Annals of Arid Zone 54(1&2): 1-7, 2015

Elemental Composition of Leaves - A Possible Predictor of Tree Survival on Rehabilitated Sodic Lignite Mine Spoils

Praveen-Kumar* and Suresh Kumar

ICAR-Central Arid Zone Research Institute, Jodhpur 342003, India

Abstract: Reclamation of sodic lignite mine spoils in arid zones by covering them with a layer of good quality soil before tree plantation is a recognized approach. This approach has evolved as scarcity of good quality irrigation water in the region limits the utility of conventional gypsum application. As the woody perennials planted at reclamation site grow, belowground growth of roots may expose them to the higher sodic conditions with time. Rehabilitation of the lignite mined area is an expensive proposition and mortality of planted trees at later stage can jeopardise the whole program. Therefore, changes in elemental composition in tree leaves planted at spoil *vis-à-vis* that at non-mined site were used to investigate reasons of their long term survival. Results showed that the species of trees that survived at spoils had higher concentration of most of the elements than those growing at non-mined site. Of these, P, K, Ca and Mg were more important as tree species having equal or higher concentration of either all or most of these elements in leaves after one year of growth *vis-à-vis* those at non-mined site survived for over three years. Thus difference in concentration of phosphorus, potassium, calcium and magnesium in the tree leaves, a year after plantation at spoil, *vis a vis* of trees at non-mined site can indicate their potential for long term survival on spoils.

Key words: Lignite mine spoil, rehabilitation, chemical composition, planted trees.

Lignite is an important source of energy for thermal power generation and a predominant fuel source for cement industry, brick kilns and lime stone kilns. Many areas of Barmer, Bikaner, Jodhpur and Jaisalmer districts of India have large deposits of lignite spread over 2,650 km^2 and 30 to 50 m below the surface (Praveen-Kumar *et al.*, 2005). The reserves consist of 8-10 seams of 0.3 to 2 m thickness, which are separated by variegated clay, black clay and/or shale. Overburden comprise of a top layer of soil (0.2 m) or sand dune (<5 m), about 20 m thick layer of bentonite and sub-bentonite, and about 5 m thick layer of greenish clay. Lignite is mined through open cast mining and the pit is backfilled with overburden as the mining moves forward. Thus, backfilled pit consists of a mixture of bentonite, sub-bentonite, clay and sand. Since bentonite, inherently contains high concentration of Na^+, surface layers of spoils also have high Na^+. High Na^+ can adversely affect the seedling germination (Esechie *et al.*, 2002; Hosseini *et al.*, 2002; Masciandaro *et al.*, 2002) and restricts nitrification (Laura, 1991; Luna-Guido *et al.*, 2000) and can thus seriously hamper establishment and growth of plants. Therefore, lignite mine spoils remain barren for years.

Mining is one of the important industries in India, but, reclamation of spoils is a recent concept especially in arid zones. Further, spoil is not the soil in the genesis sense and thus have vastly different nutrient supplying capacities (Berg, 1978). Changing properties of sodic spoils is extremely difficult (Power *et al.*, 1977) more so in arid region where water scarcity limits efficacy of conventional gypsum application. Therefore, Power *et al.* (1977) advocated (i) covering of sodic spoils with good quality soil initially and (ii) planting the vegetation in the soil layer subsequently for rehabilitation of the spoils. Therefore, vegetation planted on spoils must be tolerant to sodic conditions as the downward growth of roots may increasingly expose these roots to highly sodic conditions with time making them prone to the risk of survival.

Rehabilitation of the lignite mined area is an expensive proposition and mortality of trees after an initial period of growth may jeopardise the whole programme (Raizada and Juyal, 2010; Klaus and Hans-Georg, 2014). In order to be able to survive such highly sodic subsurface environment, they need to have some suitable mechanism to internalise it in their metabolism. One of the strategy in plants grown on sodic soils is that they absorb and thus contain high

---

*E-mail: pkumar_bhatnagar@yahoo.com

Na^+ (Salama *et al*., 2000) but balance it by altering concentration of ions to survive under sodic conditions (Drihem and Pilbeam, 2002; Vigo *et al*., 2002). Rajpar *et al*. (2002) reported that ability of Kharchia wheat to maintain Na:K ratio is a major reason of its salt tolerance. Similar trend has been reported by Verma and Srivastava (1998) for pigeonpea, Singh *et al.* (1998) for chikku trees and Nigam *et al.* (2002) for mango trees. Importance of maintenance of Na/K, Na/Ca, Na/Mg ratio by rapeseed, rice, barley and desert plants have also been highlighted by Soni and Vasistha, 1987; Claudia *et al*., 1995; Porcelli, 1995, Mahgoub, 1999; Wang *et al*., 2004). Since K, Ca, and Mg are adsorbed from the soil, changes in their concentration would also indicate the capacity of spoil to supply these nutrients and may affect long term survival of plants.

We estimated concentration of N, P, K, Ca, Mg, Zn, Fe, Cu and Mn in the leaves of one year old planted trees at spoil and non-mined site to (i) assess the alterations in nutrient concentration of planted trees at spoils and (ii) to relate the changes in nutrient concentration with survival of planted trees on lignite spoils. Used these interpretations to assess the long term survival of the planted trees at spoil and evaluated our assessment by revisiting the site after three years.

Materials and Methods

Study area is situated in Barmer district (24°58′ and 26°32′N and 70°5′ and 72°52′E). Maximum temperature during summer touches 48°C which goes down to 2°C in winter. Average annual rainfall and potential evapo-transpiration are 268 mm and 1857 mm, respectively. Most of the rainfall is received during July to September.

Barren heaps of spoils were the dominant feature of the area initially. These heaps were first levelled in the experimental area of about 20 ha and then a layer of dune sand was spread over it. Due to initial variations in topography, mechanical earth movement, thickness of dune sand over spoil ranged between 30-60 cm. After a year of stabilization, soil samples were collected from different depths and analysed for physico-chemical properties by standard procedures (Jackson, 1958). Seedlings of 13 woody perennials species viz. *Azadirachta indica, Salvadora oleoides, Prosopis cineraria, Aacacia tortlis, Tecomella undulata, Tamarix aphylla, Dichrostachys nutans, Cholophospermum mopane, Acacia senegal, Circidium floridum, Acacia nubica, Parkinsonia aculeata* and *Ziziphus rotundifolia* were planted in the experimental area. Seedlings were planted in pits. Each pit was 60x60x60 cm and filled with mixture of dune sand and farmyard manure (FYM) in the ratio of 1:2. Woody perennials were planted in rows with plant x plant distance of 3 m and row x row distance of 9 m. Weeding and soil working operations were carried out as per requirement. Survival percentage of the trees was recorded after a year.

Leaf samples from trees were collected after one year of transplantation. Leaves from 20 tree of each species were sampled, dried. Leaves of four tree of each species were randomly mixed to give five samples which were treated as replicate. The leaves of the same woody perennials growing on unmined sites were collected and treated as control. These leaves were dried and ground and processed for chemical analysis of N, K, Ca, Mg, Fe, Cu, Zn, Mn. For estimating N, 0.5 g sample of powdered leaves or ground natural vegetation were weighed into Kjeltec tube and digested in sulphuric acid on a lead block digester. N in digest was estimated using Tacator FIAStar5010. For all other elements leaf powder was digested in tri-acid mixture (Sulphuric acid:Nitric acid: Perchloric acid in ratio of 9:3:1). Potassium was estimated using Flame photometer. Ca, Mg, Fe, Cu, Zn and Mn content in tri-acid digest was estimated using atomic absorption spectrophotometer.

Results and Discussion

Survival percentage of trees of all the species, a year after planting, ranged between 80 to 100% both at spoils and at non-mined site. It was lowest for *Tamaryx aphylla* while *Colophospermum* mopane, *Prosopis cineraria* and *Acacia senegal* recorded 100% survival. All other species varied between 85 (*Circidium floridum*) to 98 (*Salvadora oleoides*). However, during the revisit of the site, three years after planting, mortality in *Azadirachta indica, Prosopis cineraria, Ziziphus rotundifolia* was high observed whereas all other species were thriving well.

Spoils had higher pH and EC than of non-mined soils (Table 1). Sodium content in the

Table 1. Some physico-chemical properties (range, mean and standard deviation) of lignite mine spoils and soil of non-mined area (results from 20 samples)

Property	Non-mined site		Spoils	
	0-0.30 m	0.30-0.60 m	0-0.30 m	0.30-0.60 m
pH	8.1±0.2	8.3±0.1	8.7±0.6	8.4±0.6
EC (dS m^{-1})	0.6±0.5	0.4±0.0	6.9±2.7	7.2±2.7
Total C (mg kg^{-1})	2.5±0.03	2.2±0.12	2.1±0.05	3.0±0.35
Na (mg g^{-1})	0.01±0	0.01±0	1.59±0.63	1.68±0.45
Ca (µg g^{-1})	210±5	212±5	307±96	372±90
Mg (µg g^{-1})	84±3	86±1	107±51	135±47
Cl (µg g^{-1})	Tr	Tr	43±31	42±27
Total N (µg g^{-1})	338±2	329±3	129-±22	126±26
Total S (mg g^{-1})	0.03±0	0.03±0	7.87±1.17	7.30±0.87
Alkaline $KMnO_4$ N (µg g^{-1})	15.3±3.5	12.4±1.1	12.4±1.13	12.0±1.0
$NaHCO_3$ P (µg g^{-1})	3.6±0.17	3.8±0.5	1.9±0.1	1.5±0.3
NH_4OAc K (µg g^{-1})	217±8	202±4	104±28	87±9
DTPA-Fe (µg g^{-1})	6.0±0.3	5.4±0.2	14.8±1.9	9.4±1.5
DTPA-Mn (µg g^{-1})	10.2±0.5	9.5±0.4	15.2±1.8	16.0±1.2
DTPA-Zn (µg g^{-1})	0.7±0.0	0.7±0.0	9.2±0.3	9.2±0.4
DTPA-Cu (µg g^{-1})	0.4±0.0	0.43±0.03	0.9±0.1	0.8±0.2

spoils was 150 times than at non-mined site. Similarly, calcium and magnesium content at spoils were higher than at non-mined site, but contents of alkaline-$KMnO_4$ extractable nitrogen, phosphorus and potassium were lower in spoils. As a consequence of differences in chemical properties of spoils and soil of non-mined site, the elemental composition of trees planted at spoils and at non-mined site was also different (Table 2-4).

Elemental composition of planted woody perennials

Average concentration of Na in the tree leaves across the species, was higher at spoils than at non-mined site (Table 2). Singh and

Table 2. Concentration of sodium, nitrogen, potassium, calcium and magnesium in biomass of planted trees at spoils and non-mined site

Tree species	Na (mg g^{-1})		N (mg g^{-1})		P (µg g^{-1})		K (mg g^{-1})		Ca (mg g^{-1})		Mg (mg g^{-1})	
	N	S	N	S	N	S	N	S	N	S	N	S
Azadirachta indica	0.46	2.10	21.5	25.0	467	452	11.91	8.12	34.15	18.28	3.85	2.56
Salvadora oleoides	0.58	5.80	16.3	19.8	430	684	9.87	12.02	136.58	156.81	3.14	5.21
Prosopis cinerearia	0.34	1.23	20.1	22.1	1065	1039	11.31	5.63	32.54	18.02	3.17	2.54
Acacia tortilis	0.50	1.59	21.5	27.6	613	837	9.43	12.88	32.61	33.85	2.08	4.89
Tecomella undulata	0.49	1.36	27.3	29.1	982	1147	12.94	19.82	20.82	33.12	8.33	10.39
Tamarix aphylla	15.80	25.43	21.0	26.0	536	703	7.36	12.05	83.21	129.79	3.56	4.96
Dichrostachys nutans	0.71	1.23	22.1	22.1	588	776	11.34	15.33	12.18	26.50	5.59	10.18
Cholophospermum mopane	2.50	2.60	21.7	23.1	910	970	12.03	14.06	54.68	68.75	7.86	8.96
Acacia senegal	2.88	3.50	37.1	32.9	970	1115	15.44	17.22	38.52	45.62	7.54	9.37
Circidium floridum	3.60	9.40	31.5	32.4	1398	1506	14.06	19.05	27.89	35.65	5.87	9.57
Acacia nubica	0.65	3.70	35.7	36.2	987	1103	12.27	18.33	23.54	31.27	6.87	8.49
Parkinsonia aculeata	0.96	4.10	32.2	33.6	1154	1227	15.68	19.62	19.57	23.58	7.89	8.68
Ziziphus rotundifolia	0.36	0.99	18.5	20.1	987	867	12.53	10.51	15.52	13.35	5.27	4.28
Average	2.29	4.85	25.1	26.92	853	1010	11.89	14.36	40.76	48.97	5.41	7.01

N = Non-mined site; S = Spoils.

Table 3. Concentration of zinc, iron, manganese and copper in biomass of planted trees at spoils and non-mined site

Tree species	Zn (μg g^{-1})		Fe (μg g^{-1})		Mn (μg g^{-1})		Cu (μg g^{-1})	
	N	S	N	S	N	S	N	S
Azadirachta indica	15	45	227	297	35	72	22	22
Salvadora oleoides	20	28	276	312	50	65	15	21
Prosopis cinerearia	42	55	420	520	38	67	10	30
Acacia totrilis	20	25	475	542	58	85	21	24
Tecomella undulata	55	65	614	722	32	55	31	28
Tamarix aphylla	31	35	485	605	80	104	25	22
Dichrostachys nutans	42	45	482	587	39	42	28	45
Colophospermeum mopane	55	71	420	474	54	57	15	23
Acacia senegal	23	35	517	730	88	110	9	12
Circidium floridum	39	52	387	485	62	81	12	14
Acacia nubica	26	41	400	434	50	69	13	19
Parkinsonia aculeata	57	74	533	602	89	97	23	22
Ziziphus rotundifolia	32	35	285	307	54	61	14	19
Average	35	46	43	509	56	74	18	23

N = Non-mined site; S = Spoils.

Yadav (1999) and Rajpar *et al*. (2002) have also reported higher Na content in variety of plants grown on sodic soils. Concentration of different elements and ratio of Na:K, Na:Ca and Na:Mg amongst 13 species studied at both sites varied widely (Table 2, 3 and 4). Average concentration of N, P, K, Ca, Mg, Zn, Fe, Mn and Cu in the tree leaves across the species, was also higher at spoils than at non-mined site (Table 2, 3 and 4). However, some species showed a deviation from this trend viz. *Acacia senegal* for nitrogen, and *Azadirachta indica*, *Propsopis cineraria* and *Ziziphus rotundifolia* for phosphorus, potassium and calcium. *Azadirachta indica* and *Ziziphus rotundifolia* showed deviation for magnesium. All species had higher concentration of Zn, Fe and Mn at spoils than at non-mined site but four species in case of copper did not follow this trend. Quist and Williams (1999) have also shown varied response to N, P, K, Ca, Mg, Na, Zn, Fe, Mn, Zn and Cu concentration in different tree species following irrigation with

Table 4. Ratio of sodium with potassium, calcium and magnesium in biomass of planted trees at spoils and non-mined site

Tree species	Na:K		Na:Ca		Na:Mg	
	Non-mined site	Spoils	Non-mined site	Spoils	Non-mined site	Spoils
Azadirachta indica	0.04	0.26	0.01	0.11	0.12	0.82
Salvadora oleoides	0.06	0.48	0.01	0.04	0.18	1.11
Prosopis cineraria	0.03	0.22	0.01	0.07	0.11	0.48
Acacia tortilis	0.05	0.12	0.02	0.05	0.24	0.32
Tecomella undulata	0.04	0.07	0.02	0.04	0.06	0.13
Tamarix aphylla	2.15	2.11	0.19	0.20	4.44	5.13
Dichrostachys nutans	0.06	0.08	0.06	0.05	0.13	0.12
Colophospermum mopane	0.21	0.18	0.05	0.04	0.32	0.29
Acacia senegal	0.19	0.20	0.00	0.08	0.38	0.37
Circidium floridum	0.26	0.49	0.13	0.26	0.61	0.98
Acacia nubica	0.05	0.20	0.03	0.12	0.09	0.44
Parkinsonia aculeata	0.06	0.21	0.05	0.17	0.12	0.47
Ziziphus rotundifolia	0.03	0.08	0.03	0.06	0.08	0.19
Average	0.25	0.36	0.05	0.10	0.53	0.84

low quality water whereas Vigo *et al*. (2002) had reported decrease in concentration of N, P, K, Ca, Mg, Fe, Mn and Zn in olive trees grown under sodic soils.

Average of the ratio of Na:K, Na:Ca and Na: Mg across the species was 14 to 100% higher at spoil (Table 4). Similar trend was recorded in most species except *Colophospermum mopane* for Na:K, Na:Ca and Na:Mg and *Dicrostachys nutans* for Na:Ca and Na:Mg.

Since spoils have very high sodium content, it can be argued that accumulation of higher elemental concentration in planted species at spoils *vis-à-vis* non-mined site was in response to higher sodium content in spoil and its absorption by plants. Thus, accumulation of higher elemental concentration appeared as survival strategy of plants in sodic spoils. Similarly, concentration of most elements was higher in trees at spoils that at non-mined site. Evidently, only those trees which can accumulate higher concentration of most elements can survive under sodic spoils. But in contrast to this general trend P, K, Ca and Mg concentration in the leaves of *Azadirachta indica, Prosopis cineraria, Ziziphus rotundifolia* were lower but concentration of most micronutrients followed the general trend. We have mentioned earlier that survival figures of these species after a year were above 80%. However, during revisit of the site after three years, complete mortality of all the plants of *Azadirachta indica, Prosopis cineraria* and *Ziziphus rotundifolia* was observed whereas all other species were thriving well. It is pertinent to mention here that both, *Prosopis cineraria* and *Ziziphus rotundifolia* being components of climax formation should have ideally survived in this environment. Their complete mortality indicated some drastic change in the soil composition in their root zone that did not allow these species to survive. Assessment of this mortality against chemical composition of leaves showed that leaves of these species had lower P, K, Ca and Mg concentration whereas the opposite was true for the species that survived. Singh *et al*. (2005) and Yadav and Singh (2006) have also reported higher drop in the P, K, Ca and Mg content in leaves of aonla and in salt sensitive genotypes of mango respectively. This clearly indicated more important role of these elements in ensuring survival of trees at mined spoils. It is understandable as rupture of the cell wall under stress is a major cause of mortality and higher concentration of calcium and magnesium may increase cell wall stability as they are constituent of the cell wall. QiAng *et al*. (2008) have reported increased survival of oats under sodic conditions after treatment with calcium

In a number of studies on sodic soils, Na:K, Na:Ca, Na:Mg ratios in plants is used as indicator for plant salt tolerance. This was not observed in our study as these ratios in most

Table 5. Content of different elements and the ratios of Na:K, Na:Ca and Na:Mg in biomass of naturally occurring vegetation at spoils and non-mined site

Natural vegetation	Non-mined site	Spoils	Non-mined site	Spoils	Non-mined site	Spoils	Non-mined site	Spoils
	Nitrogen (mg g^{-1})		Potassium (mg g^{-1})		Calcium (mg g^{-1})		Magnesium (mg g^{-1})	
High Na accumulators	14.91	18.01	13.57	14.80	15.09	15.29	4.05	6.80
Low Na accumulators	15.40	18.71	12.42	12.85	14.32	12.08	5.70	7.54
Sodium excluders	18.60	21.20	13.14	17.13	11.89	12.01	5.15	6.91
	Zinc (µg g^{-1})		Iron (µg g^{-1})		Manganese (µg g^{-1})		Copper (µg g^{-1})	
High Na accumulators	30	45	171	213	63	65	15	13
Low Na accumulators	35	49	221	262	60	83	9	15
Sodium excluders	29	45	293	338	85	113	11	12
	Na (mg g^{-1})		Na:K		Na:Ca		Na:Mg	
High Na accumulators	4.22	10.16	0.32	0.69	0.47	0.93	1.03	1.49
Low Na accumulators	5.73	8.34	0.47	0.72	0.49	0.70	1.32	1.34
Sodium excluders	14.46	8.82	0.99	0.68	1.39	0.86	3.61	1.99

of the trees at spoils were higher than at non mined site and these ratios in no way explained survival or mortality of plants. Similar point of view has been reported by Aslam (2003). Therefore, it can be deduced from the results that tree mortality at spoils was better indicated by comparative concentration of P, K, Ca, Mg in the leaves of plants growing at spoil and at non-mined site than the conventional indicators like Na:K, Na:Ca, Na:Mg ratios.

Conclusions

High plant mortality in rehabilitation program of sodic mine spoils after their initial survival is often attributed to increasing Na content in surface soil with time and more exposure of roots to deeper layers of spoil with high Na content. Therefore, changes in elemental composition of tree leaves, a year after planting, at sodic mine spoil *vis a vis* of trees at non-mined site were compared to indicate the differences and to relate them with long term survival of trees planted at mine spoils. It was concluded that plant survival at lignite mine spoils involved higher accumulation of most of the elements. Of all the elements P, K, Ca and Mg play a major role and the woody perennials that did not accumulate all or most of these elements struggled to survive for long time. It is also concluded that using ratios of Na:K, Na:Ca and Na:Mg as in case of crops to indicate their ability to survive on sodic soils, however, can not predict survival of woody perennials on mine spoils because of deeper root system of woody perennials.

References

Al-Karaki, G.N. 2000. Growth water use efficiency and mineral acquisition by tomato cultivars grown under salt stress. *Proceedings of Regional Symposium on Irrigation Management and Saline conditions*, June 1999, JUST, Ibrid, Jordan

Aslam, M., Noor, M., Qureshi, M.H., Ahmad, Z., Nawas, S. and Akhtar, J. 2003. Calcium and salt tolerance. *Communications in Soil Science and Plant Analysis* 34: 3013-3031.

Berg, W.A. 1978. Limitations in use of soil tests on drastically disturbed lands. In *Reclamation of Drastically Disturbed Lands* (Eds. F.W. Schaller and P. Sutton). pp. 653-664. American Society of Agrionomy Madison, USA.

Drihem, K. and Pilbeam, D.J. 2002. Effect of salinity on accumulation of mineral nutrients in wheat grown with nitrate nitrogen or mixed ammonium nitrate nitrogen. *Journal of Plant Nutrition* 25: 2091-2113.

Esechie, H.A., Al-Saidi, A. and Al-Khanjari, S. 2002. Effect of sodium chloride salinity on seedling emergence in chickpea. *Journal of Agronomy and Soil Science* 188: 155-160.

Freytag, Klaus and Thiem, Hans-Georg 2014. State of the lignite rehabilitation and current challenges. *Proceedings of the 12th International Symposium Continuous Surface Mining - Aachen 2014*. Part of the series Lecture Notes in Production Engineering pp. 631-642.

Hosseini, M.K., Powell, A.A. and Bingham, I.J. 2002. Comparison of germination and early seedling growth of soybean in saline conditions. *Seed Science Research* 12: 165-172.

Jackson, M.L. 1973. *Soil Chemical Analysis*. Prentice Hall of India Pvt. Ltd., New Delhi.

Laura, R.D. 1991. Effect of sodicity on the mineralization of nitrogen in soil. *International-Journal of Tropical Agriculture* 9: 174-181.

Luna-Guido, M.L., Beltran-Hernandez, R.I., Solis-Ceballos, N.A., Hernandez-Chavez, N., Mercado-Garcia, F., Catt, J.A., Olalde-Portugal, V. and Dendooven, L. 2000. Chemical and biological characteristics of alkaline saline soils from the former lake Texcoco as affected by artificial drainage. *Biology and Fertility of Soils* 32: 102-108.

Mahgoub, E.M.I. and Sayed Ahmed, M.S. 1999. The genetics of sodium and potassium uptake and translocation in barley (*Hordeum vulgare* L.). *Arab Universities Journal of Agricultural Sciences* 7: 129-143.

Masciandaro, G., Ceccanti, B., Ronchi, V., Benedicto, S. and Howard, L. 2002. Humic substances to reduce the salt effect on plant germination and growth. *Communications in Soil Science and Plant Analysis* 33: 365-378.

Nigam, J.K., Sant, R., Misra, K.K. and Ram, S. 2002. Uptake and distribution of K, Na and S ions in salt treated seedlings of mango. *Indian Journal of Horticulture* 59: 17-23.

Porcelli, C.A., Flavio, H. Gutierrez Boem and Lavado, R.S. 1995. The K/Na and Ca/Na ratios and rapeseed yield under soil salinity and sodicity. *Plant and Soil* 175(2): 251-255.

Power, J.F., Sandoval, F.M. and Ries, R.E. 1977. Restoration of productivity to disturbed land in northern great plains. In *The Reclamation of Disturbed Arid Lands* (Ed. R.A. Wright), pp. 33-49. University of New Mexico Press, Albuquerque.

Praveen-Kumar, Kumar, S., Sharma, K.D., Chaudhry, A. and Gehlot, K. 2005. Characteristics of lignite mine spoil and approach for rehabilitation in arid regions. *Arid Land Research and Rehabilitation* 19: 1-14.

QiAng, X., Xin, X., Zhao-Yan, Jiao-Kun., Herbert, S.J. and Hao-Lin 2008. Salicylic acid, hydrogen peroxide and calcium-induced saline tolerance associated with endogenous hydrogen peroxide homeostasis in naked oat seedlings. *Plant-Growth-Regulation* 54: 249-259.

Quist, T.M. and Williams, C.F. 1999. Irrigation water quality and ion balance in leaves of deciduous ornamental trees. *Journal of Plant Nutrition* 22: 1011-1019.

Rajpar, I., Sial, N.B. and Mastoi, A. 2002. Effect of soluble salts and soil conditioner (polyacrylamide) on some soil properties, growth and ion uptake and yield of transplanted wheat seedlings. *Pakistan Journal of Applied Science* 2: 750-756.

Raizada, A. and Juyal, G.P. 2010. Tree species diversity, species regeneration and biological productivity of seeded *Acacia catechu* Willd. In Rehabilitated Limestone Mines in the North West Indian Himalayas. *Land Degradation and Development*, doi:10.1002/ldr.1067

Rivelli, A.R., James, R.A., Munns, R. and Condon, A.G. 2002. Effect of salinity on water relations and growth of wheat genotypes with contrasting sodium uptake. *Functional Plant Biology* 29: 1065-1074.

Rivelli, A.R., James, R.A., Munns, R. and Condon, A.G. 2002. Effect of salinity on water relations and growth of wheat genotypes with contrasting sodium uptake. *Functional Plant Physiology* 29: 1065-1074.

Salama, Z.A., Fawzi, A.F.A. and Ghanem, S.A. 2000. Growth, nutrient uptake and anti-oxidant levels in salinized wheat plants. *Egyptian Journal of Physiological Sciences* 24: 129-148.

Singh, D.M., Singh, B.P. and Singh, S.P. 2005. Effect of sodicity levels on plant survival, mineral composition and total chlorophyll content in Aonla (*Emblica officinalis* Gaertn.). *Horticultural Journal* 18: 1-3.

Singh, G., Bhist, J.K., Singh, N.T., Daga, J.C. and Singh, G. 1998. Evaluation of fruit plants for sodicity tolerance. *Range Management and Agroforestry* 19: 87-91.

Singh, K. and Yadav, J.S.P. 1999. Effect of soil salinity and sodicity on seedling growth and mineral composition of *Pongamia pinnata*. *Indian Forester* 125: 618-622.

Soni, P. and Vasistha, H.B. 1987. Reclamation of rock phosphatase mine at Maldeota. *Proceeding of the Symposium on Recent Advances in Plant Sciences.* (Eds. M.R. Sharma and B.K. Gupta) held at DAV College, Dehra Dun.

Tattini, M. and Gucci, R. 1999. Ionic elations of Phillyrea latifolia L. plants during NaCl stress and relief from stress. *Canadian Journal of Botany* 77: 969-975.

Verma, J. and Srivastava, A.K. 1998. Differential response of Na/Ca ratio in potassium uptake and overall growth of pigeon pea (*Cajanus cajan*) subjected to salt stress. *Journal of Potassium Research* 14: 59-67.

Vigo, C., Therios, I.N., Patakas, A., Karatassou, M. and Nastou, A. 2002. Changes in photosynthetic parameters and nutrient distribution of olive plants (*Olea europaea* L.) cultivar 'Chondrolia Chalkidikis' under NaCl, Na_2SO_4 and KCl salinities. *Agrochimica* 46: 33-46.

Wang, S., Wan, C., Yanrong, W., Chen, H., Zhou, Z., Fu, H. and Sosebee, R.E. 2004. The characteristics of Na^+ and K^+ and free roline distribution in several drought-resistant plabnts of Alxa desert, China. *Journal of Arid Environment* 56: 525-539.

Yadav, V.K and Singh, H.K. 2006. Effect of exchangeable sodium on mineral composition of mango (*Mangifera indica* L.) rootstock. *Scientific-Horticulture* 10: 103-124.