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Review Articles

Strategies of increasing crop production and productivity in problem soils

I. A. Jehangir, M. H. Khan and Z. A. Bhat
Division of Agronomy, SKUAST-K, Shalimar Srinagar (J&K) India -191 121

Abstract: Problem soils are those which owing to land or soil characteristics cannot be economically used for cultivation of crops without adopting proper management strategies. More than 50 per cent of 143 m ha-1 (net cultivated area) falls in the category of problems soils. More than 90 per cent of the land in the north eastern states alone is affected by soil acidity of varying degrees which have restricted the crop choice in more than 70 per cent of gross cropped area in this region to cereals particularly the rice. The amelioration of 25 million hectares promises additional 25 million tones of food grains. Besides, the fertilizer use as well its efficiency is also poor due to unfavorable pH conditions. The soil degradation due to salinity and alkalinity problems had affected significant chunk of fertile tracts, covering an area of about 67.27 lac hectares. The emphasis should therefore be given to solve these soil problems by adopting different management strategies like addition of different amendments, choice of crop, irrigation and drainage management for increasing the production as well as productivity on sustainable basis.

Key words: Crop production, crop productivity, problem soils mitigation strategies

Introduction

Apart from providing self sufficiency in food, the agriculture has enabled to produce important products. During last four decades our country has gone through several revolutions viz., Green, White, Blue and Tea and second largest producer of rice, wheat, ground nut, sugarcane, fruits and vegetables (Sen, 2003). However we can not ignore the fact that productivity level in food grains is still way behind our European counter parts. Despite our huge food reserves a majority of our population are hungry with increasing famine face to it. More importantly the increasing demand for food and other allied products due to fast growing population has lead to over explosion of our natural resource basis and had ultimately degraded and polluted them. Non availability of cultivated lands had compelled us to practice arable forming on land which is not suitable for cultivation and thus has put more stress on this ecologically vulnerable recourse. About 50 % of 143m ha area of our country is presently affected by various soil problems. The concept of problem soil does not bring concrete definition. Each soil type is specific formation by the interaction of parent material, calamite, organism, topography and time. The deriving soil properties leave consequences for the use of man. The possible type of agricultural use of given soil may vary considerably. Thus the problem soil is always related to a specific land use situation. However in general problem soils are defined as those which owing to land or soil characteristics can not be economically used for cultivation of crops without adopting reclamation measures. Broadly there are three types of problem soils

- Acid soils
- Saline soils
- Alkaline soils

Soil acidity

Acid soils may be defined as the soil systems proton donating capacity during its transition from a given state to reference state. In India acid soils cover an area of about 89.94m ha (Sharma and Sarkar 2005) of which maximum area is covered by Madaya Pradesh (Table 1).

Sources of soil acidity

- Leaching due to heavy rain fall
- Acid parent material
- Acid forming fertilizers and soluble salts
- Humus and other organic acids
- Aluminosilicate Minerals
- Carbon Dioxide
- Hydrous Oxides
- Aluminium and Iron Polymers

Production constraints

Increased solubility and toxicity of Al, Mn and Fe; deficiency of Ca and Mg; reduced availability of P and Mo and reduced microbial activity with decreasing pH are characteristic features of acid soils. Toxic concentrations of aluminum have been reported in sedentary soil with pH below 5.0 and alluvial soil with pH below 4.5. Al toxicity in soil reduces length and branching of roots (Sarkar and Debnath, 1989).

Acidity of varying degrees had restricted the crop choice in more than 70% of gross cropped area in north eastern states to cereals particularly rice with a meager area under pulses and oilseeds with poor productivity level (Velayutham and Bhattacharyya, 2000) Table 2.

Table 1: Extent of acid soils in different states of India (million ha.)

States	Strongly acidic (pH < 4.5)	Moderately acidic (pH 4.5-5.5)	Slightly acidic (pH 5.5-6.5)	Total
ArunachalPradesh	4.78	1.74	0.27	6.79
Assam	0.02	2.31	2.33	4.66
Bihar	-	0.04	2.32	2.36
Chhatisgarh	0.15	6.30	4.39	10.84
Goa	-	0.11	0.19	0.30
Himachal Pradesh	-	0.16	1.62	1.78
Jammu&Kashmir	-	0.09	1.48	1.57
Jharkhand	-	1.00	5.77	6.77
Karnataka	-	0.06	3.25	3.31
Kerala	0.14	2.87	0.75	3.76
Madhya Pradesh	-	1.12	10.60	11.72
Maharashtra	-	0.21	4.33	0.54
Manipur	0.42	1.44	0.32	2.19
Meghalaya	-	1.19	1.05	2.24
Mizoran	-	1.27	0.78	2.05
Negaland	0.12	1.48	0.05	1.65
Orissa	-	0.26	8.41	8.67
Sikkim	0.28	0.32	-	0.60
Tamil Nadu	0.21	0.35	4.29	4.85
Tripura	0.06	0.75	0.24	1.05
Uttranchal	-	1.18	2.30	3.48
WestBengal	-	0.56	4.20	4.76
Total	6.19	24.81	58.94	89.94

[Source: NBSS LUP, Nagpur, 2005]

Table 2: Expected loss of productivity due to acidification

Class	pH	Degree	Loss in productivity
0	>6.5	Nil	Nil
1	5.5-6.5	Slight	Up to10
2	4.5-5.5	Moderate	10-25
3	3.5-4.5	Strong	25-50
4	3.5	Moderate	>30

Management strategies

Management of acid soils should be directed towards enhanced crop productivity either through addition of amendments to correct the soil abnormalities or by manipulating the agronomic practices depending upon climatic and edaphic conditions.

a) Soil amelioration

Lime has been recognized as an effective soil ameliorant as it reduces Al, Fe and Mn toxicity and increase base saturation, P and Mo availability of acid soils. Liming also increases the atmospheric Nitrogen fixation as well as nitrogen mineralization in acid soils. The reaction of soil amelioration is as follows:

$$\text{Soil Colloid} + CaCO_3 \longrightarrow \text{Soil Colloid-}Ca^{++} + H_2O + CO_2$$

Common problems in acid soils in respect of chemical properties like (i) low pH (ii) low CEC (iii) low base saturation could be managed by simply amelioration by liming which improves pH, base status, and CEC (Sahu and Patnaik, 1990) (Table 3).

Table 3: Effect of lime and organic matter on change in pH, CEC and base saturation of acid Alfisol

Locations	Initial pH	Initial CEC [cmol(p^+)kg^1]	Lime*			Organic matter **		
			pH	CEC [cmol(p+)kg^1]	BSP	pH	CEC [cmol(p+)kg^1]	BSP
Jashipur	4.6	7.8	6.3	8.2	66.9	5.2	6.9	56.3
Samkhunta	5.2	9.0	6.2	9.2	90.4	5.3	10.6	43.4
Suakati	5.6	11.6	6.5	12.0	80.0	5.9	10.7	45.0
Bargain	6.5	4.6	7.7	5.3	99.1	6.7	4.7	56.4
Mahisapat	6.0	4.6	6.7	4.8	94.1	66.3	4.6	66.7
Semiliguda	5.6	6.5	6.8	7.1	99.2	5.9	7.4	64.3
Bhubaneswar	4.4	2.8	6.0	3.4	96.2	4.8	3.3	57.8

[Sahu and Patnaik, 1990]

Pattanayak *et al.* (2001) used lime stone @ 50% LR for amelioration of acid inceptisol for growing Okra crop. Lime application either alone or in combination with FYM significantly influenced the fruit yield, which resulted in 19 and 42% increase over control (Table 4).

Bal (2001) carried out an experiment on yield of green gram as influenced by soil amendments under acid soils, results of which depicted that with the integrated crop management practices like lime application to soil, seed treatment with Mo and Co, seed inoculation with rhizobium and FYM application yield of 450Kg of grain ha^{-1} which was 88% higher to control (Table 5)

Table 4: Effect of lime application on yield and nutrient uptake by okra crop

	pH at harvest	Fruit yield (t/ha $^{-1}$)	Nutrient uptake (kg ha $^{-1}$)					
			N	P	K	Ca	Mg	S
Control	5.6	4.51	39.7	5.5	41.8	24.2	10.2	3.8
Lime	6.6	4.9 (19)*	46.9	7.3	47.5	27.8	12.0	4.8
FYM	5.8	5.70 (26)	54.6	8.8	59.3	31.6	13.5	5.5
Lime + FYM	6.4	6.40 (48)*	60.7	9.8	65.5	36.2	14.9	6.2
CD (P=0.05)		0.38	2.9	0.49	3.3	2.1	0.5	0.3

Initial pH 5.90 [Source : Pattanayak *et al*., 2001]

Table 5: Yield of green gram as influenced by soil amendment, seed treatment with micronutrients and seed inoculation in acid *Alfisol*

Treatment	Yield (q/ha)	Use efficiency (kg grain/kg nutrient)			Extra N gain (kg ha $^{-1}$)
Control	2.4	-	-	-	-
Rhizobium (R)	3.1 (29)*	4.0	1.7	2.3	12.0
R + Mo + Co	3.3 (38)	5.2	2.2	3.0	38.0
R + Lime (L)	3.7 (54)	7.4	3.1	4.3	41.0
R + Mo + Co + L	4.5 (88)	12.0	5.1	7.0	60.0
CD (P=0.05)	0.2	-	-	-	-

Data in the parenthesis indicate per cent increase over control (Source: Bal, 2001)

Table 6: Soil reaction preference of different crops

Crops	Optimum pH range
Cereals	
Maize, sorghum, wheat, barley	6.0-7.5
Millets	5.0-6.5
Rice	4.0-6.0
Oats	5.0-7.7
Legumes	
Field beans, soybeans, pea, lentil etc.	5.5-7.5
Berseem	6.0-7.5
Groundnut	5.3-6.6
Miscellaneous crops	
Sugarcane	6.0-7.5
Cotton	5.0-6.5
Potato	5.0-5.5
Tea	4.0-6.0

Source : Mandal *et al.* (1975)

Table 7: Crop varieties tolerant to soil acidity (pH<5.5) for different states

Acid soil region/state	Crop	Varieties
Assam	Rape seed	Varuna, Sonmukhi
	Summer greengram	K851, Sonmugu
Himachal Pradesh	Soybean	Bragg, Ph1, Harasoya
	Gobhi sarson	ONK1, Hoyala, HPN-3
Jharkhand	Blackgram	KU-301
Kerala	Vegetable cowpea	Bhagyalakshmi
	Cowpea (Bush type)	V-16
Meghalaya	French bean	HUR-15
Orissa	Grondnut	Smruti
	Pigeon pea	UPAs-120
West Bengal	Mustard	Sanjukta, Pusa bold
	Wheat	K9107, PBW 343

Source: ICAR Net Work Project on Acid Soils, 2005

b) Crop choice

Selection of crops tolerant to acidity is an effective tool to counter this soil problem and breeding of such varieties is of specific importance for attaining higher productivity particularly in the areas where liming is not economical. From the Table 6, it is evident that rice and tea are most acid tolerant crops and thus can be grown successfully in the areas suffering from acid soils (Mandal *et al.*, 1975).

c) Varieties tolerant to soil acidity

The growing of crop genotypes/cultivars tolerant to soil acidity is another strategy to increase productivity of acid soils. The varieties identified for this purpose are given in (Table 7)

B. Saline soils

Saline soils also known as solonchaks, are those that contain appreciable amounts of soluble salts so as to interfere with plant growth. Saline soils are characterized by EC>4dsm^{-1}, pH<8.5, ESP<15.the state wise extent of salt affected soils is as shown below (Table 8):

Table 8: State wise extend of salt affected soils in India (ha)

State	Saline	Sodic	Total
Andhra Pradesh	77598	196609	274207
Andaman & Nicobar islands	77000	0	77000
Bihar	47301	105852	153153
Gujarat	1680570	541430	2222000
Haryana	49157	183399	232556
Karnataka	1893	148136	150029
Kerala	20000	0	20000
Madhya Pradesh	0	139720	139720
Maharashtra	184089	422670	606759
Orissa	147138	0	147138
Punjab	0	151717	151717
Rajasthan	195571	179371	374942
Tamil Nadu	13231	354784	368015
Uttar Pradesh	21989	134671	1368960
West Bengal	441272	0	441272
Total	2956809	3770659	6727468
Jammu and Kashmir	-	17,500	17,500

[Source: Sharma *et al*., 2007]

Development of saline soils

Saline soils are formed when ever; climate, soil, and hydrological conditions favor accumulation of soluble salts in root zone and are influenced by;

Climate

Salt affected soils are common in arid and semiarid region that receive inadequate and irregular precipitation to accomplish leaching of salts originally present in the soil profile. Normally if the area gets more than 1000 mm rainfall annually, then saline soils are not formed. The accumulation of salts in the surface layer can also be enhanced by cool wet season alternating with hot dry season.

Soils

Normally light textured soils get salinised than heavy textured soils because;

a) Light textured soils are highly drained and thus the salts get leached out easily and quickly.
b) These soils have low CEC and thus retain fewer salts than heavy textured soils.
c) Light textured soils have poor capillary rise and thus are likely to get less affected by shallow brackish water table.

Hydrological conditions

The following hydrological conditions may favor water logging and accumulation of salts resulting in formation of saline soils.

i. Low-lying areas resulting in surface accumulation of salts brought about by runoff from outside. In coastal areas, the inundation of surface soils by sea water during highs tides and ingress of sea water through rivers estuaries and underground aquifers are major causes of salinity development.
ii. Contributions from the high aquifers and/or adjoining areas through seepage may increase the total salts and/or raise the water table encouraging the development of salinity.
iii. On introduction of irrigation in an area, the ground water generally rises or forms perched water table. Rise in water table is the major cause of soil degradation in many irrigated areas.

Salinity tolerance of crops

Usually it is difficult to fix a limit of tolerance where the plant will fail to grow. Generally plants suffer a slow death with the increase in soil salinity. However based on average soil ECe and generalized plant response, the following salinity classes have been recognized (Table 9).

Management strategies

a) Leaching

Leaching is done to reduce the root zone salinity to desired levels through removal of excess salts. Leaching efficiency in saline soils primarily depends upon soil type, depth of applied soil water, soil profile characteristics, absorption and exchange reactions during leaching. Quality of water is also an important factor for leaching the saline soils.

Table 9: Soil salinity classes and crop growth

Soil salinity class	ECe, dS/m	Effect on crop plants
Non-saline	<2	Salinity effects negligible
Slightly saline	2-4	Yield of sensitive crops may be restricted
Moderately saline	4-8	Yield of many crops restricted
Strongly saline	8-16	Only tolerant crops yield satisfactory
Very strongly saline	>16	Only a few very tolerant crops Yield satisfactorily

b) Crop choice

Yield reduction in saline soils can be minimized through selection of salt tolerant crops. The list is given as below;

Tolerant	Medium tolerance	Sensitive
Barley	Wheat	Legumes
Cotton	Rice	Beans
Sugar beet	Oats, maize, potato, sorghum	Groundnut

c) Proper seed placement

Plants are generally most sensitive at early vegetative stages of growth and become more tolerant at later stages. It is well known that salts tend to accumulate on the ridges away from the wet zone when irrigation is adopted. Putting the seed off centre of the seed row will put the seed in minimum salinity and optimum moisture conditions. Under high salinity alternate row should be left unirrigated, this will ensure maximum accumulation of salts in that (nnirrigated) area and leave furrows free of salts and fits for planting seed.

d) Method of raising plant

Germinating seeds are severely affected by osmotic effects of salinity, resulting in higher mortality and thus poor crop stand; the crop should be raised by transplanting seedlings. For this, older seedlings raised in nursery on good soil should be used.

e) Method of water application

Efficient water management leads to increased crop yield under saline conditions. Drip, sprinkler and pitcher irrigation have been found to be more efficient than conventional flood irrigation method, since relatively lesser amount of water is required under the improved methods. Drip and pitcher methods are very useful for saline soils as they add water directly in to root zone at controlled rates and even saline waters can be used under these methods without any detrimental effects on crop growth owing to dilution of salts at root zone.

f) Use of mulches

The upward movement of salts is reduced by mulching due to decreased evaporation. The addition of organic matter improves physical conditions of soil and more water holding capacity keeps salts in diluted form.

C. Alkali soils

Alkali soils, also known as sodic soils, are those that contain measurable amounts of soluble salts capable of alkaline hydrolysis, mostly Co32- and HCo3- of Na+, which in presence of $CaCo_3$ give the soils high pH and poor physical conditions. These soils are characterized by Ec dsm-1<4, pH> 8.5, ESP>15.

Major production constraints

These soils due to high ESP, possesses poor physical properties. The high sodium content of soils leads to dispersion of fine clay particles resulting into low permeability, crusting and hardening of surface soil upon drying as a result the aeration, soil water movement and root growth is impeded. Besides high Na content is often toxic to many plants which exhibits poor growth and yield in these types of soils .these soils have poor aggregate stability, low organic matter contents, toxic concentration of CO_2 and HCO_3 poor microbial growth and reduced availability of N, K, Zn, Fe etc.

Management strategies

- Amendments
- Land leveling and shaping
- Plant population
- Age of seedlings
- Green manuring
- Continuous cropping

Water management

i) Drainage

ii) Irrigation

Crop choice

a) Amendments

To have successful crops in alkali soils, ESP of the soil must be lowered, which can be achieved by application of amendments. Amendments are those materials which 1)directly supply Ca for replacement of exchangeable Na^+ or (ii) furnish Ca^+ indirectly by dissolving calcite, natively found in alkali soils, due to their acidulating action or by increasing the partial pressure ofCO_2.The Ca^{2+} so mobilized is used to replace Na+ from the exchange complex and thus reclaims the alkali soil. Various types of amendments used for reclaiming alkali soils are as follows;

b) Land leveling and shaping

To ensure proper water management and uniform leaching of salts, the filed should de leveled properly. The big fields should be divided into small parcels and leveled. Drastic removal of surface soil will expose the subsoil containing caco3, which can pose difficulties in reclamation and cropping of the area.

c) Plant population

Because of the hard crust on the surface, germination percentage is often low in alkali soils. Plant population further decreases because of high rate of mortality especially during early stages of plant growth. This together with poor tillering can reduce crop yield. Crop stand in alkali soils can be improved by increasing the seed rate and reducing the plant distance.

d) Age of seedlings

Generally crop tolerance, in rice old seedlings (40-45 days) have been found to establish better than younger seedlings (25-30 days). Similarly by establishing by tree species, planting old seedlings has proved to be beneficial.

e) Green manuring

Application of green manure can help to enhance OM Content, increases partial pressure of CO_2 lower pH, enhance solubility of native $CaCo_3$ and add considerable amount of plant nutrients in the soil. For this sesbania which is tolerant to both high ESP and water logging is an ideal crop.

f) Continuous cropping

On application of amendments leaching and cropping, replaced Na^+ keeps downwards and there is continuous reduction in exchangeable sodium of the soil through out the soil profile. Therefore land should continuously cropped to keep the downward movement of replaced Na^+ and soluble salts.

g) Water management

Water management is an important aspect of alkali soil management, as soil remains saturated for longer periods of time after irrigation or rain due to poor drainage, which the importance of drainage as well as irrigation management.

h) Drainage

As alkali soils basically have low infiltration rate, all the rain water accumulates t o create surface water logging and anaerobic condition which results in suffering of plants from oxygen stress. To avoid this surface drainage, especially during rainy season is must.

i) Irrigation

Irrigation management in alkali soils poses peculiar problems due to clogging action of dispersed soil particles and low stability of soil aggregates, which limits the water and air permeability of those soils. Normally a surface method of irrigation such as furrow or basin type flood method is used. However keeping in view their susceptibility to surface water logging, the sprinkler method could be promising because of its ability to supply water uniformly and in small quantity.

Conclusion

It is therefore imperative that to solve these soil problems and make the lands highly productive on a sustainable basis. We need to adopt the management strategies suitable to specific locations which will be economically feasible and workable at farmer's field. As we all know the estimated production target is going to increase sharply within a very short span of time, so we have to give the emphasis on increasing current yield level through the adoption of management strategies like addition of amendments, use of suitable crop varieties and choice of crops irrigation and drainage management.

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