FRUIT CULTIVATION IN SALT-AFFECTED SOILS: CONSTRAINTS AND MANAGEMENT OPTIONS

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ABSTRACT

Horticulture is increasingly being seen as a sunrise sector with huge growth potential. In many developing and underdeveloped countries, horticultural crops are being promoted to achieve the intertwined goals of sustainable food and nutritional security, equitable growth and rural prosperity. In the last few decades, India has made rapid strides in the production of horticultural crops. Globally, India is the second largest producer of fruits. Despite huge socio-economic and environmental benefits, the growth of Indian fruit industry continues to be hampered by different constraints. Low productivity of fruits vis-à-vis other major producers, huge post-harvest losses and negligible presence in global export market are some of the factors hindering India from becoming a leader in the global fruit trade. Majority of the fruit crops are highly sensitive to biotic and abiotic stresses with about three-fourths of the fruit crops listed known to be highly sensitive to salinity and the related soil constraints. As further expansion of area under fruit crops seems possible only in marginal situations, this paper attempts to shed light on the properties of the marginally productive salt-affected soils, mechanisms underpinning salt tolerance and doable interventions for growing fruit crops under saline conditions.

Key words: Fruit crops, ion toxicity, management practices, salinity, water scarcity.

1. INTRODUCTION

Salinity is an encompassing term used to describe saline and sodic soils, and the marginal quality groundwater unsuitable for crop irrigation. A soil is considered to be 'salt-affected' when either excess soluble salts or excess exchangeable sodium or both adversely affect the soil properties and plant growth. Depending on the values of soil saturation paste extract electrical conductivity (EC_e), pH (pH_s) and exchangeable sodium percentage (ESP), salt-affected soils (SAS) are grouped into saline ($EC_e \geq 4$ dS m^{-1}, $pH_s < 8.2$ and high ESP< 15) and sodic ($EC_e < 4$ dS m^{-1}, $pH_s > 8.2$ and ESP >15) categories. Under certain conditions, both excess soluble salts and exchangeable sodium may be present resulting in saline-sodic conditions ($EC_e \geq 4$ dS m^{-1}, $pH_s > 8.2$ and ESP >15) (Sharma and Singh, 2015). Based on FAO/UNESCO soil map of the world (1970-1980), the global extent of SAS was earlier computed to be 831 Million ha (M ha) consisting of 397 M ha saline and the remainder 434 M ha sodic soils. Although this estimate is still widely used, recent studies suggest comparatively higher global extent of salinity and the associated problems; especially in irrigated arid and semi-arid regions across the world (Wicke *et al*., 2011). Notwithstanding the discrepancies in such estimates, it is certain that salinity continues to impose substantial costs on global food production and environmental sustainability.

Weathering of rocks and primary minerals is the dominant natural process responsible for salt accumulation in the soil and groundwater. Deposition of wind-borne salts and ingress of sea water also contribute to soil salinization to varying extents. Sea water intrusion is likely to heighten in the coming decades due to climate change impacts and intensive pumping of the coastal aquifers putting the coastal lands at increased risk of salinization. Naturally formed saline and sodic soils have been reported from about 100 countries across continents indicating the ubiquitous presence of salts in the soil and water; albeit in small to moderate amounts. Term 'primary salinity' is used to designate such naturally formed SAS where use of salt tolerant cultivars often in conjunction with doable agronomic interventions is a *sine qua non* to harness their productivity. In contrast, 'secondary salinity' refers to the salinization of agricultural lands due to anthropogenic activities (Shabala and Munns, 2012; Sharma and Singh, 2015).

Excessive and indiscriminate irrigation at the neglect of drainage and land clearing for crop production are the drivers of secondary salinization in irrigated and dryland regions, respectively. High susceptibility of irrigated lands to waterlogging and salinization is attributed to prolonged use of saline water for irrigation, seepage from canals and water channels and deep drainage beyond the root zone. Salt removal by the crops is often insignificant such that salts present in the irrigation water keep accumulating unless appropriate leaching and drainage interventions are implemented to remove them below the root zone. Salt tolerant crops have nearly half the leaching requirement compared to salt sensitive crops suggesting that development of crops and cultivars capable of enduring salinity and related problems without appreciable reductions in economic yield can greatly lessen the management expenses by curtailing the costs of irrigation and drainage. In drylands, replacement of deep rooted perennial vegetation with shallow rooted annual crops proves conducive to the percolation of much larger amounts of rainfall below the root zone resulting in wetter and salty soil profiles. Perennial tree- and pasture-based farming systems are suggested to contain the dryland salinity problem (Shabala and Munns, 2012).

A recent investigation suggests that globally over 1100 M ha area suffers from salinity. In South Asia including India, nearly 52 M ha area is salt-affected. It further reveals that a vast proportion of global SAS (~85%) have only slight to moderate constraints while the rest 15% severely affected lands pose complex and often unmanageable obstacles to crop production (Wicke et al., 2011). This observation points to the fact that relentless salinity onslaught has affected new agricultural areas in spite of ongoing reclamation efforts. It also underscores the need for precise delineation of SAS to identify the easily manageable pockets where feasible solutions can lead to tangible outcomes. It is increasingly becoming evident that salinization of newer areas has surpassed the reclamation efforts in several salt affected countries. In India, for example, an estimated 2.0 M ha salt-affected area has been reclaimed while 6.73 M ha still suffers from salinity and nearly 16 M ha is predicted to become salinized by 2050. It leads to the conclusion that reactive measures put into effect after salinization has attained damaging levels have become, by and large, irrelevant and that focus should shift to devise the ways and means that ensure simultaneous improvements in crop yields and soil quality with the minimal water and energy usage. While reclamation efforts need to be further strengthened, innovative tools for sustained returns from saline/partially reclaimed lands and for arresting the salinization of new areas are urgently needed.

2. FRUIT CULTIVATION: A DRIVER OF SOCIO-ECONOMIC DEVELOPMENT

Global fruit and vegetable production increased by about 3% over the last decade. In 2011, total global production of fruits was around 640 Million tonnes. Continued increase in production is largely driven by the area expansion in Asia (FAO, 2013). India is a leading producer of horticultural crops and ranks second in the fruit production globally. In the past few years, horticultural production has steadily increased. Surprisingly, India's total horticultural production surpassed foodgrain output during 2012-13 and 2013-14. Horticulture sector plays a pivotal role in the socio-economic development. Compared to the majority of field crops, horticultural crops are much more remunerative and provide handsome returns to the growers. Currently, horticultural crops together contribute ~29% to India's agricultural GDP and support ~20% of the agricultural labour force from ~13% of the total cropped area. Concerted R&D efforts and favourable policy initiatives have created a congenial environment for the sustained growth of Indian horticulture industry (ICAR-IIHR, 2015). Commercial fruit and vegetable production is seen as a viable option to harness the potential of marginally productive and undulating lands for poverty reduction and higher farm incomes provided that production, post-harvest and marketing constraints are adequately dealt with (Braidotti, 2013).

In addition to high incomes to the growers, horticultural production being a labour-intensive activity also contributes to poverty reduction by providing assured employment opportunities to the rural youth and women. Regular consumption of fruits and vegetables is known to improve the human health. According to World Health Organization, low consumption of fruits and vegetables contributes to 1.7 million deaths worldwide (FAO, 2013). In contrast to prescribed daily minimum intake of 400 g (5 daily servings with an average serving size of 80 gm) of fruit and vegetables (excluding potatoes, cassava and other starchy tubers) for the prevention of micronutrient deficiencies and chronic health problems such as heart diseases and cancer, current average fruit and vegetable intake in India is abysmally low, *i.e.*, 3.5 servings day^{-1} consisting of 1.5 servings of fruits and 2 servings of vegetables. Notwithstanding the fact that proportion of household expenditure on total food items has decreased in both rural and urban households, the proportion of income spent on fruits and vegetables has not changed much and the average Indian diet continues to be skewed towards cereals with fruits and vegetables constituting only 9% of the total calorie intake (Mukherjee *et al*., 2016).

3. CONSTRAINTS HAMPERING THE GROWTH OF INDIAN FRUIT INDUSTRY

Despite huge benefits in terms of higher incomes, employment generation and poverty alleviation, development of Indian fruit industry is hampered by a myriad of constraints. Low productivity of fruits, ascribed to the poorly managed low density and senile orchards, compared to other major fruit growing countries is a cause for concern. With the exception of banana and papaya, average fruit productivity stands at 12.0 t ha^{-1}. Most of the fruit crops are inherently susceptible to biotic and abiotic stresses. On an average, insect-pest, disease and weed problems lead to 20% yield reduction which can reach up to 80% in cases of severe infestation (ICAR-IIHR, 2015). Climate change and its anticipated long-term impacts, *inter alia*, higher atmospheric temperature and CO_2 concentration, intense heat waves, glacial ice melt, reduced river flows and sea level rise could further accentuate these problems. Climate change induced changes in tree phenology and reproductive behaviour, shifts in production belts, decrease in irrigation water availability and more losses due to abiotic stresses and pest-diseases outbreaks are increasingly becoming noticeable. Furthermore, continual shrinkage of productive farmlands and fresh water has necessitated the development of doable technologies for extending fruit cultivation in degraded areas suffering from constraints such as low water availability and salinity (ICAR-IIHR, 2015). Although demand for processed and value added products has consistently increased over the years, value addition is limited to only about 2% of the total fruits produced hampering the export competitiveness vis-à-vis other major fruit producers like China, Brazil and the United States (Bung, 2017). Post-harvest losses in fruits and vegetables are alarmingly high; 20-30% of the total production is wasted due to poor linkages between the field and fork resulting in huge monetary losses (~Rs. 30,000 crore year^{-1}) (Arumugam and Manikandan, 2011). It is due to these reasons that despite being a leading producer, India is also a net importer of fruits and vegetables (Mukherjee *et al*., 2016). Consistent with the goal of doubling the farmers' income, Government of India has recently initiated many programmes to make farming a rewarding activity. In this regard, 'Mission for Integrated Development of Horticulture (MIDH)' was launched in 2014-15 to promote the holistic development of horticulture in the country by reducing the cost of cultivation, increasing the per unit yields and ensuring remunerative prices to the growers (midh.gov.in).

4. IRRIGATION-INDUCED SALINITY: A RISING THREAT

Although net sown area in India has remained static around 141 Million ha over the past few decades, unabated increase in human population has necessitated agricultural intensification to meet the growing food needs. Concerted efforts towards technology development have led to quadrupling of foodgrain production surpassing nearly threefold increase in human population from 361 million to 1140 million over 1951-2011. Nonetheless, most of the growth in agricultural productivity has come from irrigated areas while rainfed regions continue to languish (Srinivasa Rao *et al.*, 2015). Although irrigation has played a critical role in sustaining the food production, on-farm irrigation mismanagement has come at the expense of severe land degradation. Irrigation-induced salinization has emerged as a severe environmental problem in many areas of Punjab, Haryana, Rajasthan and Uttar Pradesh important for the national food security. There is ample evidence that 'Punjab pattern of agricultural development', origins of which are traced back to the Green Revolution period (mid 1960s-mid 1980s), has virtually become unsustainable. Severity of the problem can be gauged by the fact that continual decline in farm incomes due to stagnant crop harvests, higher costs of cultivation, depleting soil fertility, secondary salinity and increasing debt burden has eventually led to rampant cases of farmer suicides in the region (Chand, 1999; Gill and Singh, 2006). In addition to large tracts of fertile Indo-Gangetic Plains affected by salt and waterlogging problems (Sharma *et al.*, 2016a), salinity has kept farming on tenterhooks in many other areas.

Twin menaces of salinity and waterlogging are also increasingly coming to fore in different fruit growing areas of the country. Salinity has emerged as serious hurdle to commercial viticulture in semi-arid areas of peninsular India having nearly 90% grape area of the country. Bhargava *et al.* (2006) found that groundwater salinity (EC_{IW}) rose from average 0.84 dS m^{-1} during 1980-1981 to 1.11 dS m^{-1} during 1999-2004 in the grape growing areas of Maharashtra and Karnataka. Out of the total samples tested, 49% had EC_{IW} <1.0 dS m^{-1} considered safe for grapevines, 30% had EC_{IW} between 1.0-2.0 dS m^{-1} at which growth is suppressed, 18% had EC_{IW} >2.0 dS m^{-1} where rootstock use becomes absolutely essential, and 3% showed EC_{IW} >4.0 dS m^{-1} at which salt tolerance of the commonly used rootstocks breaks down. A subsequent study also confirmed steadily deteriorating irrigation water quality leading to higher salt accumulation in vineyards in Pune, Sangli, Solapur and Nashik districts. In 2013-14, average irrigation water salinities (EC_{IW}) were 1.6 and 2.3 dS m^{-1} in Solapur and Sangli, respectively, compared to the corresponding values of 1.3 and 1.6 dS m^{-1} in 2007-08 (Mohan, 2015). High salinity in soil and groundwater, drought and strong winds are the major limitations to mango production in the Saurashtra region of Gujarat where traditionally grown Kesar variety has gained reputation in the global export market. Techniques such as drip irrigation using rain water and mulching have made it possible to raise profitable high density mango orchards under such conditions (Nathwani, 2014). Use of potential salt tolerant rootstocks is also being explored to tide over the salinity problem; especially in coastal lands suffering from sea water ingress (Balan, 2017). Commercial Kinnow cultivation in Fazilka district of Punjab and the adjoining areas is threatened by the rising watertable. In areas with shallower watertables (<0.5 m), considerable increase in soil salinity (EC_2= 1.13-2.84 dS m^{-1}; pH= 8.51-9.05) has led to large scale Kinnow decline (Fig. 1). Even in areas with relatively deeper watertables (~ 1.5-2 m), 'apparently healthy' Kinnow plantations seem to be at risk. Unabated decline has enhanced the livelihood vulnerability of the farmers who previously fetched remunerative returns from the sale of Kinnow fruits. A survey conducted in ber growing areas of Haryana revealed that salinity is a severe impediment to profitable ber cultivation in areas having saline groundwater (~3.0-10.0 dS m^{-1}). Salinity caused marked reductions in fruit yield with saline irrigated trees invariably tending to bear small crops compared to the trees irrigated with either good quality or less saline water. For example, fruit yield of 20 year old trees of Gola variety decreased from average 0.2 t $tree^{-1}$ to 0.1 t $tree^{-1}$ when irrigation water salinity (EC_{IW}) increased from ~6.0 dS m^{-1} to ~10.0 dS m^{-1} under similar agro-climatic conditions. Development of waterlogged sodic lands and the repeated instances of resodification in Sharda Sahayak canal command, if left unaddressed, can spell doom for the flourishing mango industry of Lucknow district (ICAR-CSSRI, 2017). Climate change induced rise in sea level can accentuate the problem of sea water ingress in many coastal areas of country where different fruits and plantation crops are grown on a commercial scale (Sharma and Singh, 2015).

Fig. 1 Salinity-induced Kinnow decline in Fazilka district of Punjab, India (Photo: Anshuman Singh).

5. EFFECTS OF SALT STRESS

Salinity retards water absorption by the plants by raising the osmotic pressure of the soil solution. Salinized plants facing 'physiological drought' fail to extract the available water. Osmotic stress induced water deficiency in saline soils is strikingly similar to the effects of drought. Osmotic stress constitutes the first phase of growth inhibition in salt stressed plants while salts still remain outside the plant. Reduced rate of cell expansion, decrease in stomatal conductance and low availability of CO_2 eventually limit the rate of photosynthesis (Shabala and Munns, 2012). Irrigation creates favourable conditions for crop growth by alleviating the osmotic stress. Irrigated soils have high soil moisture content and low salt concentration while the reverse is true for the dry saline soils (Abrol *et al.*, 1988). Second phase of salt stress begins with the entry of salts inside the plants. In absence of effective salt exclusion by the roots, salts accumulate to the toxic levels causing a range of ion specific physiological abnormalities. Soils with the high levels of Na^+ exhibit the reduced availability of K^+, Ca^{2+} and NH_4^+. Excess Na^+ results in the depolarization of plasma membrane hampering the passive uptake of essential cations such as K^+. Again, Na^+ not only competes with K^+ for major binding sites in the key metabolic processes such as protein synthesis but also increases K^+ efflux from cytoplasm (Shabala and Munns, 2012). As an essential micronutrient, Cl^- modulates the enzymatic activities, serves as a co-factor in photosynthesis, stabilizes membrane potential and regulates the cell turgor and pH. However, in high concentrations, Cl^- becomes toxic. Cl^- concentrations as low as 4-7 mg g^{-1} prove limiting to the salt sensitive species whereas adverse effects in tolerant species appear at relatively higher Cl^- levels (15-50 mg g^{-1}). Root exclusion and restricted translocation of Cl^- to shoots are necessary to prevent salt injury symptoms in citrus and grapes (Tavakkoli *et al.*, 2010). In salt stressed plants, continued accumulation of reactive oxygen species (ROS) causes the oxidative stress. Osmotic stress induced decrease in stomatal conductance and excessive Na^+ accumulation in the cytosol together impair the photosynthetic machinery so that light captured by the photosynthetic pigments is only partially utilized. This accelerates ROS production in leaves leading to lipid peroxidation, DNA and protein denaturation, and ion leakage. ROS activate a certain class of K^+ channels resulting in heavy K^+ loss from the cytosol (Shabala and Munns, 2012).

6. SALT STRESS SYMPTOMS

Excess salts in the growing medium hamper plant growth in two ways. Reduced water uptake, *i.e.*, 'water-deficit effect of salinity' leads to the initial reductions in the growth rate. Shortly, salt ions enter inside the plant in the transpiration stream and interfere with key physiological processes further reducing the growth. This is referred to as the 'salt-specific' or 'ion-excess effect of salinity'. In fruit plants, salinity suppresses the plant height, emergence of new branches and leaves while hastening the senescence of older leaves. In most of the cases, salt injury symptoms initially appear as the yellowing, scorching and chlorosis of the leaf margins. If salt stress is not relieved, leaves soon become chlorotic, develop necrotic spots and eventually shed off the plant. Salinized plants show significant reductions in the fresh and dry weights of shoots and roots. In certain crops like guava, plant height and stem girth may be relatively less affected by salinity but branch emergence and leaf production significantly decrease giving the salinized plants an upright and sparse look (ICAR-CSSRI, 2016; Fig. 2). In contrast to the annual plants, which tend to become relatively more salt tolerant with age, majority of the fruit crops become salt sensitive as they grow older. It is possibly due to gradual translocation of the salts stored in roots to leaves coupled with a slower growth rate in the older plants. Moreover, salt sensitive species like citrus and stone fruits often absorb excessive amounts of salt ions in soils otherwise considered to be normal for other crops. In some fruit crops, use of salt excluder rootstocks may decrease Na^+ and Cl^- toxicity implying that osmotic stress will mainly be responsible for most of the deleterious effects in the composite plants (Singh *et al.*, 2016).

Depending on species, either ion toxicity or osmotic stress may account for the salt-induced injury. Grapevine growth seems to be highly sensitive to water deficit than to an equivalent salinity level suggesting that besides predominant organic osmolytes (tartrate and malate) salt uptake also contributes to osmotic adjustment in the grape leaves (Cramer *et al.*, 2007). Higher NaCl levels (80 and 160 mM) reduced the plant height, leaf number, total leaf area and dry matter by >50% compared to control in *Ziziphus spinachristi* L., a wild fruit species distributed in Asia and Africa. At 160 mM NaCl, leaf Na^+ and Cl^- levels increased by 81- and 21-fold, respectively, over control but leaf N, P and K concentrations were not significantly affected indicating the role of Na^+ and Cl^- in osmotic adjustment (Sohail *et al.*, 2009). Addition of NaCl into irrigation water increased the leaf and root Na^+ and Cl^- concentrations in *Citrus limonia* seedlings and olive (cv. Arbequina) cuttings causing decline in plant dry mass production, stomatal conductance and net photosynthesis. Growth reduction was apparently due to ionic effects and not due to osmotic stress since both the species maintained a leaf pressure potential higher than in control leaves (Melgar *et al.*, 2008). In most of the fruit crops, shoot growth is more sensitive to salt stress than root growth. In certain species such as avocado, however, root growth is more affected. In avocado plants treated with 25 mM NaCl, leaf biomass production, leaf initiation and elongation rates decreased by 19.5%, 12%, and 5%, respectively, while root volumetric growth and root elongation rate reduced by 65% and 75%, respectively (Bernstein *et al.*, 2004).

Fig. 2 Salt stress symptoms in guava cv. Allahabad Safeda planted under shallow watertable saline conditions at Nain Experimental Farm, Panipat. Note the progressive loss of leaves, sparse growth, reduced fruiting and plant mortality with increasing salinity (in clock wise direction; Photo: Anshuman Singh)

7. MECHANISMS OF SALT TOLERANCE

Regulation of salt uptake may occur either at the whole plant or at cellular and molecular levels. At the whole plant level, both halophytes and glycophytes tend to achieve salt tolerance by the selective ion uptake, preferential loading of K^+ into xylem and retention of Na^+ in the basal stem and root tissues (Munns *et al*., 2002). The relative contribution of these mechanisms to salt exclusion is essentially a genotype-dependent phenomenon. Salt exclusion assumes great significance as plants transpire 30-70 times more water than they use for cell expansion. In non-excluder genotypes, shoot salt concentrations can shortly peak to the toxic levels (Munns, 2002). Salt exclusion is especially desirable in perennial fruit crops which retain the leaves for much longer periods than annual crops having short-lived leaves. In perennial species, high shoot: root ratio, high intrinsic growth rate and absence of an apoplastic pathway in roots are the features which reduce the rate of salt loading into the transpiration stream. In relatively more salt tolerant species, there would be little retranslocation of absorbed Na^+ or Cl^- in the phloem to prevent the salt export to the actively growing shoot tissues. Halophytes also possess specialized cell types called salt glands or bladders for salt excretion (Munns, 2002; Munns *et al*., 2002).

At the cellular (organelle) level, plants sequester the excess salts present in the cytoplasm in the cell vacuole, a process called ion compartmentation, to protect the metabolic enzymes from salt damage. Both Na^+ and Cl^- inhibit the enzymatic activities at concentrations above 100 mM. After Na^+ and Cl^- have been sequestered in the cell vacuole, a variety of inorganic and organic solutes accumulate in the cytoplasm (*i.e*., osmotic adjustment) to balance the osmotic pressure of the ions in the vacuole. In comparison to salt exclusion, ion compartmentation and salt excretion, osmotic adjustment requires more energy use to synthesize the solutes. Again, accumulation of compatible organic solutes requires much more energy compared to that needed for inorganic ions (*i.e*., 3.5, 34, 41 and 50 moles of ATP for Na^+, mannitol, proline and glycine betaine, respectively; Munns, 2000).

At the molecular level, different ion channels and transporters regulate the net movement of salts across the cell membranes. Under normal conditions, plants maintain a high cytosolic K^+/Na^+ ratio. Higher extracellular Na^+ concentrations, however, favour the passive transport of Na^+ over K^+. As hydrated ionic radii of Na^+ and K^+ are strongly similar with each other, ion channels often fail to discriminate between them. Na^+ ions can be transported into the cell through low- and high-affinity K^+ transporters (Blumwald, 2000). Low-affinity K^+ channels with low K^+/Na^+ selectivity are more adversely affected by Na^+ ions. Salt stressed plants must maintain more high-affinity K^+ channels for adequate K^+ uptake (Zhu, 2007). Three types of low affinity K^+ channels- inward rectifying channels (KIRCs), outward rectifying channels (KORCs) and voltage-independent cation channels (VICs)- are known. In contrast to voltage dependent KIRCs and KORCs having a high K^+/Na^+ selectivity ratio at physiological K^+ and Na^+ concentrations, VICs exhibit a relatively high Na^+/K^+ selectivity and are implicated in Na^+ uptake at high salt levels (Blumwald, 2000). Integrated membrane proteins (IMPs) present in plasma membranes play a crucial role in different cell functions including control of the solute movement across the membranes. High-affinity potassium transporters (HKTs) are a class of IMPs occurring only in plants. While some HKT proteins are highly selective for Na^+, others exhibit affinity for K^+. Moreover, the selectivity of certain HKT proteins may change depending on the ionic environment (Waters *et al.*, 2013).

Available evidence suggests that in many species higher Cl^- concentrations, and not Na^+, cause the toxicity symptoms. Nonetheless, little is known about Cl^- uptake and translocation mechanisms in plants. Some of the key traits that control Cl^- transport processes in plants include reduced net xylem loading, intracellular compartmentation and efflux of Cl^- from roots. Restricted loading into xylem prevents excess Cl^- accumulation in the shoot tissues. In some species, Cl^- is preferentially sequestered in leaf epidermis to lessen the toxicity to the photosynthetically active mesophyll cells. In contrast to extensively studied K^+ channels, there is paucity of information on genes and proteins involved in anion movements in plants. Recent studies have shown that several traits may contribute to reduced Cl^- loading into shoots (Cl^- exclusion); previously considered to be controlled by a single dominant gene. A few genes and proteins directly or indirectly regulating Cl^- flux in plants include the aquaporins (regulating the water flow in roots) and ATP binding cassette (ABC) transporters. Transcriptome analysis of two citrus genotypes differing in Cl^- exclusion revealed the possible involvement of several anion transporter families (Teakle and Tyerman, 2010).

8. ASSESSMENT OF SALT TOLERANCE

Salt tolerance of a given plant species or genotype can be assessed using two criteria, *viz*., percent reduction in 'biomass' or 'yield' production under saline and normal conditions over a period of time. Salt tolerance of a crop can be assessed by plotting its relative yield as a continuous function of soil salinity. Maas and Hoffman (1977) proposed that this response curve could be represented by two line segments, *viz*., '*a tolerance plateau with a zero slope*' and '*a concentration-dependent line*' whose slope indicates the yield reduction per unit increase in salinity. The point at which the two lines intersect designates the threshold, *i.e.* the maximum soil salinity (EC_e) that does not reduce yield below that obtained under normal conditions. It is pertinent to mention, however, that threshold salt tolerance reported by Maas and Hoffman (1977) serves only as a guideline to understand the relative salt tolerance among crops as absolute tolerance varies with the agro-climatic conditions, genotypes and management practices. Furthermore, data in most of the cases represent the salt tolerance of a single cultivar or few cultivars; they do not necessarily represent the salt tolerance of species. In case of woody fruit crops, another limitation is that these data are applicable when Na^+ or Cl^- excluder rootstocks are used or when these ions do not predominate in the soil. Despite these discrepancies, the data are useful in showing the wide range of salt tolerance across species, and in that yield has a different pattern of response than vegetative biomass (Munns *et al.*, 2002).

9. SALINITY MANAGEMENT OPTIONS IN FRUIT CROPS

Several options can be exercised for expanding the area under fruit crops in salt-affected regions (Table 1). It appears to be a safe option to raise the fruit orchards in lands having moderate salinity and relatively deeper watertables as majority of them are harmed by the elevated salt and moisture levels in the root zone. In lands where watertable lies below 2 m, and preferably at 4-5 m depth from the surface, there will be least possibility of damage as direct contact between deep growing tree roots and saline water will not occur. Upward movement of water brings the dissolved salts to the root zone. Plants suffer from severe salt stress when the watertable is <1.5 m below the soil surface. Depth of watertable is a major factor governing the rate of evaporation; in areas where watertable depth is 1.5-3.0 m evaporation will be minimal (Salama *et al*., 1999). In waterlogging free degraded sodic lands having assured fresh water supplies feasible interventions like gypsum application could prove very effective (Singh *et al*., 1997). In either case, availability of quality planting material of salt tolerant genotypes is desirable as it can considerably reduce the dependence on other means of salinity management. Although such 'salt-affected lands of horticultural relevance' provide ample scope for crop diversification through fruit crops, there are constraints that need to be addressed. Third, and the challenging, option relates to putting the waterlogged salty lands under fruit crops. Over the years, it has become difficult to reclaim and utilize such lands even through time tested management practices including gypsum application and drainage such that they lie barren for extended periods of time. An 'ensemble of technologies', *inter alia*, land shaping, storage of rain/canal water, salt tolerant cultivars, mulching and drip irrigation is suggested to enhance the economic value of such lands.

Table 1. Context-specific choice of salinity management practices in fruit crops.

Watertable depth	Soil type	Main limitations	Strategies
Deep (> 2m)	Saline	Marginal to moderate salinity, osmotic stress and specific ion toxicities	Leaching, use of salt tolerant cultivars, drip irrigation
	Sodic	High pH (9.0-10.0), degraded soil structure, water stagnation and ionic imbalances	Improved planting methods; gypsum application (5-10 kg pit^{-1}); selection of drought and salt tolerant cultivars
	Partially reclaimed sodic	Moderate pH (~8.5), unfavourable soil structure and susceptibility to resodification	Integrated fruit-based farming systems for resource recycling, integrated crop management practices and micro-irrigation
Shallow (< 2m)	Saline	High to very high salt stress and related hazards like hypoxia	Land shaping, raised bed planting, storage of canal/rain water for irrigation, drip irrigation and salt tolerant cultivars
	Sodic	Structural problems, impeded drainage, wetter soil profiles and oxygen depletion	Inversion of soil column, integrated crop-fish module, planting on pond dykes, rainwater harvesting and drip irrigation

Different techniques available for salinity management in fruit crops are briefly discussed under the following heads:

9.1 IMPROVED PLANTING TECHNIQUES

Waterlogging free sites are always desirable for raising fruit trees. Of late, however, growing land scarcity and food security concerns are making it difficult to spare the lands under staple crops for horticultural production. In large parts of north-western India suffering from poor soil health and stagnant crop yields, farmers seem to be reluctant to switch over from rice-wheat system to the more remunerative horticultural crops. This state of affairs has necessitated the development of appropriate planting techniques to revive the productivity of waterlogging prone salty lands through fruit crops. Experiments conducted under shallow saline watertable conditions indicate the possibility of commercial cultivation of guava (cv. Allahabad Safeda) and bael (cv. NB-5) in saline soils irrigated with saline water (EC 3.0-4.0 dS m^{-1}). Planting on raised beds and the amelioration of planting pits with FYM considerably enhance the salt tolerance in young plants [Fig. 3]. Simple land shaping interventions have also made it possible to raise high value horticultural crops in waterlogged sodic lands of Central Indo-Gangetic Plains and the coastal saline lands otherwise lying unproductive. Land shaping interventions are based on the premise that inverting less saline deeper soil profiles upside down would make the surface soil congenial for crop growth by lowering the watertable and improving the soil properties (ICAR-CSSRI, 2016). Ten different fruit species were evaluated in a highly sodic land (pH ~10.0). Planting was done in the auger-holes and pits containing 5-20 kg gypsum. Increasing gypsum dose had a positive effect on tree growth. After 7 years, Indian jujube, jamun, guava, aonla and karonda were found to be suitable species for such soils (Dagar *et al*., 2001). Auger planting holes are especially effective in promoting water and air flux and root growth in calcareous sodic soils having a sub-soil hardpan.

Fig. 3 Raised bed planting of bael cv. NB-5 and guava cv. Allahabad Safeda under shallow saline watertable conditions of Nain Experimental Farm, Panipat (left) and tractor mounted auger for piercing the hard pans in sodic soil (right) (Photo: Anshuman Singh).

9.2 AMENDMENTS, MICROBIAL INOCULANTS AND PLANT GROWTH REGULATORS

In addition to gypsum, the preferred amendment for sodic soils, other materials have also been successfully used to alleviate salt injury in fruit crops. Amelioration of planting pits with sand and FYM (20 kg each pit^{-1}) considerably improved the properties of a moderately sodic soils (pH ~9.0) resulting in better establishment of litchi cv. Rose Scented (Saxena and Gupta, 2006). Fruit plantations also lead to steady improvements in the properties of sodic soils. Among different fruit and agro-forestry land uses in a semi-reclaimed sodic soil, the minimum (6.8) and the maximum (9.5) soil pH at 1.5-2.0 m depth was noted in litchi and *Eucalyptus* plantations. The highest soil organic carbon storage (133 t C ha^{-1}) was observed in the guava land use. Long-term improvements in soil properties under fruit trees may be due to *in situ* decomposition of the litter, deeper root growth and nutrient mineralization in the root zone (Sharma *et al*., 2016b). Arbuscular mycorrhizal (AM) fungi alleviate the detrimental effects of salinity by stabilizing photosynthesis, regulating the ion and water uptake by roots and by enhancing the accumulation of compatible solutes and antioxidant compounds. In AM symbiosis, the fungus forms an appressorium on the root surface and enters the root cortex by extending its hyphae. The hyphae form arbuscules and vesicles in the cortex. Inoculation with a mixture of two AM fungi (*Glomus intraradices* and *Glomus mosseae*) significantly improved the growth in NaCl stressed (50 mM) Cleopatra and Alemow seedlings compared to the salinized but non-inoculated plants (Navarro *et al*., 2011). Rhizospheric and endophytic bacteria (CSR-G-1, CSR-B-2, and CSR-B-3) have been found promising to enhance salinity tolerance in different horticultural crops. Their growth enhancing and bioameloiration properties are due to higher activities of superoxide dismutase, phenyl alanine lyase, catalase, peroxidase, phenols, and proline in the treated plants (Damodaran *et al*., 2014).

Of late, interest in plant growth regulators as a tool for salinity management has considerably increased. Endogenous hormones regulate important physiological processes linked to salt tolerance. Under stress conditions, indole acetic acid (IAA) increases water use efficiency by enhancing the stomatal resistance to transpiration. Gibberellins modulate ionic balance and endogenous abscisic acid levels in the salinized plants. Cytokinins such as kinetin reduce the severity of salt stress by up-regulating endogenous polyamine levels (Rajkumar *et al*., 2016). Paclobutrazol (PBZ), an anti-gibberellin growth retardant, has been used in many fruit crops to overcome the salt induced oxidative stress and other adverse effects. It improves the salt tolerance by regulating the plant water relations, promoting the activities of proline and antioxidant enzymes and by protecting the photosynthetic pigments (Hu *et al*., 2017). Salicylic acid, an endogenous plant growth regulator, is also known to improve abiotic stress tolerance in plants in trace amounts (0.05 mM) mainly by stimulating the transient accumulation of IAA and ABA (Shakirova, 2007). Despite these beneficial effects, it remains to be seen whether such growth regulators exert a similar influence under field conditions as most of such experiments have been carried out under relatively controlled environment.

9.3 NUTRIENT MANAGEMENT

Majority of the fruit crops being sensitive to excess Na^+ and Cl^- ions, sodium and chloride free fertilizers are recommended to prevent any adverse impacts on orchard productivity and health. Similar to normal soil conditions, nutrient management plans under saline conditions should ideally be based on soil and leaf tests and should take into account the specific nutritional requirements at a particular crop stage. Consistent with the fact that appropriate nutrition management is a key to sustaining tree growth, fruit yield and quality, specific fertilizer management guidelines have been developed for the crops irrigated with saline water. In both Na^+ and Cl^- sensitive crops, potassium sulphate (K_2SO_4), and not potassium chloride, should be used. Fertigation with water soluble fertilizers should be done wherever possible to save the nutrients and to prevent the groundwater contamination. Some nitrogen and calcium supplements have been found to partly alleviate the salt induced injury in fruit crops.

9.4 SALT EXCLUDER ROOTSTOCKS

Reduced salt uptake by the plant roots can considerably enhance the plant growth and yield under saline conditions. Rootstocks that either fully or partially exclude Na^+ and Cl^- ions and/or preferentially accumulate K^+ may be used for conferring salt tolerance to the scion cultivars. Of late, a few breeding projects seek to combine traits such as high water use efficiency, drought tolerance and salt tolerance into a single rootstock so that they can simultaneously tolerate multiple stresses. Certain genetic factors govern the salt tolerance of a given rootstock. For example, polyembryonic mango rootstocks often outperform the monoembryonic ones in saline soils (Bright *et al*., 2001). Tetraploid citrus seedlings may be more salt tolerant than diploid genotypes. Genome duplication leads to physiological and anatomical changes resulting in differential capacities for mineral uptake and transport. Under two NaCl levels (40 and 80 mM), diploid *Citrus macrophylla* seedlings accumulated more Na^+ and Cl^- in leaves than tetraploids. Leaf K^+ concentrations declined in diploid but not in the tetraploid seedlings obviously due to differences in nutrient absorption and translocation (Ruiz *et al*., 2016). Fine root turnover, a trait unique to citrus relative *Poncirus trifoliata*, enables the plants to continuously produce fine roots to remove the excess salt ions. This mechanism, critical in delaying the ion accumulation, seems to be transferable to related species through inter-generic hybridization (Tozlu *et al*., 2000). In citrus, Na^+ and Cl^-

exclusion mechanisms are independent traits suggesting that a good Na^+ excluder would not necessarily be an effective Cl^- excluder and vice versa (Sykes, 1992).

A list of salt tolerant rootstocks identified in selected fruit crops is furnished in Table 2. This list, however, is only illustrative as several such rootstocks have been reported in other fruit crops. Moreover, ongoing researches are expected to unravel many more potential salt excluders in the future. It is worth mentioning that salt exclusion capacity in some of the widely used rootstocks breaks down when salinity exceeds the critical threshold. For example, grape rootstock Dog Ridge was introduced in India to cope up with salinity and drought stresses. Initial results suggested that non-grafted Dog Ridge roots could tolerate up to 6.5 dS m^{-1} NaCl-induced salinity. Later on, however, its ability to sustain prolonged saline irrigation became questionable spurring interest in other rootstocks (Sharma *et al*., 2011). Furthermore, Dog Ridge induces scion vigour, uneven bud sprouting and dead wood formation resulting in reduced bud fruitfulness and low fruit yield in Thompson Seedless vines (Satisha *et al*., 2016).

Table 2. Salt excluder rootstocks identified in fruit crops.

Crop	Rootstock(s)	Finding	Reference
Mango	Gomera-1	Salt stressed (EC_e ~2.5 dS m^{-1}) Osteen scion on Gomera-1 had much lower leaf Na^+ and Cl^- than on Gomera-3.	Duran Zuazo (2003)
	M. zeylanica	*M. zeylanica* had higher CO_2 assimilation and root K^+/Na^+ ratio but lower leaf/root Na^+ than *M. indica* 13-1 at 60 mM NaCl.	Schmutz (2000)
Citrus	Cleopatra mandarin	Excluded Cl^- at the lowest salinity (NaCl induced osmotic potentials of -0.10, -0.20 and -0.35 MPa) but not at higher levels; Sour orange and Rough lemon were not able to exclude Na^+/Cl^- even at -0.10 MPa.	Zekri and Parsons (1992)
	Rangpur lime	A good Cl^- excluder; salt tolerance capacity of citrus rootstocks decreases in the order: Cleopatra> Rangpur lime> SB812 (*C. sunki* x *P. trifoliata*)> x639 (*C. reshmi* x *P. trifoliata*).	Boman *et al*. (2005)
Guava	Crioula	Salinity drastically suppressed seedling emergence, growth and biomass production in Paluma and Ogawa, but Crioula was least affected.	Sá *et al*. (2016)
Grape	140Ru, St. George and Schwarzmann	Strong Cl^- excluders; Ramsey (syn. Salt Creek) is not a strong Cl^- excluder as believed but simultaneously tolerates drought and moderate salt stress.	Fort and Walker (2011)
Almond	Hansen 536 & Bright’s	A long term (20 y) trial revealed that peach-almond hybrids (Hansen 536, & Bright’s) were far superior over peach rootstocks (Halford, Lovell, Nemaguard, and Nemared) with regard to Na^+ and Cl^- exclusion.	Doll *et al*. (2013)

Pistachio	*P. atlantica*	*P. atlantica* outperforms *P. vera* with regard to low Na^+ and Cl^- uptake, higher K^+/Na^+ and Ca^{2+}/Na^+ selectivity and ability to resume normal growth and fruiting after stress relieve.	Mehdi-Tounsi *et al.* (2017)

Salt tolerance is a complex biological trait governed by several genes whose expression is highly influenced by the environmental variables. For example, in citrus species, around 60 different traits seem to directly or indirectly influence the salt tolerance (Raga *et al*., 2016). Thus, despite significant strides in deciphering the physiological regulation of salt stress, genetic and molecular mechanisms imparting salt tolerance in fruit crops remain elusive. This has impeded the progress in developing salt tolerant rootstocks through conventional breeding techniques.

Many studies suggest that genetic transformation could be a very effective tool to enhance salt tolerance by transferring the genes from other species. Preliminary results clearly indicate that stable expression of appropriate transgenes can remarkably increase the salt tolerance even in highly salt sensitive species. *Agrobacterium*-mediated integration of vacuolar Na^+/H^+ antiporter gene (AtNHX1) from *Arobidopsis* into kiwifruit genome considerably enhanced the salt tolerance of transgenic plants (up to 200 m mol l^{-1} NaCl). Transgenic lines outperformed wide-type plants with regard to osmotic adjustment and antioxidant activities (Tian *et al*., 2011). Constitutive expression of a *Vitis vinifera* dehydrin (DHN) of the YSK_2 type (VvDhn) allowed for a more vigorous growth in transgenic tobacco plants than in wild-type (WT). Transgenic lines were able to germinate under 300 mM mannitol. Adult plants expressing VvDhn also displayed improved tolerance to both drought and salt stresses (Jardak-Jamoussi *et al*., 2016). Genetic transformation of lemon rootstock *Citrus macrophylla* with *Arabidopsis* gene CBF3/DREB1A led to better growth in salinized transgenic lines in comparison to wild-type plants (Alvarez-Gerding *et al*., 2015). In spite of such encouraging results, most of the transgenic development programmes are in infancy stage and a range of biological, regulatory and public safety concerns need to be adequately addressed before the actual field application of the genetically transformed genotypes.

9.5 IRRIGATION TECHNIQUES

As saline and sodic soils are often also underlain with low quality water, water use efficient techniques are recommended to allow the sustained use of saline water without impairing the soil properties in the long run. In many salinity affected parts of India, about 25 % of the groundwater contains either excess dissolved salts or residual sodium carbonate rendering it unsuitable for irrigation. Nonetheless, farmers’ grappling with acute fresh water shortages have no other choice but to irrigate their crops with such water further exacerbating the salinity and waterlogging problems. In many areas of Haryana, fruit growers construct the cemented farm ponds to store the rainfall/canal water for conjunctive use with saline water (Fig. 4). Available evidence suggests that this could be a sustainable practice in areas having light textured soils and moderate rainfall to leach the salts accumulated in the previous season. Adoption of drip irrigation and simple agronomic interventions such as mulching can further enhance the viability of this practice.

Fig. 4 Cemented pond for storing the fresh canal water in a rainfed saline field at Hisar, India (left) and a drip irrigated vineyard in South Australia (right) (Photo: Anshuman Singh).

Despite the fact that water is a critical resource that needs to be sustainably used, unsustainable anthropogenic practices have caused continued depletion of fresh water. Globally, 70% of the annual available water is used in agriculture to irrigate only 17% cultivated area that provides 40% of the global food production. Consistent with the fact that even small savings (~15%) in agricultural use can more than double available water for domestic and industrial use, counties like Israel have made onerous efforts to maximize the water use efficiency by the large scale adoption of micro-irrigation practices (Barak, 2014). Drip irrigation offers a number of advantages such as improved soil-water regime, partial soil wetting, minimum salinity hazard to plants, water savings, weed control and higher yields. Very high impact of drip technology in Israel is evident from the fact that of the 1,129 Million cubic meters of water used by agriculture annually nearly 30% is wastewater and 16% saline water applied through drip (Megersa and Abdulahi, 2015). Despite multifarious benefits and policy thrust, restricted adoption of drip irrigation in India is worrisome. A study conducted in 9 Indian states revealed that small farmers see micro-irrigation as a capital intensive technology suited only to the large farmers having access to capital and technical knowhow. As a consequence, only about 12% of the potential drip irrigation area and 8% the potential sprinkler area is covered in the country with large variations across states. In order to promote the uptake of drip irrigation, reductions in capital cost of the system, provision of technical support for operation and maintenance, relaxation of farm size limitation in providing subsidies and creation of a single state level agency have become necessary (Palanisami and Raman, 2012).

CONCLUDING REMARKS

Taking a serious note of the agrarian distress adversely affecting the farmers' livelihoods, Government of India has set the target of doubling the farmers' income by the year 2022. Efforts to improve the land productivity and assured remunerative returns to the farmers will be the keys to realize this goal. Previous attempts to enhance the farm profits have unwittingly led to land degradation in different parts of the country. Accordingly, agricultural technologies capable of providing higher incomes without jeopardizing the environmental sustainability are needed. Despite many efforts, farm diversification through horticultural crops remains sluggish. Given the fact that future expansion in area under fruit crops will only be possible in marginal areas suffering from problems such as salinity and fresh water scarcity, feasible interventions such as improved planting methods, use of amendments, salt tolerant rootstocks and drip irrigation are suggested to enhance the salt tolerance in high value fruit crops. Recent innovations such as genetic engineering provide a new opportunity to develop multiple stress tolerant genotypes capable of simultaneously tolerating two or more stresses; albeit with caution. Continual refinements in existing technologies are equally important to unlock the economic potential of saline lands through fruit crops.

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