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Techniques of controlling salinity in irrigated agriculture for sustainability

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ABSTRACT : Worldwide 10-50 per cent of irrigated agriculture is facing problems of waterlogging and soil salinity which cause loss of around 1.5 million hectare land annually. The problems of alkalinity and salinity coupled with waterlogging affect about 7.3 million hectares land in India, which reduce agricultural productivity. At the same time agriculture is facing increase in water demand at 2.4 per cent annually during 2005 -2030 as well as reducing share of water due to competing demand from industry and urbanizations. Therefore, to fulfill food and nutritional security of nation on sustained basis, both salt affected soils and waters need to be managed using appropriate techniques. Techniques for controlling salinity that require relatively minor changes are more frequent irrigations, selection of more salt-tolerant crops, additional leaching, residue management, chemical amendments, pre-plant irrigation, bed forming and seed placement. These require significant changes in management such as, changing the irrigation method, altering the water supply, land-leveling, modifying the soil profile, and installing surface as well as subsurface drainage. Where possible, furrow planting may help in obtaining better stands and crop yields under saline conditions. Studies have shown that yield obtained by the drip method with saline water was almost equal to that produced when the high quality water was applied by this method. Therefore, improved agricultural production and water productivity on sustained basis could be realized by application of techniques to manage salt affected soils and waters.

KEY WORDS : Soil salinity, Salt tolerance, Seed placement, Leaching, Bio-drainage, Surface and Sub-surface drainage, Water management

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The problems of waterlogging and soil salinity are common world over. About 10-50 per cent of the irrigated lands in various countries have been affected and 1.5 million ha area is lost annually due to these problems. The waterlogged saline soils are found all over the country. In India, about 8.6 million ha area has been waterlogged saline, of which 5.6 million ha is found in irrigation commands. The irrigation development expected sustained benefits in the country, but big constraint is the problems of waterlogging and salinity development over large irrigated areas. Salinity from irrigation can occur over time since almost all water even natural rainfall contains some dissolved salts (ILRI, 1989). At the same time agriculture is facing increase in water demand at 2.4 per cent annually during 2005 -2030 as well as reducing share of water due to competing demand from industry and urbanizations. Therefore, to fulfill food and nutritional security of nation on sustained basis, both salt affected soils and waters need to be managed using appropriate techniques.

Severity of problem :

Extent of waterlogged and salt affected areas for some states in India (Ghosh, 1991 and Tyagi, 1999) has been presented in Table 1. Water logging and salt problem have been experienced in irrigation projects all over the country examples given in Table 2. Construction of drainage canals, field drains and avoiding wastage of canal supplies have been adopted as remedial measures. However, lack of maintenance, operational constraints of large irrigation projects, and construction of highways, railway embankments and other obstructions, without providing for adequate drainage facility are still the major factors for water logging (Singh *et al.*, 2011). In the Chambal Command area soils became water logged with a few years of introduction of irrigation. In many coastal areas excessive groundwater exploitation has caused seawater intrusion, worsening the salinity problem.

Excessive soil salinity affects the soil structure and can reduce crop yields. High concentrations of salt in the soil can result in a physiological drought condition. That is, even though the field appears to have plenty of moisture, the plants wilt because the roots are unable to absorb the water. Thus, salinity control of irrigated land (Table 2) is necessary to prevent yield reductions where saline water is used for irrigation or where saline shallow water tables exist. These problems adversely affect the targets of food production and reduced efficiency of capital investment in irrigated agriculture as well as have become an environmental concern. Sustainable agriculture could be achieved if its all components, *viz.*, environment, society and economy remain in balance (Ott, 2003 and Adams, 2006). This paper discusses various techniques for addressing the issues of salinity management for sustainable agriculture by adopting efficient irrigation and drainage methods coupled with soil and crop management practices.

Salinity management

Soil salinity could be reduced by leaching soluble salts out of soil with irrigation water. Salinity control depends on the amount of leaching water and salinity of irrigation water. In addition drainage waters from irrigated lands and effluent from city sewage and industrial waste water can impact salinity of water. Most salinity problems in agriculture result directly

Table 1: Geographical, waterlogged and salt affected areas of some states in India

State	Geographical area (million hectares)	Waterlogged area (million hectares)	Salt affected area (million hectares)
Andhra Pradesh	27.44	0.339	0.813
Bihar	17.40	0.363	0.400
Gujrat	19.60	0.484	0.455
Haryana	4.22	0.275	0.455
Karnataka	19.20	0.036	0.404
Kerala	3.89	0.012	0.026
Madhya Pradesh	44.20	0.057	0.242
Maharashtra	30.75	0.111	0.534
Orissa	15.54	0.196	0.400
Punjab	5.04	0.199	0.520
Rajasthan	28.79	0.348	1.122
Tamilnadu	12.96	0.128	0.340
Uttar Pradesh and Uttaranchal	29.40	1.980	1.295
Total	258.43	4.528	7.006

Table 2: Some of major irrigation projects affected by salinity and water logging

Projects	States
Chambal Command	Rajasthan and M.P
Indira Gandhi Canal Project	western Rajasthan
Kosi and Gandak Project	Bihar
Tungabhadra Project	Karnataka
Nagarjunasagar Project	Andhra Pradesh
Kakrapar Project	Gujarat

Table 3: Techniques for controlling salinity requiring relatively minor and significant changes in management

Relatively minor changes	Significant changes
More frequent irrigations	Changing the irrigation method
Selection of more salt-tolerant crops	Altering the water supply
Additional leaching	Land-leveling
Residue management	Modifying the soil profile
Chemical amendments	Surface and subsurface drainage
Pre-plant irrigation	
Bed forming and seed placement	

from the salts carried in the irrigation water. Salts begin to accumulate as water evaporates from the surface and withdrawn by crop.

Techniques for controlling salinity also, require relatively minor changes and significant changes in management (Table 3). Soil salinity control involves water table control and flushing in combination with tile drainage or another form of subsurface drainage (Abrol *et al.*, 1988 and Bureau of Reclamation, 1993). Many studies have revealed that saline soils can be used successfully for crop growth without long-term hazardous effects on crops and soils if proper practices such as adoption of furrow irrigation on salt leaching, selecting appropriately salt-tolerant crops and artificial subsurface drainage (Moreno *et al.*, 1995; Hanson and May, 2004; Hanson *et al.,* 2006; Roberts *et al*., 2008) are established. The salinity management techniques may be classified as (i) mechanical, (ii) biological and (iii) chemical measures.

Mechanical measures :

Leaching :

Leaching is the basic management tool for controlling salinity. Water is applied in excess of the total amount used by the crop and lost to evaporation. The strategy is to keep the salts in solution and flush them below the root zone. The amount of water needed is referred to as the leaching requirement or the leaching fraction. Excess water may be applied with every irrigation to provide the water needed for leaching. However, the time interval between leaching does not appear to be critical provided that crop tolerances are not exceeded. Hence, leaching can be accomplished with each irrigation, every few irrigations, once yearly, or even longer depending on the severity of the salinity problem and salt tolerance of the crop. An occasional or annual leaching event where water is ponded on the surface is an easy and effective method for controlling soil salinity. In some areas, normal rainfall provides adequate leaching.

Seed placement :

Obtaining a satisfactory stand is often a problem when furrow irrigating with saline water. Growers sometimes compensate for poor germination by planting two or three times as much seed as normally would be required. However, planting procedures can be adjusted to lower the salinity in the soil around the germinating seeds. Good salinity control is often achieved with a combination of suitable practices, bed shapes and irrigation water management. In furrow-irrigated soils, planting seeds in the center of a single-row, raised bed places the seeds exactly where salts are expected to concentrate. This situation can be avoided using salt ridges.

With a double-row raised bed planting, the seeds are placed near the shoulders and away from the area of greatest salt accumulation. Alternate-furrow irrigation may help in some cases. If alternate furrows are irrigated, salts often can be moved beyond the single seed row to the non-irrigated side of the planting bed. Salts will still accumulate, but accumulation at the center of the bed will be reduced. With either single- or double-row plantings, increasing the depth of the water in the furrow can improve germination in saline soils. Another practice is to use sloping beds, with the seeds planted on the sloping side just above the water line. Seed and plant placement is also important with the use of drip irrigation. Where soil and farming practices permit, furrow planting using single row bed, double row bed and sloping bed may help in obtaining better stands and crop yields under saline conditions.

Water management :

Surface and sub-surface drainage :

Shallow water tables also contribute to the salinity problem by restricting the downward leaching of salts through the soil profile. Drainage could be used for removal of surplus ground and surface water and dissolved salt from the land. Installation of a subsurface drainage system is about the only solution available for this situation. The original clay tiles have been replaced by plastic tubing. Modern drainage tubes are covered by a sock made of fabric to prevent clogging of the small openings in the plastic tubing. Lowering of water-table was effective in raising the yield of rice from 1.5 ton/ha to about 2.5 ton/ha in the Kerala state of India by a subsurface drainage system installed at farmers' fields to improve acid-sulphate and peat soils. The lowering of the water table permitted the acids and related toxic elements to be washed down to a deeper depth with the next flooding of the field and also have contributed to a better aeration of the soil, with a subsequent improvement of the quality of the organic matter. A similar is possibly occurring in restrictively drained areas of Pulau Petak, south Kalimantan, Indonesia (Oosterbaan ,1990). A subsurface drainage system was effective to reclaim saline soils in an area with upward seepage of salty groundwater in the Sampla area of the Haryana (Rao *et al*., 1990).

Water transportation :

Any open water is subject to evaporation which leads to higher salt concentrations in the water. Evaporation rates from water surfaces often exceed 0.25 inch a day during spring and summer months. Thus, the salinity content of irrigation water will increase during the entire time water is transported through irrigation canals or stored in reservoirs. Replacing irrigation ditches with pipe systems will help stabilize salinity levels. In addition, pipe systems, including gated pipe and lay-flat tubing, reduce water lost to canal seepage and increases the amount of water available for leaching.

Preplant and frequent irrigation :

Salts accumulated near the soil surface during fallow periods, or when water tables are high or when off-season rainfall is below normal badly reduce seed germination and seedling growth unless the soil is leached before planting. Salts concentrations increase in the soil as water is extracted by the crop. Generally, salt concentrations are lowest following irrigation and higher just before the next irrigation. Increasing irrigation frequency maintains more constant moisture content of the soil. Thus, more of the salts are then kept in solution which aids the leaching process. Surge flow irrigation is often effective at reducing the minimum depth of irrigation that can be applied with furrow irrigation systems. Thus, a larger number of irrigations are possible using the same amount of water. Frequent irrigation with sprinkler and drip is very effective at flushing salts.

Changing irrigation method :

Surface irrigation methods are usually not sufficiently flexible to permit changes in frequency of irrigation or depth of water applied per irrigation. As a result, irrigating more frequently might improve water availability to the crop but might also waste water. Converting to surge flow irrigation may be the solution for many furrow systems. Otherwise a sprinkler or drip irrigation system may be required. Most plants require a continuous supply of readily available moisture to grow normally and produce high yields. After an irrigation the soil moisture content is maximum and the salt concentration or the osmotic pressure of the soil solution is minimal *i.e.* favorable for crop growth. As the soil dries out, the concentration of salts in the soil solution and therefore, its osmotic pressure increases making the soil water increasingly difficult to be absorbed by the plants.

Thus, infrequent irrigation aggravates salinity effects on growth as plants would be subjected to very high soil moisture stresses. On the other hand, more frequent irrigations, by keeping the soil at higher soil moisture content prevent the concentration of salts in the soil solution and tend to minimize the adverse effects of salts in soil. Therefore, crops grown in saline soils must be irrigated frequently compared to crops grown under non-saline conditions so that plants are not subjected to excessively high soil moisture stresses due to combined influence of excess salts and low soil water contents.

Sprinkler irrigation is an ideal method for irrigating frequently and with small quantities of water at a time. Leaching of soluble salts is also accomplished more efficiently when the water application rates are lower than the infiltration capacity of the soil and such a condition cannot be achieved by flood irrigation methods. In a field experiment flood irrigation required three times more water as sprinkling to reduce soil salinity by the same increment (Nielsen *et al.*, 1966). Sprinkler irrigation also has the advantage that small local differences in the level of the field will not cause non-uniform water application and salt leaching.

Irrigation practices can often be modified to obtain a more favourable salt distribution in relation to seed location or growing roots. It is well known that salts tend to accumulate in the ridges when using furrow type irrigation. With each irrigation salts leach out of the soil under the furrows and build up on the ridges. The zone of maximum salt accumulation is in the top of the ridges. Where soil and farming practices permit, furrow planting using single row bed, double row bed and sloping bed may help in obtaining better stands and crop yields under saline conditions.

Drip and sprinkler irrigation :

In the trickle or drip irrigation method water is supplied continuously at a point source and in the immediate vicinity of plant roots. It has been found useful irrigating with water of high salinity. The method has the advantage that it keeps the soil moisture continuously high in the root zone, therefore, maintaining a low salt level. The roots of the growing plants tend to cluster in the high soil moisture zone near the trickles and, therefore, avoid the salts that accumulate at the wetting front. Comparison of field trials of sprinkler and drip irrigation methods using water of two qualities (Goldberg *et al.*, 1976) is presented in Table 4. The good quality water had an electrical conductivity of 0.4 dS/m and the saline water an electrical conductivity of 3 dS/m.

The yield difference between the two methods of water application was greater when saline water was used. Further, the yield obtained by the drip method with saline water was almost equal to that produced when the high quality water was applied by this method. A more favourable distribution of salts in the soil profiles with drip irrigation in comparison with the sprinkler and furrow methods (Goldberg *et al.*, 1976) was also shown at the end of the growing season on a sweet corn plot, although in the drip irrigation method appreciable salt accumulation is likely to occur between the rows depending on the inter and intra row space between the drip points. Although sprinkler and trickle irrigation methods are highly efficient, both from the view of water use and salinity control.

Drip irrigation is considered to be the most efficient

Table 4: Effect of irrigation method and water quality on the yield of tomato (t/ha)

Irrigation method	Electrical conductivity of water (dS/m)	
	0.4	3.0
Drip	66.7	65.0
Sprinkler	52.0	39.2

irrigation method because it can distribute water uniformly, control the amount of water applied precisely, reduce evaporation and deep percolation, and minimize salinity effects (Elfving, 1982; Batchelor *et al.,* 1996; Ayars *et al.*, 1999; Karlberg and Frits, 2004). Soil moisture content is the highest near the drip line and decreases with distance from the drip line. Under surface drip, salt patterns around a drip line reflect the water flow patterns. Low soil salinity occurs near the emitter. Zones of low salinity also extend downward beneath the drip lines, the result of leaching directly below the drip lines. Salinity increases with depth and distance from the emitter. Midway between the drip lines, soil salinity near the soil surface is very high because little or no leaching occurs at that location. The salinity values near the emitter reflect the salinity of the irrigation.

Salt patterns under subsurface drip irrigation differ slightly because of upward flow of water above the drip line. In the vicinity of the drip tape, low soil salinity occurs. Salinity increases with lateral distance from the drip tape, with high salinity under the tape. Very high soil salinity occurs above the drip tape. Salts carried by water flowing upward from the drip tape cause this high salinity. No leaching occurs above the drip line during the drip irrigations. The salinity of the low salt zone depends largely on the salinity of the irrigation water and the leaching fraction.

In case of larger leaching fraction the larger the zone of low soil salinity and the smaller the zone of high soil salinity. As with surface drip irrigation, the zone of low salinity soil also increases as the leaching fraction increases for subsurface drip irrigation. If no leaching around the drip line occurs, then soil salinity can increase in the vicinity of the drip line. Soil salinity is highest near the drip line and decreased with horizontal distance and with depth. The opposite in salt distribution around the drip line occurred when leaching occurred. In many areas, excessive levels of soil salinity are caused by upward flow of shallow saline ground water. For furrow and sprinkler irrigation, soil salinity near the soil surface is controlled by the salinity of the irrigation water, while soil salinity at the deeper depths is controlled by the salinity of the shallow ground water. Under drip irrigation, however, the salinity in the near vicinity of the drip line is controlled by the salinity of the irrigation water, the amount of leaching, and the flow pattern around the drip line.

Biological measures :

Salt tolerant crops :

Generally, both yield and quality in crops is decreased by salinity. But, many crop species and varieties have been identified as salt tolerances (Maas and Hoffman, 1977, Francois and Maas, 1978 Maas, 1990) (Table 5). There is a wide range in

Table 5: Some of salt tolerant and sensitive crop varieties

Tolerant	Moderately tolerant	Moderately sensitive	Sensitive
Barley	Cowpea	Maize	Bean
Cotton	Oats	Millet	Sesame
Sugar beet	Rye	Groundnut/Peanut	Carrot
Asparagus	Safflower	Rice	Okra
	Sorghum	Sugarcane	Onion
	Soybean	Sunflower	Almond
	Wheat	Alfalfa	Apple
	Beet, red	Broccoli	Apricot
	Squash, zucchini	Cabbage	Avocado
	Fig	Cauliflower	Blackberry
	Jujube	Celery	Cherry
	Olive	Corn	Gooseberry
	Papaya	Cucumber	Grapefruit
	Pineapple	Eggplant	Lemon
	Pomegranate	Lettuce	Lime
		Muskmelon	Mango
		Potato	Orange
		Pumpkin	Peach
		Radish	Pear
		Spinach	Plum
		Tomato	Raspberry
		Turnip	Sapote, white
		Watermelon	Strawberry
		Grape	

plant species with respect to response to salinity. Sugar beet, sugar cane, dates, cotton and barley are among the most salt tolerant; whereas beans, carrots, onions, strawberries and almonds are considered sensitive (Maas, 1986). However, as salinity increases beyond some threshold tolerance, yield decline is inevitable. When salt concentrations in the soil water reach toxic levels, leaves or shoots may exhibit visible symptoms of tip or edge burning or scorching due to high internal concentrations of salts. Other visible symptoms may be associated with nutrient imbalances caused by competitive interactions between Na^+ and Ca^{2+} or K^{4+}, or between Cl^- and nitrate (Grattan and Grieve, 1992). Depending upon crop species and salinity concentration, salt in the crop root zone may also influence the rate of plant development by increasing or decreasing the time to crop maturity (Shannon *et al.,* 1994).

In some crops, salinity changes plant growth habit or increases succulence (Luttge and Smith, 1984; Shannon *et al.,* 1994). Many crops have little tolerance for salinity during seed germination, but significant tolerance during later growth stages. Some crops such as barley, wheat and corn are known to be more sensitive to salinity during the early growth period than during germination and later growth periods. Sugar beat and safflower are relatively more sensitive during germination, while the tolerance of soybeans may increase or decrease during different growth periods depending on the varieties.

Salinity could be categorized from non- saline to very strongly saline (Table 6) for the purpose of crop selection for saline soils. At relatively low salinity, especially among crop species such as cotton or the halophytic sugar beet, some salinity may actually improve crop production. This effect has been attributed in some instances to an improvement in water use efficiency of the plant (Letey, 1993). High levels of soil salinity can be tolerated if salt-tolerant plants are grown. Sensitive crops lose their vigour in slightly saline soils, most crops are negatively affected in moderately saline soils, and only salinity resistant crops thrive in severely saline soils (Ayers and Westcot, 1976; Blaylock, 1994).

There is potential yield reduction with increasing salinity of soils for field and vegetable crops (Ayers and Westcot, 1976 (Table 7). Soil salinity levels and yield potential of salt-tolerance classes of horticultural and landscape plants indicate 100 per cent loss of relative growth or yield at 8, 16, 24 at 32 dS/m for sensitive, moderately sensitive, moderately tolerant and tolerant crops, respectively (Blaylock. 1994). Yields of most crops are not significantly affected where salt levels are 0 to 2 dS/m. Generally, a level of 2 to 4 dS/m affects some crops. Levels of 4 to 5 dS/m affect many crops and above 8 dS/m affect all but the very tolerant crops (Cardon *et al*., 2011).

Residue management :

The exposed soils have higher evaporation rates than those covered by residues. Residues left on the soil surface reduce evaporation. Thus, less salt will accumulate and rainfall will be more effective in providing for leaching. Evaporation and resulting salt accumulation, tends to be greater in bare soils. Fields need to have 30 to 50 per cent residue cover to significantly reduce evaporation. Under crop residue, soils remain wetter, allowing fall or winter precipitation to be more effective in leaching salts, particularly from the surface soil layers where damage to crop seedlings is most likely to occur.

Table 6 : Salinity rating and electrical conductivity, deci-Siemens per metre (dS/m)

Soil depth (cm)	Non-saline	Weakly saline	Moderately saline	Strongly saline	Very strongly saline
0-60	<2	2-4	4-8	8-16	>16
60-120	<4	4-8	8-16	16-24	>24

Table 7: Potential yield reduction from saline soils for

	Relative yield decrease (%)			
	0	10	25	50
	(ECe, dS/m)			
Broccoli	2.8	3.9	5.5	8.2
Cucumber	2.5	3.3	4.4	6.3
Cantaloupe	2.2	3.6	5.7	9.1
Spinach	2.0	3.3	5.3	8.6
Cabbage	1.8	2.8	4.4	7.0
Potato	1.7	2.5	3.8	5.9
Sweet corn	1.7	2.5	3.8	5.9
Lettuce	1.3	2.1	3.2	5.2
Onion	1.2	1.8	2.8	4.3
Carrot	1.0	1.7	2.8	4.6

Plastic mulches used with drip irrigation reduce salt concentration from evaporation. Sub-surface drip irrigation pushes salts to the edge of the soil wetting front, reducing harmful effects on seedlings and plant roots.

Bio-drainage :

Salt balance is one of the most important issues to be addressed by biodrainage. The driving force behind the biodrainage concept is the consumptive water use of plants. The aim of biodrainage is to remove excess groundwater through the process of transpiration by vegetation and thereby reducing problem of salinity. This is achieved by enhancing the transpiration capacity of the landscape by introducing high-water use vegetation types in large enough areas to balance recharge/discharge processes to maintain groundwater balances below the rootzone of the agriculture crops. The rates of transpiration and groundwater uptake by trees underlain by relatively shallow (5-8 m below surface) water tables, were very high, exceeding the annual evaporation from pasture by a factor 3-6 (Greenwood *et al.,* 1985). Biodrainage crops need to be salt tolerant. The water use capacity of trees and other crops decreases with increase in water salinity.

The *Eucalyptus* species are suitable for biodrainage. Other suitable species for biodrainage may be *Casuarina glauca, Terminalia arjuna, Pongamia pinnata* and *Syzygium cuminii,* etc.In the case of Eucalypt species, it reduces to about one-half of potential when the water salinity increases to about 8 dS/m (Oster *et al.,* 1999). In high-salinity environments plant salt uptake might be negligible in relation to the salts present in the system, under low-salinity scenarios salt balance by plant uptake and removal might be achievable (Heuperman *et al.*, 2002).

Properly designed parallel strip plantations of *E. tereticornis* should be raised on farmers' field and in block plantation along canals for the uniform reclamation of waterlogged areas of semi-arid regions having alluvial sandy loam soils in Haryana, India. These plantations also be raised on potentially waterlogged areas to prevent their conversion into waterlogged areas (Ram, *et al*., 2008). Biodrainage may be attributed to reclamation of waterlogged area, controlling of water table, providing shelter belts, provide additional wood and forest products, biodiversity, and limited salinity control. A relatively large area of land requirement is estimated at about 10 per cent of irrigated area.

Chemical amendments :

In sodic soils (or sodium affected soils), sodium ions have become attached to and adsorbed onto the soil particles. This causes a breakdown in soil structure and results in soil sealing or cementing, making it difficult for water to infiltrate. Chemical amendments are used in order to help facilitate the displacement of these sodium ions. Amendments are composed of sulphur in its elemental form or related compounds such as sulfuric acid and gypsum. Gypsum also contains calcium which is an important element in correcting these conditions. Some chemicals amendments render the natural calcium in the soil more soluble. As a result, calcium replaces the adsorbed sodium which helps restore the infiltration capacity of the soil.

Polymers are also being used for treating sodic soils. The use of amendments does not eliminate the need for leaching. Excess water must still be applied to leach out the displaced sodium. Chemical amendments are only effective on sodium-affected soils. Amendments are ineffective for saline soil conditions and often will increase the existing salinity problem.

Conclusion :

The issues of salinity management for sustainable agriculture could be addressed by adopting efficient irrigation and drainage methods coupled with soil and crop management practices. The salinity management techniques could involve mechanical, biological and chemical measures or a combination of two or all. Techniques for controlling salinity imply minor changes or more frequent irrigations, selection of salt-tolerant crops, leaching, residue management, chemical amendments, pre-plant irrigation, bed forming and seed placement. These require significant changes in management such as, changing the irrigation method, altering the water supply, land-leveling, modifying the soil profile, bio-drainage and installing surface as well as subsurface drainage. Furrow planting could help in obtaining better stands and crop yields under saline conditions. Studies have shown that yield obtained by the drip method with saline water was almost equal to that produced when the high quality water was applied by this method.

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■ REFERENCES

Abrol, P., Yadav, J.S.P. and Massoud, F.I. (1988). Salt-affected soils and their management FAO Soils Bulletin 39. FAO Soil Resources Management and Conservation Service, Soil Resources, Management and Conservation Service FAO Land and Water Development Division, Food and Agriculture Organization of the United Nations, ROME, ITALY.

Adams, W.M. (2006). The Future of Sustainability: Re-thinking environment and development in the twenty-first century. Report of the IUCN Renowned Thinkers Meeting, 29–31 January 2006.

Ayers, R.S. and Westcot, D.W. (1976). Water quality for agriculture, irrigation and drainage Paper 29, FAO, ROME.

Ayars, J.E., Phene, C.J., Hutmacher, R.B., Davis, K.R., Schoneman, R.A., Vail, S.S. and Mead, R.M. (1999). Subsurface drip irrigation of row crops: a review of 15years of research at the Water Management Research Laboratory. *Agric. Water Manage*., **42**: 1–27.

Batchelor, C.H., Lovell, C.J.and Murata, M. (1996). Simple microirrigation techniques for improving irrigation efficiency on vegetable gardens. *Agric. Water Manage*., **32**: 37–48.

Blaylock, Alan D. (1994). Soil salinity and salt tolerance of horticultural and landscape plants. Cooperative Extension Service, Department of Plant, Soil and Insect Sciences, College of Agriculture.B-988. University of Wyomimg.

Bureau of Reclamation (1993). Drainage manual: A guide to integrating plant, soil and water relationships for drainage of irrigated lands, Interior Dept., Bureau of Reclamation, 1993, ISBN 0-16-061623-9.

Elfving, D.C. (1982). Crop response to trickle irrigation. *Hort. Rev*., **4**: 1–48.

Francois, L.E. and Maas, E.V. (1978). *Plant responses to salinity: an indexed bibliography*. USDA, ARM-W-6, Washington, D.C.: USA.

Gosh, S.P. (1991). *Agro-climatic zone specific research-Indian perspective under NATP*. ICAR, Krishi Bhawan, NEW DELHI, INDIA :539.

Goldberg, D., Gornat, B. and Rimon, D. (Eds.) (1976). Drip irrigation—principles, design and agricultural practices. Drip Irrigation Scientific Publications, ISRAEL.

Grattan, S.R. and Grieve, C.M. (1992). Mineral element acquisition and growth response of plants grown in saline environments. *Agric. Ecosys. Environ*., **38**: 275-300.

Greenwood, E.A.N., Klein, L., Beresford, J.D. and Watson, G.D. (1985). Differences in annual evaporation between grazed pasture and Eucalyptus species in plantations on a saline farm catchment. *J. Hydrologist*, **78**: 261-278.

Hanson, B.R. and May, D.M. (2004). Effect of subsurface drip irrigation on processing tomato yield, water table depth, soil salinity, and profitability. *Agric. Water Manage.,* **68**: 1–17.

Hanson, B.R., Hutmacher, R.B. and May, D.M. (2006). Drip irrigation of tomato and cot-ton under shallow saline ground water conditions. *Irrig. Drain. Syst.,* **20**: 155–175.

Heuperman, A.F., Kapoor, A.S. and Denecke, H.W. (2002). Biodrainage: principles, experiences and applications. International Programme for Technology and Research in Irrigation and Drainage. Food and Agriculture Organization of the United Nations, ROME, 2002.

ILRI (1989). Effectiveness and social/environmental impacts of irrigation projects: a Review, In: Annual Report 1988 of the International Institute for Land Reclamation and Improvement (ILRI), Wageningen, The Netherlands, pp. 18–34.

Karlberg, L. and Frits, W.T.P.V. (2004). Exploring potentials and constraints of low-cost drip irrigation with saline water in sub-Saharan Africa. *Phys. Chem. Earth.,* **29**: 1035–1042.

Letey, J. (1993). Relationship between salinity and efficient water use. *Irrig. Sci.,* **14**: 7584.

Luttge, U. and Smith, J.A.C. (1984). Structural, biophysical, and biochemical aspects of the role of leaves in plant adaptation to salinity and water stress. p. 125-150. In : *Salinity tolerance in plants: strategies for crop improvement* (Staples, R.C. and Toenniessen, G.H., eds.). New York: John Wiley and Sons, Inc.

Maas, E.V. (1986). Salt tolerance of plants. *Appl. Agric Res.,* **1**: 12-26.

Maas, E.V. (1990). Crop salt tolerance. p. 262-304. In: *Agricultural salinity and assessment management* (K.K. Tanji, ed.). Amer. Soc. Civil Eng., Manuals and Reports on Engineering No. 71. New York: ASCE.

Maas, E.V and Grieve, C.M. (1987). Sodium-induced calcium deficiency in salt-stressed corn. *Plant, Cell & Environ.,* **10** (7): 559–564,

Maas, E.V. and Hoffman, G.J. (1977). Crop salt tolerance - current assessment. *J. Irrig. Drain. Div. ASCE* **103**:115-134

Moreno, F., Cabrera, F., Andreu, L., Vaz, R., Martin-Aranda, J. and Vachaud, G. (1995). Water movement and salt leaching in drained and irrigated marsh soils of southwest Spain. *Agric. Water Manage*. **27**: 25–44.

Oosterban, R.J. (1990). Review of water management aspects., Pulau Petak, South kalimantan, Indonesia. Research on acid sulphate soils in the humid tropics, Mission report 39. ILRI, Wageningen, THE NETHERLANDS.

Oosterbaan, R.J. (1991). Agricultural Land Drainage: a wider application through caution and restraint, In: Annual Report 1991 of the International Institute for Land Reclamation and Improvement (ILRI), Wageningen, THE NETHERLANDS, pp. 21-36.

Oster, J.D., Macedo, T.F., Davis, D. and Fulton, A. (1999). Developing sustainable reuse and disposal of saline drain water on Eucalyptus. Department of Environmental Sciences, UC Cooperative Extension, University of California, Riverside, USA.

Ott, K.(2003). The case for strong sustainability. In: *Greifswald's environmental ethics*. Ott, K. and P. Thapa (eds.). Greifswald: Steinbecker Verlag Ulrich Rose.

Ram, Jeet, Dagar, J.C., Gurbachan, Singh, Lal, Khajanchi, Tanwar, V.S., Shoeran, S.S., Kaledhonkar, M.J., Dar, S.R. and Kumar Mukesh (2008). Biodrainage: Eco-friendly technique for combating waterlogging and salinity. Technical Bulletin: CSSRI / Karnal / 9 / 2008, Central Soil Salinity Research Institute, Karnal (HARYANA) INDIA, pp 24.

Rao, K.V.G.K., Kumbhare, P.S., Kamra, S.K. and Oosterban, R.J. (1990). Reclamation of waterlogged saline alluvial soils in India by subsurface drainage. In: symposium on land drainage for salinity control in arid and semi arid regions. Vol 2: 17-25, Cairo, EGYPT.

Roberts, T.L., White, S.A., Warrick, A.W. and Thompson, T.L. (2008). Tape depth and germination method influence patterns of salt accumulation with subsurface drip irrigation. *Agric. Water Manage,* **95**: 669–677.

Shannon, M.C., Grieve, C.M. and Francois, L.E. (1994). Whole-plant response to salinity. p. 199-244. In: *Plant-environment interactions* (R.E. Wilkinson, ed.). New York: Marcel Dekker, Inc.

Singh, R., Singh, R.M., Kishore,R. and Rao, K.V.R. (2011). Agricultural drainage technologies- status and Indian experience. Proceedings of National Seminar on Sustainable Management of Water Resources. Banaras Hindu University, Varanasi, 14-15 January, 2011, pp.7-28.

Tyagi, N.K. (1999). Management of salt affected Soil. In : *50 years of natural resource management research*.(Ed. G.B. Singh and B.R. Sharma.). Division of Natural Resource Management. ICAR, Krishi Bhawan, NEW DELHI, INDIA.365pp.

■ WEBLIOGRAPHY

Cardon, G.E., Davis, J.G., Bauder, T.A. and Waskom, R.M. (2011). Managing saline soils. (5/07). Fact Sheet No. 0.503. Colorado State University. *http://www.ext.colostate*.edu/pubs/ crops/ 00503.html.

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