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Full Length Research Paper

Application of silicon ameliorated salinity stress and improved wheat yield

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Management of soil salinity is an important research field around the globe, especially when associated with the limited water resources. This work aimed to improve the growth and yield of wheat (*Triticum aestivum* L. CV. Sakha-93) grown under salinity stress. A completely randomized design pot experiment with three replications was conducted in a loamy soil with various levels of salinity under local weather conditions. The treatments included five levels of salinity (2.74, 5.96, 8.85, 10.74, and 13.38 dSm⁻¹) prepared by adding NaCl to the selected soil and five treatments of Si (0, 2.1, 4.2, 6.3, and 8.4 mg Si/10 plants). Silicon was applied to wheat plants as a foliar spray 30, 45, and 60 days after sowing. Results indicated that photosynthetic pigments; N, P, and K concentrations; biomass, and grain yield significantly decreased with increasing salinity concentration. For example, in the pots treated with Si rate of 0.0 mg Si/10 plants, biomass and grain yield significantly decreased by 37 and 30%, respectively, as salinity increased from 2.74 to 13.38 dSm⁻¹. However, Na and proline concentrations increased with the increase in salinity. Supplying Si alleviated salinity stress and enhanced plant growth, e.g., at salinity concentration of 5.96 dSm⁻¹, biomass and grain yield increased by 32 and 54%, respectively, when Si rate increased from 0.0 to 6.3 mg Si/10 plants. Similarly, under the same previous salinity and Si treatments, Na and proline concentrations decreased by 10 and 23%, respectively. Eventually, application of Si to wheat enhanced its growth and yield under salinity stress.

Key words: Biomass, proline, grain yield, sodium, chlorophyll.

INTRODUCTION

Salinity, in a global scale, is a major limiting factor of negatively impacting plant growth and productivity (Kaya et al., 2003; Shahi et al., 2015). Salinity affected soils occupy ~ 800 million ha worldwide (or ~ 6% of the world's total arable land area) (Munns, 2005). In Egypt, salinity

affected soils cover approximately 900,000 ha (or, 32% of the total arable land area) (Ibrahim and Lal, 2013). In salinity conditions, a reduction in plant growth, photosynthesis activity, stomata closure, biomass yield, and nutrients concentrations in the plant tissues occur

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due to water deficit caused by osmotic imbalance (Parida and Das, 2005; Rahnama et al., 2010). Different strategies have been used to alleviate salinity stress and enhance plant tolerance to it. Applying Si to plants, as one of these strategies, has been used during the past few decades.

After oxygen, Si is considered the second most abundant element in the earth's crust comprising ~ 28% by weight (Wedepohl, 1995). Although total Si is abundant in soil, most of it may not be available to plants. Plants take up Si in the soluble form of mono-silicic acid ($\text{Si}(\text{OH})_4$), which occurs in low concentrations in the soil solution (Mitani et al., 2005). Its concentration in most of the soils may range from <1 to 200 mg Si kg^{-1} soil (Ibrahim and Lal, 2014). Several decades ago and based on the criteria suggested by Arnon and Stout (1939), Si was not considered an essential element for plants (Epstein, 1994). In 2005, however, Epstein and Bloom defined new criteria of the essential elements for higher plants upon which Si should be considered an essential element. Although considering Si as an essential element for higher plants is still in debate, it has been stated to be beneficial to alleviate biotic (e.g., plant diseases) and abiotic stresses (e.g., salinity, lodging, drought, freezing, and aluminum toxicity) (Liang et al., 2007; Van Bockhaven et al., 2013). Zhu and Gong (2014) reported that Si does not pollute the environment even when applied in higher quantities than what is required.

Plants take up Si through their roots from soil solution in the form of mono-silicic acid, which is transferred to shoots via xylem and finally precipitates as phytoliths, or plant opal in the cell walls, trichomes, and intracellular spaces (Cooke and Leishman, 2011). It was suggested that Si can be taken up by plant roots either actively or passively, or both of the two ways may coexist for the same plant (Henriet et al., 2006).

Applying Si to wheat improves photosynthetic activity. Tuna et al. (2008) in their pot experiment found a decrease in chlorophyll pigment concentration of two wheat cultivars under salinity stress compared with normal conditions. However, by applying Si, chlorophyll pigments increased under normal conditions as well as under salinity stress conditions. Researchers found salinity stress to hinder plants from absorbing nutrients, e.g., nitrogen (N), phosphorus (P), and potassium (K) resulting in reducing these nutrients concentrations in plant tissues (Reda et al., 2011). During stress conditions, plants tend to increase proline concentration in their tissues in order to facilitate water uptake and maintain osmotic balance (Filippou et al., 2014). Under salinity stress, plants take up Na^+ in higher amount than that is needed and accumulate it in their tissues, which causes detrimental effects on the plant growth and yield (John et al., 2003). However, applying Si to saline soils resulted in declining the amount of Na^+ taken up by plants (Wang and Han, 2007). We hypothesized that application of Si to wheat would increase its tolerance to

salinity stress through decreasing Na uptake, increasing N, P, K uptake, and decreasing the formation of amino acid proline in plant tissue. The aims of this work were to (1) assess the impacts of salinity stress on wheat growth, biomass, grain yield, nutrients concentrations in tissues, the uptake of nutrients in straw and grains and (2) assess the effect of silicon application on ameliorating salinity stress and improving plant growth and productivity.

MATERIALS AND METHODS

Experiment set up and design

A pot experiment was conducted in a wired greenhouse under local weather conditions at the College of Agriculture greenhouses, Zagazig University, Zagazig, Egypt. The monthly average temperature ranges from 9°C in January to 34°C in July and August and the mean annual precipitation is 51 mm (World Meteorology Organization, 2016). A factorial design with five Si treatments and one soil with five salinity concentrations was used. Pots were arranged in a completely randomized block design with three replicates. Wheat (*Triticum aestivum* L. CV. Sakha-93) seeds were obtained from the Wheat Research Department, Crops Research Institute, Agriculture Research Centre, Giza, Egypt. Seeds were sown on 15 November 2014. Twenty grains were sown in each pot. Each pot was thinned to 10 plants 12 days after sowing.

Five different concentrations of salinity were prepared by mixing a selected soil with NaCl. The selected soil (Haplargids) was collected from the soil surface to a depth of 30 cm from a private farm located in Alhousaynia County, Sharkia, Egypt. The soil was air dried, crushed, and passed through a 5-mm sieve. Closed bottom plastic pots (35 cm in diameter and 30 cm in height) were filled with 10 kg of each air dried soil mixed with NaCl. Soil salinity concentrations were 2.74, 5.96, 8.85, 10.74, and 13.38 dSm^{-1} . Soil salinity was measured using a 1:1 soil: water suspension using an EC meter (Thermo Scientific, Beverly, MA, USA). Sodium chloride was used to adjust salinity concentrations because Na^+ dominates the cations and Cl^- dominated the anions in the selected soil. Each salinity concentration was prepared by adding known weighed amounts of NaCl at different times to a 1:1 soil: water mixture of the original soil that had 2.74 dSm^{-1} . While adding NaCl to the soil, the EC was being measured spontaneously until the desired EC was reached. For example, 1.3 g NaCl was added to a 1:1 soil: water mixture (300 g soil: 300 mL water) to raise the salinity concentration from 2.74 to 5.96 dSm^{-1} , then, the added NaCl weight was calculated to fit 10 kg soil. After mixing the amount of NaCl with the 10 kg soil, a subsample was taken to measure the EC again to make sure the aimed salinity concentration was reached. These particular salinity concentrations were selected in that range because the salt affected soils in Alhousaynia County from which we collected the original soil has these salinity concentrations and even higher.

The highest salinity concentration was selected because plants do not satisfactorily yield at this concentration (Food and Agriculture Organization, 1992). Farmers in this area have been using tile drainage that had different ages and efficiencies resulting in forming different soil salinities. The highest salinity concentration (13.38 dSm^{-1}) was selected because it was the highest concentration at which wheat plants did not die after emergence. Soil chemical and physical properties were determined (Table 1). Soil pH was determined in a 1:1 (soil: water) suspension using an Orion pH meter (Thermo Scientific, Beverly, MA, USA). Particle size analysis (PSA) was determined using the pipette method (Pansu and Gauthierou, 2006). Soil organic matter was determined using the loss on ignition (LOI) method (Davies, 1974). Inorganic N was

Table 1. Physical and chemical properties of the selected soil.

Sand	Silt	Clay	Texture	pH (1:1)	SIC†	SOM‡	Plant available nutrients		
							N	P	K
(%)			(g kg ⁻¹)			mg kg ⁻¹			
42.09	32.14	25.77	Loam	8.07	55.13	7.56	67.18	7.54	102.35

† SIC (Soil inorganic carbon), ‡ SOM (Soil organic matter).

extracted by a 2 mol L⁻¹ KCl solution and measured using the micro-kjeldahl method (Keeney and Nelson, 1982). Available P was extracted using 0.5 mol L⁻¹ NaHCO₃ adjusted at pH 8.5. Phosphorus in the extraction was measured colorimetrically at 750 nm wavelength using a spectrophotometer (Milton Roy Spectronic 401, Ivyland, PA, USA) (Watanabe and Olsen, 1985). Potassium was extracted using a 1 mol L⁻¹ NH₄OAC solution (Jackson and Barak, 2005) and measured using an atomic absorption spectrometer (PerkinElmer Instruments, Waltham, MA, USA). Soil moisture condition was adjusted by weight to approximately 70% of water holding capacity (WHC).

To each pot, N (as ammonium sulfate) and P (as ordinary super phosphate) were applied at the doses of 90 mg N and 6.5 mg P kg⁻¹ soil, respectively. Nitrogen was applied in three equal amounts (each was 30 mg N kg⁻¹ soil) at 21 d after sowing, 30, and 60 days after the first dose, respectively. Phosphorus was applied before sowing. Potassium silicate (AgSil 16H, 52.8% SiO₂, PQ Silicates Ltd., Taipei, Taiwan) was used as a source of Si. To prepare the solutions, K-silicate powder was dissolved in distilled water to prepare 10,000 mg Si L⁻¹, from which we made dilutions to prepare the required concentrations (0.0, 140, 280, 420, and 560 mg Si L⁻¹). Five treatments of Si (0.0, 2.1, 4.2, 6.3, and 8.4 mg Si/10 plants) were applied as a foliar spray in three equal amounts (each was one third of the aforementioned Si rates/10 plants) three times during the tillering and booting growth stages 30, 45, and 60 days after sowing. Potassium concentrations in all of the applications were adjusted to be constant using dilute KCl. Distilled water was sprayed to represent the 0.0 mg Si/10 plants. A cardboard box was used during the Si application to protect other pots via separating the pot under application.

Physiological characteristics

After 75 days from sowing (at the booting stage), the fourth and fifth leaves from the base to the apex were collected from three plants from each plot to determine the chlorophyll pigments (Zadoks et al., 1974). Chlorophyll a, chlorophyll b, and carotenoids were determined spectrophotometrically (Milton Roy Spectronic 401, Ivyland, PA, USA) (Metzner et al., 1965). Basically, 0.1 g of a fresh leaves was ground and extracted with 5 mL 85% (v/v) acetone in a dark room. The contents were filtered and determined at absorbance of 452, 644 and 663 nm alongside a blank of untailed 85% liquid acetone. Chlorophyll pigments were calculated using the equations published by Porra et al. (1989). Proline content was determined using the ninhydrin method established by Bates et al. (1973). Briefly, 0.5 g of fresh leaf tissues was homogenized in 10 mL of 3% sulphosalicylic acid and filtered. In a test tube, 2 mL of the filtered solution was mixed with 2 mL of acid ninhydrin and 2 mL of glacial acetic acid. Contents of the test tube were placed in a water bath at 100°C and left to react for 1 h. Afterwards, the mixture was extracted with 4 mL toluene and measured at 520 nm absorbance using a spectrophotometer (Milton Roy Spectronic 401, Ivyland, PA, USA).

Plant harvesting and preparation:

Five plants from each pot were randomly selected for harvest and weighed (fresh biomass weight). Spikes and shoots were separated. Spikes were threshed manually to obtain the grain yield and conduct the chemical analyses. Straw (leaves and stems) were transferred in paper bags to an oven adjusted at 65°C and left for 3 days until the weight became constant (the biomass dry weight). Dried wheat materials were ground using a Wiley mill (Thomas-Wiley Co., Philadelphia, PA, USA) to pass a 2 mm screen, and were reground to uniformity and pass through a 1 mm screen using a UDY-Cyclone impact mill (UDY Corporation, Fort Collins, CO, USA). All of the ground subsamples were stored in polyethylene bottles for further analyses.

Chemical analyses:

For Si determination, 100 mg of the dried plant tissue materials were placed in a digesting flask containing a mixture of 5 mL concentrated nitric acid, 1 mL 70% perchloric acid, and 0.5 mL concentrated sulfuric acid (Nayar et al., 1975). The flask with its contents was placed on a hotplate (under a hood) for 1 h, or until the brown fumes stopped. The digested solution was quantitatively transferred to a 250 mL measuring flask containing 1.5 g Na₂CO₃. The later flask with its contents was boiled for 5 min, cooled, its volume was made to 250 mL, and transferred to a polyethylene bottle to be stored until determination. Silicon in the stored solution was measured colorimetrically using a spectrophotometer (Milton Roy Spectronic 401, Ivyland, PA, USA) following the molybdenum blue method (Hallmark et al., 1982). To determine Na and K, 0.1 g of the ground and dried plant tissue materials was digested overnight with 25 mL of 0.1 mol L⁻¹ HNO₃ in the room temperature (John et al., 2003). Both Na and K were measured using the atomic absorption spectrometer (PerkinElmer Instruments, Waltham, MA, USA). To determine N and P, 0.3 g of ground and dried plant tissue materials was digested with 4 mL concentrated H₂SO₄ and 1 mL of concentrated HClO₄. The digested materials were quantitatively transferred to a 100 mL volumetric flask using distilled water. N was determined using the distillation method and a micro-kjeldahl apparatus (Chapman and Pratt, 1982). Phosphorus was determined colorimetrically at 750 nm wavelength using a spectrophotometer (Milton Roy Spectronic 401, Ivyland, PA, USA) (Watanabe and Olsen, 1985).

Statistical analyses

All of the obtained data such as chlorophyll pigments, carotenoids, biomass, grain yield, proline, and concentrations of N, P, K, Na, and Si were statistically analyzed using SAS 9.4 software (SAS Institute, 2011). Two-way factorial ANOVA procedures were carried out using the mixed procedure of SAS with salinity, silicon and the interaction included as fixed effects. Both salinity and silicon were treated as

categorical variables. Orthogonal polynomials were used to compute lack-of-fit tests to determine whether or not salinity or silicon could be included instead as numeric variables for a regression analysis. It was determined that, for many responses, there was significant lack-of-fit for a linear trend for both salinity and silicon. For consistency, we use the same 2-way factorial model with salinity and silicon treated as categorical variables for each response. Treatment means were obtained using the lsmeans and all differences were obtained using lsmeans statements. Significant differences were determined at a 0.05 level after adjusting for multiple comparisons.

RESULTS AND DISCUSSION

Plant growth characteristics

Salinity was known to be a limiting factor for plant growth and productivity. Our results showed that concentrations of chlorophyll a, chlorophyll b, and carotenoids, within each individual foliar Si rate, decreased with increasing salinity stress. For example, the concentrations of chlorophyll a, chlorophyll b, and carotenoids within the Si rate of 0.0 mg Si/10 plants, significantly decreased as salinity concentration increased from 2.74 to 13.38 dSm⁻¹ (Table 2). Similarly, within the Si rate of 4.2 mg Si/10 plants, chlorophyll a and chlorophyll b significantly decreased when salinity concentration increased from 2.74 to 13.38 dSm⁻¹ (Table 2). Tuna et al. (2008) in their work on influence of silicon application on the characteristics of wheat plants grown under salinity stress found a significant decrease in chlorophyll a and chlorophyll b when salinity concentration increased. This decrease in chlorophyll a and chlorophyll b could be interpreted as a consequence of the formation of proteolytic enzymes, e.g., chlorophyllase, which is responsible for chlorophyll deterioration (Sabater and Rodriguez, 1978). Carotenoids, within the Si rate of 8.4 mg Si/10 plants, significantly decreased as salinity concentration increased from 2.74 to 13.38 dSm⁻¹ (Table 2). However, all of the applied Si rates resulted in increasing the content of chlorophyll pigments under every individual salinity concentration. For example, within salinity concentration of 2.74 dSm⁻¹, chlorophyll a, chlorophyll b, and carotenoids significantly increased when Si rate increased from 0.0 to 6.3 mg Si/10 plants (Table 2). Similarly, within salinity concentration of 8.85 dSm⁻¹, chlorophyll a, chlorophyll b, and carotenoids significantly increased as Si rate increased from 0.0 to 6.3 mg Si/10 plants. Similarly, Rios et al. (2014) found an increase in chlorophyll pigments in wheat leaves when Si was applied.

When plants encounter either salinity or drought stresses, proline content increases in their tissues in order to resist these stresses (Filippou et al., 2014). Results in Table 2 revealed that proline concentration, within each Si rate, increased with increasing salinity concentration. For example, within the Si rate of 0.0 mg Si/10 plants, proline concentration significantly increased

when salinity concentration increased from 2.74 and 13.38 dSm⁻¹. Similarly, proline concentration significantly increased within the Si rate of 8.4 mg Si/10 plants when salinity concentration increased from 2.74 and 13.38 dSm⁻¹ (Table 2). Similar to our results, Tuna et al. (2008) found an increase in proline concentration with increasing salinity concentration. As a consequence of abiotic stresses, amino acids (e.g., proline) accumulate in shoots and roots to act as sinks of excess N (Dubey and Pessarakli, 1995). However, applying Si to plants in these conditions of stress decreased proline concentration, which could be due to the reaction between proline and Si forming silaproline similar to what takes place in the human body (Vivet et al., 2000). Within each salinity level, applied Si decreased proline concentration by increasing Si rate. For example, proline concentration, within salinity concentration of 2.74 dSm⁻¹, significantly decreased when Si rate increased from 0.0 to 8.4 mg Si/10 plants (Table 2). Similarly, within salinity concentration of 13.38 dSm⁻¹, proline concentration significantly decreased when Si rate increased from 0.0 to 8.4 mg Si/10 plants.

In our experiment, plant height decreased with increasing soil salinity within each Si rate. Under Si rate of 0.0 mg Si/10 plants, plant height significantly decreased when salinity concentration increased from 2.74 to 13.38 dSm⁻¹ (Table 2). Similarly, under the applied Si rate of 6.3 mg Si/10 plants, plant height significantly decreased when salinity concentration increased from 2.74 to 13.38 dSm⁻¹. This decline in plant height could be due to the decrease in chlorophyll pigments or photosynthetic activity resulting in hindering plant growth. However, applying Si to plants ameliorated the negative impacts of salinity stress on plant height under all of the salinity concentrations, i.e., plant height increased with increasing Si concentration compared with no addition of Si (0.0 mg Si/10 plants) (Table 2). For example, within salinity concentration of 2.74 dSm⁻¹, all Si rates (2.1, 4.2, 6.3, and 8.4 mg Si/10 plants) showed an increase in plant height compared to the control (0.0 mg Si/10 plants) (Table 2). Numerically, under salinity concentration of 2.74 dSm⁻¹, plant height significantly increased from 95.1 to 108.2 cm under Si rate of 0.0 and 6.3 mg Si/10 plants, respectively. Similarly, within salinity concentration of 10.74 dSm⁻¹, it significantly increased from 84.3 to 91.2 cm under Si rates of 0.0 and 6.3 mg Si/10 plants, respectively. Generally, Si rate of 6.3 mg Si/10 plants showed the best results of plant height compared to all other Si rates under all salinity concentrations. In contrast, both 0.0 and 8.4 mg Si/10 plants showed the lowest plant height.

Salinity stress precludes plant growth and declines biomass and grain yield of wheat. Our results indicated significant decreases in biomass and grain yield by increasing salinity concentration (Figures 1 and 2). For example, biomass under Si rate of 0.0 mg Si/10 plants significantly decreased by 37% when salinity concentration

Table 2. Plant growth characteristics and chemical compositions of wheat grown under salt stress conditions and treated with Si. Within each level of Si we compare least squares means corresponding to the salinity levels. Significant differences are indicated using different lower case letters down the column. Within each level of salinity we compare least squares means corresponding to the Si levels. Significant differences are indicated using different upper case letters across the row. Significance is determined at a 0.05 level where p-values are adjusted for multiple comparisons.

Properties	Salinity	Silicon application rate (mg Si/ 10 plants)				
	(dSm ⁻¹)	0.0	2.1	4.2	6.3	8.4
Plant height (cm)	2.74	95.1 ^{aC}	97.1 ^{aC}	100.3 ^{aB}	108.2 ^{aA}	95.5 ^{aC}
	5.96	90.4 ^{bB}	94.2 ^{bA}	95.5 ^{bA}	95.6 ^{bA}	93.8 ^{abA}
	8.85	88.2 ^{bB}	92.7 ^{bA}	93.6 ^{bA}	94.6 ^{bA}	92.9 ^{bA}
	10.74	84.3 ^{cB}	89.1 ^{cA}	90.5 ^{cA}	91.2 ^{cA}	89.5 ^{cA}
	13.38	74.3 ^{dD}	82.1 ^{dC}	87.4 ^{dAB}	88.1 ^{dA}	85.4 ^{dB}
Chlorophyll a (mg g ⁻¹)	2.74	1.29 ^{aC}	1.51 ^{aB}	1.69 ^{aB}	1.76 ^{aA}	1.51 ^{aB}
	5.96	1.20 ^{abC}	1.28 ^{bC}	1.38 ^{bBC}	1.61 ^{abA}	1.43 ^{abAB}
	8.85	1.18 ^{abB}	1.23 ^{bB}	1.30 ^{bAB}	1.43 ^{bcA}	1.28 ^{bAB}
	10.74	1.09 ^{bB}	1.14 ^{bB}	1.23 ^{bAB}	1.35 ^{CA}	1.23 ^{bAB}
	13.38	1.01 ^{bC}	1.13 ^{bBC}	1.21 ^{bAB}	1.30 ^{cAB}	1.35 ^{abA}
Chlorophyll b (mg g ⁻¹)	2.74	0.70 ^{aD}	0.75 ^{aC}	0.79 ^{aB}	0.85 ^{aA}	0.74 ^{aC}
	5.96	0.65 ^{abC}	0.69 ^{abBC}	0.74 ^{abB}	0.77 ^{bcA}	0.69 ^{abBC}
	8.85	0.61 ^{bcd}	0.67 ^{bBC}	0.70 ^{bABC}	0.74 ^{CA}	0.66 ^{bC}
	10.74	0.57 ^{cC}	0.61 ^{cBC}	0.64 ^{cdAB}	0.67 ^{dA}	0.61 ^{cBC}
	13.38	0.42 ^{dC}	0.51 ^{dB}	0.59 ^{dAB}	0.62 ^{dA}	0.55 ^{dB}
Carotenoids (mg g ⁻¹)	2.74	0.56 ^{aE}	0.62 ^{aD}	0.65 ^{aBC}	0.67 ^{aA}	0.63 ^{aCD}
	5.96	0.53 ^{bD}	0.56 ^{bCD}	0.58 ^{bBC}	0.62 ^{bA}	0.54 ^{bD}
	8.85	0.48 ^{cD}	0.51 ^{cC}	0.55 ^{CB}	0.58 ^{cdA}	0.51 ^{cC}
	10.74	0.44 ^{dD}	0.47 ^{dC}	0.51 ^{dB}	0.55 ^{dA}	0.47 ^{dC}
	13.38	0.39 ^{eD}	0.45 ^{dC}	0.46 ^{EB}	0.51 ^{eA}	0.44 ^{eC}
Proline (μmol g ⁻¹)	2.74	11.5 ^{eA}	11.3 ^{eAB}	10.2 ^{eC}	8.4 ^{eD}	7.6 ^{eE}
	5.96	14.1 ^{dA}	12.8 ^{dB}	11.5 ^{dC}	10.8 ^{dD}	9.9 ^{dE}
	8.85	16.7 ^{cA}	15.6 ^{CB}	13.8 ^{cC}	13.2 ^{cC}	11.4 ^{cD}
	10.74	17.3 ^{bA}	16.5 ^{abCB}	14.9 ^{abCC}	14.6 ^{abCC}	12.2 ^{abD}
	13.38	21.5 ^{aA}	20.4 ^{aB}	19.1 ^{aC}	18.2 ^{aD}	16.4 ^{aE}

increased from 2.74 to 13.38 dSm⁻¹. Similarly, under the Si rate of 6.3 mg Si/10 plants, it significantly decreased by 27% when salinity concentration increased from 2.74 to 13.38 dSm⁻¹. Similar to our results, Tuna et al. (2008) found a decrease in wheat biomass of 39 and 54% in two wheat cultivars when exposed to salinity stress. On the other hand, within each salinity concentration, applied Si alleviated salinity stress and increased wheat biomass and grain yield. For example, under salinity concentration of 2.74 dSm⁻¹, biomass and grain yield significantly increased from 2.21 to 3.06 and from 0.88 to 1.42 g plant⁻¹ under Si rates of 0.0 and 6.3 mg Si/10 plants, respectively (Figures 1 and 2). Similarly, under salinity stress of 13.38 dSm⁻¹, biomass and grain yield significantly increased from 1.39 to 2.09 and from 0.62 to 0.83 g plant⁻¹ under Si rates of 0.0 and 6.3 mg Si/10

plants, respectively. Liang (1999) found an increase in biomass and grain yield when applied Si to barley (*Hordeum vulgare* L.) plants grown under salinity stress. Also, Ahmad (2014) found an increase in biomass and grain yield in wheat grown under salt stress and fertilized by K-silicate. Generally, the highest biomass and grain yield were observed under the lowest salinity concentration of 2.74 dSm⁻¹ and under Si rate of 6.3 mg Si/10 plants, but the lowest biomass and grain yield were observed under the highest salinity concentration of 13.38 dSm⁻¹ with no Si application (0.0 mg Si/10 plants). It is important to notice that applying Si to soils with higher salt concentration could produce higher biomass and grain yield compared to the soils with no salt stress. For example, applying Si of 6.3 mg Si/10 plants to the soil with salinity concentration of 10.74 dSm⁻¹, produced

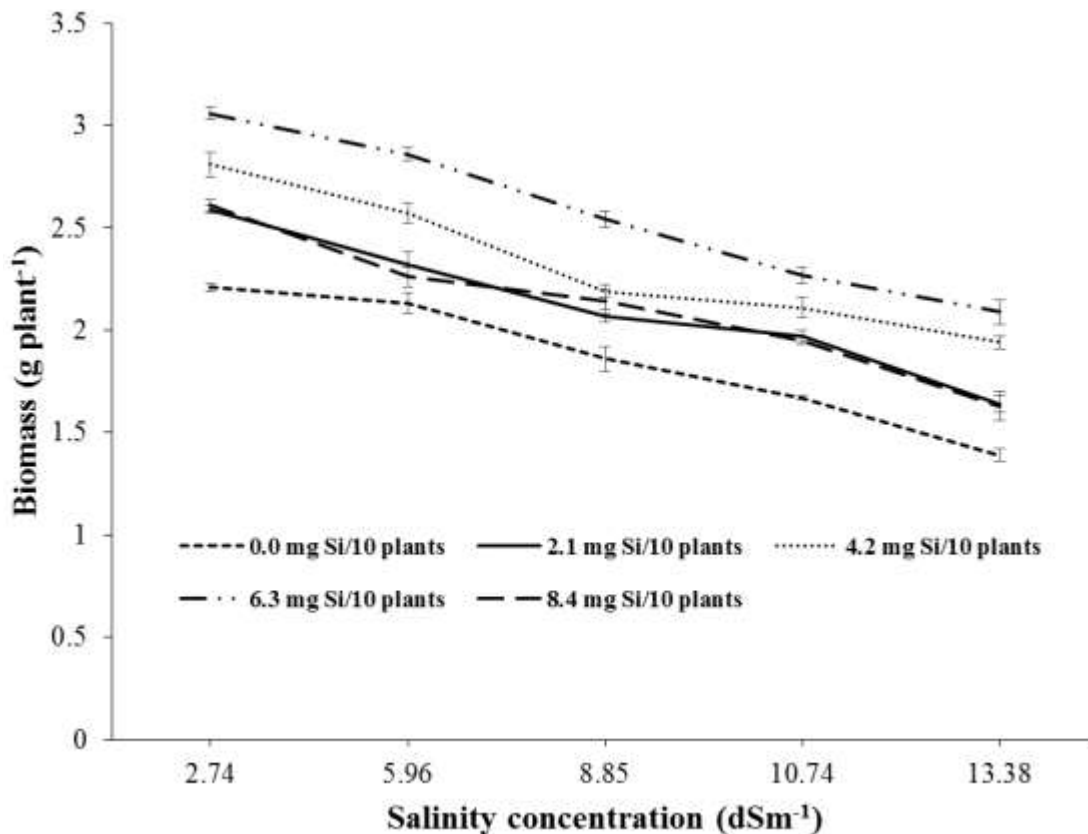


Figure 1. Impact of Si application on wheat biomass yield under different levels of salinity stress. Error bars represent standard error.

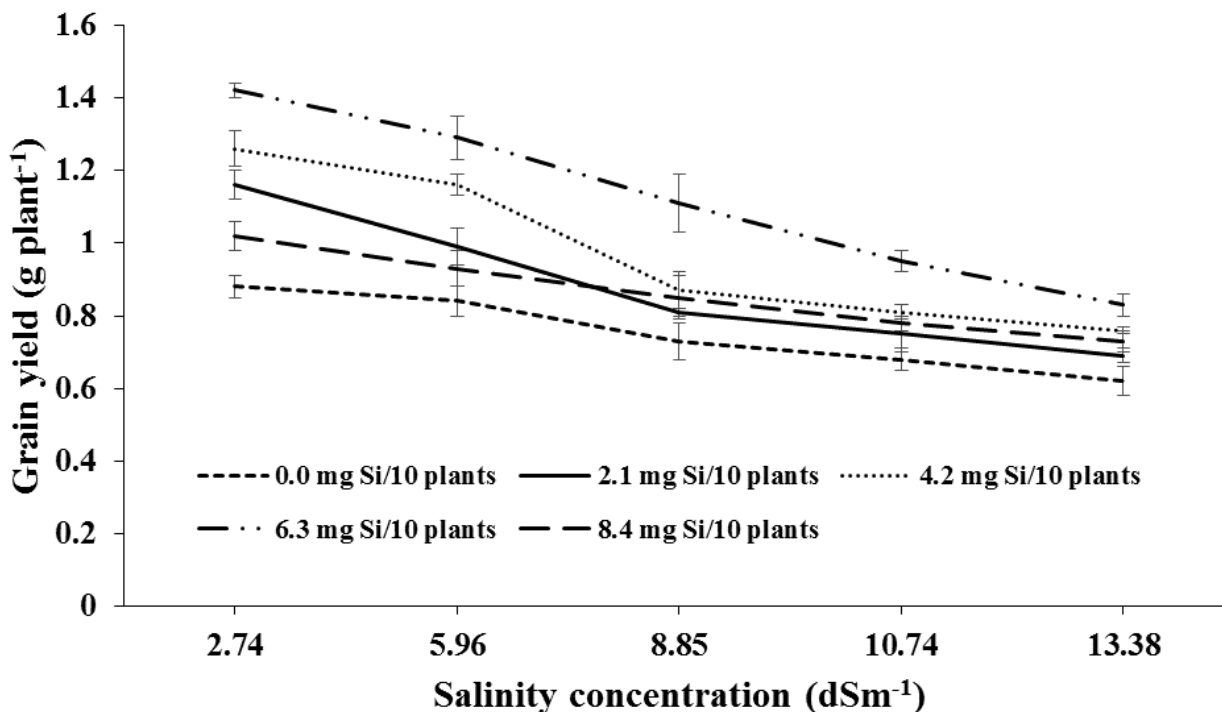


Figure 2. Impact of Si application on wheat's grain yield under salinity stress conditions. Error bars represent standard error.

Table 3. Nutrients concentrations in wheat straw under K-silicate fertilizer and salt stress conditions. Within each level of Si we compare least squares means corresponding to the salinity levels. Significant differences are indicated using different lower case letters down the column. Within each level of salinity we compare least squares means corresponding to the Si levels. Significant differences are indicated using different upper case letters across the row. Significance is determined at a 0.05 level where p-values are adjusted for multiple comparisons.

Nutrient	Salinity	Silicon application rate (mg Si/ 10 plants)				
	(dSm ⁻¹)	0.0	2.1	4.2	6.3	8.4
N (g kg ⁻¹)	2.74	13.1 ^{aD}	14.2 ^{aC}	15.5 ^{aB}	17.7 ^{aA}	13.3 ^{aD}
	5.96	12.3 ^{bD}	13.8 ^{aC}	14.5 ^{bBC}	16.3 ^{bA}	12.8 ^{abD}
	8.85	11.7 ^{bD}	12.9 ^{bC}	13.7 ^{cB}	15.3 ^{cA}	12.1 ^{cdD}
	10.74	10.3 ^{cD}	12.0 ^{cC}	13.4 ^{cB}	14.4 ^{dA}	11.5 ^{dC}
	13.38	08.5 ^{dD}	09.5 ^{dC}	11.9 ^{dB}	12.9 ^{eA}	09.5 ^{eC}
P (g kg ⁻¹)	2.74	2.7 ^{aD}	3.1 ^{aC}	3.5 ^{aB}	4.1 ^{aA}	3.1 ^{aC}
	5.96	2.4 ^{bD}	2.6 ^{bBCD}	2.8 ^{bB}	3.2 ^{bA}	2.6 ^{bBCD}
	8.85	2.0 ^{cD}	2.5 ^{bC}	2.7 ^{bABC}	2.9 ^{cdA}	2.5 ^{bC}
	10.74	1.7 ^{dD}	2.0 ^{cC}	2.4 ^{cdB}	2.7 ^{dA}	2.1 ^{cBC}
	13.38	1.1 ^{eE}	1.6 ^{dD}	2.1 ^{dB}	2.4 ^{eA}	1.6 ^{dCD}
K (g kg ⁻¹)	2.74	15.6 ^{aD}	16.7 ^{aC}	18.0 ^{aB}	20.2 ^{aA}	15.8 ^{aD}
	5.96	14.8 ^{bD}	16.3 ^{aC}	17.1 ^{bBC}	18.8 ^{bA}	15.3 ^{abD}
	8.85	14.4 ^{bD}	15.4 ^{bC}	16.2 ^{cB}	17.8 ^{cA}	14.5 ^{cdD}
	10.74	12.8 ^{cD}	14.5 ^{cC}	15.9 ^{cB}	16.8 ^{dA}	13.9 ^{dC}
	13.38	11.1 ^{dD}	12.1 ^{dC}	14.4 ^{dB}	15.4 ^{eA}	12.1 ^{eC}
N uptake (mg plant ⁻¹)	2.74	17.4 ^{aE}	20.4 ^{aC}	24.1 ^{aB}	29.1 ^{aA}	18.9 ^{aC}
	5.96	15.7 ^{bD}	18.3 ^{bC}	20.5 ^{bB}	24.8 ^{bA}	17.7 ^{abC}
	8.85	13.1 ^{cD}	16.2 ^{cC}	18.1 ^{cdB}	22.1 ^{cA}	15.5 ^{cC}
	10.74	10.2 ^{dE}	14.6 ^{dCD}	17.3 ^{dB}	19.3 ^{dA}	13.7 ^{dD}
	13.38	6.4 ^{eD}	9.11 ^{eC}	14.1 ^{eB}	16.2 ^{eA}	9.10 ^{eC}
P uptake (mg plant ⁻¹)	2.74	3.56 ^{aD}	4.44 ^{aC}	5.47 ^{aB}	6.72 ^{aA}	4.27 ^{aC}
	5.96	3.08 ^{bD}	3.49 ^{bcC}	3.99 ^{bB}	4.80 ^{bA}	3.54 ^{bcC}
	8.85	2.36 ^{cD}	3.24 ^{cC}	3.53 ^{cBC}	4.17 ^{cA}	3.22 ^{cC}
	10.74	1.68 ^{dD}	2.43 ^{bC}	3.07 ^{dB}	3.59 ^{dA}	2.59 ^{dC}
	13.38	0.81 ^{eD}	1.49 ^{eC}	2.52 ^{eB}	3.03 ^{eA}	1.68 ^{eC}
K uptake (mg plant ⁻¹)	2.74	20.8 ^{aE}	23.9 ^{aC}	27.9 ^{aB}	33.1 ^{aA}	22.4 ^{aD}
	5.96	18.9 ^{bD}	21.6 ^{bC}	24.1 ^{bB}	28.6 ^{bA}	21.1 ^{abC}
	8.85	15.9 ^{cD}	19.4 ^{cC}	21.4 ^{cdB}	25.6 ^{cA}	18.7 ^{cC}
	10.74	12.7 ^{dD}	17.6 ^{dC}	20.5 ^{dB}	22.7 ^{dA}	16.6 ^{dC}
	13.38	8.6 ^{eD}	11.5 ^{eC}	16.9 ^{eB}	19.4 ^{eA}	11.4 ^{eC}

a higher biomass of 2.27 g plant⁻¹ compared to that of 2.13 g plant⁻¹ produced from the soil with no salt stress (2.74 dSm⁻¹) that did not receive Si application (0.0 mg Si/10 plants) (Figures 1 and 2).

Nutrient concentrations and their uptake in wheat straw

Salinity stress precluded plants to take up nutrients (e.g.,

N, P, and K), which was reflected in decreasing their concentrations in plants' shoots (mixture of stems and leaves), grains, and their uptake from soils. Results in Table 3 showed significant decrease in N, P, and K concentrations in wheat's straw under each individual Si application while increasing salinity concentration. For example, concentrations of N, P, and K, under the Si rate of 0.0 mg Si/10 plants, significantly decreased as salinity concentration increased from 2.74 to 13.38 dSm⁻¹. Similarly, under the Si rate of 4.2 mg Si/10 plants, N, P,

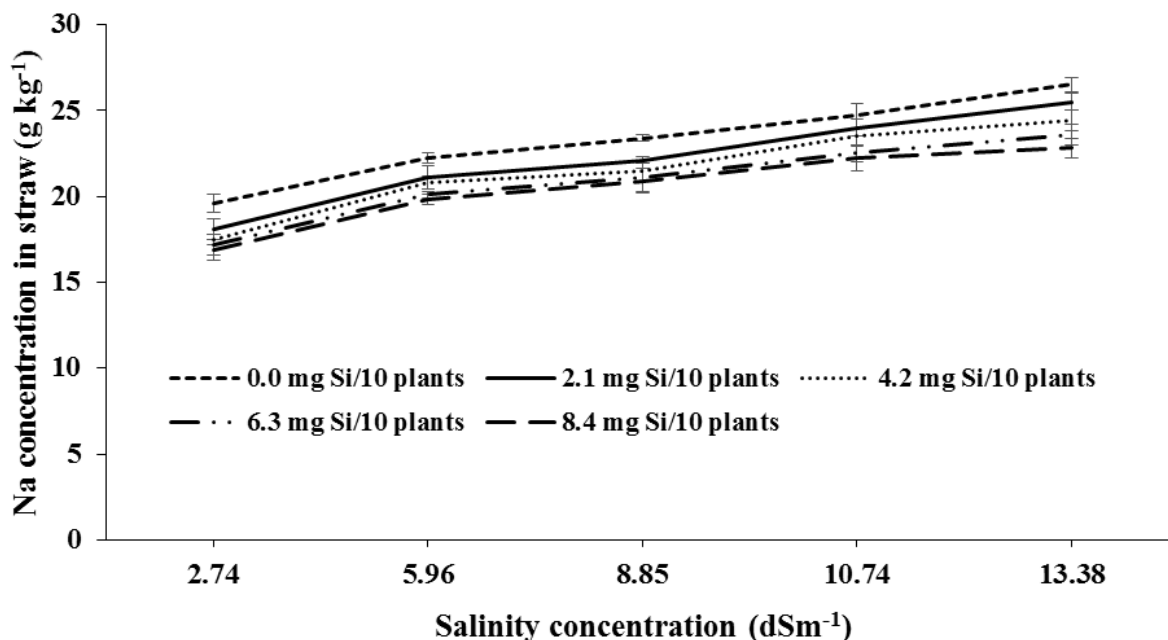


Figure 3. Impact of Si application on Na concentration in wheat's straw under salinity stress. Error bars represent standard error.

and K concentrations in straw significantly decreased when salinity concentration increased from 2.74 to 13.38 dSm⁻¹ (Table 3). However, supplying Si to wheat ameliorated salinity stress and increased the concentrations of these nutrients (N, P, and K) in straw within each individual salinity concentration. For example, within salinity concentration of 2.74 dSm⁻¹, concentrations of N, P, and K significantly increased when Si rate increased from 0.0 to 6.3 mg Si/10 plants (Table 3). Similarly, under salinity concentration of 8.85 dSm⁻¹, N, P, and K concentrations significantly increased when Si rate increased from 0.0 to 6.3 mg Si/10 plants. In their review article, Rizwan et al. (2015) reported several results of increasing the concentrations of N, P, and K in wheat straw when wheat was fertilized by Si.

Similar to the trend of N, P, and K concentrations in wheat straw, their total uptake significantly decreased within each individual Si rate with increasing salinity concentration. For example, the uptake of N, P, and K in wheat straw, within the Si rates of 0.0 and 8.4 mg Si/10 plants, significantly decreased as salinity concentrations increased from 2.74 to 13.38 dSm⁻¹ (Table 3). Results of Table 3, however, revealed an increase in the uptake of N, P, and K when supplying Si to all salinity concentrations. For example, N, P, and K uptake in wheat straw, within salinity concentrations of 2.74 and 10.74 dSm⁻¹, significantly increased when Si rate increased from 0.0 to 6.3 mg Si/10 plants.

In saline soils that have high concentration of Na, plants take up Na in higher amounts than their needs. In our work, Na concentration in wheat straw increased with

increasing salinity concentrations. Within the Si rates of 0.0 and 8.4 mg Si/10 plants, Na concentration significantly increased in wheat straw when salinity concentration increased from 2.74 to 13.38 dSm⁻¹ (Figure 3). Similar to our results, Saqib et al. (2008) in their work on alleviating salinity stress on wheat by supplying Si found an increase in Na concentration in wheat straw with increasing salinity concentration. However, applied Si resulted in declining Na concentration in straw of wheat grown under salinity stress. For example, within salinity concentrations of 2.74 and 13.38 dSm⁻¹, Na concentration in straw significantly decreased when the applied Si rate increased from 0.0 to 8.4 mg Si/10 plants (Figure 3). Under salinity stress, deposition of Si in plant roots precluded the bypass of Na⁺, which resulted in decreasing Na⁺ concentration in plant tissues (Zhang and Shi, 2013). Furthermore, an x-ray analysis of rice (*Oryza sativa* L.) grown under salinity stress conditions showed that Si deposition in the roots reduced Na⁺ uptake and transfer via the apoplastic pathway (Gong et al., 2006).

Silicon concentration in wheat straw decreased with increasing salinity stress (Figure 4). Within the Si rates of 0.0 and 8.4 mg Si/10 plants, Si concentration in straw significantly decreased when salinity concentration increased from 2.74 to 13.38 dSm⁻¹. However, applied Si to wheat ameliorated salinity stress and increased Si concentration in wheat straw. For example, within salinity concentrations of 2.74 and 13.38 dSm⁻¹, Si concentration significantly increased when applied Si rate increased from 0.0 to 8.4 mg Si/10 plants (Figure 4). Similarly, Tuna et al. (2008), and Saqib et al. (2008) found a decrease in

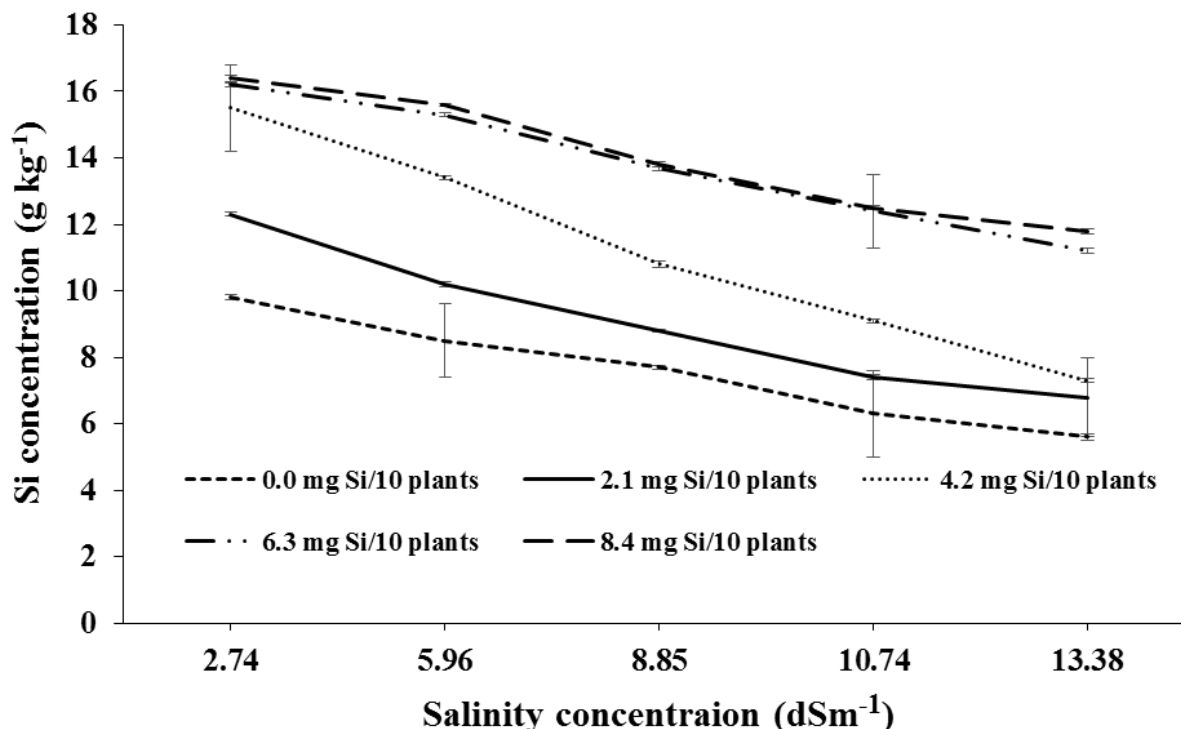


Figure 4. Impact of Si application on Si concentration in wheat's straw under salinity stress. Error bars represent standard error.

Si concentration with increasing salinity and an increase in its concentration with increasing the applied Si rates.

Nutrient concentrations and their uptake in wheat grains

Concentrations of N, P, K, and their uptake in wheat grains were also affected by salinity and Si application. Data in Table 4 revealed significant decrease in N, P, and K concentrations and their uptake under each individual Si rate by increasing salinity concentration. For example, N, P, and K concentrations under the Si rate of 0.0 mg Si/10 plants, significantly decreased when salinity concentration increased from 2.74 to 13.38 dSm⁻¹ (Table 4). Under the same previous Si rate, the uptake of N, P, and K significantly decreased when salinity concentration increased from 2.74 to 13.38 dSm⁻¹. Similarly, the three nutrients N, P, and K concentrations and their uptake under the applied Si rate of 6.3 mg Si/10 plants, significantly decreased when salinity concentration increased from 2.74 to 13.38 dSm⁻¹. However, applying Si to wheat increased the concentrations of N, P, K, and their uptake in wheat grains under all of the salinity concentrations. Results in Table 4 showed that concentrations of N, P, K, and their uptake under salinity concentration of 2.74 dSm⁻¹, significantly increased when the applied Si rate increased from 0.0 to 6.3 mg Si/10

plants. Similarly, Rizwan et al. (2015) found an increase in N, P, and K concentrations in the grains of wheat grown under salt stress when applying Si. Under salinity concentration of 8.85 dSm⁻¹, N, P, and K concentrations significantly increased when applied Si rate increased from 0.0 to 6.3 mg Si/10 plants (Table 4). Similarly, under the aforementioned salinity concentration, the uptake of N, P, and K, in wheat grains, significantly increased when the applied Si rate increased from 0.0 to 6.3 mg Si/10 plants.

Conclusions

Salinity stress decreased wheat growth, photosynthetic pigments content, nutrient (N, P, and K) concentrations and their uptake, biomass, and grain yield. In contrast, Na and proline concentrations in wheat increased with increasing salinity concentrations. Applying Si to wheat ameliorated salinity stress and increased biomass, grain yield, nutrient concentrations (N, P, and K) and their uptake, and decreased Na and proline concentrations. Further, Si application increased Si concentration in wheat straw and it was proportional to the increase in applied Si. Generally, the best results of all of the growth characteristics and nutrient concentrations and their uptakes were obtained from the Si rate of 6.3 mg Si/10 plants under salinity level of 2.74 dSm⁻¹. Conversely, the

Table 4. Nutrients concentrations in wheat grains under K-silicate fertilizer and salt stress conditions. Within each level of Si we compare least squares means corresponding to the salinity levels. Significant differences are indicated using different lower case letters down the column. Within each level of salinity we compare least squares means corresponding to the Si levels. Significant differences are indicated using different upper case letters across the row. Significance is determined at a 0.05 level where p-values are adjusted for multiple comparisons.

Nutrient	Salinity	Silicon application rate (mg Si/ 10 plants)				
	(dSm ⁻¹)	0.0	2.1	4.2	6.3	8.4
N (g kg ⁻¹)	2.74	13.6 ^{aD}	14.7 ^{aC}	16.1 ^{aB}	18.2 ^{aA}	13.8 ^{aD}
	5.96	12.8 ^{bD}	14.3 ^{aC}	15.2 ^{bBC}	16.8 ^{bA}	13.3 ^{abD}
	8.85	12.3 ^{bD}	13.3 ^{bC}	15.2 ^{bB}	15.8 ^{cA}	12.5 ^{cdD}
	10.74	10.8 ^{cD}	12.4 ^{cC}	13.8 ^{cB}	14.9 ^{dA}	11.9 ^{dC}
	13.38	08.9 ^{dD}	10.1 ^{dC}	12.4 ^{dB}	13.4 ^{eA}	10.1 ^{eC}
P (g kg ⁻¹)	2.74	3.7 ^{aD}	4.1 ^{aC}	4.5 ^{aB}	5.1 ^{aA}	4.2 ^{aC}
	5.96	3.4 ^{bD}	3.6 ^{bCD}	3.8 ^{bBC}	4.2 ^{bA}	3.7 ^{bCD}
	8.85	3.1 ^{cD}	3.5 ^{bBC}	3.8 ^{bABC}	3.9 ^{cdA}	3.5 ^{bC}
	10.74	2.6 ^{dD}	3.0 ^{cC}	3.4 ^{cdBC}	3.6 ^{dA}	3.1 ^{cC}
	13.38	2.0 ^{eE}	2.5 ^{dD}	3.0 ^{dB}	3.4 ^{eA}	2.7 ^{dCD}
K (g kg ⁻¹)	2.74	11.3 ^{aD}	12.4 ^{aC}	13.7 ^{aB}	15.9 ^{aA}	11.5 ^{aD}
	5.96	10.5 ^{bD}	12.0 ^{aC}	12.5 ^{bcBC}	14.5 ^{bA}	11.0 ^{abD}
	8.85	09.8 ^{bD}	11.1 ^{bC}	12.6 ^{bcB}	13.5 ^{cA}	10.3 ^{cdD}
	10.74	08.5 ^{cD}	10.2 ^{cC}	11.6 ^{cB}	12.6 ^{dA}	09.6 ^{dC}
	13.38	06.7 ^{dD}	07.7 ^{dC}	10.1 ^{dB}	11.1 ^{eA}	07.7 ^{eC}
N uptake (mg pl ^a nt ⁻¹)	2.74	11.9 ^{aD}	17.1 ^{aC}	20.3 ^{aB}	25.7 ^{aA}	16.3 ^{aC}
	5.96	10.7 ^{abD}	14.3 ^{bC}	17.4 ^{bB}	21.8 ^{bA}	11.7 ^{bcD}
	8.85	8.93 ^{cdD}	10.7 ^{cdBC}	12.4 ^{cdB}	17.5 ^{cdA}	10.6 ^{cdC}
	10.74	7.48 ^{dD}	9.4 ^{dC}	11.2 ^{dB}	14.3 ^{dA}	9.10 ^{dC}
	13.38	5.52 ^{eD}	6.9 ^{eCD}	9.40 ^{eB}	11.2 ^{eA}	6.81 ^{eCD}
P uptake (mg pl ^a nt ⁻¹)	2.74	3.23 ^{aD}	4.76 ^{aC}	5.72 ^{aB}	7.23 ^{aA}	4.73 ^{aC}
	5.96	2.86 ^{abD}	3.62 ^{bC}	4.43 ^{bB}	5.40 ^{bA}	3.13 ^{bD}
	8.85	2.28 ^{cdD}	2.87 ^{cC}	4.43 ^{bABC}	4.31 ^{cA}	2.96 ^{bC}
	10.74	1.86 ^{dD}	2.25 ^{dCD}	2.72 ^{deB}	3.52 ^{dA}	2.41 ^{cdBC}
	13.38	1.25 ^{eD}	1.76 ^{eC}	2.38 ^{eB}	2.82 ^{eA}	1.88 ^{dC}
K uptake (mg pl ^a nt ⁻¹)	2.74	9.91 ^{aE}	14.4 ^{aCD}	17.4 ^{aB}	22.5 ^{aA}	13.6 ^{aD}
	5.96	8.82 ^{abD}	12.1 ^{bC}	14.7 ^{bB}	18.8 ^{bA}	9.70 ^{bcD}
	8.85	7.29 ^{cdD}	8.90 ^{cdC}	11.7 ^{cdB}	14.9 ^{cA}	8.62 ^{cdCD}
	10.74	5.89 ^{dD}	7.72 ^{dC}	9.30 ^{dB}	12.1 ^{dA}	7.41 ^{dC}
	13.38	4.11 ^{eD}	5.29 ^{eCD}	7.71 ^{eB}	9.20 ^{eA}	5.33 ^{eCD}

lowest values were observed under salinity concentration of 13.38 dSm⁻¹ without Si application (0.0 mg Si/10 plants).

Conflict of Interests

The authors have not declared any conflict of interests.

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Full Length Research Paper

Evaluation of soil contamination in the surroundings of Kerala Minerals and Metals Limited (KMML) industrial area in Kollam District, Kerala, South India

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Toxic trace metals concentration in soil exerts a decisive impact on soil quality in an industrial area. In recent days, industrialization is growing at very faster rate than any other activities. Due to industrialization, the pollution load for water, air and soil is increasing day by day. Metal pollution in soil possess a serious threat to the human health and safety of agricultural production. An attempt is made here to study soil contamination due to industrial effluents and air pollutants in the surroundings of KMML (Kerala Minerals and Metals Ltd.) industrial area in Chavara, Kerala. To find out the soil pollution from the solid and liquid wastes produced due to the manufacturing process of titanium dioxide in the KMML industry, a detailed analysis was conducted on the physico-chemical characteristics of soil samples collected from the surrounding areas. The study on the physical and chemical characteristics of soil in the selected stations of KMML industrial area shows that soils are acidic in nature and the concentration of nutrients like organic carbon, organic matter, nitrogen, total phosphorus, sodium in the study stations near the industry were less than that of the control soils. The present study revealed that the heavy metal concentrations in all the study stations were high compared to the control station. The study shows that the soils in the surroundings of industrial area are contaminated with toxic elements than its normal distribution.

Key words: Soil pollution, heavy metals, industrial area, Kerala minerals and metals limited (KMML)

INTRODUCTION

Soil is an essential component of terrestrial ecosystem because the growth of plants and biogeochemical cycling of nutrients depends up on it. Soil pollution can also be a hazard to human health when potentially toxic substances move through the food chain or reach ground

water used for drinking water supplies. In comparison with air and water, the soil is more variable and complex in composition and its function as a sink for pollutants, a filter which retards the passage of chemicals to the ground water and a bioreactor in which many organic

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pollutants can be decomposed.

Environmental pollution caused by heavy metals discharged from industrial area will end up in one of the environmental segments such as air, water, soil and vegetation mainly through pathways of solid wastes, wastewater and waste gases (Haiyan and Stuanes, 2003). Although the soil pollution usually may not be as apparent as that of the air or water, since the late 20th century, the influence of urbanization on the accumulation of heavy metals in soil has aroused more and more concern from scientists all over the world (Govil et al., 2001; Romic and Romic, 2003). The deterioration of the environment quality from heavy metal contamination raising serious concerns existing as non-degradable materials, in long term can accumulate in toxic level at higher concentration and their biotransformation in food chain. A study was carried out by Elbagermi et al. (2013) on the assessment of heavy metals (Pb, Fe, Zn, Ni, Cd, Cr, and Cu) in soil and roadside dust around Misurata City Centre and industrial areas/roads in Libya during the period of October 2011 - May 2012. The study showed overall means metal concentration for main streets was significantly higher ($P < 0.05$) than for other small streets.

Seenivasan et al. (2008) reported that industrial growth is causing an enormous environmental pollution. They also pointed out that industrial activities result in the pollution of soil; as polluted soil can alter plant growth and quality, and the effects are often destructive. Pollution of the environment with heavy metals has increased dramatically since the onset of the industrial revolution. The term 'heavy metal' refers to any metallic chemical element that has a relatively high density and is toxic or poisonous at low concentrations. To a small extent they enter our bodies via food, drinking water and air. Soil pollution by heavy metals, such as cadmium, lead, chromium, copper etc. is a problem of concern. Although heavy metals are naturally present in soil, contamination comes from different sources, and among them heavy traffic is an important source in most of the roadside soils. Heavy metals occur naturally at low concentrations in soils. However, they are considered as soil contaminants due to their widespread occurrence, acute and chronic toxicity. Heavy metals get accumulated in soils and plants causing negative influence on photosynthesis, gaseous exchange, and nutrient absorption of plants resulting reductions in plant growth, dry matter accumulation and yield (Devkota and Schmidt, 2000). In small concentrations, the traces of the heavy metals in plants or animals are not toxic. Lead, cadmium and mercury are exceptions; they are toxic even in very low concentrations (Gandhimathi and Meenambal, 2012).

A study was conducted by Sharma and Raju (2013) to know the correlation between soil properties with heavy metal concentrations by cluster analysis in industrially polluted soil in Mysore, Karnataka state in India. The

relationship between different physico-chemical properties and heavy metal concentrations were analyzed by Pearson's correlation coefficient. The study concluded that, the heavy metal contents are introduced by so many sources and human activities which include industrial operations. Atmospheric deposition of contaminated dust and industrial discharge may be the prime cause of heavy metals contamination in soil. The major objectives of present study include the evaluation of physical and chemical characteristics of the soils in KMML industrial area, and to assess the heavy metal concentration in the soils of KMML industrial area.

MATERIALS AND METHODS

Study Area

The study was conducted in the surroundings of Kerala Minerals and Metals Ltd. (KMML) industry, situated at Chavara in Kollam District, Kerala during summer season (March-April 2013). KMML is located at 8°59' 54.2" N latitude and 76°32' 07.5" E longitude near the National Highway-47. The total area of KMML industry is about 210 acres. The location map of study area and study stations are given in the Figure 1. KMML is a leading Titanium dioxide manufacturing industry in India. Through the chloride route, KMML produces rutile grade Titanium dioxide pigment. Indian Rare Earths Ltd (IRE) is situated in the south western direction, 3 km away from the KMML. The IRE mines and separates the mineral sand into ilmenite, rutile, zircon etc. and are used as the raw materials for the manufacture of titanium dioxide pigment and titanium dioxide sponge metal in the KMML industry. The National Highway-47 (now NH 966) passes adjacent to the KMML industry in Chavara area. The Arabian Sea is in the western side of KMML and the other sides are residential areas with vegetation.

Sampling stations

Extensive field survey of the entire study area including Chavara block and Oachira block in Kollam District was conducted and the sampling stations were selected. The soil type of study area is sandy loam. Soil samples were collected from eleven different stations situated in the northern, eastern, southern and west endirection of the KMML factory. Four sampling stations (S1, S4, S7 and S10) were selected within ½ km from the factory in the northern, eastern, southern, and western directions respectively. The second, fifth and eighth sampling sites (S2, S5, and S8) are located 1½ km away from the factory in the three different directions. The third, sixth and ninth (S3, S6 and S9) were located 3 km away from the factory in the northern, eastern and southern directions respectively. The station, S11 is the control station, 14 km away, in the north western side of the factory, and is in a benign environment. The description of the sampling stations are given in Table 1.

Sample collection

Soil samples were collected during the summer season, in the month of April 2013. Surface soil samples were collected from the study stations at a depth of about 0 to 15 cm using a shovel by Cone and Quarter method (Allen, 1981). Soil samples were collected in thick quality polythene bags and immediately brought to

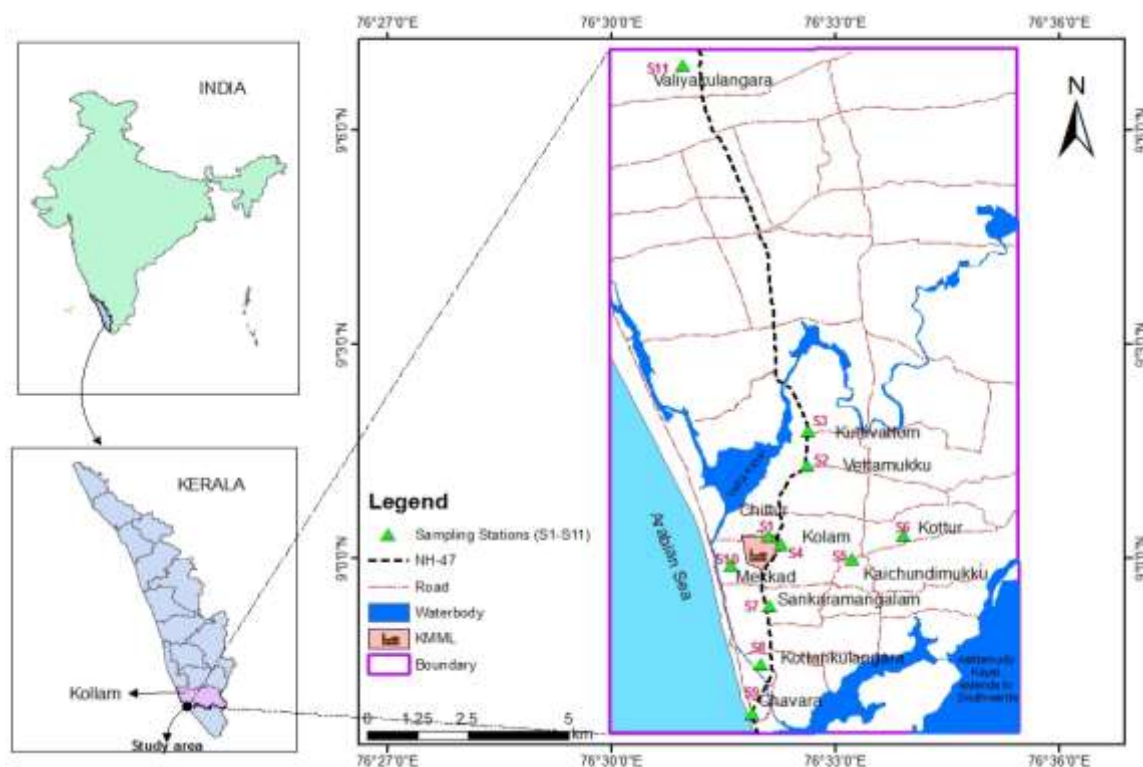


Figure 1. Location map of study area showing sampling stations.

Table 1. Description of stations selected in the study area.

Station	Location	Description of Station
Chittur	S1	Half kilometre away, in the northern side of the factory
Vettamukku	S2	One and half kilometre away, in the north-eastern side of the factory
Kuttivattom	S3	Three kilometre away, in the northern side of the factory and near to National Highway
Kolam	S4	Half kilometre away, in the eastern side of the factory
Kaichoondimukku	S5	One and half kilometre away, in the eastern side of the factory
Kottur	S6	Three kilometre away, in the eastern side of the factory
Sankaramangalam	S7	Half kilometre away, in the southern side of the factory and near to National Highway
Kottamkulangara	S8	One and half kilometre away, in the south western side of the factory
Chavara	S9	Three kilometre away, in the southern side of the factory and near to National Highway.
Mekkadu	S10	Half kilometre away, in the western side of the factory, near the effluent discharge area.
Valiyakulangara	S11 (Control)	Fourteen kilometre away in the north western direction of the factory

the laboratory for further analysis of physico-chemical parameters and heavy metals.

Soil analysis

The various physico-chemical parameters of soil samples collected were analysed following the procedures described by Trivedy and Goel (1986), Gupta (1999) and Saxena (1998). Soil pH was determined by potentiometric method using a digital pH meter.

Electrical conductivity was determined by conductometric method using a conductivity meter. The soil organic carbon (OC) was determined by wet chemical oxidation method of Walkley and Black (1934). Total nitrogen content in the soil sample was determined by Kjeldhal distillation method. The chloride content in the soil samples were determined by argentometric titration. Concentration of total phosphorus in the soil samples was determined after acid digestion by spectrophotometric method. The concentration of potassium and sodium in soil extract were determined using a Flame Photometer (Elico CL-360), based on the procedure suggested by Gupta

Table 2. Physico-chemical characteristics of soil samples.

Station	pH	Moisture content (%)	Bulk density (g/cm ³)	Specific gravity (g/cm ³)	EC (mS/cm)	Organic Carbon (%)	Organic Matter (%)	Nitrogen (%)	Total Phosphorous (mg/kg)	Potassium (mg/kg)	Sodium (mg/kg)	Chloride (mg/kg)	Sulphate (mg/kg)	C/N ratio
S1	5.26	5.53	1.28	1.38	0.053	0.039	0.067	0.042	56	30	1780	781	327.6	0.9285
S2	6.18	3.96	1.34	1.43	0.052	0.199	0.343	0.056	59	70	960	497	279.3	3.5535
S3	6.27	4.38	1.54	1.58	0.108	0.596	1.027	0.064	76	130	1470	481.5	213.6	9.3125
S4	5.59	1.91	1.42	1.53	0.082	0.071	0.122	0.021	62	230	1560	532.5	195.3	3.3809
S5	6.02	2.16	1.49	1.57	0.073	0.181	0.312	0.0266	100	370	1700	487	136.6	6.8045
S6	6.13	5.11	1.4	1.51	0.084	1.199	2.067	0.0566	221	1320	5540	471.5	91.8	21.1837
S7	5.71	3.61	1.57	1.6	0.181	0.125	0.216	0.0118	59	360	2850	745.5	83.2	10.5932
S8	6.71	4.03	1.32	1.33	0.041	0.149	0.257	0.0126	168	460	3440	639	58.2	11.8253
S9	7.29	2.45	1.55	1.61	0.194	0.099	0.17	0.046	207	2630	6870	923	82.4	2.1521
S10	4.97	8.47	1.31	1.37	0.074	0.093	0.16	0.0112	47	60	3340	938	359.8	8.3035
S11	6.93	8.68	1.34	1.38	0.04	1.256	2.165	0.0652	369	490	8050	461.5	18.2	19.2638
Average	5.96	4.161	1.422	1.491	0.0982	0.2751	0.4741	0.03754	105.5	566	2951	649.6	182.78	8.8455
Minimum	4.97	1.91	1.28	1.33	0.04	0.039	0.067	0.0112	47	30	960	461.5	18.2	0.9285
Maximum	7.29	8.68	1.57	1.61	0.194	1.256	2.165	0.0652	369	2630	8050	938	359.8	21.1837

(1999). The soil samples were subjected to diacid digestion (Gupta 1999; Alloway, 1995) and the heavy metal content (Pb, Zn, Cd, Cr, Mn, Fe) in the samples were estimated using an Inductively Coupled Plasma Atomic Emission Spectrometer (model IRIS intrepid II XSP).

RESULTS AND DISCUSSION

Physical characteristics of soil

The results of various physical characteristics of soil moisture, bulk density, and specific gravity of the soil samples analysed in the different samplings stations are given in Table 2.

Soil moisture

The moisture content in the soil samples ranged from 1.91% (S4) to 8.68% (S11), with an average

of 4.161% during the study period. Moisture content in the soils samples recorded maximum value in station 11 (control station) followed by S10 (Mekkadu) that is close to effluent discharge point from the KMML industry. The least value was recorded at station 4 (Kolam).

Bulk density

The result of bulk density in the soil samples ranged from 1.28 g/cm³ (S1) to 1.57 g/cm³ with an average of 1.422 g/cm³ (S7) during the study period. The bulk density in the sample soils recorded maximum values present in station 7. The least value reported at station 1 near the northern side of the factory. Bulk density in the soil samples showed increasing values with respect to that of the control station during the study period.

Specific gravity

The results specific gravity in the soil samples ranged from 1.33 g/cm³ (S8) to 1.61 g/cm³ (S9) with an average of 1.491 g/cm³ during the study period. Specific gravity of the control station (S11) was 1.38 g/cm³ during the study period. The specific gravity in the sample soils recorded maximum value at station 9 and minimum at station 8. Specific gravity in the soil samples showed varying values. The specific gravity of soil samples in Station-8 and Station-10 in the study area was found less than that of the control station during the study period.

Chemical characteristics of soil

The results of various chemical characteristics like pH, electrical conductivity, chlorides, sulphate,

organic carbon, organic matter, total nitrogen, total phosphorus, sodium, potassium and C/N ratio of the soil samples analysed in the different samplings stations are given in Table 2.

Soil pH

The results of pH in the soil samples ranged from 4.97 to 7.29. The lowest pH value was recorded at S10 that is 4.97, which shows that the soil nearest to the industry is highly acidic. At the control station (Station-11), the soil pH is near neutral (6.93) during the study period. The study show that, 90% of the selected stations of the study area are with acidic pH.

There is noticeable increase in pH in the stations S3, S6 and S9 which show that there is a reduction in acidity as the distance from the factory increases. In the southern side, alkaline pH (7.29) was noticed in the station 9, which is 3 km away from the KMML industry and is near to the Arabian Sea.

Electrical conductivity

Electrical conductivity (EC) is a measure of ions present in water. The conductivity of a solution increases with the increase in amount of ions. In the agricultural field electrical conductivity plays an important role, because of salinity aspect.

The results of electrical conductivity in the soil samples ranged from 0.04 mS/cm to 0.194 mS/cm, with an average of 0.0982 mS/cm during the study period, the lowest value was noted at control station and highest value was noticed at S9, near to Arabian Sea. The electrical conductivity of soils at the sampling stations in National Highway-47 (S3, S7, and S9) showed higher values compared to other stations during the study period. A similar study conducted by Sharma and Raju (2013) found that the presence of large amount of ionic substance and soluble salts have resulted in increased value of EC in the industrial effluents treated soil samples in comparison to the others. The higher values of electrical conductivity is toxic to the plants.

Chlorides

The chloride content in the soil samples ranged from 461.5 mg/kg (S11) to 938 mg/kg (S10), with an average of 649.6 mg/kg during the study period. The chloride content in the sample soils recorded maximum values in station 10, in the western side of the factory, near the effluent discharge point. The lowest value (461.5 mg/kg) was recorded at control station. High chloride content was also noted in the soils of Stations 1, 7, and 9 of the

study area. Studies by Shaji et al. (2009) revealed that well waters in the surroundings of KMML industrial area was polluted. It exhibited high BOD, COD, TDS, total hardness, calcium, chloride, nitrate, phosphate and free CO₂ which are sourced to industrial wastes being discharged into the surrounding areas.

Sulphates

The sulphate content in the soil samples ranged from 18.20 mg/kg (S11) to 359.8 mg/kg (S10), with an average of 182.78 mg/kg. The sulphate content recorded maximum values in station 10 soils, near the western side of the factory and the least value was reported at control station (S11). The sulphate content in the soil samples in all the other stations showed high values with respect to that of the control station soils during the study period.

Organic Carbon and organic matter

Soil carbon is the last major pool of the carbon cycle. The carbon that is fixed by plant is transferred to the soil via dead plant matter including dead roots, leaves and fruiting bodies (Lal, 2008). Soil carbon is primarily composed of biomass and non-biomass carbon sources. Soil organic carbon improves the physical properties of soil. It increases cation exchange capacity and water holding capacity of sandy soil and it contributes to the structural stability of clays soil by helping to bind particles in to aggregates (Leeper and Uren, 1993). Organic carbon contents play a crucial role in sustaining soil fertility, crop production and environmental quality due to their effect on soil physical, chemical and biological properties, such as soil water retention, nutrient cycling, gas flux and plant root growth (Saiju and Kalisz, 1990).

The soil organic carbon content in the study area ranged from 0.039% (S1) to 1.265% (S11), with an average 0.2751%. Maximum organic carbon content was detected in the control station (S11) and minimum organic carbon was noted at station S1. Gradual increase in organic carbon in the study stations were observed, and is in the pattern S3 >S2 >S1 and S6 >S5>S4, which suggest distance from factory brings in increased organic carbon due to the increase in vegetation. The lowest value was noted in the southern side at station (S9), three kilometres away from the southern side of the factory and also the Arabian Sea is near this station. Soil organic matter of nutrients, cations and trace elements are important for plant growth. It prevents the nutrient leaching and if integral to the organic acids that make minerals available to plants. It also buffers the soil form strong changes in pH (Leu, 2007).

The soil organic matter of the study stations ranged

from 0.067% (S1) to 2.165% (S11) with an average 0.4741% during the study period. Organic matter less than 2% is not good for any plant growth. In the present study most of the soil sample contains less than 2% organic matter. Maximum organic matter content (2.165%) was detected in control station (S11) and minimum organic matter is noted at the station S1. Gradual increase in organic matter was recorded in northern and eastern sides with respect to increase in distance of study stations from the KMML industry, and is in the pattern $S3 > S2 > S1$ and $S6 > S5 > S4$. Minimum organic matter content was recorded at S1 and S4 which can be attributed to the low soil microbial activity due to the industrial wastes in this area. The soil productivity is determined primarily by organic matter. The organic matter provides food for micro organisms, takes part in chemical reactions such as ion exchange, governs the physical properties of soil and sometimes contributes to the weathering of mineral matter (De, 1987).

Total Nitrogen

The total nitrogen content in the soils varied from 0.0112% (S10) to 0.0652% (S11) with an average of 0.03754% during the study period. The concentration of total nitrogen in the soil samples showed the maximum values at control station and minimum at station 10 (Mekkadu).

C/N ratio

The results of C/N ratio in the soils varied from 0.9285% (S1) to 8.8455 (S6), with an average of 7.336% during the study period. C/N ratio in the soil samples showed the maximum values at station S6 and minimum at station 1, near KMML industry and is half kilometre away from northern side (S1) of the factory.

Total Phosphorus

The concentration of total phosphorus ranged from 47 mg/kg (S10) to 369 mg/kg (S11) with an average of 105.5 mg/kg during the study period. The highest value reported at control station and minimum showed in station 10 near the western side of the factory. A direct relationship could not be established between the sampling stations as there is much variability in phosphorous content.

Potassium

The potassium content in the soil samples varied from 30

mg/kg (S1) to 2630 mg/kg (S9) with an average of 566 mg/kg during the study period. The highest value noted at the station 9 and lowest result shown at station 1. Gradual increase in potassium level is noticed in three sides in relation with distance from the factory. The pattern can be noted as $S3 > S2 > S1$, $S6 > S5 > S4$, and $S9 > S8 > S7$. In the control station (S11) the soil potassium content is 490 mg/kg.

Potassium is not an integral part of any major plant component but it plays a key role in a vast array of physiological process vital to plant growth from protein synthesis to maintenance of plant-water balance. Potassium is a macro nutrient that is present in high concentration in soils, but is not bio-available because it is bound to other compounds (Greenwood, 1997).

Potassium deficiency occurs frequently in plants grown on sandy soils resulting in a number of symptoms including browning of leaves, curling of leaf tips and yellowing (chlorosis) of leaves, as well as reduced growth and fertility. Potassium is required at high level by growing plants. The present study revealed decrease in soil potassium content in the KMML industrial area. Potassium has a number of important functions within plants, including balancing the charges of cellular anions, enzyme activation, and control of stomata opening and closing. Potassium activates some enzymes and plays a key role in the water balance in plants and for carbohydrate transformation (William et al., 2008).

Sodium

Sodium content in the soil samples collected from the sampling stations during summer season of the study period varied from 960 mg/kg (S2) to 8050 mg/kg (S11), with an average value of 2951 mg/kg. The highest value was noted at station 11 (control station) and lowest value at station 2.

Heavy metal content in soils

The results of the concentration of lead, zinc, cadmium, chromium, manganese and iron in soils samples analysed in the different samplings stations are given in Table 3.

Lead

The species of lead vary considerably with soil type. It is mainly associated with clay minerals, Manganese oxides, Fe and Aluminium hydroxides and organic matter. In some soil types, lead may be highly concentrated in calcium carbonate particles or in phosphate concentrations. Typical mean Pb concentration for

Table 3. Concentration of heavy metals in soil (mg/kg dry weight).

Station No.	Pb	Zn	Cd	Cr	Fe	Mn
S1	41	110	BDL	292	18180	197
S2	38	49	BDL	279	16995	215
S3	112	57	0.4	276	19345	276
S4	59	85	0.5	306	27320	286
S5	50	94	BDL	404	41435	537
S6	35	77	BDL	277	27175	193
S7	66	210	0.4	330	31800	390
S8	59	104	BDL	252	22530	306
S9	68	132	0.6	250	28815	485
S10	84	107	0.4	318	26860	389
S11 (Control)	40	58	BDL	231	19755	153
Average	61.2	102.5	0.27	298.4	28021	327.4

surface soils worldwide averages 32 mg/kg and ranges from 10 to 67 mg/kg (Pendias, 2001).

The results of lead content in the soil samples varied from 35 mg/kg (S6) to 112 mg/kg (S3), with an average of 61.2 mg/kg during the study period. The lead concentration in the road side soil samples S3 and S9 showed high values with respect to that of the control station during the study period. Lead in the soils of study stations are in the order S3> S10> S9> S7> S4, S8> S5> S1> S11> S2> S6.

Lead is not an essential element. It is well known to be toxic and its effects have been more extensively reviewed than the effects of other trace metals. Lead can cause serious injury to the brain, nervous system, red blood cells, and kidneys. Pb accumulates in the body organs which may lead to poisoning or even death. Children exposed to lead are at risk for impaired development, lower IQ, shortened attention span, hyperactivity, and mental deterioration, with children under the age of six being at a more substantial risk. Adults usually experience decreased reaction time, loss of memory, nausea, insomnia, anorexia, and weakness of the joints when exposed to lead (Baldwin and Marshall, 1999).

Cadmium

Cadmium is very mobile and bio available metal which may accumulate in crops and humans (Alloway, 1995). The cadmium content in the soil samples ranges from 0.4 mg/kg (S3, S7, S10) to 0.6 mg/kg (S9) with an average of 0.27 mg/kg. The cadmium concentration in the soil samples in S1, S2, and S5 showed BDL including control station (S11) during the study period. The results of the present study show that cadmium content in all the stations of KMML industrial area soil are within the standard permissible limit of Indian standards (Awashthi,

2000). Cadmium content in the soils of study stations are in the order S9> S4> S3, S7, S10>S1, S2, S5, S6, S8, S11. The previous studies (Mathew and Venugopal, 2006) conducted on the status of heavy metals in samples of selected soils of Kerala show that retention of Cadmium was more in the top soils than in the bottom layers.

Zinc

Zinc belongs to a group of trace metals, which are essential for the growth of humans, animals and plants and are potentially dangerous for the biosphere when present in high concentrations. The main sources of pollution are industries and the use of liquid manure, composted materials and agrochemicals such as fertilizers and pesticides in agriculture (Romic and Romic, 2003).

The zinc content in the soil samples varied from 49mg /kg (S2) to 210mg /kg (S7) with an average of 102.5mg /kg during the study period. The zinc concentration in the soil samples of study station S7 (Sankaramangalam) was showed increase. Zinc content in the soils of study stations are in the order S7> S9> S1> S10> S8> S5> S4> S6> S11> S3> S2. In the present study the soil zinc content in the different study stations in the surroundings of KMML industrial area were below the upper limits of 300 mg/kg prevention of food adulteration act (PFA) standards (Awashthi, 2000).

Chromium

Chromium is a low mobility element, especially under moderately oxidizing and reducing conditions. The normal range of chromium in soil is 100 mg/kg as reported by Ewers (1991). The chromium content in the soil samples ranged from 231 mg/kg (S11) to 404 mg/kg (S5) with an average of 298.4 mg/kg during the study period. The chromium concentration in the soil samples all other stations showed increasing values with respect to that in the control station. Chromium content in the soils of study stations are in the order S5> S7> S10> S4> S1> S2> S6> S3> S8> S9> S11.

Iron

The iron content in the soil samples varied from 16995 mg/kg (S2) to 41435 mg/kg (S5) with an average of 28021 mg/kg during the study period. The iron concentration in the soil samples in all the study stations (except station 1, 2 and 3) showed increasing values with respect to that in the control station. Iron content in the soils of study stations are in the order S5> S7> S9> S4>

S6> S10> S8> S11> S3> S1> S2.

Manganese

The manganese content in the soil samples varied from 153 mg/kg (S11-control) to 537 mg/kg (S5) with an average of 327.4 mg/kg during the study period. The manganese concentration in the soil samples in all the study stations showed increase in its value with respect to that in the control station. Manganese content in the soils of study stations are in the order S5> S9> S7> S10> S8> S4> S3> S2> S1> S6> S11.

Conclusion

Life on earth exists in a very delicate balance, where soil, air and water sustain not only human life, but the entire eco-system. Any imbalance in this ecosystem due to environmental pollution results in contamination and sets off a chain of disruption that affects all patterns of existence. Heavy metal content in the soils of study stations are in the order iron > manganese > chromium > zinc > lead > cadmium. The concentration of heavy metals Pb, Zn, Cd, Cr and Mn in the stations, S1, S4, S7 and S10 nearest (within half kilometre distance) to the KMML industry were found higher than that in the control station. The results of the study also show that soils in the vicinity of KMML industrial area have been contaminated with heavy metals at levels above the background concentrations in soil, which may give rise to various health hazards. There should be a provision to measure toxic metals in industrial effluents before dumping. Soil pollution is a reality today with as severe repercussions as water and air pollution. Soil pollution facts need to be understood, and more importantly controlled. The effects of pollution on soil are quite alarming and may cause huge disturbances in the ecological balance and health of living creatures on earth.

Conflict of Interests

The authors have not declared any conflict of interests.

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