affected soils in Dodda Seebi tank command area of Karnataka. The soils were alkaline in reaction as pH in the surface soils (8.5 to 9.0) with a tendency to increase with depth.

The pH of salt affected soils of Vanivilas command area in Karnataka ranged from 8.5 to 11.0 (Mruthunjaya and Kenchanagowda, 1993) in Cauvery command area it was in the range of 8.1 to 10.1 (Srinivasa,1999) in Keliveli of Purna valley of Maharashtra it ranged from 7.5 to 9.7 (Kewade *et al.*, 2005) and the pH of soils of Purna command area ranged from 8.1 to 10.7 (More *et al.*,1988) and in Krishnagiri Reservoir Project (KRP) area and Mettur dam Ayacut area of Tamil Nadu it ranged from 8.6 to 10.00 (Jayakumar *et al.*,2012). While the pH of sodic soils in Kanpur regions of UP varied from 8.5 to 10.3 due to presence of soluble sodium carbonate and bicarbonate (Tiwari *et al.*,1983).

Samples from sodic soils of Karnal (Haryana) were investigated for the depth wise trend of soil pH by Kanwar and Sehgal (1962). They noticed that soil pH values were found to increase with the profile depth, which was quoted to be because of fluctuating water table and higher concentrations of sodium salts. Similar trend of results have been reported by Govindarajan *et al.* (1969) and Poonia and Bhumbla (1973). However, in clay loam soils and clay soils studied by Mediratta *et al.* (1985), the pH values decreased down the profile indicating the start of sodification process from the upper layers. In addition to the above definite trends, an irregular trend may also be observed, as noticed by More *et al.* (1988) in the salt affected soils of Purna Command Area of Maharashtra.

### Electrical conductivity (EC)

Electrical conductivity, the ability of a soil solution to carry electrical current, is used to measure soluble salt concentration and is reported in  $\text{dS m}^{-1}$ . If a solution extracted from saturated soil is  $4.0 \text{ dS m}^{-1}$  or greater, then the soil is saline. The pH of these soils is generally less than 8.5 and sodium make up less than 15% of the exchangeable cations. On the other hand sodic soils were low in total salts ( $< 4 \text{ dS m}^{-1}$ ) but high in pH ( $> 8.5$ ) and ESP ( $> 15\%$ ).

In another study, Sharma *et al.* (1968) also noticed a similar trend, where in EC value recorded in surface soil was zero and it was high as  $65 \text{ dS m}^{-1}$  at a depth of 100cm. high electrical conductivity in lower depths was mainly due to leaching of salts from the upper layers and their accumulation in the lower depths on account of irrigation (Balpande *et al.*, 1996). Sahu and Dash (1993) while characterizing salt affected soils of Orissa, noticed that profiles protected by embankments, EC values increased with the depth, while in the profile that was unprotected an opposite trend was noticed.

Li and Jeanloz (1990) found negative correlations between soil temperature and electrical conductivity of all the soils tested ( $r = 0.960$  to  $0.999$ ). When soil temperature was increased from  $0^\circ\text{C}$  to  $30^\circ\text{C}$ , the electrical conductivities of the soils decreased linearly from  $3.81$ - $9.73$  to  $1.78$ - $2.48$  percent respectively.

Mehta *et al.* (1981) diagnosed 230 soil samples from farmer's field with an EC (1:2.5) of more than  $2 \text{ dS m}^{-1}$  and pH more than 10 as alkali soils, though they could have been diagnosed as saline alkali soils.

Vijaya Kumar *et al.* (2013) noticed EC value of  $17.0 \text{ dS m}^{-1}$  in the surface layer and  $15.3 \text{ dS m}^{-1}$  in the subsurface soil layer in Ongole division of Prakasam district, AP. Similar results have been reported by many authors in various parts of India.

Coasta *et al.* (1991) reported that an increase in EC of irrigation water increased EC of saturation extract but carbonates and divalent ions reduced the EC of saturation extract due to precipitation of calcite and gypsum. They also observed irrigation water with higher SAR increased the EC of saturation extract, mainly due to higher sodium concentration relative to calcium and magnesium and the greater solubility of sodium salts than calcium and magnesium.

There are reports which shown no definite trend in the vertical distribution of EC value. Walia and Rao (1996) reported that the electrical conductivity of the black soils studied were very low ranging from 0.08 to 4 dS m<sup>-1</sup>. The electrical conductivity value of sodic soils in Keliveli of Purna valley of Maharashtra ranged from 0.17 to 0.80 dS m<sup>-1</sup> (Kewade *et al.*, 2005). In North Western zone of Tamil Nadu, it ranged from 0.2 to 1.2 dS m<sup>-1</sup> (Jayakumar *et al.*, 2012) and in Vanivilas Command Area of Karnataka it varied from 1.83 to 3.68 dS m<sup>-1</sup>. Singh *et al.* (2000) while characterizing the old alluvial soils reported that electrical conductivity of soils varied from 2 to 9.6 dS m<sup>-1</sup>.

The conditions facilitating accumulation of salts in the surface horizons and the absence of leaching from the surface to lower depths have been found to be responsible for increasing the trend of the EC values in profile stratum upwards, while leaching of salts by irrigation water to the deeper layers and absence of rapid capillary rise were responsible for lower EC value in the surface layer (Sharma *et al.*, 2004). While, Kharche *et al.*, (2010) reported that slight variation in EC with increasing depth due to leaching of salts from the surface through percolating water followed by evapotranspiration resulting in the accumulation of salts in the surface horizon.

Sunita *et al.* (2010) studied the characteristics of salt affected soils in Dodda Seebi tank command area of Karnataka. EC of the surface soils ranged from 1.94 to 2.78 dS m<sup>-1</sup> and found to increase below 30 cm depth owing to leaching and hydrolysis of salt on account of irrigation.

The salt affected soils in IGNP (Indira Gandhi Nahar Project) command, Rajasthan were neutral to slightly alkaline in soil reaction (pH 7.9 to 8.8). The EC values were moderate (9.3 dS m<sup>-1</sup>) to very high (40.3dS m<sup>-1</sup>) and decreased with depth (Mandal and Sharma, 2010).

The waterlogged and salt affected soils in Gandak command area of Bihar were severe alkaline in surface soil and moderately high pH (9.1) at subsurface level (70cm). The higher EC values (19.7dS m<sup>-1</sup>) were found at surface and decreased gradually to 0.4 dS m<sup>-1</sup> at a depth of 1m (Sharma *et al.*, 2011).

Vijaya Kumar *et al.* (2013) studied the salt affected soils of Ongole division, Prakasam district (Andra Pradesh) were neutral to strongly alkaline (pH 6.5 to 9.1) in

action having electrical conductivity value higher in surface soils (17.0) than subsurface soil (15.3 dS m<sup>-1</sup>).

### 2.3 Water soluble ions:

The determination of water soluble ions in soils is important in irrigated areas to know the salt content of soils which leads to becoming saline or alkali. The water soluble salts are present in ionic form in aqueous solutions and are determined in saturation extract. The determination of water soluble ions in the saturation extract is considered to be more reliable because it is directly related to field moisture range.

Polara and Kabaria (2006) observed that water soluble cations (1:2.5 soil water extract) viz., Ca<sup>2+</sup>, Mg<sup>2+</sup>, Na<sup>+</sup> and K<sup>+</sup> of 220 surface salt affected soil samples collected from coastal Amreli district of Gujarat ranged from 0.8 to 30.1 me l<sup>-1</sup> with a mean value of 3.31 me l<sup>-1</sup>, 0.5 to 6.2 me l<sup>-1</sup> with a mean value of 1.42 me l<sup>-1</sup>, 0.7 to 120.1 me l<sup>-1</sup> with a mean value of 5.14 me l<sup>-1</sup> and 0.1 to 1.5 me l<sup>-1</sup>, with a mean value of 0.40 me l<sup>-1</sup>, respectively. They also reported that water soluble anions viz., CO<sub>3</sub><sup>-2</sup>, HCO<sub>3</sub><sup>-1</sup>, Cl<sup>-1</sup> and SO<sub>4</sub><sup>-2</sup> and they were ranged from 0.0 to 4.2 me l<sup>-1</sup> with a mean value of 0.4, 0.2 to 35.3 me l<sup>-1</sup> with a mean value of 2.43 me l<sup>-1</sup>, 0.4 to 100 me l<sup>-1</sup> with a mean value of 5.57 me l<sup>-1</sup> and 0.1 to 3.4 me l<sup>-1</sup> with a mean value of 1.06 me l<sup>-1</sup> respectively.

Polara and Chauhan (2015) studied the water soluble ions of 1:2.5 and water extract of the soils collected from each of 6 taluks of Gir Somnath district in Gujarat and reported that water soluble cations are Ca<sup>2+</sup>, Mg<sup>2+</sup>, Na<sup>+</sup> and K<sup>+</sup> ranged from 1.00 to 12.40 me l<sup>-1</sup> with a mean value of 2.43 me l<sup>-1</sup>, 0.30 to 4.60 me l<sup>-1</sup> with a mean value of 2.10 me l<sup>-1</sup>, 1.36 to 30.60 me l<sup>-1</sup> with a mean value of 6.83 me l<sup>-1</sup> and 0.01 to 0.54 me l<sup>-1</sup> with a mean value of 0.06 me l<sup>-1</sup>, respectively. They further noted that water soluble anions content are CO<sub>3</sub><sup>-2</sup>, HCO<sub>3</sub><sup>-1</sup>, Cl<sup>-1</sup> and SO<sub>4</sub><sup>-2</sup> were ranged from 0.00, 1.80 to 5.60 me l<sup>-1</sup> with a mean value of 3.33 me l<sup>-1</sup>, 1.40 to 36.70 me l<sup>-1</sup> with a mean value of 6.33 me l<sup>-1</sup> and 0.02 to 1.40 me l<sup>-1</sup> with a mean value of 0.43 me l<sup>-1</sup>, respectively. The above study revealed that Ca<sup>2+</sup> and Cl<sup>-1</sup> were dominant among water soluble ions.

Studies on the soluble ions of saturated extract (1:5) of soils collected from Sangamnar area of Ahmednagar district in Maharashtra revealed that the concentration of soluble cations were in the order of Na<sup>+</sup>>Ca<sup>2+</sup>>Mg<sup>2+</sup>>K<sup>+</sup> ranging from 0.36 to 280 me L<sup>-1</sup>, 0.54 to 43.50 me L<sup>-1</sup>, 0.18 to 48.75 me/L and 0.01 to 1.29 me L<sup>-1</sup>, respectively. The higher concentration of sodium in the study area was possibly due to precipitation of

Ca-Mg carbonate owing to high pH conditions. The study also revealed that the concentration of sodium was more than Ca and Mg indicating the process of alkalization in the shrinkswell type of soils that were predominant (Deshmukh, 2012). He also found that among the anions, chlorides were predominant followed by sulphates and bicarbonates in the soil. The  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$  and  $\text{HCO}_3^-$  ranged from 0.96 to 55.36 me  $\text{l}^{-1}$ , 0.01 to 12.07 me  $\text{l}^{-1}$  and 0.4 to 4.8 me  $\text{l}^{-1}$  respectively.

The soluble salts in saline soils mainly comprise the chlorides and sulphates of sodium, though calcium and magnesium are also present in appreciable quantities. Bicarbonates ion occur in very low amounts and carbonates are usually absent or occur only in traces in these soils (Dargan *et al.*, 1982)

Marsonia *et al.* (2008) reported that water soluble cations viz.,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$  and  $\text{K}^+$  of soils (1:2.5 soil water extract) collected from cultivated soils of Porbandar in Gujarat ranged from 0.6 to 16 me  $\text{l}^{-1}$  with a mean value of 2.65 me  $\text{l}^{-1}$ , 0.4 to 29 me  $\text{l}^{-1}$  with a mean value of 2.05 me  $\text{l}^{-1}$ , 1.25 to 54 me  $\text{l}^{-1}$  with a mean value of 7.95 me  $\text{l}^{-1}$  and 0.02 to 2.42 me  $\text{l}^{-1}$  with a mean value of 0.15 me  $\text{l}^{-1}$ , respectively. They also studied the concentration of soluble anions viz.,  $\text{CO}_3^{2-}$ ,  $\text{HCO}_3^-$ ,  $\text{Cl}^-$  and  $\text{SO}_4^{2-}$  and they were ranged from 0.02 to 2.8 me  $\text{l}^{-1}$  with a mean value of 1.08, 0.83 to 3 me  $\text{l}^{-1}$  with a mean value of 1.78 me  $\text{l}^{-1}$ , 1.6 to 82.8 me  $\text{l}^{-1}$  with a mean value of 8.86 me  $\text{l}^{-1}$  and 0.08 to 15.09 me  $\text{l}^{-1}$  with a mean value of 1.4 me  $\text{l}^{-1}$  respectively. He further stated that sodium content was higher followed by  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$  and  $\text{K}^+$  whereas among anions, chlorides were dominant followed by  $\text{HCO}_3^-$ ,  $\text{SO}_4^{2-}$  and least was  $\text{CO}_3^{2-}$ .

Anitha *et al.* (2001) revealed that water soluble cations viz.,  $\text{Na}^+$ ,  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  of saturation extract of soils collected at a depth of 0-20 cm from Konanki ORP site of Marturu mandal of Prakasham district of Andhra Pradesh ranged from 24.9 to 119 me  $\text{l}^{-1}$ , 0.75 to 41 me  $\text{l}^{-1}$ , and 0.25 to 36 me  $\text{l}^{-1}$  respectively. They also studied that water soluble anions viz.,  $\text{Cl}^-$ ,  $\text{CO}_3^{2-}$  and  $\text{HCO}_3^-$  of saturation extract ranged from 0.25 to 36 me  $\text{l}^{-1}$ , 1.0 to 16 and 1.0 to 24 me  $\text{l}^{-1}$  respectively. From the data, they further opined that sodium and chloride were the dominant in the saturation extract of soils .

In the saturation extract of salt affected soils of Vanivilas command area of Karnataka,  $\text{Na}^+$  (15.10 to 36.13 me  $\text{l}^{-1}$ ) was the dominant cation, while bicarbonate (9.30 to 16.30 me  $\text{l}^{-1}$ ) was the dominant anion followed by carbonate (0.40 to 9.10 me  $\text{l}^{-1}$ ),

chloride (3.20 to 13.50 me l<sup>-1</sup>) and sulphate (1.20 to 6.70 me l<sup>-1</sup>) (Mruthunjaya and Kenchanagowda, 1993).

Sahu and Dash (1993) observed that sodium and calcium are the most dominant cations in the saturation extract obtained from the salt affected coastal soils of Astaranga, Orissa. The proportion of magnesium increases in lower layers of pedon 3 and 4 due to their prolonged contact with marine brackish water, which has appreciable amount of chloride, a predominant anion followed by sulphate indicating the salts to be mostly of chloride and sulphate type of sodium with lesser quantity of calcium and magnesium in soils of coastal Orissa.

Bhargava, *et al.* (1981) while studying the sodic soils of Indo Gangetic alluvial plains of Hariyana concluded that sodium alone nearly account for the cations, while among the anions the order of decreasing abundance is bicarbonate, carbonate, chloride and sulphate. Similarly, Tiwari *et al.* (1983) indicated that in salt affected soils of alluvial regions of U.P. Sodium (dominant cation) is generally more in the surface soils. Carbonate happens to be the dominant anion followed by bicarbonate, chloride and sulphate.

#### **2.4 Spatial and temporal distribution of salts in soil**

Bhadrapur and Rao (1977) reported that the electrical conductivity and concentration of Na, Ca, Mg and chloride content decreased with depth of salt-affected black soils of Siruguppa (Karnataka). Poonia (1973) reported that E<sub>c</sub> of salt-affected soils was much higher than that of the normal soil profiles of Rohtak district (Punjab). He further noted that the E<sub>c</sub> was more in the surface layer which decreased downwards.

He *et al.* (2014) studied the vegetation restoration affected the profile distributions of soil moisture and salinity in various seasons in naturally salt-affected coastal saline land. The effect of vegetation restoration on the profile distributions of salt is significant. In control plots, soil moisture and salinity showed a clear seasonal trend. Soil moisture values were the highest in spring and the lowest in autumn, when values of soil salinity were the highest in summer and the lowest in winter. Relative to control plots, the seasonal trend of soil moisture and salinity under vegetation appeared to be complex for no clear trend was observed. It can be concluded that plant communities significantly affect the spatial–temporal distribution of soil salinity.

The spatial variation of soil salinity and sodicity is dependent on a number of factors viz., (i) landscape position, (ii) soil characteristics and (iii) amount of rainfall. High evaporation rate in the dry and hot climatic zone induces salt accumulation in the surface soil layers and negatively alter the soil structure, porosity and hydraulic conductivity (Kahlon *et al.*, 2012).

According to Bhadrapur and Rao (1977) the EC and concentration of ions, except sulphate, decreased with depth. The ESP values were found to be much higher as compared with those predicted from the ESP - SAR regression equation of the U.S. Salinity Laboratory.

Hossain *et al.* (2012) studied the seasonal variation of soil salinity in coastal areas of Bangladesh. Three coastal districts from three coastal regions (eastern, central and western) were selected purposively for the collection of soil samples during four different seasons (winter, pre-monsoon, monsoon and post-monsoon). Soil samples from nine coastal areas (3 in each district) were collected (during December, 2009 to November, 2010) to determine seasonal variation of soil salinity of coastal districts. Maximum soil salinity was observed in pre-monsoon, whereas, minimum was in monsoon in all coastal districts. It was observed that soil salinity starts increasing from post-monsoon and continued to increase in pre-monsoon when it reaches the highest level.

Zaka *et al.* (2003) revealed that salinity and sodicity in arid and semi-arid regions are the permanent problem due to the prevailing low rainfall and high temperature in these regions. The net soil water movement is upward direction and the salts dissolved in the soil water accumulate slowly and gradually on the surface of the soil. They further stated that water logging and salinity is due to the increase in channel irrigation and extensive exploitation of poor quality water for agriculture in non-canal commands. The condition of low rainfall, high temperature, high evaporation and low relative humidity will lead to the alkalisation of soils (Akram *et al.*, 2002).

Guo *et al.* (2014) conducted the research on relationship between spatial and temporal dynamics of major salt ions . A seasonal soil sampling was conducted from April to October 2011 in a salinized orchard soil in semiarid northwest China. Concentrations of total soluble salt and eight salt ions were measured every 2 weeks during the growing period of apple trees. Soil salt concentration increased along with

soil profile, particularly in the 60 to 120cm soil layer at all periods. The highest soil salt level was observed in period of July to October. The contents of  $\text{HCO}_3^-$ ,  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  were almost uniform in all soil layers, but the contents of  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$  and  $\text{Na}^+$  increased with soil layer. The content of  $\text{K}^+$  decreased from the upper to the deeper layers of soil profile. The distribution of  $\text{CO}_3^{2-}$  had a high temporal and spatial heterogeneity with soil depths and season.

Kaushik and Shukla (1977) while studying the development of salt-affected soils of Ganaur block in Sonapat district of Haryana found that soluble sodium was the predominant cation in the saturation extract of normal and salt-affected soils and chloride was the dominant anion in all the salt-affected profiles.

Continuous drip irrigation with saline water over the years leads to salinity in small area because drip irrigation involved in less coverage of cropped area. In drip irrigated field, EC values observed between the emitter, higher at the surface than in lower depths. Under the arid climate conditions, continuous saline water irrigation leads to annual salt build up at the surface thus scope of drip irrigation is limited (Paliwal, 1986).

Goldberg *et al.* (1971) conducted experiment I to record the salt distribution in drip irrigated vine yards in Israel. Soil samples were collected at different depths following the winter rains. Results shown that soils with a depth of 120 cm are leached by rains whereas, in arid zones with less rain fall may lead to salt accumulation.

A research was conducted to determine the salt accumulation in vineyards. Vineyards are drip irrigated with high quality water ( $0.05\text{-}0.15 \text{ dS m}^{-1}$ ). The six vineyards selected that had been drip irrigated between nine and eleven years and one for four years. Results concluded that Drip irrigation with high quality water did not show harmful build-up of root zone salinity even in nine and eleven years drip irrigated vineyards (Christen *et al.* 2007).

Munns and Tester, (2008) concluded that amount of water applied should be equal to evapotranspiration. This amount of water sufficient to provide localized leaching fraction of about 20-25 percent beneath the drip line. Amount of water applied is excess of evapotranspiration under shallow water table conditions may cause salt accumulation in the root zone.

Soil collected within the radius of 20 to 40 cm, either perpendicular or diagonal to the emitter of drip line will be the best reflect of amount of plant-available soil water. Data from research also suggest that spring soil moisture status depends on the winter precipitation patterns rather than the end of season water application (Davenport *et al.*, 2008).

Irrigation with the brackish water through the drip irrigation system leads to salt accumulation in the root zone, that can be reduced by alternating irrigation with fresh and brackish water through the drip irrigation system and also flood irrigation with the fresh water can be done to leach the accumulated salts nearer to the root zone thus reduce the secondary salinization (Wang *et al.*, 2013).

More *et al.* (1988) carried out an extensive survey to characterize the salt affected soils and found that the pH of soils ranged from 8.1 to 10.7 and CEC from 8.0 to 45 cmol (p+) kg<sup>-1</sup>. Calcium was the dominant cation in saline soils whereas Na was dominant in the sodic soils. E<sub>c</sub> were higher in surface layer and decreased down with depth in the profiles. Chlorides and sulphate were dominant in saturation extract of saline and saline-sodic soil profiles whereas bicarbonate content was relatively high in the saturation extract of sodic profile.

Rafie and Boraie (2017) studied the effect of drip irrigation system on moisture and salt distribution and concluded that higher discharge rate developed the higher salt concentration in the root zone and near the soil surface, due to shallow wetted depth, since water movement was directed horizontally rather than vertically. Capillary forces as well as the shallow wetted depth promote salt accumulation at the soil surface due to salt build up by evaporation components.

Evaluating drip, flood, and sprinkler irrigation of wine grapes (Peacock *et al.*, 1977) noticed that drip irrigation used less water while maintaining vine vigour, fruit production, and fruit quality similar to results with sprinkler or flood irrigation. Soil salt levels with sprinkling and flooding were similar but lower than observed with drip irrigation

Distribution of grape vine roots and salt under drip and full-groundcover micro jet irrigation systems (Stevens *et al.*, 1993 ) studied the three dimensional variation in root length density within the quarter of the planting area and they noticed that under

drip irrigation roots were concentrated under the vine row, whereas under microjet irrigation roots were spread across the planting area.

The effect of trickle irrigation interval on soil moisture and salt distribution and relative water use efficiency was examined in another study (Goldberg *et al.*, 1971). The effect of shorter irrigation intervals, with proportionally smaller amounts of water applied in a single irrigation, was to decrease the variations of moisture content in the root zone and establish a continuously higher moisture regime. Salts were concentrated in a surface pocket and a deep layer with a leached zone between them.

The effect of mineral nutrition and salinity on grape production and wine quality was studied by Bravdo *et al.* (1993). They noticed that the irrigation with moderate saline water  $1.2\text{--}4.2\text{ dS m}^{-1}$  was found to significantly affect the content of 16 various volatiles in Cabernet Sauvignon wines. A significant rootstock effect on Cl content of petiole as well as on wine quality was found in a saline water irrigation experiment.

A study was conducted to compare trickle and sprinkler irrigation in an avocado orchard with respect to growth and productivity, soil salinity, total annual cost of irrigation, susceptibility of the trees to root rot, and performance of the irrigation equipment (Gustafson *et al.*, 1972). The soil was a complex of sandy loam and fine sandy loam. Soil salinity was first determined when the orchard was established. At this time soil samples taken down to 2 feet did not exceed established safe levels of total soluble salts and chlorides for avocados ( $2\text{ mhos cm}^{-1}$  and  $5\text{ me l}^{-1}$  respectively). After six months of irrigation, soil salinity was determined again. For the sprinkler irrigated plots, salinity values for all depths were still within the safe limits. Under drip irrigated trees accumulation of soluble salts beyond the limits occurred in the 0 to 6 inch depth ( $3\text{ mhos cm}^{-1}$  for total soluble salts and  $8\text{ me l}^{-1}$  for chlorides). A following set of soil samples, taken after the winter rains, indicated that the rains were effective in leaching any accumulated salt from the soil.

He *et al.* (2014) studied the spatial and seasonal variations of soil salinity following vegetation restoration in coastal saline land in eastern China they noticed that Salt profiles showed the higher values in surface soil in control plots, whereas the pattern of soil salinity showed the reverse trend under vegetation. Soil moisture values were the highest in spring and the lowest in autumn, when values of soil salinity were

the highest in summer and the lowest in winter. They concluded that plant communities significantly affect the spatial–temporal distribution of soil salinity.

## 2.5 Soil salinity effects on grapevine

Grapevines are classified as moderately sensitive to salinity. This was explained by the Maas and Hoffman's yield response model, using the 'bent stick' model concluded that the yield does not reduce unless a certain concentration threshold is reached (Prior *et al.*, 1992b; Walker *et al.*, 1997). However Grapevine response to salinity, its dependent on many factors such as, soil type, climate, irrigation system and rootstock-scion combination (Clercq *et al.*, 2001; Baneh *et al.*, 2013).

The grapevine response to salinity can be divided into two phases. Phase one is the reduction of grapevine growth by osmotic stress, whereas phase two is the reduction of growth by ionic toxicities (Munns and Termaat, 1986; Munns *et al.*, 1995). The transition time between two phases is determined by the environmental conditions, the salt concentrations, grapevine state and subsequent severity of the stress. In the osmotic stress, Plant growth is reduced mainly due to the osmotic stress experienced by the plant. A high salt concentration results in the loss of water from the cells, reduction in rate of cell division, reduction in the cell elongation rates and cell size.

In the second phase, early leaf fall occurs due to accumulation of sodium and chloride ions in the shoot tissue (Tavakkoli, 2011). Effect of high salt concentrations on the plant growth is determined by the tolerance of the plant itself to salt stress and the rate of salt accumulation in the specific tissues. Whereas grapevine is moderately affected by salt stress, lateral shoot growth is inhibited. Symptoms of salt stress are usually distinguished by chlorosis, eventually leading to senescence of older leaves, reduced growth and new leaf production rate (Munns & Tester, 2008). Urdanoz and Aragues (2009) reported that the osmotic effect on grapevine growth is proportional to the decrease in the osmotic potential of the soil solution.

Prior *et al.* (1992b) reported that high levels of Na and Cl ions accumulated in the plant tissue resulted larger yield reduction. petiole analysis indicated that the Sodium and Cl in the petiole had best relationship to yield reduction in grapevines. She also recommended that the petiole chloride and sodium levels should not exceed 420 mmol.kg<sup>-1</sup> dry weight and 191 m mol kg<sup>-1</sup> dry weight respectively.

Sudhir and Murthy (2014) reported that osmotic stress leads to an increase in ion toxicities and rate of respiration, uptake of other ions decreases such as Ca, K and Mn due to excessive accumulation of Na and Cl ions, Plant growth, mineral distribution, membrane permeability and reduction in photosynthesis are linked to salt stress affected vines.

Salinity-induced stomatal closure due to reduction in transpiration, which results in negative effects on photosynthesis in the grapevine. In the salt stressed grapevines showed reduced stomatal conductance leading to accumulation of Abscisic acid in the leaves (Shani and Ben-Gal, 2005).

The method of salt exclusion is termed osmoregulation where the grapevine roots adjust the water potential at a lower level than the surrounding root substrate. Salt stress experienced by vine accumulates proline in large quantities (Owais, 2015). Fozouni *et al.* (2012) demonstrated that increasing salinity significantly increase the proline accumulation in hydroponically grown table grape varieties at different salt concentrations.

In grapevine nutrition, sodium is not considered as an essential element. Amiri and Eshghi (2015) explained that increasing concentrations of Na in the soil solution lead to leaf burn starts at the margin of the leaves later slowly spread inwards and wines prepared from that grapes contain high amount of Na. Whereas under normal conditions, the grapevine contains relatively small concentrations of Na. They also found that as the Na concentration in the soil solution increased, the root and leaf Na concentration also increased. *Vitis Vinifera* L. vines shows poor capacity for Cl exclusion under high concentration of Chloride in the leaves. Chloride toxicity may cause a reduction in the photosynthetic capacity of the plant due to non stomatal effects and chlorophyll degradation (Parihar *et al.*, 2015).

Wang *et al.* (2013) reported that concentrations of K ions found in the cytoplasm can vary from 100 to 200 mM. Whereas, the apoplastic concentrations can vary from 10 mM to 500 mM. Leaf analysis method is used to determine the plant available of K. this method is not accurate to determine the K content because K is present in free form which moves rapidly to growing organs of the grapevine and stored in the reserve organs of plants such as the shoots, trunk etc.

Grapevine accumulates 50 percent of the total K taken up in the berries. Functions of K in the berries include synthesis reactions, enzyme activation, which in turn responsible for maintenance of cell turgidity, fruit maturation as well as sugar synthesis. Potassium also involved in the transport of solutes, the barrier of assimilates and polyphenol synthesis which is helpful for berry colour and aroma (Brunetto *et al.*, 2015).

Some of the symptoms expressed by grapevines due to deficiency of K include marginal leaf burn in white grape cultivars and marginal red discoloration in red grape varieties. In extreme cases leaf curling and also defoliation have been reported (Ashley, 2011). Cramer *et al.* (2004) studied that small changes in elevation (and hence depth to the water table) affected soil Cl concentrations and water contents, and whether small changes in elevation were associated with major changes in tree health in two remnants of Eucalyptus Blakely woodland with secondary salinity. Vegetation is considered to be at risk where the water table is predicted to be less than 2 m below the soil surface, yet casual observation of areas affected by secondary salinity in the Western Australian wheat belt has suggested that small differences in elevation (< 0.5 m) are important in determining plant health.

### **3. MATERIAL AND METHODS**

Accumulation of salts in the root zone during summer can reach toxic levels. Its concentration depends on the climate, soil type, quality and quantity of irrigation water, drainage, topography etc. Grape is very sensitive crop to soil salinity and especially for chloride. In this study, a survey was made in and around Bagalkot to assess the extent of salinity in vine yards. Later, one of the vineyards was monitored to assess horizontal and vertical distribution of salts across different elevations and seasons. The details of the study area and methodologies adopted to assess the salinity parameters are presented in this chapter.

#### **3.1 General description of the study area**

The Bagalkot district is situated in the northern Karnataka with a total geographical area of 6,575 sq km. The district comes under semi-arid climate and exhibits high temperature during summer associated with cold winter. The Bagalkot Taluka lies in northern dry zone of Karnataka at 16°10'32" N latitude and 75°15'14" East longitudes at an altitude of about 524 meters above the mean sea level (Figure 1). Most of the area experiences warm and dry climate throughout the year with a mean annual rainfall of 561 mm. Maximum temperature of the area is 31°C and the minimum temperature will drop to 19.6°C recorded during the year of 2018 at Main Horticultural Research and Extension Center, UHS, Bagalkot. Thus, the district is most suitable for grape cultivation and also for processing them into valuable products viz., wine and raisin.

#### **3.2 Survey based soil salinity assessment**

Cultivation of grapes in Bagalkot Taluka is observed to a great extent. Field survey was made to identify vineyards of 8 to 10 years of age and 69 vineyards were selected for initial study. In and around Bagalkot, representative composite surface soil samples (0-20 cm) were collected during summer (March - April, 2018) from the chosen vine yards. Soil samples were taken at 30 cm away from the plant row using core samplers/ tube augers. The collected soil samples were air dried, processed and stored for measuring salinity parameters. Most of the grape vineyards are being irrigated by ground water and hence, water samples were also collected from 10 locations to assess water quality for irrigation.

### 3.3 Irrigation water quality assessment

Twenty bore well water samples were collected from nearby locations and stored in polyethylene bottles under refrigerated condition. The stored water samples were analyzed for irrigation quality parameters and characterized for salts along with their dominant cations and anions by following standard analytical procedures.

### 3.4 Detailed study on salinity parameters of a grape vineyard:

A nine years old vineyard present on a gentle slope land with reddish brown soil (Figure 2a) was selected for detailed study. The entire grape vineyard was surveyed to assess the extent of variation in the topography and then, the vineyard was marked into high, mid and low micro topographic elevations namely, high ( $E_1$ ), mid ( $E_2$ ) and low ( $E_3$ ) elevation areas (Figure 2b). Surface soils (0-20cm) and subsurface (20- 40 cm) soil samples were collected in three replications at 15, 30, 75 and 120cm horizontal distances, to assess seasonal variations during three different seasons namely  $S_1$ : February 2018 (Before back pruning),  $S_2$ : September 2018 (during growth stage) and  $S_3$ : March 2019 (at harvest). Pictorial representation on soil sampling in grape orchard is given in Figure 3. The collected samples were air dried, sieved and stored in polyethylene plastic containers for further analysis.

### 3.5 Analysis of soil and water samples for salinity parameters

The stored soil and water samples were analyzed for important salinity related parameters namely, pH, EC and water extractable cations and anions. The analytical procedures remained same for both soil and water samples except extraction procedure for water samples.

**Soil pH and Electrical conductivity (EC) of the suspension:** The soil water suspension was prepared by mixing soil and water at 1:2 ratio on weight basis (Jackson, 1973) and the suspension was stirred intermittently for half an hour. The soil pH was determined using pH meter (Model: Systronics 361) after its calibration. The soil water suspensions prepared for pH was kept overnight in undisturbed condition. The conductivity of the clear soil water suspension was recorded using electrical conductivity meter (Model: Conductivity TDS meter 308). The water samples were used directly for pH and EC measurements.

**Extraction of cations and anions:** Soluble salts present in soil were extracted using distilled water in the ratio of 1:2. Fifty gram soil and 100 ml of distilled water were taken and kept for 30 min shaking using vertical shaker. The soil water suspension was kept undisturbed for 10 min and supernatant was centrifuged at 1500 rpm. Then, the supernatant was filtered using Watsman No. 42 filter paper to get clear extract. The extractants were kept under refrigerated conditions for further analysis of cations and anions.

**Estimation of cations and anions:** Refrigerated soil-water extracts were brought to normal temperature and analysed for cations and anions. Same analytical procedures were adopted for analysis of water samples and the methods used are given below.

**Calcium and magnesium ions ( $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$ ):** Complexometric (EDTA) titration method was used for Ca and Mg estimations. At first, both Ca and Mg were determined at pH of 10 in presence of ammonia buffer solution using Erichrome black T indicator. Then, the amount of Ca alone present in the extract was determined at a pH of 12 in presence of 10% NaOH using Patton and Reader's reagent. The above two values were used to estimate magnesium content in soil-water extract and water samples (Baruah and Barthakur, 1999).

**Sodium and potassium ( $\text{Na}^+$  and  $\text{K}^+$ ):** The concentrations of potassium and sodium in soil-water extracts were determined by flame photometer (Systronics Model). The soil water extract water and water samples were fed directly to the flame photometer after standardization of the instrument (Sharma *et al.*, 1987).

**Total cations:** The above individual cations were grouped separately and their total contents were derived by their summation.

**Total carbonates and bicarbonates ( $\text{CO}_3^{2-}$  and  $\text{HCO}_3^-$ ):** The carbonates in soil water extracts were below the detectable limits. Hence,  $\text{CO}_3^{2-}$  and  $\text{HCO}_3^-$  were estimated together as total carbonates and bicarbonates. The amounts of total carbonates present in soil-water extracts and water samples were determined by standards acid titrations in presence of methyl orange indicator (Richards, 1954).

**Chlorides ( $\text{Cl}^-$ ):** The chlorides in soil-water extracts were determined by Mohr's method. A known volume of soil-water extract was taken and titrated against standard silver nitrate solution in presence of potassium chromate indicator (Richards, 1954).

**Sulphates ( $\text{SO}_4^{2-}$ ):** Water soluble sulphates in soil-water extracts were determined by turbidometric method. The turbidity was developed by precipitation of sulphate as barium sulphate using barium chloride crystals. The turbidity was measured using spectrophotometer (Spectronic-200; Thermofischer scientific) at 420 nm wavelength (Black, 1965).

**Total cations and anions:** The individual cations and anions were added separately to estimate total cations and anions in soil water extracts or water samples.

### 3.6 Statistical analysis

The survey data obtained were subjected to statistical tests using three factorial ANOVA and descriptive statistical analysis. The data on selected grape vineyard observations collected during the study were subjected to statistical analysis using the Fischer's method of analysis of variance technique as given by Sundararaj *et al*, (1972). The level of significance used in 'F' test was  $p = 0.05$ , critical values were calculated wherever the 'F' test was significant.

## 4. EXPERIMENTAL RESULTS

The grape is very sensitive for chlorides and all saline soils are prone for chloride toxicity. Thus, the grape yields and quality can drastically get affected by soil salinity. The extent of soil salinity varies depending on topography, parent material, drainage conditions, water quality and irrigation practices. Considering these facts, survey based study was carried out to assess the extent of soil salinity in vineyards and to assess the quality of water used for irrigation. A detailed study was also carried out in a selected vineyard to assess the spatial and temporal changes in soil salinity parameters. The results obtained are presented separately both the studies.

### Study I: Survey based salinity assessment of soil and water

The Bagalkot lies in northern Karnataka and experiences semi-arid conditions with higher PET than rainfall. Thus, the soils are most saline and the water used for irrigation is also expected to be saline. Hence, a survey was carried out to assess the extent of salinity in vineyards as well as irrigation water and the results obtained are presented in this section.

#### 4.1 Survey based soil salinity assessment

Soil samples from 69 vineyards were analysed for salinity parameters. The results obtained are presented in Table 1 and they are detailed in this section.

**Electrochemical properties:** The reactions of grape vineyard soils ranged from 7.09 to 8.47 with a mean value of  $7.99 \pm 0.29$ . Majority of soil samples were found to be in slightly alkaline to moderately alkaline in reaction. The electrical conductivity, an indicator of soil salinity, ranged from 0.69 to  $1.69 \text{ dS m}^{-1}$ . The mean conductivity value of  $0.98 \pm 0.23 \text{ dS m}^{-1}$  was observed. The soils were found to be slightly to moderately saline for vineyard soils.

**Water soluble cations:** The water soluble cations namely, calcium, magnesium, sodium and potassium were extracted at 1:2 soil water ratios and determined using suitable analytical methods. The water soluble-Ca content in different vineyards of Bagalkot ranged from 2.08 to  $6.50 \text{ me l}^{-1}$  and the mean was found to be  $3.82 \pm 0.89 \text{ me l}^{-1}$ . Both median and mode were found to be closer to the mean values. Among water soluble cations, calcium was found to be the most dominant. The magnesium was found

**Table 1: Soil salinity parameters of 69 vineyards surveyed in and around Bagalkot**

Salinity parameters	Range	Mean $\pm$ Stdev	Median	Mode	Skewness
pH (1:2)	7.09 – 8.47	7.99 $\pm$ 0.29	8.07	8.25	-0.90
Electrical Conductivity (1:2; dS m <sup>-1</sup> )	0.69 – 1.69	0.98 $\pm$ 0.23	0.94	0.98	0.89
Water soluble- Ca (me l <sup>-1</sup> )	2.08 – 6.50	3.82 $\pm$ 0.89	3.84	4.06	0.66
Water soluble - Mg (me l <sup>-1</sup> )	0.56 – 4.02	1.93 $\pm$ 0.67	1.73	1.46	0.86
Water soluble - Na (me l <sup>-1</sup> )	0.69 – 6.23	1.90 $\pm$ 0.90	1.53	1.52	2.50
Water soluble - K (me l <sup>-1</sup> )	0.06 – 1.49	0.32 $\pm$ 0.24	0.25	0.07	1.99
Water soluble total cations (me l <sup>-1</sup> )	5.14 – 12.58	7.97 $\pm$ 1.79	7.54	12.51	0.86
Water soluble total carbonates (me l <sup>-1</sup> )	1.08 – 4.13	2.54 $\pm$ 0.78	2.5	2.50	0.23
Water soluble – SO <sub>4</sub> <sup>2-</sup> (me l <sup>-1</sup> )	0.04 – 1.43	0.44 $\pm$ 0.41	0.27	0.10	0.91
Water soluble - Cl <sup>-</sup> (me l <sup>-1</sup> )	1.99 – 8.47	4.13 $\pm$ 1.40	3.70	3.52	1.20
Water soluble total anions (me l <sup>-1</sup> )	4.07 – 10.97	7.11 $\pm$ 1.66	6.92	8.07	0.33

to be the next dominant ion in water soluble form and it ranged from 0.56 to 4.02 me l<sup>-1</sup> with a mean value of 1.93 ± 0.67 me l<sup>-1</sup>.

The next dominant ion was found to be sodium. The highest and lowest values of sodium were 6.23 and 0.69 me l<sup>-1</sup> respectively. Majority of the soil samples recorded sodium content with a mode and median values of 1.52 and 1.53 me l<sup>-1</sup> respectively indicating most of the samples recorded in the range of 1.50 to 1.70 me l<sup>-1</sup>. The potassium contents in the vineyard soils collected at 0-20 cm away from the vine row ranged from 0.06 to 1.49 me l<sup>-1</sup>. Water soluble potassium varied with a mean values of 0.32 ± 0.24 me l<sup>-1</sup>. Among water soluble cations, potassium was found to be least dominant ion. Finally, the total water soluble cations derived ranged from 5.14 to 12.58 me l<sup>-1</sup> with a mean value of 7.97 ± 1.79 me l<sup>-1</sup>.

**Water soluble anions:** The same soil water extractants prepared for the cations were used for the determination of anions namely total carbonates, sulphates and chlorides. Water soluble total carbonates ranged from 1.08 to 4.13 me l<sup>-1</sup>. Majority of the soil samples recorded water soluble total carbonates with a mode and median values of 1.52 and 1.53 me l<sup>-1</sup> respectively. The average total carbonates in 1:2 soil water extract was found to be 2.54 ± 0.78 me l<sup>-1</sup>. The highest and lowest amounts of water soluble sulphates in vineyards recorded 0.04 and 1.43 me l<sup>-1</sup> respectively with a mean value of 0.44 ± 0.41 me l<sup>-1</sup>. Majority of the soil samples recorded sulphates concentrations with a mode and median values of 0.20 and 0.27 me l<sup>-1</sup> respectively.

Maximum and minimum concentrations of chlorides in the vineyard soils recorded were 8.47 and 1.99 me l<sup>-1</sup> respectively and the mean chloride content was 4.13 ± 1.40 me l<sup>-1</sup>. Water soluble total anions were derived by adding individual anion values. The highest and lowest water soluble total anions recorded in vineyards were found to be 0.97 me l<sup>-1</sup> and 4.07 me l<sup>-1</sup> respectively. Vineyard soils recorded a mean value of 7.11 ± 1.66 me l<sup>-1</sup> and it had the same median and mode value of 8.07 me l<sup>-1</sup>.

#### 4.2 Irrigation water quality assessment

As part of the study, 20 bore well water samples were analyzed for salinity parameters and the results obtained are tabulated and presented in Table 2.

**Electrochemical properties:** The water samples were mostly found to be slightly alkaline in nature. The pH of soil water ranged from 6.89 to 7.64 and the mean pH value

**Table 2: Salinity parameters of 20 groundwater samples surveyed in and around Bagalkot**

<b>Salinity parameters</b>	<b>Range</b>	<b>Mean <math>\pm</math> Stdev</b>	<b>Median</b>	<b>Mode</b>	<b>Skewness</b>
pH	6.89 – 7.64	7.31 $\pm$ 0.21	7.36	7.32	-0.35
EC 1:2 (dS m <sup>-1</sup> )	0.16 – 1.42	0.60 $\pm$ 0.41	0.36	0.29	0.80
Soluble - Ca (me l <sup>-1</sup> )	1.42 – 5.74	3.59 $\pm$ 1.31	3.47	3.65	-0.25
Soluble -Mg (me l <sup>-1</sup> )	1.50 – 5.87	3.77 $\pm$ 1.14	3.83	4.53	0.20
Soluble -Na (me l <sup>-1</sup> )	0.24 – 4.65	1.35 $\pm$ 1.27	0.49	2.24	1.07
Soluble -K (me l <sup>-1</sup> )	0.05 – 0.24	0.12 $\pm$ 0.06	0.11	0.07	0.66
Soluble Total cations (me l <sup>-1</sup> )	5.68 – 13.26	8.83 $\pm$ 2.01	8.67	10.44	0.38
Soluble total carbonates (me l <sup>-1</sup> )	0.48 – 5.67	2.95 $\pm$ 1.10	2.93	3.27	0.14
Soluble - SO <sub>4</sub> (me l <sup>-1</sup> )	0.07 – 0.95	0.39 $\pm$ 0.26	0.34	0.24	0.85
Soluble - Cl (me l <sup>-1</sup> )	2.16 – 7.82	3.77 $\pm$ 1.33	3.63	2.89	1.48
Soluble Total anions (me l <sup>-1</sup> )	4.68 – 11.32	7.11 $\pm$ 1.69	6.71	6.81	1.05

was found to be  $7.31 \pm 0.21$ . The electrical conductivity of water samples ranged from 0.16 to 1.42 dS m<sup>-1</sup> with a mean value of  $0.60 \pm 0.41$  dS m<sup>-1</sup>. Majority of the samples analysed were found to be safe for irrigation with conductivity of  $< 1.00$  dS m<sup>-1</sup>.

**Dissolved cations in irrigation water:** The groundwater is known to have various salts and contribute to different cations. Among cations, the calcium was ranged from 1.42 to 5.74 me l<sup>-1</sup>. Similarly, the dissolved magnesium was in the range of 1.50 to 5.87 me l<sup>-1</sup>. The mean values of magnesium and calcium in irrigation water were found to be  $3.77 \pm 1.31$  me l<sup>-1</sup> and  $3.59 \pm 1.14$  me l<sup>-1</sup> respectively. The respective medians and modes were also found in the similar range indicating majority of the samples had similar amounts of calcium and magnesium in irrigation water.

The next dominant cation was sodium and its average concentration was  $1.35 \pm 1.27$  me l<sup>-1</sup> with a range of 0.24 to 4.65 me l<sup>-1</sup>. The least amount of cation in irrigation water was found to be potassium ranging from 0.05 to 0.24 me l<sup>-1</sup> with average concentration of  $0.12 \pm 0.06$  me l<sup>-1</sup>. Thus, the total soluble cations were found to be  $8.83 \pm 2.01$  me l<sup>-1</sup> with respective minimum and maximum amounts of 5.68 me l<sup>-1</sup> and 13.26 me l<sup>-1</sup>.

**Dissolved anions in irrigation water:** The irrigation water samples had traces of carbonates and they were below the detectable limits. However, they had detectable amounts of bicarbonates. Hence, both CO<sub>3</sub><sup>=</sup> and HCO<sub>3</sub><sup>-</sup> were determined together and referred it as total carbonates. Its content ranged from 0.48 to 5.67 me l<sup>-1</sup> and its mean value was  $2.95 \pm 1.00$  me l<sup>-1</sup>. Both median (2.93 me l<sup>-1</sup>) and mode (3.27 me l<sup>-1</sup>) were almost closer to the mean value indicating similarities among water samples *w.r.t.* total carbonates.

In terms of soluble – SO<sub>4</sub><sup>=</sup>, the mean concentration in water samples was  $0.39 \pm 0.26$  me l<sup>-1</sup> and it ranged from 0.07 to 0.95 me l<sup>-1</sup>. Among anions, SO<sub>4</sub><sup>=</sup> concentration was found least in irrigation water. The concentration of chlorides in irrigation water was found higher with a mean of  $3.77 \pm 1.33$  me l<sup>-1</sup> (values ranged from 2.16 to 7.82 me l<sup>-1</sup>). The total anion contents were found almost similar to the values of dissolved cations ranging from 4.68 to 11.32 me l<sup>-1</sup> and mean of  $7.11 \pm 1.69$  me l<sup>-1</sup>.

## Study II. Spatial and temporal assessment of soil salinity in grape vineyard

A detailed study was carried out in a selected vineyard with gentle slope to assess the spatial and temporal distribution of salts/ ions in vineyard soils. The soil salinity parameters assessed from the start of the grape crop (before back pruning) till the harvest of grapes across three different micro topographic elevations namely, high, mid and low regions of the orchards. The salt distribution across the grape row (from plant rows to the inter-row space) was assessed and the results obtained in this study are presented in this section.

### 4.3 Soil reaction (pH)

The pH of surface and subsurface soils of grape vineyard collected at different elevations and distances across three seasons is presented in Tables 3a and 3b respectively. Both surface and subsurface soils were found to be ranging from slightly alkaline to highly alkaline with pH values of 7.40 to 8.27.

Three elevations of vineyard as such did not have any significant influence on soil reaction. The soils at 15 cm ( $D_1$ , 7.87) and 30 cm ( $D_2$ , 7.78) away from the plant row recorded higher alkalinity compared to the soils at 75 cm ( $D_3$ , 7.63) and 120 cm ( $D_4$ , 7.56). Similar trends were recorded in subsurface soils also. The pH of both surface and subsurface soils varied significantly in the order  $D_1 = D_2 > D_3 = D_4$ . In terms of seasons, both surface and subsurface soils recorded significantly higher pH values in samples representing ( $S_1$ ) before pruning stage compared to growth ( $S_2$ ) and harvesting stage ( $S_3$ ). However, the pH values of surface and subsurface soils at growth and harvesting stage did not vary significantly.

In terms of interactions, the three factors collectively (E x D x S) or in combinations (E x D, E x S and D x S) did not influence soil reaction at both the depths.

### 4.4 Electrical conductivity ( $EC_{1:2}$ )

The extent of salinity of vineyard was measured in terms of electrical conductivity and their corresponding values at different horizontal distances and elevations during three seasons are presented in Tables 4a and 4b for surface and subsurface soils respectively. The electrical conductivity of surface soils ranged from 0.21 to 1.51  $dS\ m^{-1}$  while, in subsurface soils, the conductivity values varied from 0.25

**Table 3a: pH of surface soils (0-20cm) of vineyard at different elevations, distances and seasons**

Distance (D) from the row	Elevation (E)												Distance Mean (D)
	E <sub>1</sub> - High			D x E <sub>1</sub>	E <sub>2</sub> - Mid			D x E <sub>2</sub>	E <sub>3</sub> - Low			D x E <sub>3</sub>	
	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		
<b>D<sub>1</sub> - 15cm</b>	8.01	7.73	7.80	<b>7.85</b>	8.00	7.80	7.73	<b>7.84</b>	8.27	7.73	7.73	<b>7.91</b>	<b>7.87</b>
<b>D<sub>2</sub> - 30cm</b>	7.91	7.61	7.75	<b>7.76</b>	7.97	7.70	7.61	<b>7.78</b>	8.00	7.68	7.71	<b>7.81</b>	<b>7.78</b>
<b>D<sub>3</sub> - 75cm</b>	7.84	7.47	7.50	<b>7.61</b>	7.90	7.50	7.47	<b>7.62</b>	7.87	7.58	7.58	<b>7.67</b>	<b>7.63</b>
<b>D<sub>4</sub> - 120cm</b>	7.77	7.40	7.41	<b>7.53</b>	7.80	7.41	7.40	<b>7.54</b>	7.79	7.51	7.51	<b>7.60</b>	<b>7.56</b>
<b>E x S Mean</b>	<b>7.88</b>	<b>7.55</b>	<b>7.61</b>	<b>7.68</b>	<b>7.92</b>	<b>7.61</b>	<b>7.55</b>	<b>7.70</b>	<b>7.98</b>	<b>7.63</b>	<b>7.63</b>	<b>7.75</b>	<b>GM 7.71</b>
<b>Season x Distance (S x D)</b>				<b>D<sub>1</sub> - 15cm</b>	<b>D<sub>2</sub> - 30cm</b>	<b>D<sub>3</sub> - 75cm</b>	<b>D<sub>4</sub> -120cm</b>	<b>Season Mean (S)</b>					
<b>S<sub>1</sub> – February 18 (Before back Pruning)</b>				8.09	7.96	7.87	7.79	<b>7.93</b>					
<b>S<sub>2</sub> – September 18 (Growth Stage)</b>				7.75	7.69	7.52	7.44	<b>7.60</b>					
<b>S<sub>3</sub> – March 19 (Harvesting Stage)</b>				7.75	7.69	7.52	7.44	<b>7.60</b>					
<b>Statistical Analysis</b>													
<b>Factor</b>	<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>		<b>Factor</b>				<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>				
<b>Elevation (E)</b>	0.03	NS		<b>Elevation x Distance (E x D)</b>				0.06	NS				
<b>Distance (D)</b>	0.03	0.10		<b>Elevation x Season (E x S)</b>				0.04	NS				
<b>Season (S)</b>	0.02	0.07		<b>Distance x Season (D x S)</b>				0.05	NS				
				<b>Elevation x Distance x Season (E x D x S)</b>				0.08	NS				

**Table 3b: pH of subsurface soils (20-40cm) of vineyard at different elevations, distances and seasons**

Distance (D) from the row	Elevation (E)												Distance Mean (D)
	E <sub>1</sub> - High			D x E <sub>1</sub>	E <sub>2</sub> - Mid			D x E <sub>2</sub>	E <sub>3</sub> - Low			D x E <sub>3</sub>	
	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		
<b>D<sub>1</sub> - 15cm</b>	7.90	7.56	7.70	<b>7.82</b>	7.95	7.70	7.56	<b>7.73</b>	7.93	7.68	7.72	<b>7.77</b>	<b>7.74</b>
<b>D<sub>2</sub> - 30cm</b>	7.87	7.54	7.63	<b>7.68</b>	7.95	7.63	7.54	<b>7.69</b>	7.89	7.65	7.67	<b>7.73</b>	<b>7.70</b>
<b>D<sub>3</sub> - 75cm</b>	7.78	7.42	7.43	<b>7.54</b>	7.86	7.43	7.42	<b>7.57</b>	7.80	7.54	7.58	<b>7.63</b>	<b>7.60</b>
<b>D<sub>4</sub> - 120cm</b>	7.72	7.19	7.29	<b>7.40</b>	7.76	7.52	7.19	<b>7.41</b>	7.69	7.48	7.49	<b>7.55</b>	<b>7.58</b>
<b>E x S Mean</b>	<b>7.82</b>	<b>7.43</b>	<b>7.51</b>	<b>7.59</b>	<b>7.87</b>	<b>7.51</b>	<b>7.43</b>	<b>7.60</b>	<b>7.83</b>	<b>7.59</b>	<b>7.59</b>	<b>7.67</b>	<b>GM 7.62</b>
<b>Season x Distance (S x D)</b>				<b>D<sub>1</sub> - 15cm</b>	<b>D<sub>2</sub> - 30cm</b>	<b>D<sub>3</sub> - 75cm</b>	<b>D<sub>4</sub> -120cm</b>	<b>Season Mean (S)</b>					
<b>S<sub>1</sub> – February 18 (Before back Pruning)</b>				7.93	7.89	7.81	7.73	<b>7.84</b>					
<b>S<sub>2</sub> – September 18 (Growth Stage)</b>				7.65	7.61	7.46	7.32	<b>7.51</b>					
<b>S<sub>3</sub> – March 19 (Harvesting Stage)</b>				7.65	7.61	7.46	7.32	<b>7.51</b>					
<b>Statistical Analysis</b>													
<b>Factor</b>	<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>		<b>Factor</b>				<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>				
<b>Elevation (E)</b>	0.02	0.05		<b>Elevation x Distance (E x D)</b>				0.03	NS				
<b>Distance (D)</b>	0.02	0.06		<b>Elevation x Season (E x S)</b>				0.02	NS				
<b>Season (S)</b>	0.01	0.04		<b>Distance x Season (D x S)</b>				0.03	NS				
				<b>Elevation x Distance x Season (E x D x S)</b>				0.04	NS				

**Table 4a: Electrical conductivity ( $\text{dS m}^{-1}$ ) of surface soils (0-20cm) of vineyard at different elevations, distances and seasons**

Distance (D) from the row	Elevation (E)												Distance Mean (D)
	E <sub>1</sub> - High			D x E <sub>1</sub>	E <sub>2</sub> - Mid			D x E <sub>2</sub>	E <sub>3</sub> - Low			D x E <sub>3</sub>	
	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		
<b>D<sub>1</sub> - 15cm</b>	1.03	0.37	0.91	<b>0.82</b>	1.51	0.46	1.36	<b>1.11</b>	1.48	0.50	1.51	<b>1.16</b>	<b>1.03</b>
<b>D<sub>2</sub> - 30cm</b>	0.99	0.29	0.79	<b>0.69</b>	1.38	0.42	1.24	<b>1.01</b>	1.40	0.48	1.36	<b>1.08</b>	<b>0.93</b>
<b>D<sub>3</sub> - 75cm</b>	0.81	0.21	0.59	<b>0.54</b>	1.03	0.36	0.96	<b>0.78</b>	1.17	0.42	1.20	<b>0.93</b>	<b>0.75</b>
<b>D<sub>4</sub> - 120cm</b>	0.69	0.21	0.47	<b>0.47</b>	0.68	0.28	0.67	<b>0.54</b>	0.90	0.37	1.06	<b>0.78</b>	<b>0.60</b>
<b>E x S Mean</b>	<b>0.92</b>	<b>0.27</b>	<b>0.69</b>	<b>0.63</b>	<b>1.15</b>	<b>0.38</b>	<b>1.06</b>	<b>0.86</b>	<b>1.24</b>	<b>0.44</b>	<b>1.28</b>	<b>0.99</b>	<b>GM 0.83</b>
<b>Season x Distance (S x D)</b>				<b>D<sub>1</sub> - 15cm</b>	<b>D<sub>2</sub> - 30cm</b>	<b>D<sub>3</sub> - 75cm</b>	<b>D<sub>4</sub> -120cm</b>	<b>Season Mean (S)</b>					
<b>S<sub>1</sub> – February 18 (Before back Pruning)</b>				1.40	1.26	1.00	0.75	<b>1.10</b>					
<b>S<sub>2</sub> – September 18 (Growth Stage)</b>				0.44	0.40	0.33	0.29	<b>0.36</b>					
<b>S<sub>3</sub> – March 19 (Harvesting Stage)</b>				1.26	1.13	0.91	0.74	<b>1.01</b>					
<b>Statistical Analysis</b>													
<b>Factor</b>	<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>		<b>Factor</b>				<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>				
<b>Elevation (E)</b>	0.02	0.07		<b>Elevation x Distance (E x D)</b>				0.05	NS				
<b>Distance (D)</b>	0.03	0.08		<b>Elevation x Season (E x S)</b>				0.03	0.10				
<b>Season (S)</b>	0.02	0.06		<b>Distance x Season (D x S)</b>				0.04	0.11				
				<b>Elevation x Distance x Season (E x D x S)</b>				0.07	NS				

**Table 4b: Electrical conductivity ( $\text{dS m}^{-1}$ ) subsurface soils (20-40cm) of vineyard at different elevations, distances and seasons**

Distance (D) from the row	Elevation (E)												Distance Mean (D)
	E <sub>1</sub> - High			D x E <sub>1</sub>	E <sub>2</sub> - Mid			D x E <sub>2</sub>	E <sub>3</sub> - Low			D x E <sub>3</sub>	
	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		
<b>D<sub>1</sub> - 15cm</b>	0.90	0.33	0.74	<b>0.66</b>	1.32	0.49	1.11	<b>0.97</b>	1.36	0.53	1.33	<b>1.07</b>	<b>0.89</b>
<b>D<sub>2</sub> - 30cm</b>	0.88	0.26	0.69	<b>0.61</b>	1.14	0.47	1.03	<b>0.88</b>	1.26	0.51	1.27	<b>1.01</b>	<b>0.83</b>
<b>D<sub>3</sub> - 75cm</b>	0.78	0.25	0.53	<b>0.52</b>	0.80	0.41	0.87	<b>0.69</b>	1.10	0.49	1.14	<b>0.91</b>	<b>0.71</b>
<b>D<sub>4</sub> - 120cm</b>	0.55	0.26	0.38	<b>0.40</b>	0.56	0.36	0.62	<b>0.52</b>	0.57	0.44	0.92	<b>0.64</b>	<b>0.52</b>
<b>E x S Mean</b>	<b>0.78</b>	<b>0.29</b>	<b>0.59</b>	<b>0.55</b>	<b>0.95</b>	<b>0.44</b>	<b>0.91</b>	<b>0.76</b>	<b>1.07</b>	<b>0.49</b>	<b>1.16</b>	<b>0.91</b>	<b>GM 0.74</b>
<b>Season x Distance (S x D)</b>				<b>D<sub>1</sub> - 15cm</b>	<b>D<sub>2</sub> - 30cm</b>	<b>D<sub>3</sub> - 75cm</b>	<b>D<sub>4</sub> -120cm</b>	<b>Season Mean (S)</b>					
<b>S<sub>1</sub> – February 18 (Before back Pruning)</b>				1.19	1.09	0.89	0.56	<b>0.93</b>					
<b>S<sub>2</sub> – September 18 (Growth Stage)</b>				0.45	0.41	0.38	0.35	<b>0.40</b>					
<b>S<sub>3</sub> – March 19 (Harvesting Stage)</b>				1.06	0.99	0.85	0.64	<b>0.88</b>					
<b>Statistical Analysis</b>													
<b>Factor</b>	<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>		<b>Factor</b>				<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>				
<b>Elevation (E)</b>	0.02	0.07		<b>Elevation x Distance (E x D)</b>				0.05	NS				
<b>Distance (D)</b>	0.03	0.08		<b>Elevation x Season (E x S)</b>				0.03	0.10				
<b>Season (S)</b>	0.02	0.06		<b>Distance x Season (D x S)</b>				0.04	0.12				
				<b>Elevation x Distance x Season (E x D x S)</b>				0.06	NS				

to  $1.36 \text{ dS m}^{-1}$ . Higher conductivity values were recorded in surface soils compared to subsurface soils during  $S_1$  (before back pruning) and  $S_3$  (at harvesting) stages.

The soil salinity was influenced by all the three factors individually and in combinations. The soils present in low lying area ( $E_3$ ) recorded higher mean electrical conductivity compared to high and mid elevation areas ( $E_1$  and  $E_2$ ) of the vineyard. The variations in electrical conductivity were recorded in the order  $E_3 > E_2 > E_1$  with corresponding values of 0.99, 0.86 and  $0.63 \text{ dS m}^{-1}$  in surface soils and 0.91, 0.76 and  $0.55 \text{ dS m}^{-1}$  in subsurface soils. In terms of horizontal distribution, the soils present next to the plant rows ( $D_1$ - 15 cm) recorded higher electrical conductivity (in  $\text{dS m}^{-1}$ ) and it decreased significantly with increase in distance in surface soils ( $D_1 > D_2 > D_3 > D_4$ ) 1.03, 0.93, 0.75 and  $0.60 \text{ dS m}^{-1}$ . However, in subsurface soils, the soils at 15 cm ( $D_1$ ) and 30 cm ( $D_2$ ) remained on par with each other and thus, the order of salinity was  $D_1 = D_2 > D_3 > D_4$  (0.89, 0.83, 0.75 and  $0.52 \text{ dS m}^{-1}$ ). In terms of seasons, the soil samples collected at harvest ( $S_3$ ) and just before pruning ( $S_1$ ) stages recorded higher conductivity whereas, the soil samples at growth stage ( $S_2$ ) recorded significantly lower salinity values. Thus, the extent of salinity ( $\text{dS m}^{-1}$ ) in surface soils varied in the order  $S_1$  (1.10)  $> S_3$  (1.01)  $> S_2$  (0.36) while, variations in subsurface soils was found to be in the order  $S_1$  (0.93) =  $S_2$  (0.88)  $> S_3$  (0.40).

In terms of interactions, elevation x distance (E x D) had no significant influence on conductivity in both surface and subsurface soils. The interaction of elevation x season (E x S) influenced salinity significantly at  $S_1$  (February) and  $S_3$  (March) stages compared to soils at  $S_2$  (September) season at all elevations. Significant differences between  $S_1$  and  $S_3$  were recorded only in high elevation areas at both the depths. Interaction of distance and season (D x S) had significant effect on electrical conductivity in most of the samples and decreased with increase in distance from the plants. The surface soils present at  $D_1$  (15 cm) and  $D_2$  (30 cm) showed significant variations *w.r.t.* three seasons due to D x S interaction effects. However, the samples at  $D_3$  (75cm) and  $D_4$  (120cm) recorded no significant difference in  $S_1$  (before pruning) and  $S_3$  (at harvest). Similar observations were made also in subsurface soils. The cumulative effect of E x D x S had no significant effect on soil salinity across treatments in both surface and subsurface soils.

#### 4.5 Water soluble cations

The water soluble cations (in 1:2 soil-water ratio) - calcium, magnesium, potassium and sodium were measured across different elevations, distances and seasons and the results are presented in this section.

**Water soluble- Ca:** The amounts of water soluble-Ca in surface and subsurface soils of grape vineyard are presented in Tables 5a and 5b respectively. High amounts of water soluble-Ca ( $4.92 \text{ me l}^{-1}$ ) was observed at 15cm distance in lower regions of the vineyard while, least concentration of  $1.93 \text{ me l}^{-1}$  was recorded at 120 cm distance in higher region. The subsurface soils had lesser amounts of water soluble calcium compared to surface soils and it ranged from 1.54 to  $4.50 \text{ me l}^{-1}$ .

In terms of elevations, *i.e.* positions of the vineyards, the surface soil samples of lower regions recorded significantly higher amounts of water soluble- Ca representing lower region of the vineyards while, least values were observed in high elevation areas. Water soluble - Ca content in surface soils varied significantly in the order  $E_3 > E_2 > E_1$ . However, it was found on par with each other in subsurface soils across all elevations. In terms of its distribution across horizontal distance, significantly high amounts of calcium were found at 15cm distance ( $D_1$ ) from the plant row and least values were observed at 120cm distance ( $D_4$ ). Comparison of mean values of calcium ( $\text{me l}^{-1}$ ) across horizontal distances were found in the order  $D_1 (4.05) > D_2 (3.72) > D_3 (3.02) > D_4 (2.56)$  in surface soil. However, the subsurface soils recorded calcium contents in the order  $D_1 (3.53) = D_2 (3.30) > D_3 (2.70) > D_4 (2.20)$  with no significant differences at 15 cm and 30 cm distance. Water soluble-Ca was also influenced by season or time of sampling. The soil samples collected at the beginning of the experiment ( $S_1$ , before pruning) and at harvest stage ( $S_3$ ) recorded higher amounts compared to soil samples representing growth stage ( $S_2$ ). The season mean values exhibited significant differences both in surface and subsurface soils. They were found in the order  $S_3 > S_1 > S_2$  with corresponding values of 3.92, 3.62 and  $2.48 \text{ me l}^{-1}$  in surface and 3.50, 3.08 and  $2.21 \text{ me l}^{-1}$  in subsurface.

In terms of interactions of elevation and distance on water soluble -Ca, the mean values of  $E \times D$  varied significantly with distance at both the depths. Comparison of interaction mean values across elevation was just similar to the effect of independent elevation factor ( $E_3 > E_2 > E_1$ ) at all distances for surface soils. However, corresponding

**Table 5a: Water soluble -Ca<sup>2+</sup> (me l<sup>-1</sup>) in surface soils (0-20cm) of grape vineyard at different elevations, distances and seasons**

		Elevation (E)											
Distance (D) from the row	E <sub>1</sub> - High			D x E <sub>1</sub>	E <sub>2</sub> - Mid			D x E <sub>2</sub>	E <sub>3</sub> - Low			D x E <sub>3</sub>	Distance Mean (D)
	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		
<b>D<sub>1</sub> - 15cm</b>	4.16	2.79	4.21	<b>3.70</b>	4.34	2.76	4.83	<b>3.98</b>	4.92	3.30	3.30	<b>4.46</b>	<b>4.05</b>
<b>D<sub>2</sub> - 30cm</b>	3.50	2.57	3.63	<b>3.37</b>	4.20	2.68	4.37	<b>3.72</b>	4.64	2.81	2.81	<b>4.07</b>	<b>3.72</b>
<b>D<sub>3</sub> - 75cm</b>	3.27	2.21	2.92	<b>2.86</b>	3.31	2.20	3.59	<b>2.98</b>	3.45	2.41	2.41	<b>3.22</b>	<b>3.02</b>
<b>D<sub>4</sub> - 120cm</b>	1.93	2.12	2.81	<b>2.58</b>	2.63	2.05	3.30	<b>2.43</b>	2.81	1.95	3.50	<b>2.69</b>	<b>2.56</b>
<b>E x S Mean</b>	<b>3.58</b>	<b>2.41</b>	<b>3.39</b>	<b>3.13</b>	<b>3.41</b>	<b>2.40</b>	<b>4.02</b>	<b>3.28</b>	<b>3.87</b>	<b>2.62</b>	<b>4.34</b>	<b>3.61</b>	<b>GM 3.34</b>
<b>Season x Distance (S x D)</b>				<b>D<sub>1</sub> - 15cm</b>	<b>D<sub>2</sub> - 30cm</b>	<b>D<sub>3</sub> - 75cm</b>	<b>D<sub>4</sub> -120cm</b>	<b>Season Mean (S)</b>					
<b>S<sub>1</sub> – February 18 (Before back Pruning)</b>				4.47	4.25	3.31	2.45	<b>3.62</b>					
<b>S<sub>2</sub> – September 18 (Growth Stage)</b>				2.93	2.66	2.27	2.04	<b>2.48</b>					
<b>S<sub>3</sub> – March 19 (Harvesting Stage)</b>				4.73	4.25	3.48	3.20	<b>3.92</b>					
<b>Statistical Analysis</b>													
<b>Factor</b>	<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>		<b>Factor</b>				<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>				
<b>Elevation (E)</b>	0.03	0.10		<b>Elevation x Distance (E x D)</b>				0.07	0.20				
<b>Distance (D)</b>	0.04	0.12		<b>Elevation x Season (E x S)</b>				0.05	0.14				
<b>Season (S)</b>	0.03	0.08		<b>Distance x Season (D x S)</b>				0.06	0.16				
				<b>Elevation x Distance x Season (E x D x S)</b>				0.10	0.28				

**Table 5b: Water soluble -Ca<sup>2+</sup> (me l<sup>-1</sup>) in subsurface soils (20-40cm) of vineyard at different elevations, distances and seasons**

Distance (D) from the row	Elevation (E)												Distance Mean (D)
	E <sub>1</sub> - High			D x E <sub>1</sub>	E <sub>2</sub> - Mid			D x E <sub>2</sub>	E <sub>3</sub> - Low			D x E <sub>3</sub>	
	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		
<b>D<sub>1</sub> - 15cm</b>	3.73	2.53	3.35	<b>3.20</b>	3.85	2.36	4.39	<b>3.53</b>	4.50	2.65	4.43	<b>3.86</b>	<b>3.53</b>
<b>D<sub>2</sub> - 30cm</b>	3.61	2.44	3.01	<b>3.02</b>	3.61	2.31	4.05	<b>3.38</b>	3.79	2.60	2.27	<b>3.49</b>	<b>3.30</b>
<b>D<sub>3</sub> - 75cm</b>	2.27	2.11	2.85	<b>2.72</b>	2.78	2.14	3.36	<b>2.76</b>	3.19	2.06	3.54	<b>2.62</b>	<b>2.70</b>
<b>D<sub>4</sub> - 120cm</b>	1.54	1.86	2.67	<b>2.06</b>	1.65	1.76	2.90	<b>2.16</b>	2.46	1.75	3.19	<b>2.37</b>	<b>2.20</b>
<b>E x S Mean</b>	<b>3.05</b>	<b>2.24</b>	<b>2.97</b>	<b>2.75</b>	<b>2.99</b>	<b>2.14</b>	<b>3.75</b>	<b>2.96</b>	<b>2.99</b>	<b>2.14</b>	<b>3.75</b>	<b>3.09</b>	<b>GM 2.93</b>
<b>Season x Distance (S x D)</b>				<b>D<sub>1</sub> - 15cm</b>	<b>D<sub>2</sub> - 30cm</b>	<b>D<sub>3</sub> - 75cm</b>	<b>D<sub>4</sub> -120cm</b>	<b>Season Mean (S)</b>					
<b>S<sub>1</sub> – February 18 (Before back Pruning)</b>				4.03	3.67	2.75	1.88	<b>3.08</b>					
<b>S<sub>2</sub> – September 18 (Growth Stage)</b>				2.52	2.45	2.10	1.79	<b>2.21</b>					
<b>S<sub>3</sub> – March 19 (Harvesting Stage)</b>				4.05	3.78	3.25	2.92	<b>3.50</b>					
<b>Statistical Analysis</b>													
<b>Factor</b>	<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>		<b>Factor</b>				<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>				
<b>Elevation (E)</b>	0.11	0.33		<b>Elevation x Distance (E x D)</b>				0.22	0.66				
<b>Distance (D)</b>	0.12	0.38		<b>Elevation x Season (E x S)</b>				0.15	0.47				
<b>Season (S)</b>	0.09	0.27		<b>Distance x Season (D x S)</b>				0.18	0.54				
				<b>Elevation x Distance x Season (E x D x S)</b>				0.30	0.94				

mean values were on par at  $E_1$  and  $E_2$  for subsurface soils. The interaction effect of elevation and season ( $E \times S$ ) significantly influenced the calcium content at all depths in surface soils ( $E_3 > E_2 > E_1$ ). However, the subsurface soils did not record any significant seasonal variations at  $E_1$ . Comparison of these mean values indicated significant differences across all three seasons ( $S_3 > S_1 > S_2$ ) in surface soils at all elevations while, they did not vary significantly in subsurface soils at harvest and before pruning ( $S_2 > S_3 = S_1$ ).

Water soluble -Ca was significantly influenced by distance and season interactions and their mean values at all distances were observed in the order -  $S_3 > S_1 > S_2$  seasons for surface soils and  $S_3 = S_1 > S_2$  seasons for subsurface soils. However, the mean values varied significantly across seasons at all distances in surface soils except at  $D_1$  and  $D_2$  in subsurface soils. The cumulative effect of elevation, distance and season ( $E \times D \times S$ ) on water soluble-Ca in general showed significantly higher values in lower regions of the vineyard at all seasons. However, the high and mid elevation regions did not vary significantly with each other in both surface and subsurface soils. The interaction effect of three factors decreased water soluble- Ca significantly during growth stage and it decreased with increase in distance across elevations. However, the interaction effect did not have significant influence *w.r.t.* seasons and elevations in subsurface soils at  $D_1$ ,  $D_2$  and  $D_3$ .

**Water soluble -Mg:** The amounts of water soluble-Mg in surface and subsurface soils of grape vineyard across three seasons at different elevations and distances are given in Tables 6a (surface) and 6b (subsurface). The magnesium content ranged from 0.68 to 3.13  $\text{me l}^{-1}$  in surface and 0.59 to 2.94  $\text{me l}^{-1}$  in subsurface soils.

The micro elevation factor had significant influence on the magnesium content in both surface and subsurface soils. The surface soils had higher water soluble-Mg contents than subsurface soils across all the treatments combinations. The mean magnesium contents varied significantly in the order  $E_3 > E_2 > E_1$  with respective values of 2.23, 1.98 and 1.82  $\text{me l}^{-1}$  and 1.93, 1.62 and 1.51  $\text{me l}^{-1}$  in subsurface soils. In terms of distance, the soils present closer to the plant row recorded significantly higher magnesium contents and it decreased with increase in distance from the plant row. Both surface and subsurface soils behaved similar to the observations made with respect to other cations. Thus, water soluble-Mg contents in surface and subsurface soils was also

**Table 6a: Water soluble -  $Mg^{2+}$  ( $me\ l^{-1}$ ) in surface soils (0-20cm) of vineyard at different elevations, distances and seasons**

		Elevation (E)											
Distance (D) from the row	E <sub>1</sub> - High			D x E <sub>1</sub>	E <sub>2</sub> - Mid			D x E <sub>2</sub>	E <sub>3</sub> - Low			D x E <sub>3</sub>	Distance Mean (D)
	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		
<b>D<sub>1</sub> - 15cm</b>	2.79	0.98	2.88	<b>2.22</b>	2.93	1.13	3.05	<b>2.37</b>	3.10	1.42	3.13	<b>2.55</b>	<b>2.38</b>
<b>D<sub>2</sub> - 30cm</b>	2.58	0.92	2.85	<b>2.12</b>	2.78	1.07	2.94	<b>2.26</b>	2.97	1.35	2.86	<b>2.40</b>	<b>2.26</b>
<b>D<sub>3</sub> - 75cm</b>	2.25	0.78	2.26	<b>1.76</b>	2.62	0.84	2.32	<b>1.93</b>	2.78	1.19	2.64	<b>2.20</b>	<b>1.97</b>
<b>D<sub>4</sub> - 120cm</b>	1.20	0.68	1.68	<b>1.19</b>	1.35	0.79	2.02	<b>1.37</b>	2.31	1.05	1.98	<b>1.78</b>	<b>1.44</b>
<b>E x S Mean</b>	<b>2.21</b>	<b>0.84</b>	<b>2.42</b>	<b>1.82</b>	<b>2.42</b>	<b>0.95</b>	<b>2.58</b>	<b>1.98</b>	<b>2.79</b>	<b>1.25</b>	<b>2.65</b>	<b>2.23</b>	<b>GM 2.01</b>
<b>Season x Distance (S x D)</b>				<b>D<sub>1</sub> - 15cm</b>	<b>D<sub>2</sub> - 30cm</b>	<b>D<sub>3</sub> - 75cm</b>	<b>D<sub>4</sub> -120cm</b>	<b>Season Mean (S)</b>					
<b>S<sub>1</sub> – February 18 (Before back Pruning)</b>				2.94	2.78	2.55	1.62	<b>2.47</b>					
<b>S<sub>2</sub> – September 18 (Growth Stage)</b>				1.18	1.12	0.94	0.82	<b>1.01</b>					
<b>S<sub>3</sub> – March 19 (Harvesting Stage)</b>				3.02	2.88	2.41	1.89	<b>2.55</b>					
<b>Statistical Analysis</b>													
<b>Factor</b>	<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>		<b>Factor</b>				<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>				
<b>Elevation (E)</b>	0.03	0.08		<b>Elevation x Distance (E x D)</b>				0.06	0.16				
<b>Distance (D)</b>	0.03	0.09		<b>Elevation x Season (E x S)</b>				0.04	0.12				
<b>Season (S)</b>	0.02	0.07		<b>Distance x Season (D x S)</b>				0.05	0.13				
				<b>Elevation x Distance x Season (E x D x S)</b>				0.08	0.23				

**Table 6b: Water soluble -Mg<sup>2+</sup> in subsurface soils (20-40cm) of vineyard different elevations, distances and seasons**

Distance (D) from the row	Elevation (E)												Distance Mean (D)
	E <sub>1</sub> - High			D x E <sub>1</sub>	E <sub>2</sub> - Mid			D x E <sub>2</sub>	E <sub>3</sub> - Low			D x E <sub>3</sub>	
	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		
<b>D<sub>1</sub> - 15cm</b>	2.34	0.84	2.59	<b>1.92</b>	2.38	0.98	2.58	<b>1.98</b>	2.94	1.28	2.82	<b>2.34</b>	<b>2.08</b>
<b>D<sub>2</sub> - 30cm</b>	2.12	0.80	2.31	<b>1.74</b>	2.28	0.91	2.41	<b>1.87</b>	2.68	1.21	2.58	<b>2.16</b>	<b>1.92</b>
<b>D<sub>3</sub> - 75cm</b>	1.30	0.73	2.10	<b>1.38</b>	2.22	0.77	2.24	<b>1.74</b>	2.26	1.13	2.47	<b>1.95</b>	<b>1.59</b>
<b>D<sub>4</sub> - 120cm</b>	1.07	0.59	1.31	<b>0.99</b>	1.20	0.55	1.63	<b>1.12</b>	1.29	0.84	1.72	<b>1.28</b>	<b>1.13</b>
<b>E x S Mean</b>	<b>1.71</b>	<b>0.74</b>	<b>2.08</b>	<b>1.51</b>	<b>2.02</b>	<b>0.80</b>	<b>2.21</b>	<b>1.62</b>	<b>2.29</b>	<b>1.11</b>	<b>2.40</b>	<b>1.93</b>	<b>GM 1.71</b>
<b>Season x Distance (S x D)</b>				<b>D<sub>1</sub> - 15cm</b>	<b>D<sub>2</sub> - 30cm</b>	<b>D<sub>3</sub> - 75cm</b>	<b>D<sub>4</sub> -120cm</b>	<b>Season Mean (S)</b>					
<b>S<sub>1</sub> – February 18 (Before back Pruning)</b>				2.55	2.36	1.93	1.19	<b>2.01</b>					
<b>S<sub>2</sub> – September 18 (Growth Stage)</b>				1.03	0.97	0.88	0.66	<b>0.89</b>					
<b>S<sub>3</sub> – March 19 (Harvesting Stage)</b>				2.66	2.43	2.27	1.55	<b>2.23</b>					
<b>Statistical Analysis</b>													
<b>Factor</b>	<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>		<b>Factor</b>				<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>				
<b>Elevation (E)</b>	0.05	0.15		<b>Elevation x Distance (E x D)</b>				0.10	NS				
<b>Distance (D)</b>	0.06	0.18		<b>Elevation x Season (E x S)</b>				0.07	NS				
<b>Season (S)</b>	0.04	0.13		<b>Distance x Season (D x S)</b>				0.08	0.25				
				<b>Elevation x Distance x Season (E x D x S)</b>				0.14	0.44				

observed in the order  $D_1 > D_2 > D_3 > D_4$ . In terms of seasons, least magnesium concentrations were recorded during growth stage ( $S_2$ ) in both surface ( $1.01 \text{ me l}^{-1}$ ) and subsurface ( $0.89 \text{ me l}^{-1}$ ) soils. However, the other two seasons  $S_1$  (before pruning) and  $S_3$  (at harvest) recorded significantly higher values. The season mean values of magnesium varied significantly at both the depths as observed *w.r.t.* other cations  $S_3 > S_1 > S_2$ .

The interaction effect of elevation and distance (E x D) and elevation and season (E x S) on magnesium contents were found significant only in surface soils and not in subsurface soils. In general, magnesium content was significantly high at lower regions and it decreased towards higher regions. In terms of distance, the mean values in surface soils were observed in the order  $D_1 = D_2 > D_3 > D_4$  at all elevations. With respect to elevation and season interaction, the mean values of water soluble-Mg varied significantly in high elevation areas ( $E_1$ ) across all seasons. However, the values remained on par in  $S_1$  (before pruning) at  $E_1$  and  $E_2$  and in  $S_3$  (at harvest) at  $E_2$  and  $E_3$  regions of the vineyards. Water soluble-Mg in surface and subsurface soils were found influenced by D x S (distance and season) in the order  $S_1 = S_3 > S_2$  at all the four horizontal distances except in subsurface soils during growth season ( $S_2$ ). The mean values of magnesium in surface soils as influenced by the interaction of D x S varied significantly during  $S_1$  (before pruning) and  $S_2$  (at growth stage) in the order  $D_1 > D_2 > D_3 > D_4$  across all the three elevations while, it was observed in the order  $D_1 = D_2 > D_3 = D_4$  in soils samples at harvest stage ( $S_3$ ). In case of subsurface soils, the mean values across three elevations were found on par with each other during growth stage ( $S_2$ ) while, it was found in the order  $D_1 = D_2 > D_3 > D_4$  at  $S_1$  – before pruning and at  $S_2$  – harvest stage.

**Water soluble-Na:** The data on total water soluble-Na content in soils of grape vineyard collected at different distances, elevations and seasons are tabulated and presented. In surface soils, water soluble-Na values ranged from 1.58 to 3.97  $\text{me l}^{-1}$  (Table 7a) similarly, subsurface soils recorded 1.47 to 3.80  $\text{me l}^{-1}$  of water soluble-Na (Table 7b).

The concentrations of sodium ( $\text{me l}^{-1}$ ) in 1:2 soil water extract of surface soils were found significantly higher at low point areas ( $E_3$ ) and it decreased significantly with increase in elevation position of the vineyard ( $E_3 > E_2 > E_1$  with respective values

**Table 7a: Water soluble - Na<sup>+</sup> (me l<sup>-1</sup>) in surface soils (0-20cm) of vineyard at different elevations, distances and seasons**

Distance (D) from the row	Elevation (E)												Distance Mean (D)
	E <sub>1</sub> - High			D x E <sub>1</sub>	E <sub>2</sub> - Mid			D x E <sub>2</sub>	E <sub>3</sub> - Low			D x E <sub>3</sub>	
	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		
<b>D<sub>1</sub> - 15cm</b>	3.18	2.45	3.21	<b>2.95</b>	3.31	2.43	3.65	<b>3.13</b>	3.58	2.62	3.97	<b>3.39</b>	<b>3.16</b>
<b>D<sub>2</sub> - 30cm</b>	3.08	2.04	3.02	<b>2.71</b>	3.27	2.03	3.47	<b>2.92</b>	3.53	2.63	3.88	<b>3.35</b>	<b>2.99</b>
<b>D<sub>3</sub> - 75cm</b>	1.81	1.69	2.41	<b>1.97</b>	2.20	1.90	3.01	<b>2.37</b>	3.30	2.25	3.28	<b>2.95</b>	<b>2.43</b>
<b>D<sub>4</sub> - 120cm</b>	1.58	2.16	2.07	<b>1.97</b>	2.08	2.19	2.57	<b>2.28</b>	2.80	3.09	2.90	<b>2.93</b>	<b>2.40</b>
<b>E x S Mean</b>	<b>2.41</b>	<b>2.11</b>	<b>2.68</b>	<b>2.40</b>	<b>2.72</b>	<b>2.14</b>	<b>3.18</b>	<b>2.68</b>	<b>3.30</b>	<b>2.65</b>	<b>3.51</b>	<b>3.15</b>	<b>GM 2.74</b>
<b>Season x Distance (S x D)</b>				<b>D<sub>1</sub> - 15cm</b>	<b>D<sub>2</sub> - 30cm</b>	<b>D<sub>3</sub> - 75cm</b>	<b>D<sub>4</sub> -120cm</b>	<b>Season Mean (S)</b>					
<b>S<sub>1</sub> – February 18 (Before back Pruning)</b>				3.36	3.29	2.44	2.15	<b>2.81</b>					
<b>S<sub>2</sub> – September 18 (Growth Stage)</b>				2.50	2.23	1.95	2.52	<b>2.30</b>					
<b>S<sub>3</sub> – March 19 (Harvesting Stage)</b>				3.61	3.46	2.90	2.52	<b>3.12</b>					
<b>Statistical Analysis</b>													
<b>Factor</b>	<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>		<b>Factor</b>				<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>				
<b>Elevation (E)</b>	0.03	0.09		<b>Elevation x Distance (E x D)</b>				0.07	0.19				
<b>Distance (D)</b>	0.04	0.11		<b>Elevation x Season (E x S)</b>				0.05	NS				
<b>Season (S)</b>	0.03	0.08		<b>Distance x Season (D x S)</b>				0.05	0.15				
				<b>Elevation x Distance x Season (E x D x S)</b>				0.09	0.26				

**Table 7b: Water soluble - Na<sup>+</sup> (me l<sup>-1</sup>) in subsurface soils (20-40cm) of vineyard at different elevations, distances and seasons**

Distance (D) from the row	Elevation (E)												Distance Mean (D)	
	E <sub>1</sub> - High			D x E <sub>1</sub>	E <sub>2</sub> - Mid			D x E <sub>2</sub>	E <sub>3</sub> - Low			D x E <sub>3</sub>		
	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>			
<b>D<sub>1</sub> - 15cm</b>	2.60	2.40	2.79	<b>2.60</b>	3.23	2.27	3.36	<b>2.95</b>	3.44	2.17	3.80	<b>3.14</b>	<b>2.90</b>	
<b>D<sub>2</sub> - 30cm</b>	2.36	2.21	2.49	<b>2.35</b>	3.20	2.14	3.16	<b>2.83</b>	3.39	2.70	3.67	<b>3.25</b>	<b>2.81</b>	
<b>D<sub>3</sub> - 75cm</b>	1.67	1.92	2.31	<b>1.97</b>	2.11	1.97	2.78	<b>2.29</b>	2.92	2.63	3.11	<b>2.89</b>	<b>2.38</b>	
<b>D<sub>4</sub> - 120cm</b>	1.47	1.52	1.53	<b>1.51</b>	1.61	1.73	2.51	<b>1.95</b>	2.00	2.68	2.72	<b>2.47</b>	<b>1.97</b>	
<b>E x S Mean</b>	<b>2.03</b>	<b>2.01</b>	<b>2.28</b>	<b>2.11</b>	<b>2.54</b>	<b>2.03</b>	<b>2.95</b>	<b>2.51</b>	<b>2.94</b>	<b>2.55</b>	<b>3.32</b>	<b>2.94</b>	<b>GM 2.52</b>	
<b>Season x Distance (S x D)</b>					<b>D<sub>1</sub> - 15cm</b>	<b>D<sub>2</sub> - 30cm</b>	<b>D<sub>3</sub> - 75cm</b>	<b>D<sub>4</sub> -120cm</b>	<b>Season Mean (S)</b>					
<b>S<sub>1</sub> – February 18 (Before back Pruning)</b>					3.09	2.98	2.23	1.69	<b>2.25</b>					
<b>S<sub>2</sub> – September 18 (Growth Stage)</b>					2.28	2.35	2.18	1.98	<b>2.20</b>					
<b>S<sub>3</sub> – March 19 (Harvesting Stage)</b>					3.32	3.11	2.73	2.25	<b>2.85</b>					
<b>Statistical Analysis</b>														
<b>Factor</b>	<b>S.Em.±</b>		<b>CD<sub>0.05</sub></b>		<b>Factor</b>						<b>S.Em.±</b>		<b>CD<sub>0.05</sub></b>	
<b>Elevation (E)</b>	0.02		0.05		<b>Elevation x Distance (E x D)</b>						0.04		NS	
<b>Distance (D)</b>	0.02		0.07		<b>Elevation x Season (E x S)</b>						0.03		NS	
<b>Season (S)</b>	0.02		0.05		<b>Distance x Season (D x S)</b>						0.04		0.10	
					<b>Elevation x Distance x Season (E x D x S)</b>						0.06		NS	

of 3.15, 2.68 and 2.40 me l<sup>-1</sup>). However, the subsurface soils of mid regions (E<sub>2</sub>) were found on par with both high (E<sub>1</sub>) and low (E<sub>3</sub>) elevation regions. In terms of distance, the soils present closer to the plant row at 15 cm recorded higher Na contents and it decreased with increasing sampling distance (D<sub>2</sub>, D<sub>3</sub> and D<sub>4</sub>). The variations were found significantly different at all the four distances. However, the subsurface soils at 15 cm (D<sub>1</sub>) and 30 cm (D<sub>2</sub>) did not show significant differences. Thus, the orders of variations in water soluble- Na were found to be D<sub>1</sub> > D<sub>2</sub> > D<sub>3</sub> > D<sub>4</sub> in surface soil and D<sub>1</sub> = D<sub>2</sub> > D<sub>3</sub> > D<sub>4</sub> in subsurface soils. In terms of seasons, soil samples representing harvesting stage (S<sub>3</sub>) and at the beginning stage (S<sub>1</sub>) had higher Na contents compared to the soils collected at crop growth stage (S<sub>2</sub>).

In terms of elevation and distance interactions (E x D) on water soluble-Na in both surface and subsurface soils, the soil samples at 15 cm (D<sub>1</sub>) and 30 cm (D<sub>2</sub>) recorded higher Na contents than soils at 75 (D<sub>3</sub>) and 120 cm (D<sub>4</sub>). The water soluble-Na contents varied significantly in the order D<sub>1</sub> = D<sub>2</sub> > D<sub>3</sub> > D<sub>4</sub> at all the three elevations. However, interaction of elevation and season (E x S) had no significant influence on water soluble-Na in surface soils but, showed significant effect in subsurface soils. Cumulative effect of elevation, distance and season interaction (E x D x S) on surface and subsurface soils revealed similar observations made with respect to distance and season and elevation as individual factors. The only deviation was that there was no cumulative effect across seasons in subsurface soils.

**Water soluble –K:** The amounts of water soluble-K present in soils at different elevations and distances across three seasons are presented in Tables 8a and b. The potassium contents in surface soils ranged from 0.35 me l<sup>-1</sup> at D<sub>4</sub> E<sub>1</sub> S<sub>1</sub> (at 120 cm distance; in high elevation areas; and at just before pruning stage) to 1.27 me l<sup>-1</sup> at D<sub>1</sub> E<sub>3</sub> S<sub>2</sub> (at 15 cm distance; low elevation areas; at growth stage). Correspondingly, the subsurface soils recorded 0.30 to 1.14 me l<sup>-1</sup> of water soluble-K.

Among three regions of different elevations, the soils at low region of grape vineyard (E<sub>3</sub>) recorded significantly higher potassium contents (0.75 me l<sup>-1</sup> and 0.63 me l<sup>-1</sup> in surface and subsurface soils). However, the values did not vary significantly with soils of mid elevation areas. Water soluble-K trend surface and subsurface soils remained same with values in the order - E<sub>3</sub> = E<sub>2</sub> > E<sub>1</sub>. Respective values *w.r.t.* water soluble-K were 0.75, 0.71 and 0.65 me l<sup>-1</sup> in surface soils and 0.63, 0.62 and 0.57 me l<sup>-1</sup>

**Table 8a: Water soluble -K<sup>+</sup> (me l<sup>-1</sup>) in surface soils (0-20cm) of vineyard at different elevations, distances and seasons**

Distance (D) from the row	Elevation (E)												Distance Mean (D)
	E <sub>1</sub> - High			D x E <sub>1</sub>	E <sub>2</sub> - Mid			D x E <sub>2</sub>	E <sub>3</sub> - Low			D x E <sub>3</sub>	
	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		
<b>D<sub>1</sub> - 15cm</b>	0.69	1.15	0.72	<b>0.85</b>	0.72	1.21	0.78	<b>0.90</b>	0.70	1.27	0.75	<b>0.91</b>	<b>0.89</b>
<b>D<sub>2</sub> - 30cm</b>	0.62	0.95	0.65	<b>0.74</b>	0.66	1.02	0.73	<b>0.80</b>	0.79	1.14	0.89	<b>0.94</b>	<b>0.83</b>
<b>D<sub>3</sub> - 75cm</b>	0.40	0.74	0.50	<b>0.55</b>	0.48	0.78	0.55	<b>0.61</b>	0.48	0.81	0.59	<b>0.63</b>	<b>0.59</b>
<b>D<sub>4</sub> - 120cm</b>	0.35	0.65	0.40	<b>0.47</b>	0.40	0.70	0.44	<b>0.51</b>	0.41	0.67	0.46	<b>0.51</b>	<b>0.50</b>
<b>E x S Mean</b>	<b>0.52</b>	<b>0.87</b>	<b>0.57</b>	<b>0.65</b>	<b>0.57</b>	<b>0.93</b>	<b>0.63</b>	<b>0.71</b>	<b>0.60</b>	<b>0.98</b>	<b>0.67</b>	<b>0.75</b>	<b>GM 0.70</b>
<b>Season x Distance (S x D)</b>				<b>D<sub>1</sub> - 15cm</b>	<b>D<sub>2</sub> - 30cm</b>	<b>D<sub>3</sub> - 75cm</b>	<b>D<sub>4</sub> -120cm</b>	<b>Season Mean (S)</b>					
<b>S<sub>1</sub> – February 18 (Before back Pruning)</b>				0.70	0.69	0.46	0.39	<b>0.65</b>					
<b>S<sub>2</sub> – September 18 (Growth Stage)</b>				1.21	1.04	0.78	0.67	<b>0.71</b>					
<b>S<sub>3</sub> – March 19 (Harvesting Stage)</b>				0.75	0.76	0.55	0.43	<b>0.75</b>					
<b>Statistical Analysis</b>													
<b>Factor</b>	<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>		<b>Factor</b>				<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>				
<b>Elevation (E)</b>	0.02	0.05		<b>Elevation x Distance (E x D)</b>				0.04	NS				
<b>Distance (D)</b>	0.02	0.07		<b>Elevation x Season (E x S)</b>				0.03	NS				
<b>Season (S)</b>	0.02	0.05		<b>Distance x Season (D x S)</b>				0.04	0.10				
				<b>Elevation x Distance x Season (E x D x S)</b>				0.06	NS				

**Table 8b: Water soluble -  $K^+$  ( $me\ l^{-1}$ ) of subsurface soils (20-40cm) of vineyard at different elevations, distances and seasons**

		Elevation (E)											
Distance (D) from the row	E <sub>1</sub> - High			D x E <sub>1</sub>	E <sub>2</sub> - Mid			D x E <sub>2</sub>	E <sub>3</sub> - Low			D x E <sub>3</sub>	Distance Mean (D)
	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		
<b>D<sub>1</sub> - 15cm</b>	0.60	1.05	0.66	<b>0.77</b>	0.64	1.14	0.70	<b>0.82</b>	0.62	1.06	0.76	<b>0.81</b>	<b>0.80</b>
<b>D<sub>2</sub> - 30cm</b>	0.50	0.87	0.59	<b>0.65</b>	0.59	0.55	0.61	<b>0.72</b>	0.57	0.88	0.68	<b>0.72</b>	<b>0.70</b>
<b>D<sub>3</sub> - 75cm</b>	0.38	0.64	0.44	<b>0.48</b>	0.43	0.69	0.49	<b>0.54</b>	0.45	0.70	0.53	<b>0.56</b>	<b>0.53</b>
<b>D<sub>4</sub> - 120cm</b>	0.30	0.52	0.35	<b>0.39</b>	0.36	0.57	0.38	<b>0.44</b>	0.35	0.60	0.39	<b>0.44</b>	<b>0.42</b>
<b>E x S Mean</b>	<b>0.44</b>	<b>0.77</b>	<b>0.51</b>	<b>0.57</b>	<b>0.51</b>	<b>0.84</b>	<b>0.54</b>	<b>0.62</b>	<b>0.50</b>	<b>0.81</b>	<b>0.59</b>	<b>0.63</b>	<b>GM 0.61</b>
<b>Season x Distance (S x D)</b>				<b>D<sub>1</sub> - 15cm</b>	<b>D<sub>2</sub> - 30cm</b>	<b>D<sub>3</sub> - 75cm</b>	<b>D<sub>4</sub> -120cm</b>	<b>Season Mean (S)</b>					
<b>S<sub>1</sub> – February 18 (Before back Pruning)</b>				0.62	0.55	0.42	0.34	<b>0.48</b>					
<b>S<sub>2</sub> – September 18 (Growth Stage)</b>				1.08	0.91	0.67	0.56	<b>0.81</b>					
<b>S<sub>3</sub> – March 19 (Harvesting Stage)</b>				0.71	0.63	0.49	0.37	<b>0.55</b>					
<b>Statistical Analysis</b>													
<b>Factor</b>	<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>		<b>Factor</b>				<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>				
<b>Elevation (E)</b>	0.01	0.02		<b>Elevation x Distance (E x D)</b>				0.02	NS				
<b>Distance (D)</b>	0.01	0.03		<b>Elevation x Season (E x S)</b>				0.01	NS				
<b>Season (S)</b>	0.01	0.02		<b>Distance x Season (D x S)</b>				0.01	0.04				
				<b>Elevation x Distance x Season (E x D x S)</b>				0.02	NS				

in subsurface soils. In terms of horizontal distance, the soils at 15 cm from the plant row ( $D_1$ ) recorded highest concentrations of water soluble-K ( $0.89 \text{ me l}^{-1}$ ) and it was found on par with the soils at 30 cm ( $D_2$ ,  $0.83 \text{ me l}^{-1}$ ). However, soils at 75cm ( $D_3$ ,  $0.59 \text{ me l}^{-1}$ ) and 120 cm ( $D_4$ ,  $0.50 \text{ me l}^{-1}$ ) recorded significantly lower values. Thus, the K contents in surface soils was in the order  $D_1 = D_2 > D_3 > D_4$ . The subsurface soils recorded slightly lesser values and the mean values decreased significantly across all the horizontal distances in the order  $D_1 > D_2 > D_3 > D_4$ . Interestingly, comparison of water soluble-K contents across three different seasons recorded very high values in both surface and subsurface soils during growth stage ( $S_2$ ) with respective mean values of 0.93 and  $0.81 \text{ me/L}$ . The soil samples collected before pruning stage ( $S_1$ ) and at harvesting stage ( $S_3$ ) recorded substantially lower values and both the values varied significantly ( $S_2 > S_3 > S_1$ ). Same trend was observed for subsurface soils also. The potassium concentration trend across seasons was in contrast to other cations studied.

In terms of interactions, distance x season ( $D \times S$ ) was the only factor which influenced K content in both surface and subsurface soils. They were found in the order of  $S_2 > S_3 = S_1$  at all the four distances. Interaction effects of other factors ( $E \times D$ ,  $E \times S$  and  $E \times D \times S$ ) had no significant influence on water soluble-K in both surface and subsurface soils.

**Water soluble –total cations:** The information on total water soluble cations in surface and subsurface soils collected at different distances, elevations and seasons from the grape vineyard are tabulated and presented in Tables 9a and 9b respectively. The total water soluble cations ranged from 5.42 to  $13.10 \text{ me l}^{-1}$  in surface soils while, subsurface soils recorded in the range of 4.37 to  $11.82 \text{ me l}^{-1}$ .

The soils of lower regions ( $E_3$ ) grape vineyard recorded significantly higher amounts of total cations ( $9.77 \text{ me l}^{-1}$  in surface soils and  $8.68 \text{ me l}^{-1}$  in subsurface soils). Contrastingly, the soils at high elevation region ( $E_3$ ) recorded significantly lesser amounts with corresponding values of 7.88 and  $6.85 \text{ me l}^{-1}$  respectively. Thus, the total cations varied significantly in the order  $E_3 > E_2 > E_1$ . In soils at  $D_1$  (15cm) recorded highest concentration and the mean values decreased significantly with increase in distance. They varied significantly in the order of  $D_1 > D_2 > D_3 > D_4$  with concentrations of 10.47, 9.76, 8.11 and  $6.87 \text{ me l}^{-1}$  respectively in surface soils. The corresponding values for subsurface soils were found to be 9.31, 8.73, 7.30 and  $5.73 \text{ me l}^{-1}$ .

**Table 9a: Water soluble total cations ( $\text{me l}^{-1}$ ) in surface soils (0-20cm) of vineyard at different elevations, distances and seasons**

Distance (D) from the row	Elevation (E)												Distance Mean (D)
	E <sub>1</sub> - High			D x E <sub>1</sub>	E <sub>2</sub> - Mid			D x E <sub>2</sub>	E <sub>3</sub> - Low			D x E <sub>3</sub>	
	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		
<b>D<sub>1</sub> - 15cm</b>	10.82	7.34	11.02	<b>9.72</b>	11.31	7.63	12.36	<b>10.38</b>	12.36	8.61	13.10	<b>11.31</b>	<b>10.47</b>
<b>D<sub>2</sub> - 30cm</b>	9.78	6.49	10.14	<b>8.80</b>	10.92	6.84	11.51	<b>9.71</b>	11.93	7.74	12.40	<b>10.76</b>	<b>9.76</b>
<b>D<sub>3</sub> - 75cm</b>	7.74	5.42	8.09	<b>7.08</b>	9.42	5.73	9.49	<b>8.21</b>	10.02	6.64	10.49	<b>9.05</b>	<b>8.11</b>
<b>D<sub>4</sub> - 120cm</b>	5.06	5.71	6.95	<b>5.91</b>	6.17	5.68	8.33	<b>6.73</b>	8.33	6.76	8.86	<b>7.97</b>	<b>6.87</b>
<b>E x S Mean</b>	<b>8.35</b>	<b>6.24</b>	<b>9.05</b>	<b>7.88</b>	<b>9.45</b>	<b>6.42</b>	<b>10.40</b>	<b>8.76</b>	<b>10.65</b>	<b>7.50</b>	<b>11.18</b>	<b>9.77</b>	<b>GM 8.80</b>
<b>Season x Distance (S x D)</b>				<b>D<sub>1</sub> - 15cm</b>	<b>D<sub>2</sub> - 30cm</b>	<b>D<sub>3</sub> - 75cm</b>	<b>D<sub>4</sub> -120cm</b>	<b>Season Mean (S)</b>					
<b>S<sub>1</sub> – February 18 (Before back Pruning)</b>				11.48	10.88	9.06	6.52	<b>9.48</b>					
<b>S<sub>2</sub> – September 18 (Growth Stage)</b>				7.82	7.05	5.94	6.05	<b>6.72</b>					
<b>S<sub>3</sub> – March 19 (Harvesting Stage)</b>				12.11	11.35	9.34	8.04	<b>10.21</b>					
<b>Statistical Analysis</b>													
<b>Factor</b>	<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>		<b>Factor</b>				<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>				
<b>Elevation (E)</b>	0.06	0.17		<b>Elevation x Distance (E x D)</b>				0.12	NS				
<b>Distance (D)</b>	0.07	0.19		<b>Elevation x Season (E x S)</b>				0.08	0.24				
<b>Season (S)</b>	0.05	0.14		<b>Distance x Season (D x S)</b>				0.10	0.27				
				<b>Elevation x Distance x Season (E x D x S)</b>				0.16	0.47				

**Table 9b: Water soluble total cations ( $\text{me l}^{-1}$ ) in subsurface soils (20-40cm) of vineyard at different elevations, distances and seasons**

Distance (D) from the row	Elevation (E)												Distance Mean (D)
	E <sub>1</sub> - High			D x E <sub>1</sub>	E <sub>2</sub> - Mid			D x E <sub>2</sub>	E <sub>3</sub> - Low			D x E <sub>3</sub>	
	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		
<b>D<sub>1</sub> - 15cm</b>	9.27	6.82	9.37	<b>8.49</b>	10.10	6.75	11.03	<b>9.29</b>	11.49	7.26	11.82	<b>10.16</b>	<b>9.31</b>
<b>D<sub>2</sub> - 30cm</b>	8.59	6.33	8.40	<b>7.77</b>	9.68	6.21	10.24	<b>8.74</b>	10.44	7.42	11.18	<b>9.68</b>	<b>8.73</b>
<b>D<sub>3</sub> - 75cm</b>	5.61	5.40	7.70	<b>6.23</b>	7.54	5.53	8.86	<b>7.33</b>	8.82	6.52	9.59	<b>8.33</b>	<b>7.30</b>
<b>D<sub>4</sub> - 120cm</b>	4.37	4.49	5.87	<b>4.91</b>	4.82	4.61	7.71	<b>5.71</b>	6.10	5.87	7.65	<b>6.56</b>	<b>5.73</b>
<b>E x S Mean</b>	<b>6.96</b>	<b>5.76</b>	<b>7.83</b>	<b>6.85</b>	<b>8.04</b>	<b>5.81</b>	<b>9.46</b>	<b>7.77</b>	<b>9.21</b>	<b>6.74</b>	<b>10.10</b>	<b>8.68</b>	<b>GM 7.77</b>
<b>Season x Distance (S x D)</b>				<b>D<sub>1</sub> - 15cm</b>	<b>D<sub>2</sub> - 30cm</b>	<b>D<sub>3</sub> - 75cm</b>	<b>D<sub>4</sub> -120cm</b>	<b>Season Mean (S)</b>					
<b>S<sub>1</sub> – February 18 (Before back Pruning)</b>				10.29	9.57	7.32	5.10	<b>8.07</b>					
<b>S<sub>2</sub> – September 18 (Growth Stage)</b>				6.91	6.68	5.83	4.99	<b>6.10</b>					
<b>S<sub>3</sub> – March 19 (Harvesting Stage)</b>				10.74	9.94	8.74	7.10	<b>9.13</b>					
<b>Statistical Analysis</b>													
<b>Factor</b>	<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>		<b>Factor</b>				<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>				
<b>Elevation (E)</b>	0.13	0.39		<b>Elevation x Distance (E x D)</b>				0.25	NS				
<b>Distance (D)</b>	0.14	0.45		<b>Elevation x Season (E x S)</b>				0.18	0.55				
<b>Season (S)</b>	0.10	0.32		<b>Distance x Season (D x S)</b>				0.21	0.64				
				<b>Elevation x Distance x Season (E x D x S)</b>				0.36	1.11				

Comparison of mean values across three different seasons also varied significantly in the order of  $S_3 > S_1 > S_2$  with corresponding values of 10.21, 9.48, 6.72  $\text{me l}^{-1}$  in surface soils and 9.13, 8.07, 6.10  $\text{me l}^{-1}$  in subsurface soils.

In terms of interaction of E x S (elevation and season), the seasonal mean values in general varied significantly across three elevations except in soil samples of  $S_2$  (growth stage) at  $E_1$  and  $E_2$ . The trend remained same even in subsurface soils. Comparison of elevation mean values across seasons indicated that the season or sampling time had significant influence on total cation and they varied in the order of  $S_3 > S_1 > S_2$  across all elevations. The same trend was observed in subsurface soils except in soil samples at  $E_1$  and  $E_2$  collected during growth stage ( $S_2$ ). In terms of distance and season (D x S) interaction, the mean values of total cations in surface soils for each season at all distances showed significant influence in the order -  $S_3 > S_1 > S_2$ . In case of subsurface soils, the same trend was observed in  $D_3$  and  $D_4$  while, it was in the order  $S_3 = S_1 > S_2$  in  $D_1$  and  $D_2$ . The interaction effect on distance showed significant variations across three seasons at both the depths except in subsurface soils representing  $D_1S_2$  and  $D_2S_2$ .

The overall cumulative effect of E x D x S indicated that the soils closer to the plant rows ( $D_1$ : 15 cm and  $D_2$ : 30cm) recorded higher total cation contents while, soil samples from  $D_3$  (75 cm) and  $D_4$  (120 cm) recorded lesser concentrations. In general, the soils of growth stage ( $S_2$ ) at both depths recorded lesser total cations than at  $S_1$  (before pruning) and  $S_3$  (at harvest). In terms of elevations, most of the soil samples representing lower region of the vineyard recorded significantly higher amounts in contrast to high elevation vineyard soil samples with significantly lesser values. Most of the soil samples representing mid elevation region of grape vineyards were found on par with corresponding samples representing either high ( $E_1$ ) or low ( $E_3$ ) elevations.

#### **4.6 Water soluble anions**

The same soil water extractant obtained for cations at 1:2 soil-water ratio, were used for the determination of anions namely, total carbonates ( $\text{CO}_3^{2-} + \text{HCO}_3^{-1}$ ), bicarbonates, chlorides and sulphates. Distribution of these anions in surface and subsurface soils of grape vineyard across different elevations, distances and seasons are given in this section.

**Water soluble carbonate and bicarbonate:** Total carbonates contents ( $\text{CO}_3 + \text{HCO}_3$ ) in 1:2 soil water extracts of surface and subsurface soil samples of grape vineyard are presented in Tables 10a and 10b respectively.

Total carbonates in surface soils ranged from 1.27 to 3.79  $\text{me l}^{-1}$  while, subsurface soils had 1.03 to 3.60  $\text{me l}^{-1}$ . Both surface and subsurface soil samples recorded significant effect of elevation on total carbonates in the order  $E_3 > E_2 > E_1$ . The corresponding total carbonate contents for surface soils were 3.13, 2.65 and 2.39  $\text{me l}^{-1}$  and for subsurface soils were 2.83, 2.32 and 2.03  $\text{me l}^{-1}$ . In terms of distance, the soils closer to the plant row ( $D_1$ -15cm) recorded higher total carbonates and it declined significantly in surface soils ( $D_1 > D_2 > D_3 > D_4$ ). The trend was almost similar in subsurface soils except total carbonate values at  $D_1$  and  $D_2$  which remained on par with each other ( $D_1 = D_2 > D_3 > D_4$ ). The soil samples collected at harvest ( $S_3$ ) and before pruning ( $S_1$ ) were observed with higher total carbonates compared to samples at growth stage ( $S_2$ ). Their values varied significantly in the order  $S_3 > S_1 > S_2$  in surface soils while, the subsurface soils were found in the order  $S_3 = S_1 > S_2$ .

In terms of interaction effects of  $E \times D$  (elevation and distance), the total carbonates decreased significantly in both surface and subsurface soils except in the soil samples representing 15 and 30 cm distances. The mean values of total carbonates representing the interaction of  $E \times S$  (elevation x season) showed variations in the order of  $S_3 = S_1 > S_2$  in surface soils at all the three elevations while, subsurface soils recorded  $S_3 > S_1 = S_2$  order. The interaction of distance and season ( $D \times S$ ) on total carbonates were found significantly higher at harvest ( $S_3$ ) in both surface and subsurface soils. In general, the total carbonates in surface and subsurface soils decreased significantly with increase in distance. However, the mean values at distance  $D_1$  and  $D_2$  during growth ( $S_2$ ) and harvest stage ( $S_3$ ) stages were found on par with each other. Similar non-significant differences were recorded in sub soils at  $D_1$  (15 cm) and  $D_2$  (30 cm). However, no specific trend was observed at 75 cm ( $D_3$ ) and 120 cm ( $D_4$ ) across three seasons. The overall interactions of elevation, distance and season ( $E \times D \times S$ ) on total carbonates in surface and subsurface soils were almost similar to the effects as observed with individual parameters.

**Table 10a: Water soluble ( $\text{CO}_3^{2-} + \text{HCO}_3^-$ ;  $\text{me l}^{-1}$ ) in surface soils (0-20cm) of vineyard at different elevations, distances and seasons**

Distance (D) from the row	Elevation (E)												Distance Mean (D)
	E <sub>1</sub> - High			D x E <sub>1</sub>	E <sub>2</sub> - Mid			D x E <sub>2</sub>	E <sub>3</sub> - Low			D x E <sub>3</sub>	
	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		
<b>D<sub>1</sub> - 15cm</b>	3.34	2.58	3.19	<b>3.04</b>	3.33	2.71	3.61	<b>3.22</b>	3.60	3.39	3.79	<b>3.60</b>	<b>3.28</b>
<b>D<sub>2</sub> - 30cm</b>	2.96	2.53	3.08	<b>2.86</b>	3.22	2.56	3.59	<b>3.13</b>	3.53	3.30	3.73	<b>3.52</b>	<b>3.17</b>
<b>D<sub>3</sub> - 75cm</b>	2.24	1.53	2.39	<b>2.06</b>	2.37	2.14	2.48	<b>2.33</b>	3.08	2.77	3.24	<b>3.03</b>	<b>2.48</b>
<b>D<sub>4</sub> - 120cm</b>	1.66	1.27	1.82	<b>1.59</b>	1.92	1.90	1.88	<b>1.92</b>	2.46	2.41	2.22	<b>2.36</b>	<b>1.95</b>
<b>E x S Mean</b>	<b>2.55</b>	<b>1.98</b>	<b>2.63</b>	<b>2.39</b>	<b>2.73</b>	<b>2.33</b>	<b>2.89</b>	<b>2.65</b>	<b>3.17</b>	<b>2.97</b>	<b>3.25</b>	<b>3.13</b>	<b>GM 2.72</b>
<b>Season x Distance (S x D)</b>				<b>D<sub>1</sub> - 15cm</b>	<b>D<sub>2</sub> - 30cm</b>	<b>D<sub>3</sub> - 75cm</b>	<b>D<sub>4</sub> -120cm</b>	<b>Season Mean (S)</b>					
<b>S<sub>1</sub> – February 18 (Before back Pruning)</b>				3.42	3.24	2.56	2.03	<b>2.81</b>					
<b>S<sub>2</sub> – September 18 (Growth Stage)</b>				2.89	2.80	2.15	1.86	<b>2.42</b>					
<b>S<sub>3</sub> – March 19 (Harvesting Stage)</b>				3.53	3.47	2.72	1.97	<b>2.92</b>					
<b>Statistical Analysis</b>													
<b>Factor</b>	<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>		<b>Factor</b>				<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>				
<b>Elevation (E)</b>	0.03	0.09		<b>Elevation x Distance (E x D)</b>				0.06	0.19				
<b>Distance (D)</b>	0.04	0.11		<b>Elevation x Season (E x S)</b>				0.05	0.13				
<b>Season (S)</b>	0.03	0.09		<b>Distance x Season (D x S)</b>				0.05	0.15				
				<b>Elevation x Distance x Season (E x D x S)</b>				0.09	0.26				

**Table 10b: Water soluble ( $\text{CO}_3^{2-} + \text{HCO}_3^-$ ;  $\text{me l}^{-1}$ ) in subsurface soils (20-40cm) of vineyard at different elevations, distances and seasons**

Distance (D) from the row	Elevation (E)												Distance Mean (D)
	E <sub>1</sub> - High			D x E <sub>1</sub>	E <sub>2</sub> - Mid			D x E <sub>2</sub>	E <sub>3</sub> - Low			D x E <sub>3</sub>	
	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		
<b>D<sub>1</sub> - 15cm</b>	2.45	2.30	2.89	<b>2.55</b>	3.04	2.28	3.34	<b>2.89</b>	3.31	3.25	3.60	<b>3.39</b>	<b>2.94</b>
<b>D<sub>2</sub> - 30cm</b>	2.24	2.09	2.71	<b>2.35</b>	2.50	2.25	3.12	<b>2.62</b>	3.17	2.92	3.14	<b>3.17</b>	<b>2.71</b>
<b>D<sub>3</sub> - 75cm</b>	1.81	1.35	2.32	<b>1.83</b>	1.87	2.08	2.33	<b>2.09</b>	2.56	2.46	3.05	<b>2.69</b>	<b>2.20</b>
<b>D<sub>4</sub> - 120cm</b>	1.52	1.03	1.62	<b>1.39</b>	1.60	1.77	1.67	<b>1.68</b>	2.25	2.02	1.97	<b>2.08</b>	<b>1.72</b>
<b>E x S Mean</b>	<b>2.01</b>	<b>1.70</b>	<b>2.39</b>	<b>2.03</b>	<b>2.25</b>	<b>2.10</b>	<b>2.62</b>	<b>2.32</b>	<b>2.82</b>	<b>2.67</b>	<b>3.01</b>	<b>2.83</b>	<b>GM 2.39</b>
<b>Season x Distance (S x D)</b>				<b>D<sub>1</sub> - 15cm</b>	<b>D<sub>2</sub> - 30cm</b>	<b>D<sub>3</sub> - 75cm</b>	<b>D<sub>4</sub> -120cm</b>	<b>Season Mean (S)</b>					
<b>S<sub>1</sub> – February 18 (Before back Pruning)</b>				2.93	2.64	2.08	1.79	<b>2.36</b>					
<b>S<sub>2</sub> – September 18 (Growth Stage)</b>				2.61	2.42	1.97	1.61	<b>2.15</b>					
<b>S<sub>3</sub> – March 19 (Harvesting Stage)</b>				3.28	3.08	2.57	1.76	<b>2.67</b>					
<b>Statistical Analysis</b>													
<b>Factor</b>	<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>		<b>Factor</b>				<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>				
<b>Elevation (E)</b>	0.07	0.22		<b>Elevation x Distance (E x D)</b>				0.14	NS				
<b>Distance (D)</b>	0.08	0.25		<b>Elevation x Season (E x S)</b>				0.10	0.30				
<b>Season (S)</b>	0.06	0.18		<b>Distance x Season (D x S)</b>				0.11	0.35				
				<b>Elevation x Distance x Season (E x D x S)</b>				0.20	0.61				

**Water soluble sulphate:** The data on water soluble sulphates in grape vineyards at different distances, elevations and seasons are presented in Tables 11a (surface soils) and 11b (subsurface soils). In surface soils, the water soluble sulphates values ranged from 0.25 to 1.17 me l<sup>-1</sup> and in subsurface soils they ranged from 0.19 to 0.90 me l<sup>-1</sup>.

The values of water soluble sulphates were found significantly higher in soils of lower region grape vineyards (E<sub>3</sub>) compared to high (E<sub>1</sub>) and mid regions (E<sub>2</sub>) and it varied in the order of E<sub>3</sub> > E<sub>1</sub> = E<sub>2</sub> in both surface and subsurface soils. In terms of distance, the sulphate contents varied significantly at both the depths (0-20 cm and 20-40 cm) and it decreased significantly with distance from plant row (D<sub>1</sub> > D<sub>2</sub> > D<sub>3</sub> > D<sub>4</sub>). Among three different seasons, the soils collected at harvest (S<sub>3</sub>) and at start of season (S<sub>1</sub>) recorded significantly higher values (S<sub>3</sub> = S<sub>1</sub> > S<sub>2</sub>) compared to values at crop growth stage (S<sub>2</sub>) at both depths. Interestingly, the interactions of individual factors (E x D; D x S; E x S) or their cumulative interaction (E x D x S) had no significant influence on water soluble sulphates in both surface and subsurface soils.

**Water soluble chloride:** The soils of grape vineyard at different distances, elevations and seasons were analyzed for water soluble chlorides and their corresponding values for different treatments are presented for surface and subsurface soils in Tables 12a and 12b respectively.

The soils present in lower elevation points of the vineyard (E<sub>3</sub>) recorded significantly higher chloride contents compared to significantly lower values in high elevation region (E<sub>1</sub>). The elevation influenced water soluble chloride contents significantly in both surface and subsurface soils (E<sub>3</sub> > E<sub>2</sub> > E<sub>1</sub>). The data analysis indicated that the distance from the plant row had a great influence. The chloride contents also varied significantly in the order D<sub>1</sub> > D<sub>2</sub> > D<sub>3</sub> > D<sub>4</sub>. The soil samples collected at harvest (S<sub>3</sub>) recorded high chloride contents while, the samples at growth stages (S<sub>2</sub>) recorded the least values.

The interaction of elevation and distance (E x D) indicated that soils closer to the plants (D<sub>1</sub>-15 cm) recorded significantly higher amounts of chloride compared to soils away from the plant row. The chloride content observed at (D<sub>3</sub>) 75 cm and (D<sub>4</sub>) 120 cm did not show significant differences in both surface and subsurface soils at all the three elevations. However, the values varied significantly in surface soils at D<sub>1</sub> (15 cm) and D<sub>2</sub> (30 cm). In terms of the interaction of elevation and season (E x S), the chloride

**Table 11a: Water soluble -  $\text{SO}_4^{2-}$  ( $\text{me l}^{-1}$ ) in surface soils (0-20cm) of vineyard at different elevations, distances and seasons**

		Elevation (E)											
Distance (D) from the row	E <sub>1</sub> - High			D x E <sub>1</sub>	E <sub>2</sub> - Mid			D x E <sub>2</sub>	E <sub>3</sub> - Low			D x E <sub>3</sub>	Distance Mean (D)
	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		
<b>D<sub>1</sub> - 15cm</b>	0.83	0.56	0.87	<b>0.75</b>	0.89	0.60	1.04	<b>0.84</b>	0.96	0.65	1.17	<b>0.94</b>	<b>0.84</b>
<b>D<sub>2</sub> - 30cm</b>	0.73	0.45	0.73	<b>0.64</b>	0.77	0.50	0.75	<b>0.67</b>	0.86	0.53	1.07	<b>0.82</b>	<b>0.71</b>
<b>D<sub>3</sub> - 75cm</b>	0.59	0.32	0.55	<b>0.49</b>	0.63	0.36	0.62	<b>0.54</b>	0.72	0.39	0.76	<b>0.62</b>	<b>0.55</b>
<b>D<sub>4</sub> - 120cm</b>	0.38	0.25	0.38	<b>0.34</b>	0.50	0.29	0.54	<b>0.44</b>	0.57	0.32	0.59	<b>0.49</b>	<b>0.42</b>
<b>E x S Mean</b>	<b>0.63</b>	<b>0.40</b>	<b>0.63</b>	<b>0.55</b>	<b>0.70</b>	<b>0.44</b>	<b>0.74</b>	<b>0.62</b>	<b>0.78</b>	<b>0.47</b>	<b>0.90</b>	<b>0.72</b>	<b>GM 0.63</b>
<b>Season x Distance (S x D)</b>				<b>D<sub>1</sub> - 15cm</b>	<b>D<sub>2</sub> - 30cm</b>	<b>D<sub>3</sub> - 75cm</b>	<b>D<sub>4</sub> -120cm</b>	<b>Season Mean (S)</b>					
<b>S<sub>1</sub> – February 18 (Before back Pruning)</b>				0.89	0.79	0.65	0.48	<b>0.70</b>					
<b>S<sub>2</sub> – September 18 (Growth Stage)</b>				0.60	0.49	0.36	0.29	<b>0.44</b>					
<b>S<sub>3</sub> – March 19 (Harvesting Stage)</b>				1.03	0.85	0.65	0.50	<b>0.76</b>					
<b>Statistical Analysis</b>													
<b>Factor</b>	<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>		<b>Factor</b>				<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>				
<b>Elevation (E)</b>	0.03	0.08		<b>Elevation x Distance (E x D)</b>				0.06	NS				
<b>Distance (D)</b>	0.03	0.09		<b>Elevation x Season (E x S)</b>				0.04	NS				
<b>Season (S)</b>	0.02	0.07		<b>Distance x Season (D x S)</b>				0.05	NS				
				<b>Elevation x Distance x Season (E x D x S)</b>				0.08	NS				

**Table 11b: Water soluble -  $\text{SO}_4^{2-}$  ( $\text{me l}^{-1}$ ) in subsurface soils (20-40cm) of vineyard at different elevation distances and seasons**

Distance (D) from the row	Elevation (E)												Distance Mean (D)
	E <sub>1</sub> - High			D x E <sub>1</sub>	E <sub>2</sub> - Mid			D x E <sub>2</sub>	E <sub>3</sub> - Low			D x E <sub>3</sub>	
	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		
<b>D<sub>1</sub> - 15cm</b>	0.70	0.42	0.68	<b>0.60</b>	0.75	0.43	0.71	<b>0.63</b>	0.77	0.46	0.90	<b>0.71</b>	<b>0.65</b>
<b>D<sub>2</sub> - 30cm</b>	0.65	0.36	0.58	<b>0.53</b>	0.66	0.40	0.68	<b>0.58</b>	0.73	0.45	0.85	<b>0.67</b>	<b>0.59</b>
<b>D<sub>3</sub> - 75cm</b>	0.42	0.30	0.51	<b>0.41</b>	0.55	0.32	0.59	<b>0.49</b>	0.69	0.37	0.65	<b>0.57</b>	<b>0.49</b>
<b>D<sub>4</sub> - 120cm</b>	0.32	0.19	0.33	<b>0.28</b>	0.40	0.27	0.49	<b>0.39</b>	0.42	0.28	0.52	<b>0.40</b>	<b>0.36</b>
<b>E x S Mean</b>	<b>0.53</b>	<b>0.32</b>	<b>0.53</b>	<b>0.46</b>	<b>0.59</b>	<b>0.35</b>	<b>0.62</b>	<b>0.52</b>	<b>0.65</b>	<b>0.39</b>	<b>0.73</b>	<b>0.59</b>	<b>GM 0.52</b>
<b>Season x Distance (S x D)</b>				<b>D<sub>1</sub> - 15cm</b>	<b>D<sub>2</sub> - 30cm</b>	<b>D<sub>3</sub> - 75cm</b>	<b>D<sub>4</sub> -120cm</b>	<b>Season Mean (S)</b>					
<b>S<sub>1</sub> – February 18 (Before back Pruning)</b>				0.74	0.68	0.55	0.38	<b>0.59</b>					
<b>S<sub>2</sub> – September 18 (Growth Stage)</b>				0.44	0.40	0.33	0.24	<b>0.35</b>					
<b>S<sub>3</sub> – March 19 (Harvesting Stage)</b>				0.77	0.70	0.58	0.45	<b>0.62</b>					
<b>Statistical Analysis</b>													
<b>Factor</b>	<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>		<b>Factor</b>				<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>				
<b>Elevation (E)</b>	0.01	0.05		<b>Elevation x Distance (E x D)</b>				0.03	NS				
<b>Distance (D)</b>	0.02	0.05		<b>Elevation x Season (E x S)</b>				0.02	NS				
<b>Season (S)</b>	0.01	0.04		<b>Distance x Season (D x S)</b>				0.02	NS				
				<b>Elevation x Distance x Season (E x D x S)</b>				0.04	NS				

**Table 12a: Water soluble - Cl<sup>-</sup> (me l<sup>-1</sup>) in surface soils (0-20cm) of vineyard at different elevations, distances and seasons**

	Elevation (E)												
Distance (D) from the row	E <sub>1</sub> - High			D x E <sub>1</sub>	E <sub>2</sub> - Mid			D x E <sub>2</sub>	E <sub>3</sub> - Low			D x E <sub>3</sub>	Distance Mean (D)
	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		
<b>D<sub>1</sub> - 15cm</b>	4.15	2.67	4.13	<b>3.65</b>	4.56	2.71	4.61	<b>3.96</b>	4.75	2.68	4.99	<b>4.14</b>	<b>3.92</b>
<b>D<sub>2</sub> - 30cm</b>	3.73	2.08	3.65	<b>3.15</b>	4.47	2.46	4.40	<b>3.79</b>	4.60	3.00	4.26	<b>3.96</b>	<b>3.63</b>
<b>D<sub>3</sub> - 75cm</b>	3.19	1.91	3.32	<b>2.79</b>	3.87	2.28	3.76	<b>3.30</b>	4.05	2.26	3.99	<b>3.44</b>	<b>3.18</b>
<b>D<sub>4</sub> - 120cm</b>	2.43	2.42	3.12	<b>2.66</b>	3.26	2.60	3.50	<b>3.12</b>	3.40	3.46	3.85	<b>3.57</b>	<b>3.12</b>
<b>E x S Mean</b>	<b>3.36</b>	<b>2.27</b>	<b>3.55</b>	<b>3.06</b>	<b>4.05</b>	<b>2.51</b>	<b>4.07</b>	<b>3.54</b>	<b>4.20</b>	<b>2.85</b>	<b>4.27</b>	<b>3.78</b>	<b>GM 3.46</b>
<b>Season x Distance (S x D)</b>				<b>D<sub>1</sub> - 15cm</b>	<b>D<sub>2</sub> - 30cm</b>	<b>D<sub>3</sub> - 75cm</b>	<b>D<sub>4</sub> -120cm</b>	<b>Season Mean (S)</b>					
<b>S<sub>1</sub> – February 18 (Before back Pruning)</b>				4.49	4.28	3.69	3.03	<b>3.87</b>					
<b>S<sub>2</sub> – September 18 (Growth Stage)</b>				2.69	2.51	2.15	2.83	<b>2.54</b>					
<b>S<sub>3</sub> – March 19 (Harvesting Stage)</b>				4.58	4.11	3.69	3.49	<b>3.97</b>					
<b>Statistical Analysis</b>													
<b>Factor</b>	<b>S.Em.±</b>		<b>CD<sub>0.05</sub></b>	<b>Factor</b>				<b>S.Em.±</b>		<b>CD<sub>0.05</sub></b>			
<b>Elevation (E)</b>	0.03		0.08	<b>Elevation x Distance (E x D)</b>				0.06		0.16			
<b>Distance (D)</b>	0.03		0.09	<b>Elevation x Season (E x S)</b>				0.04		0.11			
<b>Season (S)</b>	0.02		0.07	<b>Distance x Season (D x S)</b>				0.05		0.13			
				<b>Elevation x Distance x Season (E x D x S)</b>				0.80		0.23			

**Table 12b: Water soluble -  $\text{Cl}^-$  ( $\text{me l}^{-1}$ ) in subsurface soils (20-40cm) of vineyard at different elevations, distances and seasons**

		Elevation (E)											
Distance (D) from the row	E <sub>1</sub> - High			D x E <sub>1</sub>	E <sub>2</sub> - Mid			D x E <sub>2</sub>	E <sub>3</sub> - Low			D x E <sub>3</sub>	Distance Mean (D)
	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		
<b>D<sub>1</sub> - 15cm</b>	3.32	2.51	3.57	<b>3.13</b>	4.26	2.67	3.87	<b>3.59</b>	4.39	2.42	4.12	<b>3.64</b>	<b>3.46</b>
<b>D<sub>2</sub> - 30cm</b>	3.27	2.33	3.40	<b>3.00</b>	4.02	2.49	3.83	<b>3.45</b>	4.19	3.33	4.08	<b>3.86</b>	<b>3.43</b>
<b>D<sub>3</sub> - 75cm</b>	2.58	2.01	3.27	<b>2.62</b>	3.37	2.33	3.64	<b>3.10</b>	3.83	2.58	3.90	<b>3.44</b>	<b>3.65</b>
<b>D<sub>4</sub> - 120cm</b>	2.26	1.77	3.09	<b>2.37</b>	2.92	1.98	3.45	<b>2.78</b>	3.33	2.59	3.74	<b>3.22</b>	<b>2.79</b>
<b>E x S Mean</b>	<b>2.86</b>	<b>2.16</b>	<b>3.33</b>	<b>2.78</b>	<b>3.64</b>	<b>2.35</b>	<b>3.70</b>	<b>3.23</b>	<b>3.94</b>	<b>2.72</b>	<b>3.96</b>	<b>3.54</b>	<b>GM 3.18</b>
<b>Season x Distance (S x D)</b>				<b>D<sub>1</sub> - 15cm</b>	<b>D<sub>2</sub> - 30cm</b>	<b>D<sub>3</sub> - 75cm</b>	<b>D<sub>4</sub> -120cm</b>	<b>Season Mean (S)</b>					
<b>S<sub>1</sub> – February 18 (Before back Pruning)</b>				3.99	3.83	3.26	2.84	<b>3.48</b>					
<b>S<sub>2</sub> – September 18 (Growth Stage)</b>				2.52	2.71	2.30	2.12	<b>2.41</b>					
<b>S<sub>3</sub> – March 19 (Harvesting Stage)</b>				3.85	3.77	3.60	3.43	<b>3.66</b>					
<b>Statistical Analysis</b>													
<b>Factor</b>	<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>		<b>Factor</b>				<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>				
<b>Elevation (E)</b>	0.06	0.18		<b>Elevation x Distance (E x D)</b>				0.12	0.35				
<b>Distance (D)</b>	0.07	0.20		<b>Elevation x Season (E x S)</b>				0.08	0.25				
<b>Season (S)</b>	0.05	0.14		<b>Distance x Season (D x S)</b>				0.09	0.29				
				<b>Elevation x Distance x Season (E x D x S)</b>				0.16	0.50				

content varied significantly and found higher in lower elevation areas in contrast to lower values in high elevation areas. Across seasons the chloride content were found significantly higher at harvest and at the start of the study (before back pruning stages) compared to soil samples at growth stage. The combined effect of distance and season (D x S) decreased chloride concentration with increase in distance. Across three sampling seasons the observations made with respect to D x S interactions were similar to that of E x S in the order of February = March > September seasons at both the soil depths. The cumulative interaction effect (E x D x S) on chloride were just similar to the effect of individual factors namely, distance, season and elevation factor.

**Water soluble total anions:** The information on total anion contents in grape vineyard soils at different distances, elevations and seasons are provided in Tables 13a and 13b respectively for surface and subsurface soils. The total anion contents in surface soils ranged from 3.75 me l<sup>-1</sup> at E<sub>1</sub>D<sub>3</sub>S<sub>2</sub> (at 75 cm; in high elevation during growing season) to 9.96 me l<sup>-1</sup> at E<sub>3</sub>D<sub>1</sub>S<sub>2</sub> (at 15cm in low elevation during growth stage). Similarly, the total anion contents for the subsurface soils ranged from 2.99 me l<sup>-1</sup> to 8.62 me l<sup>-1</sup>.

The total water soluble anions in soils varied significantly *w.r.t.* elevation at both the depths and it was found in the order of E<sub>3</sub> > E<sub>2</sub> > E<sub>1</sub>. In terms of distance, the variations in total anions were found similar to that of other individual anions (D<sub>1</sub> > D<sub>2</sub> > D<sub>3</sub> > D<sub>4</sub>). The corresponding values for surface soils were 8.04, 7.51, 6.20 and 5.54 and for subsurface soils, 7.04, 6.76, 5.75 and 4.87 me l<sup>-1</sup>. The effect of season indicated that the soil samples at harvest (S<sub>3</sub>) were found with higher total anions and varied significantly with other seasons in the order S<sub>3</sub> > S<sub>1</sub> > S<sub>2</sub> with respective values of 7.65, 7.42 and 5.40 me l<sup>-1</sup> in surface soils and 6.96, 6.43 and 4.92 me l<sup>-1</sup> in subsurface soils.

The interaction effect of elevation, distance and season on total anions is presented in this section. The interaction of elevation and distance (E x D) influenced total anions contents in surface soils significantly across distance and elevation and they varied similar to the values as observed *w.r.t.* elevation and distance as individual parameters. However, the subsurface soils did not show significant interaction effects. The elevation and season (E x S) interactions did not influence total anion contents in surface soils. However, the subsurface soils recorded significant differences *w.r.t.* elevation and season. Interaction of distance with season (D x S) influenced total anions in surface soils significantly at D<sub>1</sub> distance across all three seasons (S<sub>3</sub> > S<sub>1</sub> > S<sub>2</sub>) while,

**Table 13a: Water soluble total anions ( $\text{me l}^{-1}$ ) in surface soils (0-20cm) of vineyard at different elevations, distances and seasons**

<b>Elevation (E)</b>													
<b>Distance (D) from the row</b>	<b>E<sub>1</sub>- High</b>			<b>D x E<sub>1</sub></b>	<b>E<sub>2</sub> - Mid</b>			<b>D x E<sub>2</sub></b>	<b>E<sub>3</sub> - Low</b>			<b>D x E<sub>3</sub></b>	<b>Distance Mean (D)</b>
	<b>S<sub>1</sub></b>	<b>S<sub>2</sub></b>	<b>S<sub>3</sub></b>		<b>S<sub>1</sub></b>	<b>S<sub>2</sub></b>	<b>S<sub>3</sub></b>		<b>S<sub>1</sub></b>	<b>S<sub>2</sub></b>	<b>S<sub>3</sub></b>		
<b>D<sub>1</sub> - 15cm</b>	8.32	5.81	8.20	<b>7.44</b>	8.78	6.02	9.26	<b>8.02</b>	9.30	6.73	9.96	<b>8.66</b>	<b>8.04</b>
<b>D<sub>2</sub> - 30cm</b>	7.42	5.06	7.46	<b>6.65</b>	8.49	5.52	8.75	<b>7.59</b>	8.99	6.83	9.07	<b>8.30</b>	<b>7.51</b>
<b>D<sub>3</sub> - 75cm</b>	5.97	3.75	6.30	<b>5.34</b>	6.87	4.78	6.87	<b>6.17</b>	7.87	5.42	8.00	<b>7.10</b>	<b>6.20</b>
<b>D<sub>4</sub> - 120cm</b>	4.91	3.94	5.32	<b>4.72</b>	5.73	4.79	5.91	<b>5.48</b>	6.43	6.19	6.66	<b>6.43</b>	<b>5.54</b>
<b>E x S Mean</b>	<b>6.65</b>	<b>4.64</b>	<b>6.82</b>	<b>6.04</b>	<b>7.47</b>	<b>5.28</b>	<b>7.70</b>	<b>6.81</b>	<b>8.15</b>	<b>6.29</b>	<b>8.42</b>	<b>7.62</b>	<b>GM 6.82</b>
<b>Season x Distance (S x D)</b>				<b>D<sub>1</sub> - 15cm</b>	<b>D<sub>2</sub> - 30cm</b>	<b>D<sub>3</sub> - 75cm</b>	<b>D<sub>4</sub> -120cm</b>	<b>Season Mean (S)</b>					
<b>S<sub>1</sub> – February 18 (Before back Pruning)</b>				8.80	8.30	6.90	5.69	<b>7.42</b>					
<b>S<sub>2</sub> – September 18 (Growth Stage)</b>				6.18	5.80	4.65	4.98	<b>5.40</b>					
<b>S<sub>3</sub> – March 19 (Harvesting Stage)</b>				9.14	8.43	7.05	5.96	<b>7.65</b>					
<b>Statistical Analysis</b>													
<b>Factor</b>	<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>		<b>Factor</b>				<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>				
<b>Elevation (E)</b>	0.05	0.15		<b>Elevation x Distance (E x D)</b>				0.10	0.30				
<b>Distance (D)</b>	0.06	0.17		<b>Elevation x Season (E x S)</b>				0.07	NS				
<b>Season (S)</b>	0.04	0.12		<b>Distance x Season (D x S)</b>				0.08	0.24				
				<b>Elevation x Distance x Season (E x D x S)</b>									

**Table 13b: Water soluble total anions ( $\text{me l}^{-1}$ ) in subsurface soils (20-40cm) of vineyard at different elevations, distances and seasons**

		Elevation (E)											
Distance (D) from the row	E <sub>1</sub> - High			D x E <sub>1</sub>	E <sub>2</sub> - Mid			D x E <sub>2</sub>	E <sub>3</sub> - Low			D x E <sub>3</sub>	Distance Mean (D)
	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>		
<b>D<sub>1</sub> - 15cm</b>	6.48	5.23	7.14	<b>6.28</b>	8.06	5.35	7.93	<b>7.11</b>	8.47	6.13	8.62	<b>7.74</b>	<b>7.04</b>
<b>D<sub>2</sub> - 30cm</b>	6.17	4.79	6.69	<b>5.88</b>	7.18	5.14	7.62	<b>6.65</b>	8.09	6.67	8.39	<b>7.70</b>	<b>6.76</b>
<b>D<sub>3</sub> - 75cm</b>	4.81	3.66	6.10	<b>4.86</b>	5.80	4.70	6.55	<b>5.69</b>	7.07	5.42	7.60	<b>6.70</b>	<b>5.75</b>
<b>D<sub>4</sub> - 120cm</b>	4.10	2.99	5.04	<b>4.05</b>	4.93	4.01	5.61	<b>4.85</b>	6.00	4.90	6.23	<b>5.71</b>	<b>4.87</b>
<b>E x S Mean</b>	<b>5.39</b>	<b>4.17</b>	<b>6.24</b>	<b>5.27</b>	<b>5.39</b>	<b>4.17</b>	<b>6.24</b>	<b>6.07</b>	<b>7.41</b>	<b>5.78</b>	<b>7.70</b>	<b>6.96</b>	<b>GM 6.10</b>
<b>Season x Distance (S x D)</b>				<b>D<sub>1</sub> - 15cm</b>	<b>D<sub>2</sub> - 30cm</b>	<b>D<sub>3</sub> - 75cm</b>	<b>D<sub>4</sub> -120cm</b>	<b>Season Mean (S)</b>					
<b>S<sub>1</sub> – February 18 (Before back Pruning)</b>				7.67	7.15	5.89	5.01	<b>6.43</b>					
<b>S<sub>2</sub> – September 18 (Growth Stage)</b>				5.57	5.53	4.59	3.97	<b>4.92</b>					
<b>S<sub>3</sub> – March 19 (Harvesting Stage)</b>				7.90	7.55	6.75	5.63	<b>6.96</b>					
<b>Statistical Analysis</b>													
<b>Factor</b>	<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>		<b>Factor</b>				<b>S.Em.±</b>	<b>CD<sub>0.05</sub></b>				
<b>Elevation (E)</b>	0.09	0.28		<b>Elevation x Distance (E x D)</b>				0.18	NS				
<b>Distance (D)</b>	0.10	0.32		<b>Elevation x Season (E x S)</b>				0.13	0.39				
<b>Season (S)</b>	0.07	0.23		<b>Distance x Season (D x S)</b>				0.15	0.45				
				<b>Elevation x Distance x Season (E x D x S)</b>				0.25	0.78				

it was observed in the order of  $S_3 = S_1 > S_2$  at other distances ( $D_2$ ,  $D_3$  and  $D_4$ ). However, the subsurface soils recorded significant differences *w.r.t.* both distance and season factors. The cumulative effect of all the three factors on total anions remained same as that of variations observed *w.r.t.* individual parameters. In general, the total anions remained significantly higher in the surface soils of low elevation areas of the vineyards.

## 5. DISCUSSION

All soils possess salts however, the magnitude of salinity varies. The salts present in soil affect the yield and quality of crops to different magnitudes depending on the salt content and crop susceptibility. Grape is known to be a very sensitive crop for soil salinity. Thus, cultivation of grapes in Bagalkot inherited with saline soils and with poor quality irrigation water is a challenging one. The results of both survey study and detailed study on spatial and temporal distribution of salts in a gently sloped grape vineyard are discussed in this chapter.

### Study I. Assessment of soil and water salinity based on survey

Soil samples from 69 vineyards and water samples from 20 borewells were analysed for ionic compositions of common salts present. The results obtained on the extent of different cations and anions present in different vineyards are discussed in this section. Commonly used salinity parameters for comparison are depicted in the form of box plots (Figures 4 and 5) to present their descriptive statistics.

#### 5.1. Assessment of vineyard soils and groundwater samples for salinity

Majority of the vineyard soil samples were found to be mostly suitable with soil reaction ranging from slightly alkaline to moderately alkaline with a mean pH of  $7.99 \pm 0.29$ . Similarly, the electrical conductivity did not show accumulation of salts to toxic levels with a mean conductivity values of  $0.98 \pm 0.23 \text{ dS m}^{-1}$  (almost normal soils with  $< 1.0 \text{ dS m}^{-1}$ ). The water samples recorded a pH of  $7.31 \pm 0.21$  and EC of  $0.60 \pm 0.41 \text{ dS m}^{-1}$ . Majority of the water samples analysed were also found to be safe for irrigation.

Initially, it was hypothesized that large tracts of Bagalkot, both soils and groundwater, are naturally saline (Doddamani *et al.*, 1994; Ashwin, 2014; Kirankumar, 2014). In addition, the toxicity of chloride used to be noticed in some of the vineyards during summer. Incidentally, the soil samples collected from 69 vineyards and 20 water samples did not show extreme salinity. This may be due to the location point of soil sampling within the vineyard. The salts might have accumulated at the lower region of the orchard as observed in the 2<sup>nd</sup> study, while the sampling was done in the mid region of the vineyards. Moreover, the grape growers are using coarse materials (murrum/gravel) just to provide drainage in vineyards (Nagaraja *et al.*, 2016). Majority of the orchards studied are present on red soils mostly formed from the colluvial material. The

soil pH of 7.50 to 8.00 could be attributed to the fact that the soils are mostly calcareous in nature, and hence, the soil is likely to possess pH in this range. Use of high doses of organic matter also might have contributed to maintain moderate alkalinity (Gupta *et al.*, 1990).

Among water soluble cations, the concentrations of cations was found in the order  $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$ . The dominance of  $\text{Ca}^{2+}$  and least concentration of  $\text{K}^+$  in these soils could be attributed to origin of calcareous soils from lime based parent material (Doddamani, 1994) and absence of potassium based feldspar and micaceous mica parent material (Agarwal and Ramamurthy, 1970). The presence of magnesium in soil-water extract may be attributed to application of  $\text{MgSO}_4$  in grape cultivation (Anitha, 2016; Shreekanth, 2014). Use of groundwater for irrigation might have added sodium ion to these soils (Ashwin, *et al.*, 2018). Same may be the reason for observing higher amounts of chlorides. It is well established that the salts of chloride and sodium possess high solubility (Singh *et al.*, 2014). The presence of total carbonates ( $\text{HCO}_3^+ + \text{CO}_3^-$ ) in both soil and water may be due to its accumulation and movement to water and soil. Alternate wetting and drying cycles in tropics is known to encourage release of  $\text{CO}_2$ , which in turn converts into carbonates and bicarbonates (Agarwal *et al.*, 1982). In contrast to these results, higher salinity in both soils and water samples have been reported in Bilgi, Bagalkot and Mudhol by Ashwin (2014) and Kirankumar (2014).

## **Study II. Spatial and temporal assessment of soil salinity in grape vineyard**

A detailed study was carried out in one selected vineyard possessing gentle slope to assess the spatial and temporal distribution of salts/ ions. The soil salinity parameters assessed from the start of the grape crop (before back pruning) till the harvest of grapes across three different micro topographic elevations namely, high, mid and low regions of the orchards. The salt distribution across the grape row (from plant rows to the inter-row space) was assessed and the results obtained are discussed in this section.

### **5.2 Soil reaction (pH)**

The pH of surface and subsurface soils of grape vineyards collected at different elevations and distances across three seasons is diagrammatically presented in Figures 6a and 6b respectively. The soil reaction in surface and subsurface soils ranged from slightly alkaline to highly alkaline with pH values of 7.40 to 8.27.

The micro-topographical elevation factor of the vineyard as such did not have any significant influence on soil reaction. The soils at 15 cm and 30 cm distance from the grape vine row recorded higher alkalinity compared to the soils at 75 cm and 120 cm. Similar magnitudes of soil pH were recorded in the subsurface soils also. Thus, the pH varied significantly in both surface and subsurface soils in the order  $D_1 = D_2 > D_3 = D_4$ . In terms of seasons, both surface and subsurface soils recorded variations in soil pH in the order of  $S_1 = S_3 > S_2$ . In terms of interactions, the three factors collectively (E x D x S) or in combinations (E x D, E x S and D x S) did not have any influence on soil reaction at both 0-20 cm and 20-40 cm soil depths.

The elevation factor did not have significant influence on soil reaction. This may be attributed to the fact that the study area was very small (8 acres) and the pH is less likely to vary as the vineyard soils are derived from the same parent material and formed under similar conditions in terms of vegetation, topography and time (Bohn *et al.*, 2001; Tan, 2013). The change in soil pH with alterations of exchangeable cationic equilibrium would occur over a long period of time (Chhabra, 1996; Braudy and Weil, 2002) Thus, the micro topographic elevations of the vineyard induced least changes on soil pH (Lakshmi *et al.*, 2018; Anitha, 2016). Similar magnitudes of pH in soils of Bagalkot district are reported earlier by Kirankumar *et al.* (2016) and Rekha *et al.* (2015). The extent of soil pH in grape vineyards is in concurrence with the results of Anita (2016), Shreekanth (2014), Vinod (2016). However, the soil pH can get altered in intensively irrigated areas due to alterations in ionic equilibrium (Chhabra, 1996; Bohn *et al.*, 2001). Higher pH in surface soils and soils closer to the plant rows ( $D_1$  and  $D_2$ ) may be attributed to the presence of sodium and total carbonates in higher amounts (Chhabra, 1996; Sharma *et al.*, 2011; Ashwin *et al.*, 2018).

### 5.3 Electrical conductivity ( $EC_{1:2}$ )

The extent of soil salinity in the grape vineyard in terms of its spatial and temporal distribution are depicted in Figures 7a (surface soil) and 7b (subsurface soil). The conductivity values were higher in surface soils compared to subsurface soils during  $S_1$  - February (before back pruning) and  $S_3$ - March (at harvesting) seasons. Contrastingly, the subsurface soils recorded higher EC values during  $S_2$ - September (during growth stages).

The soil salinity was influenced by all the three factors individually and in combinations. The soils present in lower regions of the vineyard ( $E_3$ ) recorded higher mean EC values compared to high and mid elevation areas ( $E_1$  and  $E_2$ ). The EC values varied significantly at both the depths in the order  $E_3 > E_2 > E_1$ . In terms of horizontal spread, soils nearer to the plant rows recorded higher electrical conductivity and it decreased significantly in soils representing between rows. Thus, EC values decreased in the order  $D_1 > D_2 > D_3 > D_4$  in both surface and subsurface soils. In terms of seasons, the soil samples collected in March ( $S_3$ - at harvest) and February ( $S_1$  – before back pruning) had higher salinity compared to the soils collected during September ( $S_2$  - growth stage) and the EC values were found in the order  $S_3 = S_1 > S_2$ . Interactions of three different factors also influenced soil salinity in both surface and subsurface soils. However, the interaction effects of  $E \times S$  and  $D \times S$  had no significant effects on conductivity. The magnitudes of interaction effects on salinity were almost similar to the effects of individual parameters.

The electrical conductivity values reflect the soluble salts present in a given soil (Chhabra, 1996; Rengasamy, 2010). Significant variations in EC values clearly demonstrate the redistribution of salts in soils across grape vineyard. The lateral movement of salts from higher regions to lower regions by percolating water might have caused higher salinity in subsurface soils (Costa *et al.*, 1991). Higher EC values in the root zone ( $D_1$  and  $D_2$ ) compared to soils between rows ( $D_3$  and  $D_4$ ) may be attributed to drip method of irrigation and evapo-transpiration water losses. Drip method of irrigation discharges water only to the root zone and thus, there is less scope for percolation from the root zone to inter rows. During evapo-transpiration process, salts are left behind in the soil only the water is removed (Davenport *et al.*, 2008). These results were also evidenced by higher EC values in surface soils compared to subsurface soils across all treatment combinations. Lower electrical conductivity during the growth stage ( $S_2$ ) may be attributed to redistribution of salts from the root zone to inter-rows and downward movement of salts by infiltrating water (Goldberg *et al.*, 1971; He *et al.*, 2014; Kijne *et al.*, 1998; Rajanna *et al.*, 2018). These salinity observations are in concurrence with the total cations and anions for the respective soil samples which are discussed later in this section. Correlation studies also indicated strong relationships of conductivity with total cations and anions. Similar observations were reported for a micro watershed at landscape level with larger area (Lakshmi, 2018).

#### 5.4 Water soluble cations

The extent of water soluble cations namely, calcium, magnesium, potassium and sodium in grape vineyard soils collected across 3 different intervals are discussed in this section.

**Water soluble- Ca:** The amounts of water soluble-Ca in surface and subsurface soils of grape vineyard are pictorially given in Figures 8a and 8b. Water soluble-Ca ranged from 1.93 to 4.92 me l<sup>-1</sup> in surface soil and 1.54 to 4.50 me l<sup>-1</sup> in subsurface soil.

Among cations, the amounts of calcium were high in soil water extracts. The micro topographical elevations of the grape vineyard influenced water soluble-Ca. Soil samples representing lower regions of the vineyards recorded significantly higher amounts of calcium compared to high elevation areas. It declined in the order of E<sub>3</sub> > E<sub>2</sub> > E<sub>1</sub> in surface soil and it remained on par in subsurface soils. The calcium mean values decreased significantly in surface soils with distance from the grape rows (D<sub>1</sub> > D<sub>2</sub> > D<sub>3</sub> > D<sub>4</sub>). In subsurface soils, the calcium was on par with each other at D<sub>1</sub> and D<sub>2</sub>. The soil samples collected at the beginning of the experiment (S<sub>1</sub>- February, 2018) and at harvest stage (S<sub>3</sub>- March, 2019) recorded higher amounts compared to soil samples representing growth stage (S<sub>2</sub>- September, 2018) indicated seasonal variations. The interaction of E x D, E x S, D x S and E x D x S factors influenced water soluble – Ca at both the depths. In general, the interaction effects of two factors were significant for the surface soils at all levels and found similar to that of influence of individual factors.

Higher amounts of calcium in the soil solution may be attributed to limestone based parent material (Doddamani *et al.*, 1994) and use of irrigation water with high calcium contents (Ashwin, 2014; Kirankumar, 2014). Preferential adsorption of calcium on the exchange site also might have contributed for its higher concentration (Tan, 2013). As indicated earlier, the movement of calcium in its salt form by percolating water might have caused its build up in low elevation areas. Drip irrigation method resulting in addition of calcium to the root zone also might have contributed for its accumulation at D<sub>1</sub> and D<sub>2</sub> (closer to the root zone) compared to soils at D<sub>3</sub> and D<sub>4</sub> (between grape rows). The seasonal variations *w.r.t.* calcium content may be explained by high evapo-transpiration during summer (S<sub>1</sub>- February and S<sub>3</sub>-March) and leaching processes during rainy season (S<sub>2</sub>- September) (Patil *et al.*, 2016; Kirankumar *et al.*, 2016). Similar reports of seasonal variations *w.r.t.* calcium *i.e.* lower Ca during rainy

season and higher amounts during summer. High additions of organic manures in the form of FYM, oil cakes, etc and use of SSP also might have added Ca to the soil solution.

**Water soluble -Mg:** The amounts of water soluble-Mg in surface and subsurface soils of grape vineyard across three seasons at different elevations and distances are pictorially presented (Figure 9a and 9b). The amounts of magnesium was in higher range in surface soils (0.68 to 3.13 me l<sup>-1</sup>) compared to subsurface soils (0.59 to 2.94 me l<sup>-1</sup>).

Micro elevation factor had influenced the magnesium content significantly in both surface and subsurface soils of grape vineyard and it varied significantly in the order  $E_3 > E_2 > E_1$ . Similar to calcium, the soils present closer to the plant row recorded significantly higher magnesium contents and it decreased in both surface and subsurface soils with increase in distance from the plant row. Thus, water soluble-Mg contents was also similar to calcium and observed in the order  $D_1 > D_2 > D_3 > D_4$ . In terms of seasons, least magnesium concentrations were recorded during growth stage ( $S_2$ ) compared to the other two seasons  $S_1$  (before pruning) and  $S_3$  (at harvest). The mean values of magnesium for season varied significantly in the order  $S_3 > S_1 > S_2$ . The interaction effect of E x D (elevation and distance) and E X S (elevation and season) on magnesium contents were found significant only in surface soils and not in subsurface soils. In general, magnesium content increased with decrease in topographic position of the vineyard and it was similar to the influence of elevation as a single factor. In terms of distance, the mean values were observed in the order  $D_1 = D_2 > D_3 > D_4$  at all elevations. The interaction of both E x S and D x S had influenced magnesium content and its concentration in most of the surface soil was more during summer ( $S_1$ – February 2018 and  $S_3$ – March, 2019) compared to rainy season ( $S_2$ - September). No specific trend was observed *w.r.t.* subsurface soils. Cumulative interaction effects of E x D x S were similar to that of observations made on water soluble-Ca.

Soils derived from limestone parent material are generally calcareous in nature and the magnesium is more likely to be deficient / lesser (Doddamani, *et al.*, 1994; Ashwin, 2014). However, addition of magnesium through irrigation water, use of  $MgSO_4$  and mineralization of added organic matter in grapes might have enhanced its content (Nagaraja, 1997). Higher amounts of magnesium in low elevation area clearly

indicate its lateral movement through percolating water (Chhabra, 1996; Kirankumar *et al.*, 2016; Patil *et al.*, 2016). These observations are also in agreement with the conductivity values of corresponding soil samples. Higher amounts of magnesium nearer to the plant row compared to soils present between rows could be due to drip irrigation methods practiced in grape cultivation along with the application of  $\text{MgSO}_4$ . Seasonal variations in magnesium contents may be attributed to percolation losses of magnesium from the root zone during rainy season at growth stage (Jena and Natarajan, 2013; Veerbhadrappa and Gundlur, 2016). In fact, higher values at the beginning of the study (April) and at harvest (March) coinciding with high evapo-transpiration further confirms the hypothesis of redistribution of salts in grape vineyards (Kijne *et al.*, 1998; Rajanna *et al.*, 2018).

**Water soluble-Na:** The information on total water soluble-Na content in soils of grape vineyard presented in Figures 10a and 10b. The water soluble-Na content was more than other cations and they ranged from 1.55 to 3.97  $\text{me l}^{-1}$  and 1.47 to 3.80  $\text{me l}^{-1}$  in surface and subsurface respectively.

The sodium content in 1:2 soil water extract were found significantly higher at both the depths in low elevation areas ( $E_3$ ) and it decreased with increase in micro-topographic elevations of the vineyard ( $E_3 > E_2 > E_1$ ). In terms of distance, the sodium contents were found higher at  $D_1$  (15 cm) and it decreased with distance away from the plant rows ( $D_2$ ,  $D_3$  and  $D_4$ ). In general, the sodium content varied significantly with distance from the plant row towards inter row spaces in the order of  $D_1 > D_2 > D_3 > D_4$  and the subsurface soils representing  $D_1$  and  $D_2$  were found on par with each other. The mean values of water soluble – Na varied significantly in the order  $S_3 > S_1 > S_2$  indicating higher concentrations during summer ( $S_1$  and  $S_3$ ) and lower concentration during rainy season ( $S_2$ ).

Cumulative interactions of all the 3 factors also altered soluble-Na contents in both surface and subsurface soils except with  $E \times S$  factors in surface soils. The soil samples closer to the rootzone (at  $D_1 - 15$  cm;  $D_2 - 30$  cm) recorded higher sodium contents than soils of inter row spaces at ( $D_3 - 75$  cm and  $D_4 - 120$  cm). It varied significantly in the order  $D_1 = D_2 > D_3 > D_4$  at all elevations. Cumulative effect of  $E \times D \times S$  interactions also influenced water soluble-Na contents and they were found to be in the order of  $D_1 = D_2 > D_3 = D_4$  at all elevations and during 3 seasons;  $S_3 = S_2 > S_1$  at all

the 3 distances and across 3 elevations; and  $E_3 > E_2 > E_1$  at all the four distances (except at  $D_1$ ) and 3 elevations.

Relative increase in sodium contents with decreasing micro topographic elevations clearly demonstrates lateral movement from higher region to lower region (Alur, 2003; Lingappa and Kuligod, 2017; Lakshmi *et al.*, 2018). Movement of salts in subsurface by percolating water is reported by several authors (Rasool *et al.*, 2014; Patil *et al.*, 2016; Kharche and Pharande, 2010; Kirankumar, 2014). Though the soils are not derived from sodium based parent material, presence of higher amounts of sodium in soil water extract may be attributed to addition of sodium through irrigation water (Ashwin *et al.*, 2018). Higher amounts of sodium in soils at the root zone ( $D_1$  and  $D_2$ ) compared to soils present in inter rows ( $D_3$  and  $D_4$ ) may be attributed to restricted percolation losses under drip irrigation methods. Leaching losses during rainy season ( $S_2$ ) and its accumulation through evapo-transpiration during summer ( $S_1$  and  $S_3$ ) explains the causes for seasonal variations (Zaka *et al.*, 2003).

**Water soluble –K:** The amounts of water soluble-K present in soils at different elevations and distances across three seasons are presented in Figures 11a and b. Among different cations, potassium was found to be least in all the soils. The potassium contents in surface and subsurface ranged from 0.35 to 1.27 me l<sup>-1</sup> and 0.30 to 1.14 me l<sup>-1</sup> respectively.

Among three regions of grape vineyard at different elevations, the soils at lower regions of grape vineyard recorded significantly higher potassium contents. Water soluble-K *w.r.t.* elevation in surface and subsurface soils were found in the order :  $E_3 = E_2 > E_1$ . The subsurface soils had lesser amounts of K compared to surface soils in all the treatments. The soils of the root zone recorded higher water soluble-K contents while, the soils representing inter rows in grape vineyard recorded significantly lower values. Thus, the K contents in surface soils was in the order  $D_1 = D_2 > D_3 > D_4$  while, it was found to be in  $D_1 > D_2 > D_3 > D_4$  order. Interestingly, the water soluble-K was very high in both surface and subsurface soils during growth stage ( $S_2$ ) compared to other two seasons ( $S_1$ ) and ( $S_3$ ). Thus, the variations were in the order  $S_2 > S_3 > S_1$  and it was in contrast to other cations studied. In terms of interactions, distance x season (D x S) was the only factor which influenced K content in both surface and subsurface soils. They were found in the order of  $S_2 > S_3 = S_1$ . Interaction of other factors namely, E x D,

E x S and E x D x S did not have any significant influence on water soluble-K in both surface and subsurface soils.

Least concentration of potassium among different water soluble cations may be due to the fact that the soils of the study area are derived from limestone and do not possess feldspars and micaceous clay minerals. Meanwhile, the soil clay colloids possess high preference for potassium and thus, it gets retained (Bohn, 2001; Tan, 2013). In relation to elevations, potassium contents in lower regions of the orchard indicate its subsurface lateral movement from higher region (Lakshmi *et al.*, 2018 ; Kirankumar *et al.*, 2016; Ashwin *et al.*, 2018). The potassium gradient with elevation also strengthens the above observations.

Addition of K-fertilizers during crop growth might have increased its content in the root zone substantially. Higher amounts of K-supplementation through fertigation and its preferential adsorption to soil colloids (Bohn *et al.*, 2001; Tan, 2013) also might have contributed for potassium in the root zone (D<sub>1</sub> and D<sub>2</sub>) compared to soils present in the inter row space (D<sub>3</sub> and D<sub>4</sub>). Potassium content during growth stage (S<sub>2</sub>) was significantly higher, in contrast to other cations. It was also higher during the other two sampling seasons (S<sub>1</sub> and S<sub>3</sub>) which may be due to the fact that the nutrients are added during the growth stage. Similar observations on higher amounts of potassium in intensively managed horticultural cropping systems viz. grapes and pomegranate are reported elsewhere (Nagaraja, 2007; He *et al.*, 2014; Shreekanth *et al.*, 2018).

**Water soluble total cations:** The information on total water soluble cations in surface and subsurface soils collected at different distances, elevations and seasons from the grape vineyard are diagrammatically presented in respective Figures 12a and 12b. The total water soluble cations ranged from 5.42 to 13.10 me l<sup>-1</sup> to 4.37 to 11.82 me l<sup>-1</sup> in surface and subsurface soils respectively.

The soils of lower regions (E<sub>3</sub>) grape vineyard recorded significantly higher amounts of total cations and it decreased significantly towards higher elevations in the order E<sub>3</sub> > E<sub>2</sub> > E<sub>1</sub>. The soils at D<sub>1</sub> (15cm) recorded highest concentration of total cations and their mean values decreased significantly with increase in distance (D<sub>1</sub> > D<sub>2</sub> > D<sub>3</sub> > D<sub>4</sub>). Comparison of mean values across three different seasons also varied significantly in the order of S<sub>3</sub> > S<sub>1</sub> > S<sub>2</sub>.

In general, the interaction effect of E x S influenced the total cations and their interaction mean values in general varied significantly ( $E_3 > E_2 > E_1$ ) across all the three seasons except in soil samples of  $S_2$  (growth stage). The interaction of both E x S and D x S factors had significant influence on total cations and they varied mostly in the order of  $S_3$  (March)  $> S_1$  (February)  $> S_2$  (September). In general, the interaction effect of above factors influenced total cations with distance and decreased in the order  $D_1 > D_2 > D_3 > D_4$  at all the 3 elevations and also across 3 seasons. The overall cumulative effect of E x D x S were almost similar to the effects of individual factors as discussed with other water soluble ions.

As discussed earlier, the lateral movement of water soluble salts from high elevation areas by percolating water along the slope through subsurface layers might have caused its accumulation in lower regions of the orchard (Chhabra, 1996; Kirankumar *et al.*, 2016; Lakshmi, 2018). The concentration gradient of total cations with elevation and its similarities with other cations further confirm lateral movement. These observations are in concurrence with the EC and other water soluble cations. Corresponding correlation coefficients also are in concurrence with the total cationic contents. Addition of different cations through irrigation water, fertilizers/ amendments and mineralization of organic matter also might have contributed (Nagaraja, 1997; Kriankumar *et al.*, 2016; Rekha *et al.*, 2015). Judicious / limited application of water through drip irrigations in grapes might have caused its buildup near the root zone. Both transpiration by plants and evaporation from soil surface results in build-up of salts as only water is removed (Chhabra, 1996; Gupta *et al.*, 2019). However, these accumulated salts might have moved to inter row regions during rainy season and thus, its build up was observed to some extent. Movement of salts in solution by infiltrating / percolating water during rainy season is reported by several authors (Lakshmi *et al.*, 2018; Kirankumar *et al.*, 2016; Ashwin *et al.*, 2018). Thus, the above phenomena might have caused lower total cationic contents during September ( $S_2$  - growth stage) compared to February ( $S_1$  - before pruning) and March ( $S_3$  - at harvest) exhibiting hot summer.

### 5.5 Water soluble anions

The soil water extracts (in 1:2 ratio) obtained for cations were used for the determination of anions and they are depicted in Figures 13a and b to 15a and b.

**Water soluble total carbonates:** Total carbonates contents ( $\text{CO}_3^{2-} + \text{HCO}_3^-$ ) in 1:2 soil water extracts of grape vineyard are presented in Figures 13a and 13b. Total carbonates in surface soils ranged from 1.27 to 3.79  $\text{me l}^{-1}$  while, subsurface soils had 1.03 to 3.60  $\text{me l}^{-1}$ . Both surface and subsurface soil samples indicated significant influence of elevation on total carbonates in the order:  $E_3 > E_2 > E_1$ . In terms of distance, the total carbonates in surface and subsurface declined significantly with distance from the plant rows in the order:  $D_1 > D_2 > D_3 > D_4$  except in subsurface soils at  $D_1$  and  $D_2$  which was on par with each other. Similarly, the variations *w.r.t.* season was in the order  $S_3 > S_1 > S_2$  in surface soils and  $S_3 = S_1 > S_2$  subsurface soils.

In terms of interaction effects of E x D, D x S and E x S, the total carbonates decreased in the order of  $D_1 = D_2 > D_3 > D_4$  in both surface and subsurface soils. This trend was observed across all the 3 seasons and at all the 3 elevations. In general, total carbonates decreased significantly with increase in distance at both the depths. The mean values of total carbonates representing the interaction of E x S (elevation x season) indicated that the soil samples across all elevations during rainy season ( $S_2$  – growth stage) recorded significantly lesser total carbonates compared to representative soil samples during summer ( $S_1$ - before pruning and  $S_2$ - at harvest). The overall interactions of elevation, distance and season (E x D x S) on total carbonates in surface and subsurface soils were almost similar to the effect of individual parameters.

Accumulation of total carbonates in lower region of the vineyard compared to high region also indicates their movement from high region to lower elevation. Similar observations were reported by Lakshmi *et al.* (2018) in their study on a micro-watershed. Higher soil pH in corresponding samples further confirms its accumulation. Positive relationship between carbonates and soil pH is a well documented (Chhabra, 1996; Kirankumar *et al.*, 2016). Higher amounts of carbonates in the root zone however, did not reflect in terms of soil pH. This could be due to higher buffering capacity of soil organic matter (Bohn *et al.*, 2001; Braudy *et al.*, 2002). Application of organic manures, oil cakes etc are widely practiced by grape growers (Anitha, 2016). This could be the reason for not observing any significant effect by interaction of elevation, distance and season. Leaching of carbonates during September ( $S_2$ - growth stage) may be attributed to its coinciding with rainy season. The pH values of soil samples representing  $S_2$

further confirm their leaching. Similar interactions of pH and total carbonates are reported by others.

**Water soluble  $\text{SO}_4^{2-}$ :** The extent of variations in water soluble -  $\text{SO}_4^{2-}$  in grape orchard soils *w.r.t.* distance, elevation and season are presented in Figures 14a and 14b. The water soluble- $\text{SO}_4^{2-}$  values ranged from 0.25 to 1.17  $\text{me l}^{-1}$  in surface soils while, it was in the range of 0.19 to 0.90  $\text{me l}^{-1}$  in subsurface soils.

Water soluble sulphates were found significantly higher in lower regions ( $E_3$ ) compared to high ( $E_1$ ) and mid regions ( $E_2$ ) of the vineyard. The values varied in the order of  $E_3 > E_1 = E_2$  in both surface and subsurface soils. In terms of distance, the sulphate contents varied at both the depths (0-20 cm and 20-40 cm) and it decreased significantly with distance from plant row ( $D_1 > D_2 > D_3 > D_4$ ). Among three different seasons, the soils collected at harvest ( $S_3$ ) and at start of season ( $S_1$ ) recorded significantly higher values ( $S_3 = S_1 > S_2$ ) compared to values at crop growth stage ( $S_2$ ) at both the depths. Interestingly, the interactions of individual factors ( $E \times D$ ;  $D \times S$ ;  $E \times S$ ) or their cumulative interaction ( $E \times D \times S$ ) had no significant influence on water soluble sulphates in both surface and subsurface soils.

Movement of water occurs along the slope as runoff on surface soils and percolation in sub surface soils. The translocation of sulphate from high to low region elevation region might have caused its accumulation in lower region of the grape vineyard. Gradual increasing sulphate content from high to low elevation region across all other treatment combinations are also in conformity with the above observations. Addition of  $\text{MgSO}_4$  and mineralization of organic matter (Anitha *et al.*, 2018) and restricted movement of sulphate due to controlled delivery of water to the rootzone might have caused higher accumulation near the plant rows ( $D_1$  and  $D_2$ ) compared to soils representing between rows ( $D_3$  and  $D_4$ ). Among anions, sulphates exhibits higher preference for adsorption by the soil colloid (Bohn *et al.*, 2001; Tan *et al.*, 2013). Upward translocation of sulphate ions along with evaporating and transpiring water might have caused accumulation in the surface layer during  $S_1$  and  $S_3$  seasons coinciding with summer months. However, leaching or percolating water in the soil might have reduced  $\text{SO}_4^{2-}$  content during growth stage  $S_2$ .

**Water soluble-Cl:** The amounts of water soluble-Cl present in soils of grape orchard at different distances, elevations and seasons for surface and subsurface soils are depicted in Figures 15a and 15b respectively.

The soils present in lower elevation areas of the orchard ( $E_3$ ) recorded significantly higher chloride contents compared to higher region ( $E_1$ ). The elevation influenced water soluble chloride contents significantly in both surface and subsurface soils ( $E_3 > E_2 > E_1$ ). The horizontal distance from the plant row also had a great influence and its concentration varied significantly in the order  $D_1 > D_2 > D_3 > D_4$ . The soil samples collected at harvest ( $S_3$ ) recorded high chloride contents while, the samples at growth stages ( $S_2$ ) recorded the least values.

The interaction of  $E \times D$ ,  $E \times S$  and  $D \times S$  indicated that soils closer to the plants (at 15 cm and 30 cm) recorded significantly higher amounts of chloride compared to soils away from the plant row (at 75 cm and 120 cm). This was true at all the 3 elevations across all 3 seasons. In terms of elevation, the chloride content was found higher in  $E_3$  (lower elevation areas) compared to  $E_1$  (high elevation areas) at all distances and during all different seasons. Across seasons the chloride content were found significantly higher at  $S_3$  (March; at harvest) and  $S_1$  (February; before back pruning) compared to  $S_2$  (September; during growth stage). Across three sampling seasons, the interaction of  $D \times S$  and  $E \times S$  were found in the order of  $S_1 = S_3 > S_2$  at both the soil depths across 3 elevations and 3 seasons. The cumulative interaction effect ( $E \times D \times S$ ) on chloride were just similar to the effect of individual factors namely, distance ( $D_1 > D_2 > D_3 = D_4$ ), season ( $S_3 > S_1 > S_2$ ) and elevation factor ( $E_3 > E_2 > E_1$ ).

Similar to other ions, lower region of the vineyard recorded higher amounts of chloride. This may be due to the fact that the chloride salts are highly soluble in water and soil colloid exhibits negative adsorption with the ions. Negative charges of both the chloride and soil colloids induce repulsion and hence, chloride is more susceptible for leaching (Singh *et al.*, 2014). This could be the reason for its higher mobility in soils compared to other anions. In arid and semiarid regions, chloride concentration in general is high in surface soil during summer due to high evapo-transpirations (Balphande *et al.*, 1996). This could be the reason for observing higher amounts of chloride during February ( $S_1$ ) and March ( $S_3$ ).

**Water soluble total anions:** The information on total anion contents in grape vineyard soils at different distances, elevations and seasons for surface and subsurface soils are provided in Figures 16a and 16b respectively. The total anion contents in surface soils ranged from 3.75 to 9.96 me l<sup>-1</sup>. Similarly, the total anion contents for the subsurface soils ranged from 2.99 to 8.62 me l<sup>-1</sup>.

The total water soluble anions in soils varied significantly *w.r.t.* elevation at both the depths and it was found in the order of  $E_3 > E_2 > E_1$ . In terms of distance, the variations in total anions were found similar to that of other individual anions ( $D_1 > D_2 > D_3 > D_4$ ). The effect of season indicated that the soil samples at harvest ( $S_3$ ) were found with higher total anions and varied significantly with other seasons in the order  $S_3 > S_1 > S_2$ .

The interaction effect of elevation, distance and season on total anions is presented in this section. The interaction of elevation and distance (E x D) influenced total anions contents in surface soils significantly across distance ( $D_1 > D_2 > D_3 > D_4$ ) at all elevations. Similarly, they also varied with elevations across all distances in the order  $E_3 > E_2 > E_1$ . However, the subsurface soils did not show significant interaction effects. The elevation and season (E x S) interactions did not influence total anion contents in surface soils. However, the subsurface soils recorded significant differences *w.r.t.* elevation and season and found in the order  $E_3 > E_2 > E_1$  across 3 seasons and  $S_3 = S_2 > S_1$  across all 3 elevations. Interaction of distance with season (D x S) influenced total anions in surface soils significantly across all three seasons ( $S_3 > S_1 > S_2$ ) at  $D_1$  while, it was in the order of  $S_3 = S_1 > S_2$  at  $D_2$ ,  $D_3$  and  $D_4$ . The cumulative effect of all the three factors on total anions remained same as that of variations observed *w.r.t.* individual parameters. In general, the total anions remained significantly higher in the surface soils of grape orchards in low elevation areas.

As discussed earlier, the lateral movement of water soluble salts from high elevation areas by percolating water along the slope through subsurface layers might have caused accumulation of anions in lower regions of the orchard (Chhabra, 1996; Kirankumar *et al.*, 2016; Lakshmi, 2018). The concentration gradient of total anions with elevation and its similarities with other cations and anions further confirm lateral movement. These observations are in concurrence with the electrical conductivity and other water soluble cations and anions. Corresponding correlation coefficients also are

in concurrence with the total cationic and anionic contents. Addition of different anions through irrigation water, fertilizers/ amendments and mineralization of organic matter also might have contributed (Nagaraja, 1997; Reddy *et al.*, 2012; Kriankumar *et al.*, 2016; Rekha *et al.*, 2018). Judicious / limited application of water through drip irrigations in grapes might have caused its buildup near the root zone. Both transpiration by plants and evaporation from soil surface results in buildup of salts as only water is removed (Chhabra, 1996; Gupta *et al.*, 1990). However, these accumulated salts might have moved to inter row regions during rainy season and thus, its buildup was observed to some extent. Movement of salts in solution by infiltrating / percolating water during rainy season is reported by several authors (Lakshmi *et al.*, 2018; Kirankumar *et al.*, 2016; Ashwin *et al.*, 2018). Thus, the above phenomena might have caused lower total anionic contents during S<sub>2</sub> – at growth stage compared to S<sub>1</sub> - before back pruning and S<sub>3</sub> - at harvest during hot summer.

## 6. SUMMARY AND CONCLUSION

The soils of northern Karnataka formed under semi arid conditions are likely to be saline. The ground water used for irrigation is also likely to be saline. Thus, use of salt rich water for irrigation in a heavy textured saline prone soil is likely to induce its accumulation. Summary of the results obtained on the soil salinity status of grape vineyards, ground water samples and its seasonal and spatial variations in a specified vineyard are presented in this chapter.

Soil reactions of the vineyard ranged from 7.09 to 8.47 with a mean value of  $7.99 \pm 0.29$ . Majority of soil samples were found to be in slightly alkaline to moderately alkaline in reaction. The electrical conductivity, an indicator of soil salinity, ranged from 0.69 to 1.69 dS  $m^{-1}$ . The mean conductivity value of  $0.98 \pm 0.23$  dS  $m^{-1}$  was observed. The soils were found to be slightly to moderately saline for vineyard soils.

Among water soluble cations, the order of dominance was found to be  $Ca^{2+} > Mg^{2+} > Na^+ > K^+$ . The water soluble-Ca and Mg contents in different vineyards were found to be  $3.82 \pm 0.89$  me  $l^{-1}$  and  $1.93 \pm 0.67$  me  $l^{-1}$ . Water soluble-Na ranged from 0.69 to 6.23 me  $l^{-1}$ . The potassium contents ranged from 0.06 to 1.49 me  $l^{-1}$  and its mean value was  $0.32 \pm 0.24$  me  $l^{-1}$ . Finally, the mean total water soluble cations in grape vineyards were found to be  $7.97 \pm 1.79$  me  $l^{-1}$ . The same extracts were used for the determination of anions. The average total carbonates and sulphates in dissolved forms were found to be  $2.54 \pm 0.78$  me  $l^{-1}$  and  $0.44 \pm 0.41$  me  $l^{-1}$  respectively. Similarly, the mean chloride content was  $4.13 \pm 1.40$  me  $l^{-1}$ . The total anions in the soil water suspension was  $7.11 \pm 1.66$  me  $l^{-1}$ .

Twenty borewell water samples were analyzed for salinity parameters. The water samples were mostly found to be slightly alkaline in nature with pH ranging from 6.89 to 7.64 (mean pH of  $7.31 \pm 0.21$ ). The electrical conductivity of water samples ranged from 0.16 to 1.42 dS  $m^{-1}$  with a mean value of  $0.60 \pm 0.41$  dS  $m^{-1}$ . Majority of the samples analysed were found to be safe for irrigation with conductivity of  $< 1.00$  dS  $m^{-1}$ .

Among cations, the magnesium was found to be most dominant and it ranged from 1.50 to 5.87 me  $l^{-1}$ . Similarly, the dissolved calcium was in the range of 1.42 to 5.74 me  $l^{-1}$ . The mean values of calcium and magnesium in irrigation water were found

to be  $3.59 \pm 1.31 \text{ me l}^{-1}$  and  $3.77 \pm 1.14 \text{ me l}^{-1}$  respectively. The next dominant cation was sodium and its average concentration was  $1.35 \pm 1.27 \text{ me l}^{-1}$  and the least was found to be potassium  $0.12 \pm 0.06 \text{ me l}^{-1}$  (with a range of 0.05 to  $0.24 \text{ me l}^{-1}$ ). Thus, the total soluble cations were found to be  $8.83 \pm 2.01 \text{ me l}^{-1}$ . Both  $\text{CO}_3^{=}$  and  $\text{HCO}_3^{-}$  were determined together and referred it as total carbonates (as  $\text{CO}_3^{=}$  was below the detectable limits). The mean concentration was found to be  $2.95 \pm 1.00 \text{ me l}^{-1}$ . In terms of soluble –  $\text{SO}_4^{=}$  and  $\text{Cl}^{-}$ , the mean concentrations were  $0.39 \pm 0.26 \text{ me l}^{-1}$  and  $3.77 \pm 1.33 \text{ me l}^{-1}$  respectively. The total anion contents were found almost similar to the values of dissolved cations ranging from 4.68 to  $11.32 \text{ me l}^{-1}$  and mean of  $7.11 \pm 1.69 \text{ me l}^{-1}$ .

The soils at 15 cm ( $D_1$ ) and 30 cm ( $D_2$ ) away from the plant row recorded higher alkalinity compared to the soils at 75 cm ( $D_3$ ) and 120 cm ( $D_4$ ). The pH of both surface and subsurface soils varied significantly in the order  $D_1 = D_2 > D_3 = D_4$ . The topography of the vineyard did not have any significant effect on soil reaction. In terms of seasons, both surface and subsurface soils recorded significantly higher pH values in samples representing ( $S_1$ ) before pruning stage compared to growth ( $S_2$ ) and harvesting stage ( $S_3$ ). In terms of interactions, the three factors collectively (E x D x S) or in combinations (E x D, E x S and D x S) did not influence soil reaction at both the depths.

The soil salinity was influenced by all the three factors individually and in combinations. The soils present in low lying area ( $E_3$ ) recorded higher EC compared to high ( $E_1$ ) and mid ( $E_2$ ) elevation areas ( $E_3 > E_2 > E_1$ ). In terms of horizontal distribution, the soils present next to the plant rows ( $D_1$ - 15 cm) recorded higher electrical conductivity (in  $\text{dS m}^{-1}$ ) and it decreased significantly with increase in distance in surface soils ( $D_1 > D_2 > D_3 > D_4$ ). In subsurface soils, the order of salinity was  $D_1 = D_2 > D_3 > D_4$ . In terms of seasons, the soil samples collected at harvest ( $S_3$ ) and just before pruning ( $S_1$ ) stages recorded higher conductivity whereas, the soil samples at growth stage ( $S_2$ ) recorded significantly lower salinity values. In terms of interactions, elevation x season (E x S); and distance and season (D x S) had significant effect on electrical conductivity in most of the samples. The surface soils present at  $D_1$  (15 cm) and  $D_2$  (30 cm) showed significant variations *w.r.t.* three seasons due to D x S interaction effects. The cumulative effect of E x D x S had no significant effect on soil EC values.

High amounts of water soluble-Ca ( $4.92 \text{ me l}^{-1}$ ) was observed at 15cm distance in lower regions of the vineyard while, least concentration of  $1.93 \text{ me l}^{-1}$  was recorded at 120 cm distance in higher region. In terms of elevations, water soluble - Ca content in surface soils varied significantly in the order  $E_3 > E_2 > E_1$ . However, it was found on par with each other in subsurface soils across all elevations. Comparison of calcium ( $\text{me l}^{-1}$ ) in surface and subsurface soils were found in the order  $D_1 > D_2 > D_3 > D_4$  and  $D_1 = D_2 > D_3 > D_4$ . The soil samples collected at the beginning of the experiment ( $S_1$ , before pruning) and at harvest stage ( $S_3$ ) recorded higher amounts compared to soil samples representing growth stage ( $S_2$ ). In terms of interactions of elevation and distance on water soluble -Ca, the mean values of  $E \times D$  varied significantly with distance at both the depths. The interaction effect of elevation and season ( $E \times S$ ) significantly influenced the calcium content at all depths in surface soils ( $E_3 > E_2 > E_1$ ). Comparison of these mean values indicated significant differences across all three seasons ( $S_3 > S_1 > S_2$ ) in surface soils and it was of the order  $S_2 > S_3 = S_1$  in subsurface soils. The cumulative effect of elevation, distance and season ( $E \times D \times S$ ) on water soluble-Ca in general showed significantly higher values in lower regions of the vineyard at all seasons. However, the high and mid elevation regions did not vary significantly with each other in both surface and subsurface soils.

The micro elevation factor had significant influence on the magnesium content in both surface and subsurface soils. The surface soils had higher water soluble-Mg contents than subsurface soils across all the treatments combinations. The mean magnesium contents varied significantly in the order  $E_3 > E_2 > E_1$ . In terms of distance, the soils present closer to the plant row recorded significantly higher magnesium contents and it decreased with increase in distance from the plant row. In terms of seasons, least magnesium concentrations were recorded during growth stage ( $S_2$ ) in both surface and subsurface soils. However, the other two seasons  $S_1$  (before back pruning) and  $S_3$  (at harvest) recorded significantly higher values.

The interaction effect of elevation and distance ( $E \times D$ ) and elevation and season ( $E \times S$ ) on magnesium contents were found significant only in surface soils and not in subsurface soils. Magnesium content in general, was significantly high at lower regions and it decreased towards higher regions. In terms of distance, the mean values in surface soils were observed in the order  $D_1 = D_2 > D_3 > D_4$  at all elevations. With respect to

elevation and season interaction, the mean values of water soluble-Mg varied significantly in high elevation areas ( $E_1$ ) across all seasons. However, the values remained on par in  $S_1$  (before pruning) at  $E_1$  and  $E_2$  and in  $S_3$  (at harvest) at  $E_2$  and  $E_3$  regions of the vineyards. Water soluble-Mg in surface and subsurface soils were found influenced by  $D \times S$  (distance and season) in the order  $S_1 = S_3 > S_2$  at all the four horizontal distances except in subsurface soils during growth season ( $S_2$ ). The mean values of magnesium in surface soils as influenced by the interaction of  $D \times S$  varied significantly during  $S_1$  (before pruning) and  $S_2$  (at growth stage) in the order  $D_1 > D_2 > D_3 > D_4$  across all the three elevations while, it was observed in the order  $D_1 = D_2 > D_3 = D_4$  in soils samples at harvest stage ( $S_3$ ).

The concentrations of sodium ( $\text{me l}^{-1}$ ) in 1:2 soil water extract of surface soils were found significantly higher at low point areas ( $E_3$ ) and it decreased significantly with increase in elevation of the vineyard. However, the subsurface soils of mid regions ( $E_2$ ) were found on par with both high ( $E_1$ ) and low ( $E_3$ ) elevation regions. In terms of distance, the soils present closer to the plant row at 15 cm recorded higher Na contents and it decreased with increasing sampling distance ( $D_2$ ,  $D_3$  and  $D_4$ ). The variations were found significantly different at all the four distances. The orders of variations in water soluble- Na were found to be  $D_1 > D_2 > D_3 > D_4$  in surface soil and  $D_1 = D_2 > D_3 > D_4$  in subsurface soils. In terms of seasons, soil samples representing harvesting stage ( $S_3$ ) and at the beginning stage ( $S_1$ ) had higher Na contents compared to the soils collected at crop growth stage ( $S_2$ ).

Interaction of elevation and season ( $E \times S$ ) had no significant influence on water soluble-Na in surface soils but, showed significant effect in subsurface soils. Cumulative effect of elevation, distance and season interaction ( $E \times D \times S$ ) on surface and subsurface soils revealed similar observations made with respect to distance and season and elevation as individual factors. The only deviation was that there was no cumulative effect across seasons in subsurface soils.

Among three regions of different elevations, the soils at low region of grape vineyard ( $E_3$ ) recorded significantly higher potassium contents. However, the values did not vary significantly with soils of mid elevation areas. Water soluble-K trend surface and subsurface soils remained same with values in the order -  $E_3 = E_2 > E_1$ . The water soluble-K contents in surface soils was in the order  $D_1 = D_2 > D_3 > D_4$ . The subsurface

soils recorded slightly lesser values and the mean values decreased significantly across all the horizontal distances in the order  $D_1 > D_2 > D_3 > D_4$ . Interestingly, comparison of water soluble-K contents across three different seasons recorded very high values in both surface and subsurface soils during growth stage ( $S_2$ ). The soil samples collected before pruning stage ( $S_1$ ) and at harvesting stage ( $S_3$ ) recorded substantially lower values and both the values varied significantly ( $S_2 > S_3 > S_1$ ).

In terms of interactions, distance x season ( $D \times S$ ) was the only factor which influenced K content in both surface and subsurface soils. They were found in the order of  $S_2 > S_3 = S_1$  at all the four distances. Interaction effects of other factors ( $E \times D$ ,  $E \times S$  and  $E \times D \times S$ ) had no significant influence on water soluble-K in both surface and subsurface soils.

The soils of lower regions ( $E_3$ ) grape vineyard recorded significantly higher amounts of total cations in both surface and subsurface soils. Contrastingly, the soils at high elevation region ( $E_3$ ) recorded significantly lesser amounts. Thus, the total cations varied significantly in the order  $E_3 > E_2 > E_1$ . The mean total cation values decreased significantly with increase in distance in the order of  $D_1 > D_2 > D_3 > D_4$ . Comparison of mean values across three different seasons also varied significantly in both surface and subsurface soils in the order of  $S_3 > S_1 > S_2$ .

In terms of interaction of  $E \times S$  (elevation and season), the seasonal mean values in general varied significantly across three elevations except in soil samples of  $S_2$  (growth stage) at  $E_1$  and  $E_2$ . Comparison of elevation mean values across seasons indicated that the sampling time had significant influence on total cation and they varied in the order of  $S_3 > S_1 > S_2$  across all elevations. In terms of distance and season ( $D \times S$ ) interaction, the mean values of total cations in surface soils for each season at all distances showed significant influence in the order -  $S_3 > S_1 > S_2$ . The interaction effect on distance showed significant variations across three seasons at both the depths except in subsurface soils representing  $D_1S_2$  and  $D_2S_2$ .

The overall cumulative effect of  $E \times D \times S$  indicated that the soils closer to the plant rows ( $D_1$ : 15 cm and  $D_2$ : 30cm) recorded higher total cation contents while, soil samples from  $D_3$  (75 cm) and  $D_4$  (120 cm) recorded lesser concentrations. In general, the soils of growth stage ( $S_2$ ) at both depths recorded lesser total cations than at  $S_1$  (before pruning) and  $S_3$  (at harvest). In terms of elevations, most of the soil samples

representing lower region of the vineyard recorded significantly higher amounts in contrast to high elevation vineyard soil samples with significantly lesser values.

Both surface and subsurface soil samples exhibited significant influence of elevation on total carbonates in the order  $E_3 > E_2 > E_1$ . In terms of distance, the soils closer to the plant row ( $D_1$ -15cm) recorded higher total carbonates and it declined significantly in surface soils ( $D_1 > D_2 > D_3 > D_4$ ). The trend was almost similar in subsurface soils except total carbonate values at  $D_1$  and  $D_2$  ( $D_1 = D_2 > D_3 > D_4$ ). The soil samples collected at harvest ( $S_3$ ) and before back pruning ( $S_1$ ) were observed with higher total carbonates compared to samples at growth stage ( $S_2$ ). Their values varied significantly in the order  $S_3 > S_1 > S_2$  in surface soils while, the subsurface soils were found in the order  $S_3 = S_1 > S_2$ .

In terms of interaction effects of  $E \times D$  (elevation and distance), the total carbonates decreased significantly in both surface and subsurface soils except in the soil samples representing 15 and 30 cm distances. The mean values of total carbonates representing the interaction of  $E \times S$  (elevation  $\times$  season) showed variations in the order of  $S_3 = S_1 > S_2$  in surface soils at all the three elevations while, subsurface soils recorded  $S_3 > S_1 = S_2$  order. In general, the total carbonates in surface and subsurface soils decreased significantly with increase in distance due to  $D \times S$  interaction. The overall interactions of elevation, distance and season ( $E \times D \times S$ ) on total carbonates in surface and subsurface soils were almost similar to the effects as observed with individual parameters.

The values of water soluble sulphates were found significantly higher in soils of lower region grape vineyards ( $E_3$ ) compared to high ( $E_1$ ) and mid regions ( $E_2$ ) and it varied in the order of  $E_3 > E_1 = E_2$  in both surface and subsurface soils. In terms of distance, the sulphate contents varied significantly at both the depths (0-20 cm and 20-40 cm) and it decreased significantly with distance from plant row ( $D_1 > D_2 > D_3 > D_4$ ). Among three different seasons, the soils collected at harvest ( $S_3$ ) and at start of season ( $S_1$ ) recorded significantly higher values ( $S_3 = S_1 > S_2$ ) compared to values at crop growth stage ( $S_2$ ) at both depths. Interestingly, the interactions of individual factors ( $E \times D$ ;  $D \times S$ ;  $E \times S$ ) or their cumulative interaction ( $E \times D \times S$ ) had no significant influence on water soluble sulphates in both surface and subsurface soils.

The soils present in lower elevation points of the vineyard ( $E_3$ ) recorded significantly higher chloride contents. The elevation influenced water soluble-Cl contents significantly in both surface and subsurface soils ( $E_3 > E_2 > E_1$ ). The data analysis indicated that the distance from the plant row had a great influence. The chloride contents also varied significantly in the order  $D_1 > D_2 > D_3 > D_4$ . The soil samples collected at harvest ( $S_3$ ) recorded high chloride contents while, the samples at growth stages ( $S_2$ ) recorded the least values.

The interaction of elevation and distance (E x D) indicated that soils closer to the plants ( $D_1$ -15 cm) recorded significantly higher amounts of chloride compared to soils away from the plant row. The chloride content observed at ( $D_3$ ) 75 cm and ( $D_4$ ) 120 cm did not show significant differences in both surface and subsurface soils at all the three elevations. In terms of the interaction of elevation and season (E x S), the chloride content varied significantly and found higher in lower elevation areas in contrast to lower values in high elevation areas. Across seasons the chloride content were found significantly higher at harvest and at the start of the study (before back pruning stages) compared to soil samples at growth stage. Across three sampling seasons, the observations made with respect to D x S interactions were similar to that of E x S in the order of February = March > September seasons at both the soil depths.

The total water soluble anions in soils varied significantly *w.r.t.* elevation at both the depths and it was found in the order of  $E_3 > E_2 > E_1$ . In terms of distance, the variations in total anions were found similar to that of other individual anions ( $D_1 > D_2 > D_3 > D_4$ ). The effect of season indicated that the soil samples at harvest ( $S_3$ ) were found with higher total anions and varied significantly with other seasons in the order  $S_3 > S_1 > S_2$ .

The interaction effect of elevation, distance and season on total anions is presented in this section. The interaction of elevation and distance (E x D) influenced total anions contents in surface soils significantly across distance and elevation and they varied similar to the values as observed *w.r.t.* elevation and distance as individual parameters. However, the subsurface soils did not show significant interaction effects. The elevation and season (E x S) interactions did not influence total anion contents in surface soils. Interaction of distance with season (D x S) influenced total anions in surface soils significantly at  $D_1$  distance across all three seasons ( $S_3 > S_1 > S_2$ ) while, it

was observed in the order of  $S_3 = S_1 > S_2$  at other distances ( $D_2$ ,  $D_3$  and  $D_4$ ). However, the subsurface soils recorded significant differences *w.r.t.* both distance and season factors. The cumulative effect of all the three factors on total anions remained same as that of variations observed *w.r.t.* individual parameters. In general, the total anions remained significantly higher in the surface soils of low elevation areas of the vineyards.

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# SPATIAL AND TEMPORAL DISTRIBUTION OF SALTS IN THE SOILS OF VINEYARD AT BAGALKOT

PALLAVI C N

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## ABSTRACT

Soils and groundwater of Bagalkot district inherently possess high salt contents. Grape, a commercially important fruit crop of the district, is highly sensitive to salt. Grape growers practice drip method for both irrigation and fertigation. Which encourages salt accumulation and thus, influencing both grape yields and quality.

A soil survey was carried out in 69 vineyards to assess the soil salinity parameters. Majority of soils were found in slight to moderately alkaline pH range (7.09 – 8.47) while, the salinity ranged from slight to moderately saline (0.69 - 1.69 dS m<sup>-1</sup>). Water soluble cations in soils were found in the order of Ca<sup>2+</sup> > Mg<sup>2+</sup> > Na<sup>+</sup> > K<sup>+</sup> while, the anions were in the order- Cl<sup>-</sup> > HCO<sub>3</sub><sup>-</sup> > SO<sub>4</sub><sup>2-</sup>. The water samples were also analysed from 20 vineyards and the water samples were mostly observed in slightly alkaline range (6.89 to 7.64). The electrical conductivity of water ranged from 0.16 to 1.42 dS m<sup>-1</sup>. The cations in the water samples were in the order of Mg<sup>2+</sup> > Ca<sup>2+</sup> > Na<sup>+</sup> > K<sup>+</sup> while, the anions were in the order Cl<sup>-</sup> > HCO<sub>3</sub><sup>-</sup> > SO<sub>4</sub><sup>2-</sup>.

A detailed study was carried out separately on spatial and temporal distribution of salts in a selected grape vineyard. The spatial distribution of salts at 15cm (D<sub>1</sub>), 30cm (D<sub>2</sub>), 75cm (D<sub>3</sub>) and 120cm (D<sub>4</sub>) from the plant rows were monitored at two different depths (0-20cm, 20-40cm) and three different stages namely before back pruning (S<sub>1</sub>), growth Stage (S<sub>2</sub>) and at harvesting Stage (S<sub>3</sub>). The vineyard was also categorized into three different elevation zones - high (E<sub>1</sub>), mid (E<sub>2</sub>) and low (E<sub>3</sub>) regions to assess movements of salts within the grape rows of the vineyard.

In the selected vineyard, pH of both surface and subsurface soils varied significantly in the order D<sub>1</sub> = D<sub>2</sub> > D<sub>3</sub> = D<sub>4</sub>. In terms of seasons, both surface and subsurface soils recorded significantly higher pH values in samples at S<sub>1</sub> stage compared to S<sub>2</sub> and S<sub>3</sub> stages. Higher conductivity values were recorded in surface soils (0.83 dS m<sup>-1</sup>) compared to subsurface (0.74 dS m<sup>-1</sup>) at all the 4 distances and 3 elevations during S<sub>1</sub> and S<sub>3</sub> stages. The soils present in low lying area (E<sub>3</sub>) recorded higher mean electrical conductivity (0.91 to 0.99 dS m<sup>-1</sup>) compared to high (0.55 to 0.63 dS m<sup>-1</sup>) and mid elevation areas (0.76 to 0.86 dS m<sup>-1</sup>) (E<sub>1</sub> and E<sub>2</sub>) of the vineyard.

Amounts of individual ions varied *w.r.t.* to elevations, distances and seasons in the order of E<sub>3</sub> > E<sub>2</sub> > E<sub>1</sub>; D<sub>1</sub> > D<sub>2</sub> > D<sub>3</sub> > D<sub>4</sub> and S<sub>3</sub> ≥ S<sub>1</sub> > S<sub>2</sub> respectively. However, the water soluble K<sup>+</sup> was differed during growth stage and found in the order S<sub>2</sub> > S<sub>3</sub> > S<sub>1</sub>. Similarly, the Cl<sup>-</sup> among anions in subsurface soils was in the order D<sub>3</sub> = D<sub>1</sub> = D<sub>2</sub> > D<sub>4</sub>.

ಬಾಗಲಕೋಟೆಯ ದ್ರಾಕ್ಷಿತೋಟದ ಮಣ್ಣಿನಲ್ಲಿರುವ ಲವಣಗಳ ಪ್ರಾದೇಶಿಕ ಮತ್ತು ಕಾಲಾಂತರ ವಿತರಣೆ

ಪಲ್ಲವಿ ಸಿ ಎನ್

2019  
ಸಾರಾಂಶ

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ಬಾಗಲಕೋಟೆ ಜಿಲ್ಲೆಯಲ್ಲಿ ದ್ರಾಕ್ಷಿಯು ಒಂದು ಪ್ರಮುಖ ಮತ್ತು ಆರ್ಥಿಕ ಬೆಳೆಯಾಗಿದೆ. ಜಿಲ್ಲೆಯ ಮಣ್ಣು ಮತ್ತು ಅಂತರ್ಜಲವು ಮೂಲತಃ ಹೆಚ್ಚಿನ ಉಪ್ಪಿನಾಂಶವನ್ನು ಹೊಂದಿದೆ. ದ್ರಾಕ್ಷಿ ತೋಟಗಳಿಗೆ ನೀರು ಮತ್ತು ರಾಸಾಯನಿಕ ಗೊಬ್ಬರಗಳನ್ನು ಹನಿ ನೀರಾವರಿ ಮೂಲಕ ನೀಡುವುದರಿಂದ ಮಣ್ಣಿನಲ್ಲಿನ ಉಪ್ಪಿನಾಂಶವನ್ನು ಉತ್ತೇಜಿಸುತ್ತದೆ. ದ್ರಾಕ್ಷಿಯು ಸವಳುವಿಕೆ ಸೂಕ್ಷ್ಮವಾಗಿರುವುದರಿಂದ ಹಣ್ಣಿನ ಇಳುವರಿ ಮತ್ತು ಗುಣಮಟ್ಟದ ಮೇಲೆ ಪರಿಣಾಮಬೀರುತ್ತದೆ.

ಮಣ್ಣಿನ ಲವಣಾಂಶ ಮತ್ತು ಧಾತುಗಳ ಪ್ರಮಾಣವನ್ನು ತಿಳಿಯಲು 69 ದ್ರಾಕ್ಷಿತೋಟಗಳಲ್ಲಿ ಸಮೀಕ್ಷೆ ನಡೆಸಲಾಯಿತು. ಸಮೀಕ್ಷೆಯ ಬಹುಪಾಲು ಮಣ್ಣಿನ ಮಾದರಿಗಳು ಸ್ವಲ್ಪ ಕ್ಷಾರೀಯದಿಂದ (7.09) ಮಧ್ಯಮ ಕ್ಷಾರೀಯದವರೆಗೆ (8.47) ಕಂಡುಬಂದಿದೆ. ಮಣ್ಣಿನ ಮಾದರಿಗಳಲ್ಲಿ ವಿದ್ಯುತ್ ವಾಹಕತೆ 0.69 ರಿಂದ 1.69 dS/m ಇರುತ್ತದೆ. ಸಮೀಕ್ಷೆ ಮಾಡಿದ ಮಣ್ಣಿನ ಮಾದರಿಗಳಲ್ಲಿ ನೀರಿನಲ್ಲಿ ಕರಗುವ ಧನ ಧಾತುಗಳು  $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$  ಮತ್ತು ನೀರಿನಲ್ಲಿ ಕರಗುವ ಋಣ ಧಾತುಗಳು  $Cl^{-} > HCO_3^{-} > SO_4^{2-}$  ಕ್ರಮದಲ್ಲಿದ್ದವು. ನೀರಿನ ಮಾದರಿಗಳನ್ನೂ 20 ದ್ರಾಕ್ಷಿ ತೋಟಗಳಿಂದ ವಿಶ್ಲೇಷಿಸಲಾಯಿತು ಆ ನೀರಿನ ಮಾದರಿಗಳು ಕ್ಷಾರಿಯ ವಾಪ್ಪಿಯಲ್ಲಿದ್ದುದು (6.89 ರಿಂದ 7.64) ಗಮನಿಸಲಾಯಿತು. ನೀರಿನ ವಾಹಕತೆ 0.16 ರಿಂದ 1.47 dS/m ವರೆಗೆ ಇದ್ದು, ನೀರಿನ ಮಾದರಿಗಳಲ್ಲಿನ ಧನ ಧಾತುಗಳು  $Mg^{2+} > Ca^{2+} > Na^{+} > K^{+}$  ಕ್ರಮದಲ್ಲಿದ್ದರೇ, ಋಣ ಧಾತುಗಳು  $Cl^{-} > HCO_3^{-} > SO_4^{2-}$  ಕ್ರಮದಲ್ಲಿದ್ದವು.

ದ್ರಾಕ್ಷಿತೋಟದಲ್ಲಿ ಲವಣಗಳ ಪ್ರಾದೇಶಿಕ ಮತ್ತು ಕಾಲಾಂತರ ವಿತರಣೆಯ ಬಗ್ಗೆ ಪ್ರತ್ಯೇಕ ಅಧ್ಯಯನ ನಡೆಸಲಾಯಿತು. ಅಧ್ಯಯನದಲ್ಲಿ ಮಣ್ಣಿನ ಮಾದರಿಗಳನ್ನು ಗಿಡಗಳ ಸಾಲಿನಿಂದ 15 cm ( $D_1$ ), 30 cm ( $D_2$ ), 75 cm ( $D_3$ ) ಮತ್ತು 120 cm ( $D_4$ ) ದೂರದಲ್ಲಿ ಮತ್ತು 0-20 cm ಮತ್ತು 20-40 cm ಪ್ರತ್ಯೇಕ ಆಳಗಳಲ್ಲಿ, ದ್ರಾಕ್ಷಿಬೆಳೆಯ ಮೂರು ಹಂತಗಳಾದ ಸವರುವಿಕೆಯ ಮುಂಚೆ ( $S_1$ ), ಬೆಳವಣಿಗೆ ( $S_2$ ) ಮತ್ತು ಕೋಯ್ಲು ಸಮಯದಲ್ಲಿ ( $S_3$ ) ಸಂಗ್ರಹಿಸಲಾಯಿತು. ದ್ರಾಕ್ಷಿ ತೋಟದಲ್ಲಿನ ಲವಣಗಳ ಚಲನೆಯನ್ನು ಅರ್ಥೈಸಲು ಮೇಲ್ಮೈನ ( $E_1$ ), ಮಧ್ಯದ ( $E_2$ ) ಹಾಗೂ ಕೆಳ ಮೇಲ್ಮೈ ( $E_3$ ) ತಾಕುಗಳಾಗಿ ವಿಂಗಡಿಸಿ ಅಧ್ಯಯಿಸಲಾಯಿತು.

ಆಯ್ದ ದ್ರಾಕ್ಷಿತೋಟದ ಎರಡೂ ಆಳಗಳಲ್ಲಿ ಮಣ್ಣಿನ ರಾಸಾಯನಿಕ ಕ್ರಿಯೆಯು  $D_1 = D_2 > D_3 > D_4$  ಕ್ರಮದಲ್ಲಿ ಗಮನಾರ್ಹವಾಗಿ ಬದಲಾಗಿರುತ್ತದೆ. ಮಣ್ಣಿನ ಮೇಲ್ಮೈ ಮತ್ತು ಕೆಳ ಮೇಲ್ಮೈ ಆಳಗಳಲ್ಲಿ ಮಣ್ಣಿನ ರಾಸಾಯನಿಕ ಕ್ರಿಯೆಯು ಬೆಳವಣಿಗೆ ( $S_2$ ) ಮತ್ತು ಕೋಯ್ಲು ( $S_3$ ) ಹಂತಗಳಿಗೆ ಹೋಲಿಸಿದರೆ ಸವರುವಿಕೆಯ ಮುಂಚೆಯ ( $S_1$ ) ಹಂತದಲ್ಲಿ ಗಮನಾರ್ಹವಾಗಿ ಹೆಚ್ಚಾಗಿದೆ. ಮಧ್ಯದ (0.76 ರಿಂದ 0.86 dS/m) ಮತ್ತು ಎತ್ತರದ (0.55 ರಿಂದ 0.63 dS/m) ಪ್ರದೇಶಗಳಿಗೆ ಹೋಲಿಸಿದರೆ ತಗ್ಗು ಪ್ರದೇಶಗಳಲ್ಲಿ (0.91 ರಿಂದ 0.99 dS/m) ಹೆಚ್ಚಿನ ವಿದ್ಯುತ್ ವಾಹಕತೆ ಕಂಡುಬಂದಿತು. ಕೆಳ ಮೇಲ್ಮೈ ಮಣ್ಣಿನ ಮಾದರಿಗಳಲ್ಲಿ ಕಡಿಮೆ (0.74 dS/m) ಹಾಗೂ ಮೇಲ್ಮೈ ಮಣ್ಣಿನ ಮಾದರಿಗಳಲ್ಲಿ (0.83 dS/m) ಹೆಚ್ಚಿನ ವಿದ್ಯುತ್ ವಾಹಕತೆ ಕಂಡುಬಂದಿದೆ.

ಪ್ರತ್ಯೇಕ ಧಾತುಗಳ ಪ್ರಮಾಣಗಳು ಅನುಕ್ರಮವಾಗಿ  $E_3 > E_2 > E_1$ ;  $D_1 > D_2 > D_3 > D_4$  ಮತ್ತು  $S_3 \geq S_1 > S_2$  ಕಂಡು ಬಂದಿರುತ್ತವೆ. ಆದರೆ, ನೀರಿನಲ್ಲಿಕರಗುವ  $K^{+}$  ಪ್ರಮಾಣವು ಬೆಳವಣಿಗೆಯ ಹಂತದಲ್ಲಿ ಹೆಚ್ಚಾಗಿದ್ದುದು ಕಂಡುಬಂದಿತು ( $S_2 > S_3 > S_1$ ). ಅಂತೆಯೇ, ಕೆಳ ಪ್ರದೇಶಗಳ ತೋಟದ ಭಾಗದಲ್ಲಿ  $Cl^{-}$  ಪ್ರಮಾಣವು  $D_3 > D_1 = D_2 > D_4$  ಕ್ರಮದಲ್ಲಿ ಕಂಡುಬಂದಿತು.