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Sustainable Management Practices Related to Salinity Control in Tree and Vine Crops

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Abstract

Successful irrigation management of tree and vine crops to control soil salinity requires adequate leaching, which is defined as sufficient water to remove excess salts from the root zone above that required to meet crop demand. Excess salts decrease growth and yield in trees and vines and may lead to more severe effects such as leaf bum and even plant death. The salt tolerances of many crops has been quantified in terms of the salinity threshold at which yield is initially affected and the expected rate of decrease in yield with increasing salinity beyond the threshold. Many root stocks have been identified which are tolerant to such effects, but the long term effects of salts are relatively unknown. Irrigation management options include flood, sprinklers and drip; of these, drip irrigation offers the most advantages in saline conditions. Other management variables which can be manipulated to reduce salinity stress effects include planting methods, fertilization, and drainage methods.

Introduction

Sustainable agricultural practices in semi-arid regions similar to the Imperial and Coachella Valleys are usually dependent upon irrigation. Irrigation of such areas has led to major increases in crop production worldwide and has contributed markedly to what has been termed the Green Revolution. However, irrigation practices are also universally plagued by salinity problems which result from failures to balance the import of water and associated salts with their removal or export on both micro and macro scales. At the field scale, salinity problems can result from the use of water of low quality (high salt content) or as a consequence of insufficient leaching and drainage. Poor drainage over large areas can eventually lead to rising water tables which not only aggravate the salinity problem but cause additional damage and can lead to the eventual loss of arable cropland.

The basic effect of salinity on fruit and vine crops is to reduce yield. This occurs through growth suppression, decreased leaf size, decreased canopy volumes, delayed maturation, leaf injury, and decreased fruit set. The causative factors include both salt concentration and specific ion composition. Management practices specific to offsetting the effects of saline agriculture involve **1)** selection of suitable crop species, varieties and root stocks, 2) choices of planting, tillage and irrigation methods, 3) provision of crop water requirements, and 4) drainage. The profit and sustainability of agricultural systems is dependent upon the how well the grower understands the principles that lead to good management choices.

Crop Selection

Crops are generally selected for marketability and suitability to the environment and rotational system. Specific varieties are selected for resistances and tolerances to local diseases and environmental stresses. Where soil or water salinity is a potential problem, then crop salt tolerance is an important determinant. Previous research has led to the development of large data bases on the salt tolerances of many crop species and varieties (Francois and Maas, 1978; 1985: Maas and Hoffman, 1977; Maas 1990). Salt tolerance can be measured most simply based on two parameters: the ***threshold*** **(EC_t)**, the salinity which is expected to cause the initial significant reduction in the maximum expected yield and the slope (s) of the yield decline. Slope is simply the percentage that yield is expected to be reduced for each unit of added salinity above the threshold value. Relative yield (Y) at any salinity exceeding EC, c-an be calculated:

$$Y = 100 - s(EC_e - EC_t) \text{ where } ECe > ECt \qquad [1]$$

Usually, salinity is measured in units of electrical conductivity of a saturated soil paste extract (EC,) taken from the root zone of the plant as averaged over time and depth. Soil paste extracts are soil samples which are brought up to their water saturation points. Electrical conductivities are measured on the filtered water extracts from these samples in units of deciSemiens per meter (ds m^{-1}), or previously as millimhos per centimeter (mmhos cm-‘). New methods use electronic probes or electromagnetic pulses to calculate EC, with less time and effort (Rhoades, 1976; Rhoades, 1993).

The established salt tolerance values for EC, and s were derived from experiments conducted on plants established under nonsaline conditions and subjected to salinity under uniform conditions; however, the application of these values to field situations, where uniformity is uncommon, can be quite reliable if the following points are considered:

1) After crop establishment, the salinity in the root zone averaged over time may be considered as the effective salinity exposure. This means that in most cases, once crops are established, there probably will be little measurable difference in a field situation as a result ciapplying 2 and 10 dS m^{-1} water in alternate irrigations applied over a crop cycle versus using a water of 6 dS m^{-1} in every irrigation. This is the result of compensating factors in both soils and plants. Research efforts are underway to determine if certain advantages can be obtained by either the application of high quality water during sensitive growth stages or by using low quality water immediately prior to or during reproductive stages; but to date, this technology has been developed for only a limited number of situations.

2) There are significant amounts of genetic differences in salt tolerance among varieties of many woody species. These differences are most commonly related to differences in the ability of rootstocks of some varieties to exclude the uptake and transport of toxic ions to the shoots. This appears to be an ion-specific

characteristic and toxicity symptoms specific to ions are manifested by different patterns and colors of leaf scorching.

3) High temperatures and low humidities may decrease the effective value of EC, and increases the value of s. Thus, significant reductions in yield will be realized at lower salinities and yield will decrease more rapidly with increasing salinity under hot, dry conditions. This is an especially important factor to consider if saline water is being used for irrigation. If salinity reaches too high a level in the root zone, it can overcome the restrictive barriers of the root membranes and result in the rapid transport of salts to the leaves, resulting in ‘firing’ or ‘scorching’, first in older leaves and then in the younger leaves. This type of damage can sometimes be associated with specific ion toxicity. Toxicities to chloride and sodium are the most common for woody crops. Two other environmental factors which can influence the measurable effects of salinity include elevated atmospheric levels of carbon dioxide and ozone. Salinity causes leaf stomates to restrict the volume of air exchanged with the environment. This usually improves water use efficiency somewhat, but reduces the amount of carbon dioxide that can be fixed by the plant and be used for growth. High carbon dioxide concentrations in the air due to the so-called “Greenhouse Effect” may, in part, offset the reduction in air exchange. If pollutants are present, reductions in air exchange may also reduce the amounts of pollutants which enter the plant, thereby decreasing damage.

Trees and vines, with the exception of olive and date palm are thought to be sensitive to salinity despite the existence of relatively few studies conducted on mature plants. Hoffman et al., (1989) noted that of the thousands of publications dealing with the effects of salinity on agricultural crops, only one reported yield effects on a deciduous fruit tree and about 50 others reported vegetative responses. Subsequent studies with ‘Santa Rosa’ plum indicated that yield reductions in this species were about 3 1% per dS m^{-1} above a threshold of 2.6 dS m^{-1}. The salt tolerance indices for a number of fruit, vine, and other woody crops are reported in Table 1 after Maas (1986). In some cases, appropriate experiments have not been conducted to establish estimates for EC, and s; therefore, only a relative rating is given.

Another way to relate salt tolerance is to rank species, rootstocks and varieties based upon there abilities to restrict the uptake of specific ions. Levy and Shalhevet (1990) found that chloride concentration in juice gave reliable indications of chloride exclusion properties of citrus rootstocks. Table 2 shows the relative rankings of a number of woody species based upon their resistances to sodium and chloride accumulation changes with age. Grieve and Walker (1983) have shown that I8-month-old rough lemon seedlings did not restrict chloride uptake as well as more mature trees in the field. The relative capability of rootstocks to restrict salt uptake varies with age and size. Sykes (1985) found that the order in which 3-month-old citrus rootstock seedlings accumulated chloride was not consistent with that of trees grafted on the same rootstocks. The relative effects of root stocks and interstocks are highly correlated with salt tolerance (Table 3).

The toxicities of specific ions is an important factor in the salt tolerance of fruit and vine crops (Bernstein 1980). Foliar uptake of chloride in 'Santa Rosa' plums exceeded 200 mmol/kg leaf dry weight (0.7%), whereas, leaf sodium remained below 10 mmol /kg (0.02%) (Hoffman et al., 1989). Other studies have reported that sulfate salts are generally less toxic than chloride salts when applied at the same concentrations (Hayward et al., 1946). Growth reduction and leaf injury of lemon (Eaton, 1942; Cerda et al, 1979) and sweet orange (Bhambota and Kanwar 1970) are greater when grown in chloride predominated salts rather than sulfate predominated salts.

There is little information on the extended effects of salts in subsequent years after treatments have been suspended (Mead et al., 1990) or on the long-term effects of concentrations of salts that are below the salinity threshold. In mature pear trees, microjet-irrigation with water of 2.1 dS m^{-1} did not cause significant yield reduction for six years; then, with no change in irrigation practices, 40% of the trees died by the ninth year (Myers et al., 1995). Large decreases in yield after more than seven years of saline irrigation were correlated with high concentrations of sodium and chloride in leaves. Bernstein speculated that the development of the heartwood and the senescence of the parenchyma cells could release sodium in future years (Bernstein et al., 1956). In almonds and stone fruit trees, sodium accumulated in the woody tissues, limiting its transport to the leaves. Over time, accumulation sites may become overloaded, resulting in transport to the leaves and resulting in yield losses and, eventually, death. Whereas, sodium exclusion mechanisms seem to relate to ability of xylem parenchyma cells to extract sodium from the xylem stream and sequester it in the woody root and stem tissues; chloride exclusion appears to be primarily controlled by root membranes, related to sterol ratios (Walker, 1986).

Planting and Tillage

There are a number of methods that are used to avoid salinity stress during the germination and emergence stages of plant growth. In general, plants are more sensitive to salinity during the early growth stages. Poor management can lead to the development of soil crusting and excessive buildup of salt in the shallow root zones of establishing seedlings. Preplant leaching is one of the most common methods of alleviating salinity stress at this growth stage. 'Row and bed crops are planted on the edges of flat beds or in the middle of sloped or M-shaped beds so that salts do not accumulate in the seedling root zones. In tree and vine crops little to no research has been conducted to determine the effects that levels of salts below the threshold values may have on crops during later, fruit bearing years. However, it has been noted with vine and tree crops that rootstocks play an important role in the prevention of chloride uptake to the shoots and that this is one of the key factors in salt tolerance (Bernstein, 1969; Cooper and Gorton, 1952; Maas, 1986).

In the presence of high salinity, another important factor, in addition to the total amount of soluble salts in the root zone, is the proportion of toxic salts to those macro- and micronutrient of similar chemical properties. For example, high sodium to calcium ratios can affect plant nutrition as well as the physical properties of soils. Many studies have shown that crops are injured by high ratios of sodium to calcium (Grattan and Grieve, 1992). The addition of approximately 1000 to 2000 mg L^{-1} calcium to irrigation solutions containing 2400 mg L^{-1} sodium chloride reduced growth inhibition and defoliation in 2-year-old navel orange scions budded to either Cleopatra mandarin or Troyer citrange rootstocks (Bañuls et al., 1991). High sodium concentrations may also decrease potassium availability. Greater selectivity of potassium over sodium may also be an important character in rootstock selection (Storey and Walker, 1987).

Proper fertility is necessary in both saline and nonsaline conditions. Salinity and nutrient stresses are additive (Maas, 1993). At high soil fertility levels there is a larger reduction in yield per unit increase in salinity than under low fertility conditions. This phenomena is also true with varieties with high growth and yield potential; these varieties are subject to greater reductions in yield due to salinity increases than are lower yielding varieties (Shannon, 1985). Almost all environmental stresses (high temperatures, low fertility, low soil moisture) will add to and greatly exacerbate salinity stress. Salinity and water stress-are additive in their effect on transpiration and yield, but a unit of osmotic potential is not necessarily equivalent to a unit of matric potential. Usually, water stress will reduce plant stress more than salt stress on a unit per unit basis (Meiri, 1984).

Irrigation and Crop Water Requirements

Adequate leaching is an essential part of any irrigation management scheme. Leaching should keep salts in the root zone below the EC, concentration of the crop. The amount of water that is required by a crop is dependent upon the consumptive use of the crop, the leaching requirement (LR), and irrigation efficiency. Consumptiveuse is dependent upon the crop and the atmospheric environment. The LR is the amount of water needed to remove salts from the root zone above the consumptive use requirement of the crop. When salinity is increased, LR increases. When EC, is exceeded, consumptive use and transpiration decrease, plant yield is reduced and canopy relationships change. The net effect is that total water needed for crop production may remain the same due to the compensatory effects of reduced plant use and. increased leaching requirement, but the changes in canopy development may decrease irrigation efficiency. Thus, the water production function which relates yield to relative transpiration is a crop-specific function and does not seem to be related to irrigation water salinity. Actual transpiration and yield are both reduced by salinity in accordance with the production function.

High sodium concentrations in soils and waters may decrease soil permeability and prevent effective leaching of salts. Suitability of soils and waters are measured using a parameter called the sodium adsorption ratio (SAR); guidelines and means for calculation of SAR and LR are given elsewhere (Ayers and Westcot, 1976). Soil amendments are sometimes a necessary part of management schemes to reduce SAR.

Uniformity and Frequency of Irrigation

Crops irrigated with sprinklers are subject to injury not only from salts in the soil but also from salts absorbed directly through wetted leaf surfaces (Maas, 1985). In general, trees with waxy leaves are less susceptible than others; however, when saline sprays directly contact leaf surfaces, salts can accumulate to toxic levels in leaf tissues and decrease yields. When 22-year old Santa Rosa plums were irrigated with minisprinklers, yields were reduced primarily due to decreased fruit set and foliar damage was observed due to increased levels of both sodium and chloride in the tissues (Mantell et al., 1989). Yield reductions persisted in the second year even though salinity spray treatments had been discontinued.

In tree and vine crops, the extent that leaves are wetted can be minimized by sprinkling under the canopy. However, even with under-canopy sprinklers, severe damage of the lower leaves can occur (Harding et al., 1958). The extent of foliar injury depends upon the concentration of salt in the leaves; but weather conditions and water stress can influence the onset of injury. For instance, salt concentrations that cause severe leaf injury and necrosis after' a day or two of hot, dry weather may not cause any symptoms when the weather remains cool and humid.

Many of the sprinkler irrigation waters used in the Western USA contain high levels of sodium and chloride ions that readily injury the foliage of many woody crops. Although sodium absorption is usually not a problem with grape cultivation with surface irrigation (Bernstein et al., 1969), toxic levels may accumulate when wetted by sprinkler irrigation. Chloride, in contrast, is the principal toxic ion for grape vines growing under saline conditions (Bernstein et al., 1969). While several rootstocks have been identified that restrict chloride accumulation from soil (Sauer, 1968), they are of little benefit if chloride is absorbed directly through the leaves. If sprinkler irrigation must be used, then good water management is essential. Since foliar injury is related more to frequency of sprinkling than duration (Francois and Clark, 1979), infrequent, heavy irrigations should be applied rather than frequent, light irrigations. Slowly rotating sprinklers that allow drying between cycles should be avoided, since this increases the wetting-drying frequency. Sprinkling should be done at night or in the early morning when evaporation is less. In general, poorer quality water can be used for surface-applied irrigation than can be used for sprinkler irrigation.

Drip irrigation, which is frequently used with tree and vine crops, gives the greatest advantages when saline water is used. Drip irrigation avoids wetting of the leaves with saline water and maintains relatively high soil water potentials. Since drip irrigation is normally applied frequently, there is a continuous leaching of the soil volume from which the plant extracts water. Leaching can be provided intermittently, between growing seasons and preferably supplemented by seasonal rainfall.

The timely application of saline water during fruit development has been used as a strategy to improve sugar content in melons or soluble solid content in tomatoes (Shannon and Francois, 1978). In response to some moderate levels of salt and drought stress, fruit trees sometimes exhibit significant increases in fruit set and yield, but usually at a cost in subsequent years due to reduced biomass production. Another disadvantage may be due to decreases in shipping quality. Francois and Clark (1980) found that increasing salt stress delayed fruit maturation in Valencia oranges but did not effect fruit quality. Their results also indicated that salinity had no effect on total soluble salts (TSS) in 'Valencia oranges, but Bielorai (1988) measured slight increases in TSS and sugar contents of 'Shamouti' oranges when chloride concentration was 450 mg L^{-1} (ppm) in the irrigation water. In general, the literature is divided on this subject and the effects of salinity on TTS and sugar content in citrus fruit appears inconclusive (Maas, 1993).

Soil salinity in tree and vine crops is characteristically nonuniform. Salinity concentrations and compositions vary in space in up to three dimensions and with time. Salinity often rises during the summer seasons and then decreases with winter rams. Under such circumstances. correlating yield responses to such variable salinity is difficult.

Drainage

The establishment of irrigation without regard to local and regional drainage schemes has resulted in the downfall of economies and civilizations (Shannon, 1987; van Schiifgaarde, 1994). As long as a net downward flux of water is maintained through drainage, salinity build-up in the plant root zone can be avoided. Critical factors in the management of saline waters are the depth to the water table, and maintenance of soil hydraulic conductivity and porosity (Oster, 1994). The critical depth to the water table is determined by the crop aeration requirement. High sodium adsorption ratios (SAR) can lead to decreased hydraulic conductivity in soils with significant clay contents. But soils with medium to high clay contents also have significantly greater water-holding capacities than sandy soils and will not dry out as rapidly at a given evapotranspiration rate.

Under irrigated agriculture, excessive irrigation without adequate drainage can lead to rising water tables. If water tables become too high salts can move to the soil surface through capillary action. High water tables can be used as water sources by some deep-rooted crop, but such circumstances may not be beneficial if subsurface water is too saline. Poor soil aeration due to flooding, poor drainage or high water tables can increase the apparent salt sensitivity o f trees and vines. Even under nonsaline conditions, sodium uptake by sweet orange root stocks increased when soil oxygen was limiting (Labanauskas et al., 1966). When watertables were raised from 90 cm to 30 cm, the vegetative growth of one-year-old Washington navel orange and Balady mandarin scions were reduced but the extent of growth reduction was dependent upon both salinity and root stock (Minessy et al., 1974). Cleopatra mandarin root stock appeared more tolerant of shallow water tables than sour orange.

Subsurface drainage systems are often used to lower the water table and provide for salt removal. Recycling strategies have been proposed for the reuse of drainage waters on salt tolerant crops either directly or after blending the water with good quality water (conjunctive use) (Rhoades, 1987). However, the laws of mass balance apply and these strategies all fail if the salts cannot eventually be removed from the agricultural system. Furthermore, drainage systems and pumping costs are an additional overhead for the grower. The most efficient strategy is to reduce the rate of drainage with proper irrigation efficiency and leaching.

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Table 1. Salt tolerances of fruit, vine and other woody crops (Maas, 1986).

Common name	Botanical name	Threshold	Slope	Rating
Almond	***Prunus dulcis***	1.5	19	S
Apple	***Malus sylvestris***			S
Apricot	***Prunus armeniaca***	1.6	24	S
Avocado	***Persea americana***			S
Blackberry	***Rubus sp.***	1.5	22	S
Boysenberry	***Rubus ursinus***	1.5	22	S
castor-bean	***Ricinus communis***			MS
Cherry, sweet	***Prunus avium***			S
Cherry, sand	***Prunus Besseyi***			S
currant	***Ribes sp.***			S
Date	***Phoenix dactylifera***	4.0	3.6	T
Fig	***Ficus carica***			MT
Gooseberry	***Ribes sp.***			S
Grape	***Vitus sp.***	1.5	9.6	MS
Grapefruit	***Citrus paradisi***	1.8	16	S
Guayule	***Parthenium argentatum***			
Jojoba	***Simmondsia chinensis***			T
Jujube	***Ziziphus jujuba***			MT
Lemon	***Citrus limon***			S
Lime	***Citrus aurantifolia***			S
Loquat	***Eriobotrya japonica***			S
Mango	***Mangifera indica***			S
Olive	***Olea europaea***		-	MT
Orange	***Citrus sinensis***	1.7	16	S
Papaya	*Carica papaya*			MT
Passion fruit	Passiflora edulis			S
Peach	Prunus persica	1.7	21	S
Pear	Pyrus communis			S
Persimmon	Diospyros virginiana			S
Plum; Prune	Prunus domestica	1.5	18	S
Pomegranate	Punica granatum			MT
Pummel0	Citrus maxima			S
Raspberry	Rubus idaeus			S
Rose apple	Syzygium jambos			S
Sapote, white	Casimiroa edulis	–		S
Tangerine	Citrus reticulata			S

- Threshold values given as dS/m; slope values reported as percent yield reduction.
- Crops classified as sensitive (S), moderately sensitive (MS), moderately tolerant (MT), and tolerant (T).

Table 2. Citrus rootstocks ranked in order of decreasing ability to restrict chloride and sodium transport to scions (from Embleton et al., 1973).

Common name	Botanical name	Ion restriction rankings	
		Chloride	Sodium
Sunki mandarin	*Citrus reticulata*	1	11
Grapefruit	C. *paradisi*	2	12
Cleopatra mandarin	C. *reticulata*	3	2
Chinese box orange	*Severina buxifolia*	4	
Rangpur lime	*C. hybrid*	5	5
Sampson tangelo	*C. paradisi x C. reticulata*	6	13
Rough lemon	*C. jambhiri*	7	4
Sour orange	*C. aurantium*	8	1
Ponkan mandarin	*C. reticulata*	9	15
Citrumelo 4475	*Poncirus trifoliata x C. paradisi*	10	9
Trifoliate orange	*P. trifoliata*	11	
Cuban haddock	*Citrus hybrid*	12	7
Sweet lemon	*C. limon*	13	
Calamondin	*C. reticulata x Fortunella sp.*	14	16
Sweet orange	*C. sinensis*	15	6
Sweet lime	*C. aurantifolia*	16	
Savage citrange	*P. trifoliata x C. sinensis*	17	8
Alemow	*C. macrophylla*	18	
Rusk citrange	*P. trifoliata x C. sinensis*	19	3
Troyer citrange	*P. trifoliata x C. sinensis*	20	10
Carrizo citrange	*P. trifoliata x C. sinensis*	21	
Ganjanimma	*C. aurantifolia*	22	

- Numbers indicate a general order but not necessarily significant differences among rootstocks.
- Missing numbers due to lack of data.

Table 3. Variation in salt tolerance based on orchard yields among citrus species having diierent rootstocks and interstocks (from Maas, 1993).

Scion/Interstock	Rootstock	Threshold	Slope
Grapefruit			
var. Marsh seedless	Sour orange	1.2	13.5
Lemon			
var. Verna/Sanquina orange	Sour orange	1.5	10.5
var. Verna/Sanquina orange	Cleopatra mandarin	2.1	13.7
var. Vema	Macrophylla	1.0	14.2
Orange			
var. Navel	unknown	1.4	15.0
var. Valencia	Troyer citrange	0.9	11.8
var. Shamouti	Sour orange	1.7	12.4

- Threshold values given as dS/m; slope values reported as percent yield reduction.