Soil and Water Management Practices for Fruit Cultivation in Salt Affected Soils

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Introduction

Presence of excess salts in soil and groundwater is a severe impediment to crop production in severeal irriagted and rainfed areas of the world. A recent estimate puts the global extent of salt-affected land area at 1128 m ha, which is considerably higher than previous estimates (831-955 m ha) (Wicke *et al.,* 2011) indicating a steady rise in the problem. Although soil salinity caused by the natural factors has been reported from about 100 countries of the world, relentless development of irrigation-induced waterlogged salty lands is increasingly jeopardizing agricultural sustainability and food security in many araes. Severity of the problem is evidenced by the fact about 20% of global irrigated lands have either become less productive or completely unsuitable for crop production due to waterlogging and the accompanying rise in salinity or sodicity. If current trends continue unabated, nearly half of the global arable lands would become salinized by 2050. Besides direct adverse effects on soil properties and crop growth, salinity also deteriorates groundwater quality (UNCCD, 2017).

While salinity onslaught continues to threaten sustainable land use, a sizeable portion of arable lands is also increasingly being grabbed by housing, infrastructure and industrial sectors resulting in the net loss of the cultivated land (Chand, 2017). By comparison, global food demand has steadily increased and is expected to rise in the foreseeable future. These developments have placed considerable pressure on productive, yet shrinking, land resources. Available evidence suggests that intensive input use devoid of environmental concerns often causes irreparable losses in soil quality; a fact evidenced by secondary salinization, fresh water depletion and a range of other environmental problems in many parts of north-west India (Sharma *et al.,* 2016). These observations lead to the conclusion that while productive farmlands need to be safeguarded from further degradation, less productive or abandoned lands must be restored for meeting the ever rising food and nutritional needs.

'Salt-affected soils' (SAS) is a collective term to describe soils with either excess soluble salts or exchangeable sodium. Depending on soil saturation paste extract values of electrical conductivity (EC_e), pH (pH_s) and exchangeable sodium percentage (ESP), soils are grouped into saline ($EC_e \geq 4$ dS m^{-1}, $pH_s < 8.2$, ESP< 15) and sodic (EC_e< 4 dS m^{-1}, pH_s >8.2, ESP >15). When both EC_e and ESP exceed the threshold values, the soil is called 'saline-sodic'. Conventionally, saline soils are reclaimed by leaching with fresh water and sodic soils by applying suitable amendments followed by water ponding to remove the salts below the root zone. Over the years, however, growing fresh water shortages have emerged as a serious hurdle in the reclamation increasing the interest in alternative means of soil reclamation. India has an important place in the production of many horticultural crops and is currently the second largest producer of fruits in the world. In comparison to majority of the field crops, fruit cultivation can generate higher incomes and employment opportunities while ensuring nutritional security of the farm families. Notwithstanding considerable increase in fruit production in the last few decades, India still remains a net importer of fruits and vegetables (Mukherjee *et al*., 2016). Poor orchard upkeep coupled with the losses caused by biotic and abiotic stresses, and high post harvest losses are the major factors responsible for low production and reduced availability of fruits. While attempts to increase average productivity may come at the cost of environmental degradation, extending fruit cultivation to prime croplands is virtually impossible. Fierce competition for land use among different sectors of economy and decreasing availability of fresh water imply the need to harness the productivity of marginal lands for expanding the area under fruit crops. In light of these facts, this article presents an overview of feasible soil and water management options for growing fruit crops in salt-affected soils.

Managing Salt Affected Soil for Fruit Production

The options available for growing fruit crops in salt-affected soils can broadly be grouped into four categories, *viz*., 'salt tolerant crops and cultivars', 'improving the root zone conditions', 'reducing crop evapotranspiration losses' and 'irrigation management for reducing salt hazard'. The strengths and weaknesses of such salinity management techniques and practices are discussed in the following sections:

1. Salt Tolerant Crops and Cultivars

1.1. Salt tolerant crops: Notwithstanding the fact that majority of fruit crops exhibit high sensitivity to salinity (Bernstein, 1980), there are several species that perform well under saline conditions. Such species, in addition to producing nutrient rich fruits, have other significant social and environmental roles making them an inseparable part of the local farming systems. Some of the prominent examples include Indian jujube, bael and jamun. While the former two are potential crops for dryland saline areas, jamun shows tolerance to waterlogging prone saline soils. Indian jujube and related species are widely distributed in saline arid and semi-arid regions of western India. Both bael and jamun trees are popular backyard trees in several states of India. Notwithstanding their critical livelihood supporting roles in areas where they are conventionally grown, such potential species largely remain underutilized in terms of production and trade. These observations, however, do not imply that other fruit crops are unsuitable for saline and sodic soils. In fact, relatively high salt tolerance in some cultivars even in extremely salt sensitive crops like citrus and mango coupled with improved management practices have been instrumental in their commercial cultivation in salt-affected soils. Excess salts may not always be the sole limitation to fruit cultivation in salt-affected soils. Other stresses including shallow watertable, drought and nutrient toxicities often co-exist with salinity. Occurrence of two or more such stresses together can be more problematic to deal with. This suggests the need to identify cultivars that can perform well under such situations. Much of the existing knowledge on physiological basis and management of salt tolerance in fruit crops comes mainly from crops like citrus and grapes (Singh and Sharma, 2018) reflecting their huge economic values. Nonetheless, the precise basis of salt tolerance even in such extensively studied crops is poorly understood impeding the development of salt tolerant cultivars through genetic improvement.

1.2. Salt tolerance threshold: Based on a review of information available from different sources, Mass and Hoffman (1975) published a list indicating the relative salt tolerance of different agricultural crops including some fruit crops (Table 1). While ranking different species for salt tolerance, they considered only those studies that reported both root zone salinity and the corresponding yield data. However, non-availability of yield data prompted the use of growth related data in some fruit and nut crops. Furthermore, insufficient quantitative data in some crops necessitated the use of qualitative data for drawing plausible conclusions. However, these data only indicate the relative salt tolerance of a particular crop, and the absolute tolerance would vary with genotype, agro-climatic conditions and crop management practices. Marin *et al.* (1995) screened 26 olive cultivars using 100 mM NaCl solution. After 49 days of salt treatment, relative growth decreased by 16-70% in different cultivars. Relative growth was below 30% that of control in salt sensitive cultivars (Pajarero, Chetoui, Galego and Meski), 60-70% in most tolerant cultivars (Nevadillo, Jabaluna, Escarabajuelo, Caiiivano and Picual) and intermediate in others like Zorzariega, Redondil, Alamefio and Arbequina. Such studies demonstrate that crop genotypes vary widely in salt tolerance.

Table 1. Salt tolerance threshold in selected fruit crops (Source: Maas and Hoffman, 1975)

Fruit crop	Salinity at initial yield decline (dS m^{-1})	% Yield decrease per unit increase in salinity beyond threshold	Salt tolerance rating
Almond	1.5	19	S
Apple*	….	….	S
Apricot	1.6	24	S
Avocado*	….	….	S
Berries (*Rubus*)	1.5	22	S
Date palm	4.0	3.6	T
Grape	1.5	9.6	MS
Grapefruit	1.8	16	S
Lemon*	….	….	S
Olive*	….	….	MT
Strawberry	1.0	33	S

**Assessment based on qualitative data. Note: S- Sensitive, T- Tolerant, MS- Moderately sensitive, MT- Moderately tolerant.*

1.3. Salt tolerant rootstocks: Salt tolerant rootstock cultivars have also been identified in many fruit crops (Table 2). They protect the scion cultivars from salt injury mainly by partially excluding Na^+ and/or Cl^- ions, and restricting their transport to the shoots and leaves. Again, some such rootstocks also exhibit selective uptake of K^+ and Ca^{2+} to overcome Na^+ toxicity, enhanced accumulation of osmolytes (e.g., proline) and maintenance of photosynthesis for lessening the salt injury. It is, however, pertinent to mention that most of the observations reported here (Table 2) are based on results of relatively controlled pot experiments and may not be reproducible under field conditions. This is because researchers often employ a single salt (NaCl) for developing salinity while salt composition may be quite different in the field soil (Grieve et al. 2012). Again, factors other than salt composition including soil texture, watertable depth and nutrient constraints (e.g., boron toxicity) are likely to greatly influence salt tolerance response under field conditions. These observations imply that in order to accurately predict salt tolerance threshold, diverse genotypes need to be screened under conditions closely mimicking the local field conditions.

Table 2. Salt tolerant rootstocks in different fruit crops

Crop	Rootstock	References
Apple	'M 26', 'M9'	Motosugi *et al*. (1987)
Citrus	'Cleopatra', 'Gou Tou Cheng'	Levy *et al.* (1999)
	'Rangpur lime'	Storey (1995)
Guava	'Crioula'	Sá *et al.* (2016)
Grape	'Dogridge', 'Salt Creek' (syn. 'Ramsey')	Upreti and Murti (2010)
	V. berlandieri × *V. rupestris* (110R, 1103P, 99R, B2/56)	Jogaiah *et al*. (2014)
	'1103 Paulsen'	Walker *et al*. (2004)
Indian jujube	*Z. rotundifolia*	Gupta *et al*. (2002)
	Z. nummularia	Meena *et al*. (2003)
	Z. spina-christi	Sohail *et al*. (2009)
Mango	'13-1'	Kadman *et al*. (1976)
	'Gomera-1'	Duran *et al.* (2003)
	M. zeylanica	Schmutz (2000)
	'GPL-1' and 'ML-2'	Damodaran *et al*. (2013)
	'Olour', 'Nekkare'	Pandey *et al*. (2014)
Prunus spp.	'GF_{677}'	Massai *et al*. (2004)
	'Myrobalan', 'Bright's Hybrid'	El-Motaium *et al*. (1994)
Pear	*Pyrus betulifolia*	Okubo and Sakuratani (2000)
Pistachio	*P. atlantica*, `UCB-1'	Ferguson *et al*. (2002)
Pomegranate	'Tab-o-Larz'	Karimi and Hassanpour (2017)

It has also been shown that salt exclusion efficiency of some rootstocks diminishes upon prolonged exposure to salinity and grafting with commercial scion cultivars. A relevant example in case is the grape rootstock 'Dog Ridge' introduced in India for commercial use in drought- and salt-affected soils. While own rooted 'Dog Ridge' performed well to short-term exposure to NaCl-induced salinity (≤6.5 dS m^{-1}), grafted plants could not endure prolonged exposure to saline irrigation. Saline irrigated 'Thompson Seedless' vines on 'Dog Ridge' and 'Salt Creek' rootstocks showed leaf blackening and necrosis symptoms during ripening stage due to lower K^+ and toxic Na^+ levels in leaf blades. In contrast, vines on 'B2-56' and '1613C' maintained a higher K^+: Na^+ ratio resulting in less injury (Sharma *et al*., 2011). Some potential salt tolerant rootstocks also exhibit poor graft compatibility with commercial scion cultivars. For example, incompatibility of jujube rootstock *Z. nummularia* with scion cultivars like 'Gola' is ascribed to poor callus production at the graft union, phloem degeneration in scion shoots and development of a necrotic layer between the scion and rootstock which eventually result in 'inverted bottleneck' symptoms in the composite plants (Verma et al. 2000). Non-availability of planting material (e.g., seeds, cuttings) in sufficient quantities may also hinder commercial applications of salt tolerant rootstocks in propagation.

2. Improving the Root Zone Conditions

2.1. Improved Methods of Orchard Establishment: A survey of literature reveals few innovative ways of orchard establishment which improve tree establishment, reduce mortality, ensure resource conservation and come at a lower cost than conventional pit method of planting in salt-affected soils.

In situ planting: When moved from nursery to the field, tree saplings suffer from some kind of stress necessitating adequate care in planting for better establishment. Improper transplanting can particularly be detrimental to plant survival and growth in stressful situations. In salt-affected soils, newly planted saplings often decline and succumb due to twin constraints of water deficit (osmotic shock) and ion toxicities. Two tide over this problem, *in situ* planting of rootstocks and subsequent budding/grafting with desired scion cultivars can be a better choice. In this method, polybag grown nursery rootstock seedlings directly planted in the field are budded after attaining proper height and thickness (Pathak, 2003). *In situ* orchard establishment techniques have been developed in crops like aonla, bael, ber, jamun and grapes. Ber orchards developed by *in situ* method tend to develop a deep tap root system capable of drawing water from the lower depths. Successful *in situ* budding of 'Gola' scion buds on different rootstocks (*Z. rotundifolia*, *Z. spina-christi* and *Z. mauritiana* cv. Tikadi) has been demonstrated under waterlogged saline conditions (ICAR-CSSRI, 2018).

Planting on elevated beds: In soils with a shallow saline watertable (≤2 m below the surface), oxygen deletion in the root zone and direct exposure of roots to salts often considerably increase tree mortality. Even salt tolerant fruit crops fail to establish when planted on surface of such lands. This problem can partly be overcome by planting on raised beds. Ridge planting (45 cm high) could ensure the survival of 50% of the aonla plants while complete mortality was seen in sub-surface planting treatment; apprantely due to considerable reduction in root zone salinity in the former than in latter system (EC_e 12-18 dS m^{-1}) (Tomar and Gupta, 1985). Commercial mango cultivation on saline soils (EC_e 2.5-3.5 dS m^{-1}; pH 8.0-8.5) was possible through the adoption of improved management practices including planting on 60 cm high and 180 cm wide ridges (Gunjate et al. 2009). Guava (cv. Allahabad Safeda) and bael (cv. NB-5) plants could endure high soil salinity (EC_e 4.0-10.0 dS m^{-1}) when planted on raised beds (~2 feet) and irrigated with marginally saline water (3-4 dS m^{-1}). While raised bed planting minimized the possibility of direct contact between plant roots and saline watertable, application of less saline water enhanced salt leaching beyond the root zone (Singh et al. 2018).

Planting in auger-holes: In some sodic soils, presence of an impenetrable sub-surface clay pan impedes water and air flows and root growth. Studies have shown that tractor drawn auger can be used to pierce this hard pan for overcoming these limitations. Ber, guava, jamun and tamarind could be successfully grown in a degraded alkali land (pH 10.5) by planting in the gypsum treated augerholes (~25 cm diameter and 160-180 cm deep) (Singh et al. 1997). Ber, guava, jamun and karonda showed complete survival when planted in amendment treated auger-holes (120 cm deep, 45 cm dia. at surface and 20 cm at base) in a sodic soil (pH_2 >10.0; ESP ~90.0) having ~40 cm thick precipitated $CaCO_3$ layer (Singh et al. 2008).

2.2. Soil and water amendments: In addition gypsum, some other amendments also improve plant establishment and growth in salt-affected soils when applied before planting. Planting pit treatment with sand and FYM (20 kg each pit^{-1}) was found effective for litchi (cv. Rose Scented) cultivation in a sodic soil (Saxena and Gupta, 2006). Incorporation of gypsum and FYM in the pit soil mitigated the adverse effects of diluted spent wash (EC 0.93 dS m^{-1}, SAR 7.3 $(mmol/l)^{½}$ irrigation in ber, sapota and pomegranate (Meena *et al.*, 2011). Banana plants receiving gypsum, FYM and 120% higher dose of potassium had higher bunch weight than non-treated plants in sodic soils (Sathiamoorthy and Jeyabaskaran, 2001). Application of pyrite, FYM and sand in planting pits considerably reduced soil ESP, bulk density, penetration resistance and EC such that mango and litchi could grow profusely (Singh *et al*. 2001). Studies have also shown that amendment applications can also overcome salinity hazard in irrigation water. Gypsum and sulphitation pressmud treated grapevines produced 11.3% and 31.0% higher yields, respectively, than vines receiving sodic tubewell water (RSC 6.4 meq L^{-1}) alone (DARE, 2015). Mixing of polyacrylamide (PAM @ 10 and 20 ppm) in irrigation water (EC_{iw} 6.2 dS m^{-1}) decreased water repellency index by 27 and 40%, respectively, compared to control in pomegranate orchard soils. Higher dose of PAM (20 ppm) could completely ameliorate the adverse effects of saline irrigation (Tadayonnejad *et al.*, 2017).

2.3. Arbuscular mycorrhizal fungi: Arbuscular mycorrhizal fungi (AMF) treatment can improve crop salt tolerance by increasing the availability of major nutrients like N, P, Ca and Mg, maintaining a favourable K^+/Na^+ ratio, increased accumulation of benign osmolytes and maintain leaf photosynthesis. AMF treated salt stressed pomegranate plants had higher root and shoot P and lower shoot Cl^- than control plants (Arab Yarahmadi *et al.*, 2018). AMF inoculation, either alone or in combination with bacterial consortium, improved plant water balance, K^+/Na^+ ratio and leaf photosynthesis in salt treated (NaCl 150 or 250 mM) grape rootstock 'Dogridge' (Upreti *et al.*, 2016). AMF treatment decreased electrolyte leakage, enhanced P and K uptake, and higher proline accumulation in salinized rough lemon (*C. jambheri*) seedlings (Zarei and Paymaneh, 2014).

2.4. Plant growth substances: Some authors have found that exogenous applications of certain plant growth substances improve plant salt tolerance. Watering with 1.0 mM salicylic acid (SA) solution alleviated NaCl (35 mM) effects on strawberry growth by improving leaf relative water content, chlorophyll and nutrient levels, and decreasing the electrolyte leakage (Karlidag *et al*., 2009). Pretreatment with SA (0.5 and 1.0 mM) partly negated the adverse effects of 200 mM NaCl in olive cv. Oueslati by restricting Na^+ translocation to the leaves, and enhancing the activity of non-enzymatic antioxidants (polyphenol and flavonoid) (Methenni *et al*., 2018). In 'Nemaguard' peach, saline irrigation caused about 60% reduction in plant growth. However, paclobutrazol (PBZ) treated plants showed only 30% reduction in growth, less defoliation, lower extent of salt injury symptoms, and higher rates of leaf gas exchange than salinized plants. Regardless of salinity level, PBZ application had a repressive effect on Na^+ and Cl^- accumulation in different plant parts (El-Khashab *et al*., 1997). Combined use of PBZ (250 ppm) and putrescine (50 ppm) improved proline and Ca^{2+} accumulation while restricting Na^+ transport to the leaves in salt treated sour orange seedlings (Sharma *et al*., 2013).

2.5. Overcoming nutritional constraints: Plants is saline soils suffer both from ion toxicities and mineral ion imbalances. Reduced uptake of essential nutrients can be ascribed either to direct competitive inhibition by Na^+ and Cl^- ions or to a decrease in soil osmotic potential restricting the mass flow of nutrients to plant roots. Again, a considerable amount of many nutrients often leach to the groundwater after drainage or leaching. High pH, ESP, poor organic matter, oxygen depletion and degraded physical environment can further accentuate nutrient deficiencies in sodic soils (Swarup and Yaduvanshi, 2004). Nutrient recommendations for fruit crops in salt-affected soils should be based on factors like spatial-temporal variations in root zone salinity, depth and distance of active root growth, soil physical conditions and irrigation water quality. Nutrient plans should be in sync with soil and leaf nutrient status. Fertilizers having Na^+ (e.g., $NaNO_3$) or Cl^- (e.g., KCl) can exacerbate the salinity problem and should be avoided. Frequent (low concentration) applications along with irrigation water (*i.e*., fertigation) can give better results than a single time soil application (Boman *et al*., 2005). Certain organic manures and composts, besides partly alleviating salt injury, can ensure a steady supply of nutrients for an extended period of time. However, despite being less costly, organic inputs need to be applied in large amounts for good results and this may restrict their commercial use. In soils where high pH and associated problems suppress micronutrient availability, foliar application of single nutrients instead of nutrient mixtures is suggested.

3. Reducing Crop Evapotranspiration Losses

3.1. Mulching: Excess irrigation with fresh water only temporarily reduces the root zone salinity. Salts tend to move upward in response to evaporation gradient and re-accumulate in the surface layers within a few months of leaching. Even if fresh water is easily available, over-irrigation may have some undesirable effects including decrease in soil temperature and the consequent adverse effects on root growth. Evidently, other measures would be required to keep salt levels in check without altering the soil properties (Dong *et al*., 2009). Mulching with organic and inorganic materials can be an easy solution to prevent upward movement of salts with additional benefits like improved soil moisture availability, reduced weed growth, stable soil temperature and reduced erosive impact of rainfall. Plastic film and concrete mulches significantly reduced crop ET in a Chinese jujube (*Zizyphus jujuba* Miller) orchard in a saline soil resulting in higher WUE than control without any adverse effects on fruit yield and quality (Sun *et al*., 2012). Baggase or plastic mulch coupled with spray of a biodegradable acrylic polymer reduced grape irrigation water requirement by 25% (Sharma and Upadhyay, 2013). Mulching with sugarcane baggase, wheat and safflower reduced the actual water requirement by 30-70% in a drip irrigated pomegranate orchard. Baggase mulched trees (7-10 kg $plant^{-1}$) displayed the highest WUE and fruit yield (Meshram *et al*., 2017). Application of chipped pruned branches as *in situ* organic mulch has potential for improving soil organic matter and nutrient availability, and controlling soil erosion in Mediterranean citrus groves (Cerdà *et al*., 2018). Mulched drip irrigation (MDI), involving surface drip irrigation and film mulching, is a popular practice in some arid areas of China. Besides curtailing soil evaporation losses and improving soil thermal regime, MDI results in higher WUE and precise delivery of water and nutrients. However, surface accumulation of salts in MDI fields is a significant concern. Applied water percolates only up to 60 cm depth suggesting the needs for further refinements in design and management of MDI systems for sustained benefits (Zhang *et al*., 2014).

3.2. Canopy management: Slow growing dwarf plants can sometimes outperform their tall counterparts in salt exclusion; a fact attributable to low transpiration rates and consequently less water (and salt) absorption by small sized plants. This implies that pruning of excess growth may partly arrest water loss through transpiration resulting in relatively less salt uptake. Fruit trees adapted to dry saline areas often have sparse foliage; at least during a part of the year probably to lessen the harmful impacts of heat, water and salinity stresses. For example, better adaptation of aonla and ber to rainfed saline soils than other fruit trees can be ascribed partly to a thin foliage and partly to a deep root system arresting the transpiration rate and facilitating water absorption from lower depths, respectively. Aonla trees exhibit 'fruitlet dormancy' with fruitlets (fertilized ovaries) remaining dormant during hot summer months and resuming active growth in the rainy season. Ber trees also shed the leaves and enter into dormancy during summer months. These morphological adaptations mean that virtually no water is required for supporting growth in the summer season; a period witnessing heat stress and evaporation induced salt accumulation in the upper soil surface.

3.3. Windbreaks: Planting of windbreaks improves water availability in crop fields by regulating the microclimate and reducing the evapotranspiration (Campi *et al*., 2012). Windbreaks modify the orchard microclimate by decoupling it from atmospheric influences, reducing the wind speed and evaporation. Because rate of water removal from the sheltered area is generally lower than open fields, humidity increases and evaporation decreases. Sheltered fields also experience lesser advective influence on evaporation resulting in more efficient water use by the fruit trees and vines. Increase in humidity may also partly nullify adverse effects of low temperature and unseasonal frost (Norton, 1988). Biofencing with casuarina reduces the impact of hot winds on mango trees in salt-affected soils (Gunjate *et al*., 2009).

3.4. Anti-transpirants: Plants utilize only a fraction of absorbed water in metabolism while the rest (~99%) is lost to the atmosphere through transpiration. Obviously, reduced transpiration can minimize water stress. Foliar spray of some chemicals called anti-transpirants can reduce the transpiration rate in three ways: by reducing the absorption of radiant energy and thus lowering the leaf temperature; forming a thin transparent film on leaves hindering water loss, and by preventing full stomatal opening decreasing the loss of water vapor (Davenport *et al*., 1969). Kaolin, a silicate mineral, prevents water loss from leaves by partially reflecting photosynthetically active radiation and reducing stomatal conductance. Kaolin application reduced crop ET losses while improving photosynthetic water productivity in well watered bean and Clementine tangor, and in salt stressed tomato plants (Boari *et al*., 2015). Kaolin application alleviated drought stress in olive cv. Chondrolia Chalkidikis by increasing the leaf water content, succulence and CO_2 assimilation rate (Denaxa *et al*., 2012). Supplemental irrigation and anti-transpirant (folicote and vapor-guard) sprays improved plant growth and fruit yield of fig (*Ficus carica*) in an arid rainfed area (Al-Desouki *et al*., 2009).

4. Irrigation Management for Reducing Salt Hazard

4.1. Supplemental irrigation using rainwater: Supplemental irrigation with harvested rainwater can stabilize fruit production in rainfed saline areas. A variety of structures like field bunds, trenches, terraces and micro-catchments have been found suitable for *in situ* rainwater harvesting while farm ponds and tanks can be used to store rainwater *ex situ*. Harvested water can be directly used either in irrigation or for groundwater recharge for improving groundwater quantity and quality. *In situ* water harvesting in continuous trenches has been found an efficient technique for preventing decline and improving fruit yields in Nagpur mandarin orchards in Vertisols of Central India (Panigrahi *et al*., 2015). Shallow conical micro-catchments (1.0 m radius) should be constructed for improving soil moisture availability in ber orchards in arid areas (Ojasvi *et al*., 1999). Rainwater harvesting in farm ponds is a viable solution for mitigating the growing water scarcity; especially in areas frequently impacted by droughts resulting in crop failures. Rainwater stored in farm ponds is used for assured irrigation of pomegranate and grapes in many areas of Maharashtra (SANDRP, 2017). A rooftop rainwater harvesting structure (557.7 m^2) has been developed for providing supplemental irrigation to crops like guava and pomegranate in arid areas (Kumar *et al*., 2006).

4.2. Conjunctive use of fresh and saline groundwater: High salinity in groundwater often renders it unsuitable for irrigation. Nonetheless, growers facing fresh water supply constraints have no other option but to irrigate their lands with low quality water. Field trials conducted in north-west India have indicated the possibility of irrigation with saline and canal (fresh) water in cyclic and/or blending modes provided there is sufficient rainfall to leach a major part of salts accumulated during the irrigation season. Conjunctive irrigation can partly reduce the dependence on fresh water while preventing the further rise in watertable. However, little is known about the viability of this practice in perennial fruit crops. Storage of canal water in an auxiliary reservoir of 1500 m^3 capacity was used to drip irrigate pomegranate, Kinnow and guava crops in a salt-affected soil at Abohar, Punjab. Drip irrigation resulted in up to 30% saving in water use than surface irrigation (Kumar et al. 2013). In some saline areas of Haryana, canal water stored in farm ponds is mixed with saline groundwater for irrigating fruit crops like Kinnow and ber. However, storage and blending practices come at an additional expenditure raising the cost of production. Evidently, rainwater harvesting can minimize such expenses.

4.3. Pitcher irrigation: In this method, porous clay pots placed in the soil provide controlled irrigation to plants with rate of water diffusion being governed by factors like crop ET and soil water tension. Crop water use efficiency in pitcher irrigation is several times higher than surface methods of irrigation and sometimes even higher than drip irrigation. Unlike drip irrigation, however, there is less clogging problem and no power requirement in pitcher method (Bainbridge, 2002). It is due to these benefits that pitcher irrigation offers an easy means of getting stable crop yields in salt-affected soils, and has been successfully used for establishing fruit plantations in arid saline regions. Singh *et al*. (2011) reported that rainwater collected in underground water tanks was applied through pitchers to raise ber and lasora trees in an area where saline groundwater was the only source of irrigation. Pareek *et al.* (2003) observed that planting of cactus cladodes at 5 cm depth in east-west direction and provision of slow water releasing pitchers ensured the highest biomass production than planting in north-south direction and irrigation by basin method.

4.4. Drip irrigation: Leaching of salts beyond the root zone is necessary for the sustained application of saline irrigation waters. Application of excess water than actually required for crop ET needs is termed as the 'leaching requirement'. Depending on factors like climatic conditions, root zone salinity and crop salt tolerance, either occasional or seasonal or regular leaching may be necessary. Although surface methods of irrigation leach a considerable portion of salts, they require the heavy use of water. Again, in many situations, development of shallow watertables restricts the downward movement of salts. Owing to these constraints, drip and sprinkler methods of irrigation are suggested for curtailing water wastages, ensuring high WUE and achieving leaching in salt-affected soils. Among these two methods, drip irrigation is more better than sprinkler method because salts do not accumulate on foliage and are constantly leached out of the active root zone (Hanson and May, 2011). Depending on crop, drip irrigation can result in up to 50% reduction in irrigation water use without any adverse effects on soil properties and crop yield (Stevens *et al*., 2012). Drip irrigation has been successfully used to grow fruit crops in many salinity affected areas of India; guava at Abohar, Punjab (Mandal *et al*., 2007), mango at Jamnagar, Gujarat (Gunjate *et al*., 2009) and in sapota, ber and pomegranate at Indore, Madhya Pradesh (Meena *et al*., 2011). In spite of potential benefits and an enabling policy environment, slow penetration of drip technology in India remains a concern. Furthermore, in states like Maharashtra where drip technology has gained farmers' acceptance, recommended irrigation scheduling is often ignored resulting in the excess application of water and the consequent problems of waterlogging and salt accumulation (Marathe & Babu, 2017).

Conclusions

Preceding discussion highlights the potential of several doable technologies for enhancing the salt tolerance of fruit crops. Depending on factors like crop species, climate and salinity level, a combination of techniques is likely to give better results than a single intervention in the long run. In spite of high potential, less than expected use of some techniques like use of salt tolerant rootstocks and drip irrigation remains a concern.

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