RESOLUTION OF NUTRITIONAL FACTORS AFFECTING CROP PRODUCTIVITY IN USAR SOILS IN UTTAR PRADESH

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ABSTRACT

Usar soils form a large proportion of the cultivable land in Uttar Pradesh. Crop production on such soils, amongst other factors, is severely limited due to alkaline reaction, some toxic constituents and deficiencies of certain essential plant nutrients. Present studies deal with the availability of essential plant nutrients in native usar soils of central Uttar Pradesh and in soils alkalised by sodium salts or irrigated with waters of graded SAR (Sodium Adsorption Ratio). Study of available information on Usar soils suggest that availability of plant nutrients in these soils is a function of soil alkalinity, salinity and the actual ionic constituents of the soil. It is also affected by the genotype and the stage of plant growth. Crop productivity in usar soils can be markedly improved by suitable mineral amendments along with the selection and use of tolerant crop varieties.

INTRODUCTION

About 1.2 million hectares of agricultural land in Uttar Pradesh is infested with saline, sodic or both conditions. Most of these salt affected halomorphic soils lie in the semi-arid or arid tracts of the State representing old alluvium 'Bangar' These are commonly known as 'Usar' (LEATHER, 1893), which on the basis of certain physico-chemical properties can be further classified into five categories as under (U.S.D.A., 1954):

Soil Classes	E. Ce. (m.mhos/cm. at 25°C)	E.S.P.	pH	S.S.P.
Saline-nonsodic=Solanchak	>4	<15	<8.5	<50
Saline—sodic	>4	>15	<8.5	>50
Non—saline-sodic=Solonetz	<4	>15	8.5—10	>50
Non-saline-nonsodic=Normal	<4	<15	Appx. 7	Low
Degraded alkali=Solodi	<4	>15	As low as 6	

Data obtained from the study of some halomorphic soils of U. P. (Table 1) suggested that crop productivity on these soils is restricted by saline, alkali or saline-alkali conditions. In most of these soils (Table 1) Na^+ is the dominant cation and CO_3^{--5} HCO^- and less often Cl^{--} and $SO_4^{--}9$ the dominant anions. These may also contain excessive amounts of soluble boron, molybdenum and lithium (KANWAR & RANDHAWA, 1974) all of which greatly limit crop production.

Table 1—Ionic composition of some halomorphic soils of Uttar Pradesh

District	Class*	E.C$_e$. m.mhos/cm.	E.S.P.	cations m. eq./L (sat. extract)				Anions m. eq./L (sat. extract)				References
				Na+	K+	Ca++	Mg++	CO_3+	HCO_3-	SO_4--	Cl-	
Varanasi	N	<1	4	2	0.3	2.1	0.5	1	Tr.	..	0.8	Agarwala *et. al.* (Unpublished).
	NSA	2.6-3.6	74—85	30—49	<0.1	0.1-1.1	0.1	10	7—11	..	1.7-3.9	
	SA	5—10	77—93	63—155	<0.1-0.2	0.1-1	0.2-0.4	40—68	22—61	..	0.6-9	
Ghazipur ..	SA	8—9	8—98	134—138	0.1-0.2	0.3-0.4	0.1	80—86	21—33	..	1.7-10	do.
Sultanpur	NSA	2	32	23	<0.1	1.1	0.1	4	7	..	3	do.
	SA	11	75	169	<0.1	0.3	0.4	52	21	..	3	
Pratapgarh	N	<1	1.5	2	0.1	2.4	0.4	2	1	..	1	do.
	NSA	1.4-3.4	35—41	9—33	<0.1	0.2-1.1	<0.1-0.2	6	2—20	..	2—3	
	SA	6.8	64	134—140	0.1	0.3-1.0	0.2	72—86	30—40	..	2—3	
Unnao ..	SA	6-7.5	55—107	47—65	..	0.3-0.9	< 0.1	4—58	11—39	9—83	1.1-2.8	do.
	N	<1-1.8	0.1-4.5	3.5-7.0	..	1.5-4.4	<0.1-0.2	0.5-1	2—5	2—5	0.3-8	
	NSA	1.4-3.7	24—85	5.2-74	..	0.4-1.6	<0.1	0.5-12	5—17	5—24	0.4-2	
	NSA	1.4-3.7	24—85	5.2-74	..	0.4-1.6	0.1	0.5-12	5—17	5—24	0.4-2	
Hardoi ..	SAA	13	70	145	1.5	3.5	1.0	90	51	Tr.	8	Agarwal & Yadav (1954).
	NSA	3	23	27	Tr.	2.0	0.5	Tr.	18	Tr.	10	
Lucknow ..	SA	17	45	156	0.8	8	3	142	13	Tr.	14	do.
Azamgarh ..	SA	11	..	116	..	1	..	3	9	112	2	Agarwal & Gupta (1968).

**N*=*Normal* (*Non Saline—Non Alkali*); *SA*=*Saline-Alkali or Saline-Sodic*; *NSA*=*Non-Saline-Alkali*.

SALINITY

In addition to reducing the availability of water for various metabolic processes (BLACK, 1967) and inducing physiological dryness (SCHIMPER, 1898), salinity causes adverse growth and metabolic effects. This may either be a consequence of high concentration of the toxic constituents of the usar soils (BERNSTEIN & HAYWARD, 1958; HAYWARD & BERNSTEIN, 1958), or may result from the disturbance in plant metabolism leading to accumulation of some toxic metabolites like putrescine, H_2O_2, Cl compounds in particular plant parts (STROGONOV, 1964). Accumulation of ions may take place as a result of their differential uptake (KOVDA, 1949; GERALDSON, 1960; FAKHR, 1961; LAGERWERFF & EAGLE, 1961) following structural changes in the membranes regulating selective uptake of ions (OKNINA, 1953) or by ion antagonism and synergism (FRIED & BROESHART, 1967).

Plant species and varieties differ in their tolerance to total salinity (U.S.D.A., 1954), as also to excess concentrations of individual cations (THORNE & PETERSON, 1954) or anions (MAGSITAD, 1945). The difference in tolerance to excess concentration of a particular ion has been attributed to varietal difference in efficiency of absorption and translocation of ions (BERNSTEIN & PEARSON, 1956).

The sensitivity of a plant to toxic effects of excess ions vary from ion to ion. GAUCH AND WADLEIGH (1944) have reported that beans are more resistant to Mg^{++} toxicity than Na^+ toxicity. They are also more sensitive to SO_4^{--} toxicity than Cl^- toxicity. When rice and barley plants were raised with excess (isoequivalent) concentrations of principal ions contributing to salinity in sand culture or natural conditions, it was observed that (i) bicarbonate and carbonate of sodium are more toxic than sodium chloride or sodium sulphate and (ii) the toxic effect of 'Reh' (natural salt afflorescence on the surface of saline-alkali soils) solution (unneutralised) was equitable to that of $NaHCO_3$ and Na_2CO_3 and that of neutralised (by H_2SO_4+HCl mixture) reh equitable to Na_2SO_4 and NaCl solutions (AGARWALA *et al.*, unpublished). Recently, KANWAR AND KANWAR (1971) have reported that in certain crops residual effect of sodium carbonate is more harmful than that of HCO_3^-.

KOVDA (1949) and FAKHR (1961) have shown that as a result of cationic and anionic antagonism in saline soils, uptake of sodium, magnesium and chloride increased and that of iron, potassium and manganese decreased. Their results for phosphorus and sulphur were, however, at variance. KOVDA (1949) observed that salinity increased phosphorus uptake and decreased sulphur uptake. FAKHR (1961), on the other hand, observed that salinity caused an increase in sulphur and decrease in phosphorus uptake of plants. KOVDA (1949) also observed a decrease in the uptake of calcium and FAKHR (1961) an increase in the uptake of boron in plants as a result of salinity. GERALDSON (1960) reported that tomatoes grown on saline substrates exhibited higher incidence of 'blossom-end' rot of tomatoes, a condition attributed to calcium deficiency. Excess concentration of SO_4^{--} promote the uptake of sodium and restrict the absorption of calcium (HAYWARD & WADLEIGH, 1949) which may cause deficiency of the latter in some varieties of lettuce (DONEEN & GROGAN, 1954). Sulphate promoted sodium uptake has been attributed by BROWN, WADLEIGH AND HAYWARD (1953) to induced sodium toxicity in susceptible plant species.

Work done by the authors and their associates (Table 2) indicate that excess concentration of ions responsible for saline conditions cause nutrient imbalance in the plants

Table 2—Nutritional effects of different ions contributing to soil salinity

Ion	Nutritional effects on other elements			References
	Enhances the uptake of	Decreases the uptake of	Inconsistent	
Cl^- ..		N (Bean) ..	P, N	Reifenberg & Rosovsky (1947); Gauch & Wadleigh (1942).
	Mn (Bushbean & Sweet corn)			Jackson, Westermann & Moore (1966).
CO_3^{--} (Na)		P (Groundnut) ..		Sanjivareddy & Rajeswara Rao (1967).
HCO_3^- (Na)	Mg (Dallisgrass) ..	Mg (Rhodes grass)		Gauch & Wadleigh (1951).
HCO_3^-	Na (tomato & tobacco)	K (tomato & tobacco)		Shimose (1964).
	K, Na (Bean leaves)	Ca (Bean leaves) ..	Mg (Bean leaves)	Wadleigh & Brown (1952).
	Ca, Mg, Na (Bean roots)	K (Bean roots) ..		
Ca^{++} ..		K (beans & some carrot vars.)	K (other spp.)	Bernstein & Hayward (1958).
	Cl (fruit trees) ..		Cl (other spp.)	Brown, Wadleigh & Hayward (1953); Gauch & Wadleigh (1945).
	K (Rhodes grass) ..	K (Dallis grass) ..		Gauch & Wadleigh (1951).
$Ca^{++}Na^+$: 1 : 10	K (wheat & maize)	K (lucerne) ..		Steyn (1959 a & b).
Na^+ : K^+ : Ca^+	K (barley roots) ..	Na (several plants)		Jacobson, Hannapel, Moore & Scheadle (1961).
Na^+ : K^+		K (barley roots) ..		Jacobson, Hannapel, Moore & Schaedle (1961).
Mg^{++}		Ca, K ..		Hayward & Wadleigh (1949).
Synth. sea water	Na (all spp) ..		other ions ..	Lunin, Gallatin & Batchelder (1963, 1964b)
	Na, Mg, Cl (rice)	K, Ca, S (rice) ..		Pasricha, Patra & Sahoo (1975).
	In rice and barley (sand culture)			
Na^+ ..	Mo	Ca ..	..	Agarwala *et. al.* (unpublished).
K^+ ..		Mg ..	..	
Ca^{++} (Cl^-) ..		Zn	..	
Cl^- ..		Mg ..	..	
CO_3^{--} & HCO_3^-	S ..	Ca, Mg, Cu, (Zn) ..		

due to ion antagonism. On the basis of studies on the effect of synthetic saline irrigation waters applied on a variety of plants at different stages of growth, BATCHELDER, LUNIN AND GALLATIN (1963) concluded that cationic composition of plants is affected by the equilibrium composition of soil solution, soil physical properties and crop specificity. This is in agreement with our general observations briefly compiled in Table 2.

The toxic effects of excess concentration of HCO_3^- and CO_3^{--} can be attributed to one or more of the following:

1.—their alkaline reaction which affect the availability of nutrients (TRUOG, 1948);

2.—increase in sodium adsorption on the soil exchange complex due to increase in SAR (Sodium Adsorption Ratio) resulting from precipitation of calcium and magnesium (BOWER, 1961; KELLEY 1962).

3.—induction of iron (BROWN, 1956, 1961) or zinc deficiency (BINGHAM, 1963; STUKENHOLTZ, OLSEN, GOGAN & OLSON, 1966; UDO, BOHN & TUCKER, 1970).

The fertility status of the soil specially the level of N, P and K, singly or in combination, markedly influence the deleterious effects of salinity on the growth and ion uptake of plants. Supply of NO_3^- and PO_4^{---} retard the accumulation of chloride in barley (REIFENBERG & ROSOVSKY, 1947), K^+ reduces the accumulation of Na^+ in barley (HEIMAN, 1959; HEIMAN & RATNER, 1961); Ca decreases the inhibition in K uptake in barley resulting from sodium excess (JACOBSEN, HANNAPEL, MOORE & SCHAEDLE, 1961); and adequate supply of basal nutrients reduced the detrimental effects resulting from excess uptake of Na^+ and Cl^- and reduced uptake of K^+ in barley (GRENWAY, 1963). Additional supply of adequate NPK has been reported to mitigate the reduction in growth and increase in total nitrogen content of bean plants resulting from salinity (LUNIN, GALLATIN & BATCHELDER, 1964b) and this according to LUNIN AND GALLATIN (1965a & b) is mainly due to the P component. Recently, RAVIKOVITCH AND NAVROT (1976) have reported beneficial effect of manganese and zinc application on the growth of berseem, tomato and millet plants raised on soils salinised with NaCl.

ALKALINITY

Besides adversely affecting the hydraulic conductivity (MARTIN, RICHARDS & PRATT, 1964) and other physical properties of soil that retard seedling emergence, root growth and root penetration (ALLISON, 1964) alkali conditions of the soil restrict plant growth and cause nutritional effects due to alkaline reaction, high E.S.P. (KELLEY, 1964) and sodium toxicity. Excess levels of adsorbed sodium induce high pH values which may induce toxicity of OH ions at pH 10.5 or above (OLSEN, 1953) or of aluminium, at high pH in non-saline conditions (JONES, 1961). It may also cause an imbalance in nutrient availability (TRUOG, 1948; STILES, 1961; KELLEY, 1964; BLACK, 1967) or a disturbance in microbial activity.

Plant species and varieties differ in their tolerance to excess concentrations of adsorbed sodium (Table 3, PEARSON, 1960). BERNSTEIN AND PEARSON (1956) suggested that plant reaction to E.S.P. is reflected in the tolerance of plants to alkalinity. MARTIN and his co-workers (MARTIN, HARDING & MURPHY, 1953; MARTIN & BINGHAM, 1954; MARTIN & JONES, 1954; JONES, MARTIN & BITTERS, 1957; MARTIN & ERVIN, 1957; MARTIN, BITTERS & ERVIN, 1959a; MARTIN, JONES & ERVIN, 1959b; MARTIN, ERVIN & SHEPHERD, 1961), on the other hand, suggested that this could be better evaluated on the basis of absolute levels of exchangeable sodium. Work done by authors and their associate on different crops grown on native usar soils, soils artificially alkalised with sodium salts, and soils irrigated with waters of graded levels of SAR suggest that soil characteristics like cation exchange capacity, calcareousness and fertility and plant factors like the genotype and the stage of growth markedly modify plant response to excess concentrations of soil

Table 3—Tolerance of plants to soil E.S.P. (after Pearson, 1960)

Sensitivity	E.S.P. levels to which sensitive	Plants
Very sensitive	2—10	Decicuous fruits, nuts, citrus and avocado trees.
Sensitive	10—20	Beans
Moderately tolerant	20—40	Clover, oats, tall fescue grass, rice and dallis grass.
Tolerant	40—60	Wheat, cotton, alfalfa, barley, tomato and beets.
Very tolerant	>60	Crested and fairway wheat grass, rhodes grass and tall fescue grass.

E.S.P. (Table 4). Thus it was observed (**Agarwala** *et al.*, 1964a & b, unpublished) that: (i) Sodium salt used for alkalisation, the cation exchange capacity of the soil and the soil calcareousness, all modified the effect of E.S.P. on yield of rice plants grown in pot culture. (ii) The effect of E.S.P. in inhibiting yield of barley was mitigated by NP amendment to soil. (iii) The tolerance of sugarbeet to high levels of soil E.S.P. increased with increase in the age of plants.

Table 4—Plant response to soil E.S.P. (Agarwala *et al.*, 1964a & b and unpublished)

Plants	E. S. P. level at which 50% depression in yield found								
	In natural usar		In artificially alkalised						
			Low C.E.C. soils			High C.E.C. soils			
	Pot culture	Field	Na_2CO_3	$NaHCO_3$	Na_2SO_4	SAR (HCO_3)	Na_2CO_3	$NaHCO_3$	SAR (HCO_3)
Radish	24	..	..	..	..	..	..	..	..
Gram	..	..	..	..	..	..	>32	>41	..
Sugarbeet	..	..	..	..	..	..	..	..	..
(6 weeks)	..	..	49	37	..	..	62	>77	..
(12 weeks)	..	..	..	..	..	..	..	..	..
Oats	47	..	49	37	..	..	62	77	..
Paddy T.9	>11.4	>4	>20	>20	30	15	..	77	71
Barley K.12	48—54	10—25	..	..	..	..	..	..	..
Barley with NP amendment	68	..	45	>50	..	74	>45	>49	..

Growth of some sensitive plants like avocado (**Ayers**, 1950; **Martin** & **Ervin**, 1957), citrus and stone fruits like almonds and plums (**Lilleland, Brown** & **Swanson**, 1945; **Brown, Wadleigh** & **Hayward**, 1953; **Martin** & **Bingham**, 1954; **Martin** & **Jones**,

1954; MARTIN, HARDING & MURPHY, 1953; JONES, MARTIN & BITTERS, 1957; MARTIN, ERVIN & SHEPHERD, 1961) is depressed as a result of increase in the accumulation of sodium at levels of soil exchangeable sodium that do not effect soil physical properties or affect the uptake of other nutrient elements. Such direct effects of adsorbed sodium are to some extent comparable to toxicity effects of excess Na^+ in solution culture. High levels of exchangeable sodium in soils are also reported to cause nutrient imbalance resulting in the deficiency of some and toxicity of other elements (KELLEY, 1964)—(Tables 5 & 6). For certain sensitive plants like sunhemp, a small rise in E.S.P. level may cause marked nutrient imbalance that may inhibit the growth of plants (YADAV & MEHTA, 1963, 1964).

Table 5—High E.S.P. effect on sodium and macronutrient content of plants

Effect on	Increased (+) Decreased (—) or Inconsistent (+ —)	Plant species, plant parts and other specific soil conditions	References
1	2	3	4
Sodium :			
	+	Most plants including orange (leaves), *Eragrostis* (roots) and rice.	Most workers
	+—	Orange (leaves) on Yolo sandy loam	Martin, Bitters & Ervin (1959a)
		Eragrostis (leaves and stem)	Satyanarayana & Rao (1963)
		Rice (LCEC alkalised Na_2SO_4)	Agarwala *et al.* (1964a)
Potassium :			
	—	Most plants excluding onion but including rice, beans and avocado (roots).	Most workers
	+	Avocado (leaves)	Martin & Bingham (1954)
		Beans	Bernstein & Pearson (1956), Lunin *et al.* (1964a)
		Orange (leaves & stem)	Martin *et al.* (1959a & b)
		Orange (leaves) on Yolo sandy oam	Martin *et al.* (1961)
		Eragrostis (roots & whole plant)	Satyanarayana & Rao (1963)
	+—	Orange (roots) & onion	Martin *et al.* (1959a & b, 1961)
		Eragrostis (leaves & stem)	Satyanarayana & Rao (1963)
		Rice (LCEC alkalised Na_2SO_4)	Agarwala *et al.* (1964a)
Calcium :			
	—	Most plants including beans & *Eragrostis* (stem, roots, & whole plant).	Most workers
	+—	*Eragrostis* (leaves)	Satyanarayana & Rao (1963)
		Beans	Lunin *et al.* (1964a)

Table 5—(*Contd.*)

1	2	3	4
Magnesium :			
	—	Most plants including wheat, pea, alfalfa, rice & barley.	Many workers
		Rice & Barley (LCEC alkalised Na_2CO_3)	Agarwala *et al.* (1964a)
		Rice (HCEC natural usar)	Agarwala *et al.* (1964b)
	+	Clover	Bernstein & Pearson (1956)
		Alfalfa	Nightingale & Smith (1966)
		Rice & barley (LCEC alkalised $NaHCO_3$)	Agarwala *et al.* (1964a)
		Wheat (at 2 months growth)	Mehrotra & Das (1973)
	+—	Alfalfa & Cotton	Bernstein & Pearson (1956)
		Rice (LCEC alkalised Na_2SO_4)	Agarwala *et al.* (1964a)
		Avocado (leaves)	Martin & Bingham (1954)
		Beans	Lunin *et al.* (1964a)
		Pea (at maturity)	Mehrotra & Das (1973)
Phosphorus :			
	—	Wheat	Singh & Chawla (1943)
		Sanhemp	Yadav & Mehta (1963, 1964)
		Rice (HCEC natural usar)	Agarwala *et al.* (1964b)
		Wheat, barley, oats & wheat grass	Pearson & Bernstein (1958)
	+	Rice & barley (LCEC alkalised)	Agarwala *et al.* (1964a)
		Tomato	Thorne (1944); Bains & Fireman (1964)
	+—	Many plants including rice but excluding wheat, barley, oats and tomato.	Martin & Bingham (1954); Chang & Dregne (1954); Bernstein & Pearson (1956); Pearson & Bernstein (1958); Martin *et al.* (1959a, 1961); & Bains & Fireman (1964)
Sulphur :	+	Beans	Bernstein & Pearson (1956)
		Rice	Pearson & Bernstein (1958)
		Rice & barley (LCEC alkalised)	Agarwala *et al.* (1964a)
		Safflower	Bains & Fireman (1964)
	—	Tomato	Bains & Fireman (1964)
		Berseem	Pasricha & Randhawa (1971)

Table 5—(*Contd.*)

1	2	3	4
	+—	Avocado, beets, clover, alfalfa, wheat, barley, oats, tall fescue grass, wheat grass.	Martin & Binbham (1954; Bernstein & Pearson (1956); Pearson & Bernstein (1958)
		Rice (HCEC natural usar)	Agarwala *et al.* (1964b)
Nitrogen:			
	+	Avocado	Martin & Bingham (1954)
		Beans	Bernstein & Pearson (1956)
		Tomato	Bains & Fireman (1964)
		Barley & rice (LCEC alkalised)	Agarwala *et al.* (1964a)
	—	Barley	Cairns *et al.* (1962)
		Pearlmillet	Maliwal & Paliwal (1971)
		Safflower	Bains & Fireman (1964)
		Sunhemp	Yadav & Mehta (1963, 1964)
		Rice (HCEC natural usar)	Agarwala *et al.* (1964b)
	+—	Beets, clover and alfalfa	Bernstein & Pearson (1956)
		Orange (leaves and roots) on clay loam	Martin *et al.* (1959a)

LCEC=Low Cation Exchange Capacity; HCEC=High Cation Exchange Capacity.

Literature on the effect of soil E.S.P. on macro and micronutrient composition of plants presented in Tables 5 & 6 would indicate that the effect of high E.S.P. in creating ionic imbalance in plants is greatly conditioned by the complementary anions, some soil characteristics, plant genotypes and the stage of their development.

SALINE ALKALI CONDITIONS

When both saline and alkali conditions are simultaneously present in the soil, as is the case with most Usar soils of Uttar Pradesh (Table 1), the picture of nutrient availability to plants becomes more complicated. The constituents of salinity and alkali conditions often counteract certain effects and augument others. Crop response to these conditions is also affected by the genotype and soil characteristics operating at the soil-root interphase. In natural Usar soils of U. P., Agarwal and Yadav (1956) suggested an additive effect of exchangeable sodium and salinity in reducing crop growth. Lagerwerff and Holland (1960) reported opposite effects of SAR and salinity on carrot. For alfalfa, Chang (1961) reported additive effects of E.S.P. and soluble salts at their medium levels but not at their excess levels; Bernstein (1962) also reported pronounced affects of soil E.S.P. on crop growth at low but not at high salinity levels in the rooting medium. Agarwala *et al.* (unpublished) also found evidence for both augmenting and counteracting effects of E.S.P., EC_e. and total alkalinity (soluble $CO_3^{--} + HCO_3^{-}$), variable values of which are commonly met in the Usar soils of Uttar Pradesh. Their observations,

Table 6—High E.S.P. effect on micronutrient content of plants

References	Plant	Effect of E. S. P. on micronutrient elements						
		Fe	Mn	Cu	Zn	Mo	B	Cl
Thorne (1944)	Tomato ..	—+	—					
Martin *et al.* (1953)	Orange Seedlings..		—					
Martin *et al.* (1959a) ..	Do ..		—				—	
Martin *et al.* (1961) (base saturated and excess lime series)	Orange seedlings..	—		—+	—			
(acid series) ..	Do. ..	—+		—	—+			
Martin & Bingham (1954) ..	Avocado ..		+					
Bains & Fireman (1964) ..	Safflower	—	—	—	—	+	—	—
	Tomato ..	+	—	+	—	+	—	—
Jones *et al.* (1952) ($NaNO_3$ fertilizer use)	Citrus ..				Def. Symp.			
Agarwala *et al.* (1964a) (Na_2CO_3, $NaHCO_3$ alkalised)	Rice ..	+	+					
	Barley ..	—	+	—	—	+		
Agarwala *et al.* (1964b) (Natural usar)	Rice ..	+	—	—		—+	+	
Maliwal & Paliwal (1971) ..	Pearlmillet	—	—					
Pasricha & Randhawa (1971) ..	Berseem ..					+		

*(+)=Increase; (—)=Decrease; (—+)=Inconsistent, increase at some and decrease at some other level

based on pot culture trials on natural usar soils of widely varying saline/alkali combinations is summarised in Table 7. This study suggests that (i) the effect of the different factors on the availability of nutrients to different plants was always not the same, (ii) both E.S.P. and E.Ce. individually depressed but total alkalinity increased the uptake of Mo in oats, (iii) E.S.P. and total alkalinity individually increased but E.C$_e$. depressed the uptake of B in barley, an observation at variance with FAKHR (1961). This may partly explain the lack of boron accumulation and boron toxicity symptoms in plants grown on saline-sodic soils containing high amounts of soil 'available' boron (AGARWALA *et al.*, 1964a & b) and the observation that maximum level of tissue molybdenum is found at some high level of soil E.S.P. (which is not necessarily the highest) (AGARWALA *et al.*, 1964a). NAYYAR (1972) also attributed high availability of molybdenum in saline-alkali soils (SINGH & SINGH, 1966; PASRICHA & RANDHAWA, 1971) to increased solubility of organic matter (possibly due to soluble CO_3^{--} & HCO_3^- ions) in these soils.

Native soil fertility also affects plant response in saline-sodic soils. CAIRNS, BOWSER and their associates in Canada (CAIRNS, MILNE & BOWSER, 1962; CAIRNS, BOWSER, MILNE & CHANG, 1967) have recently obtained evidences for a role of nitrogen fertilisation in improving growth and decreasing sodium uptake by plants grown on solonetz soils. POONIA

Table 7—Significant relationship of individual saline-sodic soil factors to the dry matter yield and nutrient composition of plants. Open signs denote total correlations 'r' and signs in parenthesis partial correlations eliminating effects of other two soil factors. Plants raised in pots on soil collected from Unnao (U. P.) : 3⅓ weeks growth (Agarwala *et al.*, unpublished).

Effect on	E. S. P.		$E.C_e$.		Total alkalinity (CO_3^{--} + HCO_3^-)	
	Barley	Oats	Barley	Oats	Barley	Oats
Yield ..	—(—)	—(—)	—	—	—	—
Na ..	+	+				
K ..	—(—)	—(—)	—	—	—	—
Ca ..	—(—)	—(—)	—	—	—	—
Mg ..	—(—)	—(—)	—	—	—	—
P ..	+	+	+	+	+	+
S ..		—		—		—
Fe ..	+(+)		+		+	
Mn ..	—	—	—(—)		—	
Cu ..	+(—)		+	(+)	+	(—)
Zn ..	—(—)		+		+	
Mo ..		—(—)		(—)		(+)
B ..	+(+)		+(—)		+(+)	

AND BHUMBLA (1974) have observed that FYM application increases the total uptake of calcium by barley plants grown on a saline-alkali soil from a readily soluble calcium source (like gypsum) but not from an insoluble source (like calcium carbonate). AGARWALA *et al.* (unpublished) have observed that N, P, or K amendments to usar soils of central U. P. resulted in an increase in the yield and tissue concentration of particular nutrient elements in barley. Application of potassium depressed the uptake of sodium; phosphorus amendment depressed the uptake of manganese and molybdenum, and nitrogen amendment depressed the uptake of phosphorus and increased that of potassium. JONES (1965) has reported that application of K reduced the excessive molybdenum content in corn leaves and PASRICHA AND RANDHAWA (1971) have reported that S application, especially as gypsum, reduced the toxic concentrations of molybdenum in berseem plants. The authors and their associates have also observed that NP amendments to saline alkali soils partially counteract the adverse effect of (i) high E.S.P. on yield, tissue calcium and tissue copper, (ii) high $E.C_e$. on yield and that of (iii) high total alkalinity on yield, tissue sodium and tissue phosphorus.

Since the magnitude of the plant nutritional problems encountered in usar soils vary with the chemical composition of the soils and is also determined by the plant genotypes, in order to resolve and ameliorate them it is but necessary to evaluate their nutrient status by suitable soil tests and plant analysis. Agarwala, Sharma, Sinha and Mehrotra (1964b) showed that water soluble or exchangeable sodium, water soluble calcium, total soil nitrogen, Olsen's (1964) phosphorus, and $HClO_4$—H_2SO_4 digestible copper and zinc (Jackson, 1958) can help in identifying their available status in non-saline alkali soils under paddy cultivation. Studies are, however, required to determine the suitability of these soil tests for better crop yields in saline-alkali soils.

A series of experiments conducted at authors' laboratory to study the relative tolerance of different varieties of rabi and kharif crops to application of graded levels of synthetic bicarbonate SAR irrigation waters in soil pot culture has shown marked differences in the tolerance of plant genotypes to saline-alkali conditions. *Triticale* var. Armidillo was found by us (Agarwala *et al.*, unpublished) to be particularly tolerant to excess constituents of usar soils.

CONCLUSIONS

Low crop yields of plants grown on usar (saline/sodic) conditions can be largely attributed to multiple nutrient disorders. Besides other factors, basic characteristics of the soil and genetic make up of the plant determine the plant's reaction to the nutrient disorder in soils. Productivity of the soils can be markedly improved by making a critical appraisal of the nutrient status of the plant, by using suitable ameliorative methods like supplementation of nitrogen, phosphorus, potassium, zinc, iron, manganese and other amendments, and/or selecting crops and varieties tolerant to salinity-alkalinity conditions.

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