Society for Advancement of Wheat Research
ICAR-Indian Institute of Wheat & Barley Research
Karnal - 132 001, India

Journal of Wheat Research
7(2):45-51
Homepage: http://epubs.icar.org.in/ejournal/index.php/JWR

Research Article

Declining farm productivity and profitability due to soil degradation in North India

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Article history

Received: 20 October, 2014
Revised : 22 December, 2014
Accepted: 23 December, 2014

Citation

Thimmappa K, Y Singh, Raju R, RS Tripathi, S Kumar, Sendhil R and D Mitrannavar. 2015. Declining farm productivity and profitability due to soil degradation in North India. *Journal of Wheat Research* 7(2):45-51

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Abstract

Alkali soils are an important category of salt-affected soils and present predominantly in the Indo-Gangetic plains of Northern India. Soil alkalinity and other forms of land degradation reduce the productivity of the crop as well as the farm household income. The purpose of the study is to measure the adverse effects of soil alkalinity on crop production and its consequent impact on farm income. The study observed a substantial reduction in the crop productivity and farm income. The farm income decreased with increase in soil alkalinity level. The annual potential and actual losses per ha were ₹ 10714 and ₹ 7737, respectively, due to the adverse effects of soil alkalinity. It is suggested that these lands should be reclaimed on priority basis to improve soil productivity, farm income and livelihood security of resource-poor farmers.

Key words: Soil alkalinity, land degradation, Soil pH, Indo-Gangetic basin, gypsum

1. Introduction

Land degradation due to soil alkalinity is a serious problem in the arid and semi-arid regions of India. The deterioration of land resources caused by salt accumulation is a continuous process resulting from insufficient precipitation, inadequate irrigation, poor drainage and irrigation with poor quality water (Abrol and Dahiya, 1974). It is observed that about 75 countries are facing these problems (Szabolcs, 1994). Salt-affected soils cover approximately 7 per cent of the total global area and cause global income losses of approximately US$12 billion per year (Ghassemi *et al.*, 1995). Land degradation could be a serious threat to food production and rural livelihoods by the year 2020 (Scherr and Yadav, 1996).

In India, 6.73 mha land is salt-affected, out of which 3.77 mha are alkali soils and 2.96 mha are saline soils (NRSA, 1996). Alkali soils are an important category of salt-affected soils and present predominantly in Indo-Gangetic plains of Northern India. The area under salinity and alkalinity has increased steadily over the last few decades in the Indian Indo-Gangetic basin (Gupta and Abrol, 2000). The formation of alkaline soils in this region is due to constant weathering of alumino-silicate minerals in the catchment area produces a continuous supply of sodium, potassium, calcium and magnesium salts. Due to arid and semi-arid climate, the water evaporates in the post-rainy months leaving sodium carbonates (Na_2CO_3) and bi-carbonates ($NaHCO_3$) on the soil surface, which lead to formation of alkali soils in this region (Chhabra, 1996). In saline-alkali and alkali soils, plants face nutritional problems that range from deficiencies in several nutrients to the presence of phytotoxic levels of Na^+ and Cl^- (Naidu and Rengasamy, 1993). High concentrations of salts have detrimental effects on germination of seeds and plant growth (Rahman *et al.,* 2008).

The extremely high salt concentration in the root zone reduces the overall crop productivity as plants face abnormal morphological, physiological and biochemical changes that cause harmful effects on germination, high seedling mortality, poor crop stand, stunted growth and yield reduction (Ashraf and Sarwar, 2002).

As the use of alkali soils for crop production is expected to increase in the near future, the sustainable use of such soils for food and feed production will become a serious issue. (Qadir *et al*., 2006). It was observed that small farmers are unable to produce sufficient quantities of foodgrains for family consumption due to lower crop yield in alkalinity affected regions (Thimmappa *et al.,* 2013). Hence, soil alkalinity needs greater attention to improve the crop yield, farm income and foodgrain production. Despite the considerable efforts being made, sufficient scientific information is still required to evaluate the damage caused by alkalinity, which would help the planners to make suitable policies for rapid implementation of alkali (sodic) land reclamation programmes. The present study attempts to evaluate the economic losses due to alkalinity at farm level.

2. Materials and methods

2.1 General features of the study area: Farmers are facing a serious problem of soil alkalinity in arid and semi-arid regions of Indo-Gangetic plains in India. An exhaustive study was conducted in an alkalinity affected village of Indo-Gangetic region in one of the most populous Indian State of Uttar Pradesh. The village, Ahemi is located at an elevation of 139 meters above the mean sea level. The area represent a semi-arid subtropical climate characterized by hot summer and a cool winter, with mean annual rainfall of 800 mm, most of which occurs during June to September. The average farm size was 0.44 ha and a majority of the farmers belongs to marginal category (Table 1).

Table 1. Socio-economic profile of the sample farmers

Particulars	Percentage / value
(I) General information	
(a) Family size (No.)	7
(b) Literacy level (%)	46
(c) Age (years)	45
(d) Average farm size (ha)	0.44
(e) Annual rainfall (mm)	600-850
(f) Temperature (°C)	3-40
(II) Classification of farm holdings (%)	
(a) Marginal (<1 ha)	96
(b) Small (1 to 2 ha)	3
(c) Medium (>2 to < 10 ha)	1
(d) Large (> 10 ha)	0
(III) Sources of family income (%)	
(a) Crop production	62.9
(b) Livestock	2.0
(c) Service	0.1
(d) Business	5.0
(e) Others	30.0

The crop production was the most important activity contributing 62.9 per cent to the total household income. Many farmers (30%) supplemented their household income by engaging themselves or their family members in off-farm activities. Farmers grow crops in *kharif* season (June–October) and *rabi* seasons (November–March). Transplanted paddy (*Oryza sativa*) is the most popular *kharif* season crop. Wheat (*Triticum aestivum*) is grown after rice in the *rabi* season. In the 'moderate' soil alkalinity class, ESP varies from 15– 40, and only rice is grown in *kharif* season and lands remain barren during *rabi* season. There is no crop being cultivated in the 'severe' soil alkalinity class due to extreme alkalinity levels (ESP >40).

2.2 Analytical approach: The village has a total agricultural land of 355.13 ha. The degraded land has varying levels of soil alkalinity constituted 14.11 per cent of total land holdings owned by 117 farmers. The landholdings have been classified into 'normal', 'slightly affected', 'moderately affected' and 'severely affected' based on the extent of alkalinity hazard (Table 2). Soil alkalinity is usually quantified by the exchangeable sodium percentage (Van der Zee *et al*, 2010). The soil pH also indicates the presence of soil alkalinity due to an intimate relationship between ESP and pH of the saturation paste (Chhabra, 1996). In the 'normal' lands, alkali hazards are negligible and ESP (<15) is in the tolerance limit. The ESP is around 15 in the 'slight' alkalinity soil class. Farmers grew both rice and wheat in these categories of land. The alkalinity hazards are high in 'moderate' alkalinity soil class and farmers grew only rice crop. Farm lands are left uncultivated in 'severe' alkalinity soil category lands due to extremely high pH and ESP. Out of the total agricultural land, 304.98 ha (85.88%) belongs to 'normal' category. The total degraded land due to alkalinity was 50.15 ha. Out of total degraded land, 4.33 ha (1.22%) area was under 'slight', 17.95 ha (5.05%) was under 'moderate' and 27.87 ha (7.85%) was under 'severe' soil alkalinity class.

Table 2. Distribution of landholdings under different alkalinity classes in Ahemi village

Soil alkalinity class	pH*	ESP*	Area (ha)	Area (%)
Normal	< 8.5	< 15	304.98	85.88
Slight	8.5-9.0	< 15	4.33	1.22
Moderate	9.1-9.8	15-40	17.95	5.05
Severe	>9.8	>40	27.87	7.85
Total	-	-	355.13	100

*Source: * Mandal et al., 2010.*

The land holdings and soil alkalinity data were collected from Uttar Pradesh government records. About 85% farm households who were having degraded lands and 100 farmers having normal land were surveyed. Information on various aspects of crop production and cropping intensity were collected from the selected farm households on standardized and pre-tested questionnaire through participatory rural appraisal techniques. The costs and returns have been estimated based on 2013 prices.

All the input and output parameters pertaining to rice and wheat production were based on the average values of three years with a view to the minimize the seasonal fluctuations in the selected variables. The cost included all direct expenses paid in cash and kind for crop production such as hired human labour, machine labour, seeds, fertilizers, irrigation, plant protection measures, overhead charges and imputed value of family labour. The overhead charges includes the land revenue paid to the state government, charges paid for repairs, maintenance and depreciation of fixed assets, interest on working capital and fixed capital. Gross income comprises the total value of main product and by-products. Net income was calculated by taking the difference between gross income and cost of cultivation.

The farm income losses caused by alkalinity were estimated by subtracting the net income per ha in each soil alkalinity class from the net income of the 'normal' soil class for each crop. The potential farm income losses per ha were calculated by multiplying estimated farm income loss values with corresponding proportional areas of alkalinity classes. The actual farm income losses per ha in *Kharif* and *Rabi* has been estimated by multiplying the potential farm income losses with the corresponding cropping intensities.

3. Results and discussion

3.1 Distribution of salt affected soils in Uttar Pradesh: Salt development is a process that depends nonlinearly on both salt concentration and composition of soil water. In hot climates, soil water composition is subject to temporal variation due to dry–wet cycles (Van der Zee *et al.*, 2010). Further, it also depends on climate, topography, geology, soil mineral weathering, drainage, hydrology, source and method of irrigation, underground water quality and crop production practices (Ghassemi, *et al.*, 1995). The distribution of salt-affected soils in Uttar Pradesh, shown in Table 3, reveals that the salt-affected soils are widely distributed in different parts of the state and occupy 1.36 mha area, which is 5.68 per cent of the total geographical area of the state. Under alkali soils, largest area is in Mainpuri (123042 ha), followed by Azamgarh (97751 ha, Etawah (69076 ha), Raebareli (86586 ha) and other districts. The occurrence of soil alkalinity has adversely affected crop productivity in these districts. These present major challenges to environment and sustainable livelihood security of the people living in the region.

Table 3. Distribution of salt-affected soils in Uttar Pradesh

District	Sodic land[1] (ha)	Sodic area to total geographical area (%)	Sodic area reclaimed by 2006-07[2] (ha)	Reclaimed area to total sodic land (%)
Mainpuri	123042	44.58	61963	50.36
Azamgarh	97751	23.09	34215	35.00
Etawah	97042	41.99	42830	44.14
Raebareli	86586	18.79	69146	79.86
Hardoi	84341	14.09	55729	66.08
Sultanpur	79389	17.90	68015	85.67
Jaunpur	78807	19.52	36867	46.78
Pratapgarh	72229	19.43	42702	59.12
Etah	69076	15.54	42829	62.00
Unnao	59687	13.09	53713	89.99
Farrukhabad	54373	24.93	22450	41.29
Kanpur	54218	8.78	44723	82.49
Aligarh	43670	11.96	37176	85.13
Lucknow	42704	16.89	17684	41.41
Allahabad	42333	8.24	18350	43.35
Other districts	283713	1.57	276464	97.44
Uttar Pradesh	1368960	5.68	924856	67.56

Source: [1]NRSA (1996). [2] Information provided by Uttar Pradesh Land Development Corporation, Government of Uttar Pradesh.

3.2 Cropping intensity: The average cropping intensity during 2009-2012 was 146 per cent (Table 4). The cropping intensity was higher (97%) in *kharif* season than the *rabi* season (49%). Transplanted rice is the main *kharif* season crop. Rice tolerate higher alkalinity condition and some traditional salt tolerant varieties can withstand high pH up to 10 (Mishra and Bhattacharya, 1980). Rice is often recommended as a desalinization crop, because it grows well in standing water and its above ground parts can consume alkalinity in alkaline soil (Wang, *et al.*, 2010).

Table 4. Cropping intensity by soil alkalinity classes

Soil alkalinity class	Cropping intensity (%)			
	2009-2010	2010-2011	2011-2012	Average
Normal	197	198	198	198
Slight	192	197	197	195
Moderate	95	95	97	96
Severe	93	95	95	94
Annual average	144	146	147	146
Average in *Kharif*	97	97	98	97
Average in *Rabi*	48	49	49	49

The cropping intensity in *rabi* season was lower (49%) because of larger cultivable area was left fallow due to higher alkalinity levels. The farmers grew wheat crop in *rabi* season which is generally regarded as moderately tolerant to alkali soil (Munns, *et al.*, 2006; Lin, *et al.*, 2012). Hence, cropping intensity depends on the extent of land degradation and decreased with increase in soil alkalinity levels.

3.3 Crop yields: The severity of soil alkalinity varied across the village and remarkably reduced the crop yield (Table 5 and Table 6).

Table 5. Average yield of rice (t/ha) in different alkalinity classes

Year	Soil alkalinity class			
	Normal	Slight	Moderate	Severe
2009 - 2010	4.81	3.26	2.10	0.00
2010 - 2011	4.89	3.28	2.23	0.00
2011 - 2012	4.82	3.21	1.89	0.00
Average	4.84	3.25	2.07	0.00
Yield loss (%)	-	33	57	100.00

Note: No crop production in 'severe' sodicity class land.

Table 6. Average yield of wheat (t/ha) in the different soil alkalinity classes

Year	Soil alkalinity class			
	Normal	Slight	Moderate	Severe
2009- 2010	4.45	2.48	0	0
2010 - 2011	4.63	2.54	0	0
2011 - 2012	4.51	2.42	0	0
Average	4.53	2.48	-	-
Yield loss (%)	-	45	100	100

Note: No crop production in 'moderate' and 'severe' sodicity classes during rabi season

The rice yield decreased from 4.84 t/ha in 'normal' soils to 3.25 t/ha in 'slight' soil alkalinity class, indicating 33 per cent decline. Several studies have shown that crop yield decreases with increase in the level of alkalinity (Dwivedi and Qadar, 2011; Chhabra, 2002; Abrol and Bhumbla, 1979). The yield reduction was drastic (57%) in 'moderate' soil salinity class. A large number of studies indicated that the alkalinity inhibits shoot and root growth of rice seedlings and had the smallest biomass when grown under alkali conditions (Van Aste, et al., 2003; Wang, et al., 2011; Chhabra, 1996).

The wheat yield decreased from 4.53 t/ha in 'normal' soil to 2.48 t/ha in 'slight' land class, depicting 45 per cent yield loss (Table 6). The wheat yield loss was greater at the higher alkalinity levels (Sharma *et al.*, 2010). Yield of wheat is highly dependent on the number of spikes produced by each plant. Alkali conditions negatively affect the number of spikes produced per plant (Maas and Grieve, 1990) and its fertility (Fatemeh, *et al.*, 2013; Seifert, *et al.*, 2011). Alkali soils usually have poor availability of most micronutrients, which is generally attributed to high soil pH (Naidu and Rengasamy, 1993). In addition, poor physical properties of sodic soils, which directly limit crop growth through poor seedling emergence and root growth, also exhibit indirect effects on plant nutrition by restricting water and nutrient uptake and gaseous exchange (Curtin and Naidu, 1998) which ultimately result in reduced crop yield and quality (Grattan and Grieve, 1999).

There was no wheat production in 'moderate' and 'severe' soil alkalinity classes due to high pH. A high pH condition damages plants directly and causes deficiencies of nutritional minerals such as iron and phosphorus (Guan *et al.*, 2009). The 'severe' category of soil alkalinity class remained barren in both the seasons due to high alkalinity as ESP ranged from 65 to 90 and pH varied from 9.5 to 11. Heavy salt stress generally leads to reduced growth and even plant death (Parida and Das, 2005; Qadar, 1998).

3.4 Cost of cultivation and production: The cost of cultivation for rice (Table 7) and wheat (Table 8) were uniform across the soil alkalinity classes, due to use of inputs and farm operations remained almost same across the soil alkalinity classes. However, alkalinity impacted on the unit cost of production. It has remarkably increased per tonne cost

Table 7. Average cost of production of rice crop in various soil alkalinity classes

Year	Soil alkalinity class						
	Normal		Slight		Moderate		Severe
	(₹/ha)	(₹/t)	(₹/ha)	(₹/t)	(₹/ha)	(₹/t)	(₹/ha)
2009 - 2010	41166	8558	39651	12163	37983	18087	0
2010 - 2011	41470	8480	39499	12042	37832	16965	0
2011 - 2012	41015	8509	39196	12211	38135	20177	0
Average cost	41217	8516	39449	12139	37983	18410	0
Increase in cost of production (%)	-	-	-	43	-	116	-

Note: No crop production in 'severe' sodicity class land during kharif season.

Table 8. Average cost of production of wheat crop in various soil alkalinity classes

Year	Soil alkalinity class						
	Normal		Slight		Moderate		Severe
	(₹/ha)	(₹/t)	(₹/ha)	(₹/t)	(₹/ha)	(₹/t)	(₹/ha)
2009 - 2010	31915	7172	27903	11251	-	-	-
2010 - 2011	32622	7046	28139	11078	-	-	-
2011 - 2012	32607	7230	28139	11628	-	-	-
Average cost	32381	7149	28060	11319	-	-	-
% increase in cost of production	-	-	-	58	-	-	-

Note: No crop production in 'moderate' and 'severe' sodicity classes during rabi season.

of rice by 116 per cent in 'moderate' soil class compared to the 'normal' soil class. The per tonne production cost of wheat has increased by 58 per cent in 'slight' soil class. This indicates that production costs per tonne of produce increases with higher alkalinity level, due to lower crop productivity at the higher level of soil alkalinity.

3.5 Gross and net returns: Rice (*Kharif* season crop) and wheat (*Rabi* season crop) production costs and returns were estimated for each salinity class (Table 9). The gross income of rice and wheat decreased with increase in soil quality deterioration. Net income decreased more sharply compared to gross income with increase in alkalinity level, because the total cost of production remained almost uniform throughout the soil alkalinity classes.

Table 9. Average returns and cost (₹/ha) per season (2009-2012)

Alkalinity class	Gross return		Total cost		Net returns	
	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi
Normal	77423	72405	41217	32381	36206	40024
Slight	51875	39563	39449	28060	12427	11503
Moderate	33073	-	37983	-	-4910	-

Note: 'Moderate' sodicity category lands were kept fallow only during rabi season. 'Severe' sodicity category lands were kept fallow in both the seasons.

The net income from 'slight' land class was lower (₹ 12427/ha) compared to net income (₹ 36206/ha) from 'normal' land in *kharif* season, depicting a loss of ₹ 23780 per ha. The farmers incurred income loss (₹ 4910/ha) in 'moderate' soil alkalinity class. In *rabi* season, decline in the net income was 71 per cent in 'slight' soil alkalinity class and the 'moderate' land class was kept fallow. The rate of income loss increased with higher levels of alkalinity. Hence, it was clear that the soil alkalinity adversely affected the net income across the soil alkalinity classes and income losses were more in higher alkalinity levels.

Table 10. Potential and actual damage caused by soil alkalinity (₹ per ha)

Year	Kharif		Rabi		Agricultural year	
	Potential damage	Actual damage	Potential damage	Actual damage	Potential damage	Actual damage
2009	5135	4993	5389	2618	10524	7611
2010	5128	4987	5693	2765	10821	7752
2011	5351	5203	5446	2646	10797	7849
Average	5204	5061	5509	2676	10714	7737

Source: Authors' estimates

3.6 Estimation of farm income losses: The knowledge regarding the extent of income losses at different alkalinity levels are essential for the management of degraded lands and planning agricultural policy. Such losses can influence the livelihood and food security of resource poor farmers. The farm income losses were estimated by subtracting the net income per ha in each soil alkalinity class from the net income of the 'normal' soil class for each crop. The potential farm income losses per ha has been calculated by multiplying estimated farm income loss values with corresponding proportional areas of alkalinity classes in accordance with Table 2.

The actual farm income losses per ha in *kharif* and *rabi* has been estimated by multiplying potential farm income losses with the corresponding cropping intensities. The average cropping intensities in *kharif* and *rabi* were 97 and 49 per cent, respectively, accordance with the cropping intensity data of Table 4. In order to calculate the actual income loss per ha, the potential income loss figures for *kharif* and *rabi* were multiplied by the factors 0.97 and 0.49, respectively.

The total potential and actual farm income losses per agricultural year per ha has been estimated by summing up *kharif* and *rabi* seasons income loss values (Table 10). The annual potential and actual losses per ha due to alkalinity were ₹ 10714 and ₹ 7737, respectively. The overall potential annual farm income loss in Ahemi was ₹ 0.54 million due to soil alkalinity.

It may be summarized that soil alkalinity is one of the major problems that negatively affect the farm production and income. The level of crop productivity and farm income are the major factors that decide the livelihood of farmers and hence it is a matter of serious concern for the policy makers. Several international developmental agencies, central and state governments are making efforts to reclaim the existing sodic land to augment the farm productivity in India. However, still a large part of agricultural land is out of cultivation due to salt related problems. Therefore, it is suggested that these lands should be reclaimed on a priority basis to improve the soil productivity and farm income so as to raise the livelihood security of resource-poor farmers.

References

1. Abrol IP and DR Bhumbla. 1979. Crop response to differential gypsum application in a highly sodic soil and tolerance of several crops to exchangeable sodium to under field conditions. *Soil Science* **127**(1): 79-85.
2. Abrol IP and IS Dahiya. 1974. Flow-associated precipitation reactions in saline-sodic soils and their significance. *Geoderma* **11**: 305-312.
3. Ashraf MY and G Sarwar. 2002. Salt tolerance potential in some members of *Brassicaceae*: Physiological studies on water relations and mineral contents. In: Prospects for Saline Agriculture (Eds.) R. Ahmad and KA Malik. Kluwer Academic Publishers, Netherlands, pp. 237-245.
4. Chhabra R. 1996. Soil Salinity and Water Quality, Oxford and IBH Publication, New Delhi.
5. Chhabra R. 2002. Salt-affected soils and their management for sustainable rice production - key management issues: a review. *Agriculture Review* **23**(2): 110-126.
6. Curtin, D and R Naidu. 1998. Fertility constraints to plant production. In: Sodic Soil: Distribution, Management and Environmental Consequences (Eds.) ME Sumner and R Naidu. Oxford University Press, New York, pp. 107–123.
7. Dwivedi, RS and A Qadar. 2011. Effect of sodicity on physiological traits. In: Sustainable Management of Sodic Lands (Eds.) DK Sharma, RS Rathore, AK Nayak and VK Mishra. Central Soil Salinity Research Institute, Karnal, Haryana.
8. Fatemeh R, AK Pouya and N Karimian. 2013. Wheat yield and physico-chemical properties of a sodic soil from semi-arid area of Iran as affected by applied gypsum. *Geoderma* **193–194**: 246-255.
9. Ghassemi F, AJ Jakeman and HA Nix. 1995. Salinisation of Land and Water Resources: Human Causes, Extent, Management and Case Studies. CABI Publishing: Wallingford.

10. Grattan SR and CM Grieve. 1999. Salinity–mineral nutrient relations in horticultural crops. *Scientia Horticulturae* **78**: 127–157.

11. Guan B, D Zhou, H Zhang, Y Tian, W Japhet and P Wang. 2009. Germination responses of *Medicago ruthenica* seeds to salinity, sodicity, and temperature. *Journal of Arid Environment* **73**:135–138.

12. Gupta RK and IP Abrol. 2000. Salinity build-up and changes in the rice–wheat system of the Indo-Gangetic Plains. *Experimental Agriculture* **36**: 273–284.

13. Lin J, X Li, Z Zhang, X Yu, Z Gao, Y Wang, J Wang, Z Li and C Mu. 2012. Salinity-sodicity tolerance in wheat: Seed germination, early seedling growth, ion relations and solute accumulation. *African Journal of Agriculture Research* **7**(3): 467-474.

14. Maas EV and CM Grieve. 1990. Spike and leaf development in salt-stressed wheat. *Crop Science* **30:** 1309–1313.

15. Mandal AK, RC Sharma, G Singh and JC Dagar. 2010. Computerized data base on salt affected soils in India. Technical Bulletin: CSSRI/ Karnal/2/2010, Central Soil Salinity Research Institute, Karnal, India.

16. Mishra B and RK Bhattacharya. 1980. Limits to varietal tolerances to sodicity in rice. *In: International Symposium on Salt Affected Soils.* Central Soil Salinity Research Institute, Karnal.

17. Munns R, AR James and A Läuchli. 2006. Approaches to increasing the salt tolerance of wheat and other cereals. *Journal of Experimental Botany* **57** (5): 1025-1043.

18. Naidu R and P Rengasamy. 1993. Ion interactions and constraints to plant nutrition in Australian sodic soils. *Australian Journal of Soil Research* **31**: 801–819.

19. NRSA and Associates. 1996. Mapping salt-affected Soils of India on 1:250000. National Remote Sensing Agency, Hyderabad.

20. Parida AK and AB Das. 2005. Salt tolerance and salinity effects on plants: A review. *Ecotoxicology Environmental Safety* **60**: 324–349.

21. Qadar A. 1998. Alleviation of sodicity stress on rice genotypes by phosphorus fertilization. *Plant and Soil* **203**: 269–277.

22. Qadir M, AD Noble, S Schubert, RJ Thomas and A Arslan. 2006. Sodicity-induced land degradation and its sustainable management: problems and prospects. *Land Degradation and Development* **17**: 661–676.

23. Rahman M, UA Soomro, MZ Haq and S Gul. 2008. Effects of NaCl Salinity on Wheat (*Triticum aestivum* L.) Cultivars. *World Journal of Agricultural Sciences* **4** (3): 398-403.

24. Scherr Sara J and S Yadav. 1996. Land Degradation in the Developing World: Implications for Food, Agriculture, and the Environment to 2020, International Food Policy Research Institute, Washington, D.C. U.S.A.

25. Seifert C, IO Monasterio and DB Lobell. 2011. Satellite based detection of salinity and sodicity impacts on wheat production in the Mexicali Valley. *Soil Science Society of America Journal* **75**(2): 699-707.

26. Sharma PK, SK Sharma and IY Choi. 2010. Individual and combined effects of waterlogging and sodicity on yield of wheat (*Triticum aestivum L.*) imposed at three critical stages. *Physiology and Molecular Biology of Plants* **16**(3):317–320.

27. Szabolcs I. 1994. Soils and salinization. In: Handbook of Plant and Crop Stress, Pessarakli M (Eds.) Marcel Dekker, New York, pp. 3–11.

28. Thimmappa K, RS Tripathi, R Raju and YP Singh. 2013. Livelihood security of resource poor farmers through alkali land reclamation: An impact analysis. *Agricultural Economics Research Review* **26:**139-147.

29. Van Aste PJA, MCS Wopereisl, S Haefelel. Quid Isselmou, M. and Kropff, M.J. (2003) Explaining yield gaps on farmer-identified degraded and non-degraded soils in a Sahelian irrigated rice scheme, *Net Journal of Agricultural Sciences* **50**(3/4): 277-296.

30. Van der Zee S.E.A.T.M., Shah, S.H.H., Van Uffelen, C.G.R., Raats, P.A.C. and Dal Ferro, N. (2010) Soil sodicity as a result of periodical drought, *Agricultural Water Management* **97**:41–49.

31. Wang, H., Wu, Z., Chen, Y., Yang, C. and Shi, D. (2011) Effects of salt and alkali stresses on growth and ion balance in rice (*Oryza sativa L.*). *Plant Soil and Environment* **57:** 286–294.

32. Wang, M.M., Liang, Z.W., Yang, F., Ma, H.Y., Huang, L.H. and Liu, M. (2010) Effects of number of seedlings per hill on rice biomass partitioning and yield in a saline-sodic soil. *Journal of Food Agriculture and Environment* **8**: 628–633.