The Potential Use of Drip Irrigation Systems for Sustainable Agriculture Under Saline Water and Soil Conditions

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Abstract

This paper discussed the use of drip irrigation systems for sustainable agriculture under saline water and soil conditions. The use of saline water is well pronounced and many management strategies were developed to minimise the negative effects of saline water on the crop yield and the soil as well as the environment. The management strategies aim at the reducing salt accumulation in the soil profile and matrix potential in the root zone. Drip irrigation systems that are known, as a modern irrigation method can be very effective on reducing the negative effects if it is properly laboured. In this paper, the managing principles of drip irrigation system were shown and emphasised their importance.

Tuzlu Su ve Toprak Şartları Altında Sürdürülebilir Tarım için Damla Sulama Sistemlerinin Potansiyel Kullanımı

Özet

Bu makalede tuzlu su ve toprak şartları altında sürdürülebilir tarım için damla sulama sistemlerinin potansiyel kullanımı tartışıldı. Tuzlu suyun kullanımında neler yapılması gerektiği analtıldı ve çevreye olduğu kadar bitki verimine ve toprağa olan negatif etkisini en aza indirmek için birçok yönetim stratejileri üzerinde duruldu. Yönetim stratejilerinde toprak profilinde tuz birikimi ve kök bölgesindeki matriks potansiyelin azaltılması amaçlandı. Modern sulama metodu olarak bilinen damla sulama sistemleri gereken çaba gösterildiğinde negati,f etkiyi azaltmada çok etkili olabilir. Bu makalede, damala sulama sisteminin yönetim prensipleri ve önemleri vurgulandı

Introduction

Soil salinization is not only one of the major problems in agriculture but also, one of the main environmental issue. Due to the various factors, soil salinization occurs largely in the arid and semi-arid regions that cover about 46% of the world (Sonmez et al., 1996). On the saline soils, the agricultural production may be reduced or ceased because of the salts in the soil profile. In history, soil salinization caused many civilizations to vanish. Salinization could occur by several natural factors as well as unproper irrigation practices.

A mixture of soluble salts is present in the root zone of all soils. If the concentrations of these salts become excessive, losses in crop production will result (Hoffman, 1986). Yield reduction may result from osmotic stress caused by the total soluble salt concentration, from toxicities or nutrient imbalances created when specific solutes become excessive, or from a reduction of water penetration through the root zone caused by excess sodium inducing a deterioration of soil permeability. The leaching is the key to alleviating salinity stress. During the leaching proses, the net downward movement of soil water through the root zone leaches the salts. Salts are leached whenever water applications exceed evapotranspiration, provided soil infiltration and drainage rates are adequate. In some regions, rainfall periodically flushes salts; in others, provisions must be made for adequate leaching.

Bahceci (1984) reported that according to Kovda (1967), in the world, the saline areas were increased from eight million ha at the beginning of the 19^{th} century to 40 million ha at the end of 19^{th} century and to160 million ha in 20^{th} century. These areas were largely in the arid and semi-arid regions in India, Pakistan, China, Sudan, Algeria and Egypt among others.

Turkey having a 28.5 % of arable land (Tekinel, 1999) is affected by the salinity and sodicity problems. An area of 1.517.695 ha is affected by various levels of salinity and sodicity problems in Turkey. This amount corresponds to 2% and 12% of total surface area and total irrigable land of Turkey, respectively (Sonmez, 1996). It is crucial to reclaim these areas and/or applying better management techniques to regain these areas if they are out of production and/or increase the production for rapidly increasing food and fibre demand. The best way in dealing with salinity problems is being pre-active by using better techniques and management to prevent the salinization. Considering most salinity problems occur due to the mismanagement of irrigation systems, the most suitable irrigation method, frequency and amounts must be adapted to either preventing salinization or reducing the effect of salinity on the crop.

Irrigation is one of the most effective factors in increasing the crop yield. Several irrigation networks have been established over the world to obtain higher yield per unit area. However, in time, large land was salinized with mismanagement and unproper irrigation practices. Undoubtedly, irrigation is the most prevalent and widespread problem limiting crop productivity in irrigated agriculture (Stainberg and Shalhevet, 1984). In the arid and semi-arid regions, about 50% of the irrigated land are affected by various levels of salinization.

The irrigation technique pronounced to be effective on the salinity problems is the drip irrigation. With drip irrigation, soil moisture could be kept high continuously, at least in a part of root zone. This maintains a low level of salt concentration which, in turn, results in leaching the zone below the drippers. The roots in the growing plants tend to cluster in this leached zone of high moisture near the drippers avoiding the salt that accumulates at the wetting front and thus, resulting in a relatively good crop production (Hamdy, 1991).

In this article, trickle irrigation system and its managing principles under saline water and saline soil conditions are discussed and there are given some stand points of drip irrigation to be used for sustainable agriculture.

Drip (trickle) Irrigation System

The drip (trickle) system transports water by an extensive pipeline network near the plant, and the water is given directly to the plant root zone. Trickle irrigation methods are characterised by the same features (Bucks and Davis, 1986). These are the high frequency/low volume, localised over a along period application of water, low pressure requirement, and application of water near or into the plant's root zone.

Modern-day surface trickle system was done in Israel in 1963; and in USA in 1964. Today, many studies on design, operation and management principles of trickle system have been under taken. Davely et al., (1973); Jobling, (1973); Keller and Karmeli (1975); Goldberg et al., (1976); Merriam and Keller (1978); Keller (1979); Howel et al., (1981); Nakayama and Bucks (1986), Keller and Bliesner (1990), and Kanber (1999) can be considered among these. The advantages and disadvantages, and the effects on the crop yield of trickle irrigation were studied intensively throughout the world. Some of these studies are Schweers and Grimes (1976); Maber (1979); Mostaghimi et al., (1981); Pai Wu (1982); Armstrong and Wilson (1982a, b); Oron et al., (1982); Wample and Farrar (1983); Oron (1984); Tekinel et al., (1989); Tekinel and Çevik (1993); Yavuz (1993); Çetin (1997); Şenyiğit (1998); Keser (1998); Ertek (1998); Kanber (1999).

Drip irrigation has contributed to a marked increase of yield in agriculture in the last decade. The system transports water directly to plant and its roots for ready use. A snag of this technique is that it is not applicable to all plants and land types in contrast to the other methods. Prior to and following the years of the Second World War, plastic pipes were used in drip irrigation on land and in greenhouses in Britain (Goldberg et al., 1976; Gustafson 1973). The present day drip irrigation concept was initially developed in Israel in 1963 following similar improvements in the U.S.A. (Bucks and Davis 1986). The 70's and mid 80's were devoted to design and project planning for drip irrigation systems as discussed in detail by Goldberg et al., (1976); Keller and Karmeli (1975), Jobling (1973); Merriam and Keller (1978); Dasberg and Bresler (1985); Nakayama and Bucks (1986); Cuenca (1989); and Keller and Bliesner (1990). On the other hand, James (1988) studied advantages and disadvantages of the system.

The drip irrigation system since it works under low pressure, is also called "low-pressure irrigation". The water is given through drippers or injectors. The water leaving the dripper at zero pressure enters the soil by gravity and moves downwards. The distribution in the soil has the shape of a dry onion head. The area wetted by each dripper is limited by the lateral flow of the water in the soil.

A drip irrigation system consists of the pump, control unit, network and the drippers. The schematic diagram for a typical trickle system is given below (Figure 1).

The network consists of the mains, manifolds and drippers. Though all water resources may be used in this system, care should be taken to ensure that it does not contain sediments and floating matter.

The dripper outputs vary from one to ten litres per hour depending on their usage, operating pressure and type. For fruit orchards, flow rates ranging from 4 to 10 litres per hour are required while the vegetables can be irrigated with one to two litres per hour.

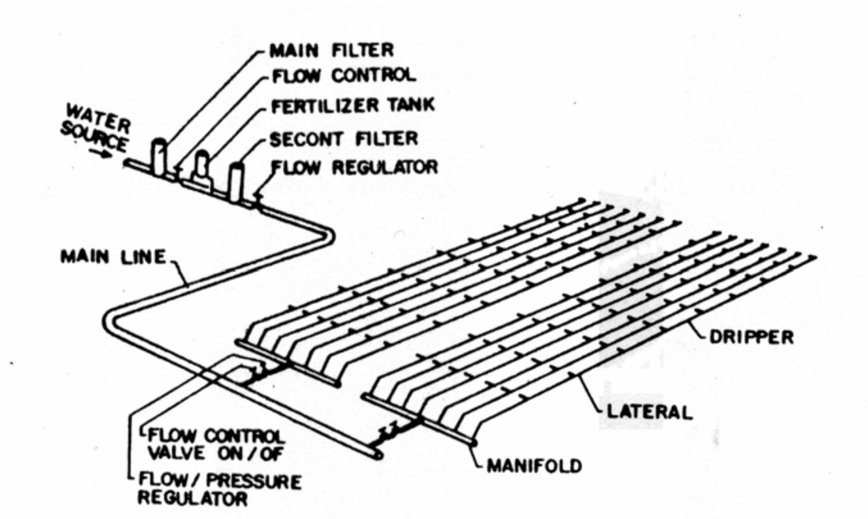

Figure 1. A basic trickle/drip irrigation layout.

The advantages and disadvantages of the drip irrigation systems are summarised and given below:

(1) More and better yield is obtained since the soil moisture is maintained at a such level that plants are not under water stress; (2) Problematic soils and waters may be used; (3) Land levelling is not required; (4) More land may be irrigated with less water; (5) Irrigation efficiency is very high; (6) Operation is easy; (7) Water may be given together with fertilisers and pesticides; (8) Disease and pest development is low.

Its limitations may be summarised as follows. (1) The initial investment costs are rather high; (2) Declogging is difficult and time consuming; (3) Salinity is higher on the soil surface and between two drippers; (4) The system wets only a part of the plant root in which shrinkages and output losses may be seen if sufficient water and nutrients are not given; (5) Large trees may fall when strong winds occur; (6) It requires a well-trained workforce; (7) Dust problems may arise in dry strips.

When all its advantages and drawbacks are taken together, there are enough superiority to prefer dripping irrigation system to other systems. In fact, an abundant and high-quality crop production is capable of compensating for the high investment costs. Likewise, in areas where water is scarce and expensive and where the traditional irrigation systems have important constraints, drip irrigation appears to be the sound choice.

The classical evapotranspiration concept is totally abandoned in drip irrigation systems, since the evaporation from the soil surface is almost zero. The moisture level in the soil is maintained at field capacity slightly over it as a result of the irrigation carried out throughout the year, the plant transpiration is at the highest potential level and the potential evapotranspiration is equal to the potential transpiration.

Managing Principles of Drip Irrigation System under Saline Conditions

Plant response to soil salinity is considered to be independent of the irrigation method provided the space-time distribution of salinity in the root zone is integrated properly. Thus, the criteria for water quality is applicable to all irrigation systems with the exception of foliar damage from wetting crop leaves. To make irrigation, drainage and agronomic management decisions, one can use crop salt tolerance data and leaching requirement criteria with the appropriate determination of the average root zone salinity level.

1. Plant Response to Salt Affected Soils

The predominant influence of salinity stress on plants is growth suppression. In most cases, growth decreases linearly as salinity increases beyond a threshold level. This effect is similar whether adding nutrients or salts like sodium chloride, sodium sulphate, or calcium chloride, which are common in saline soils, increases the salinity. The osmotic stress created by the total concentration of soluble salts more effect on the plant growth than on the level of any specific solute. However, an excess concentration of an individual solute can be detrimental to some crop species in addition to that caused by its osmotic effect.

1.1. Crop Response to Salinity

The response of crop to salinity is of great practical significance in agriculture because the problem becomes more severe year after year as the soil and water resources are more intensively and more extensively exploited. Cultivation of saline soils and the use of saline water are unavoidable for further expansion of agriculture (Somani, 1991).

Crop response to salinity depends greatly on their ability to development and yield under saline conditions. Some crops can produce acceptable yields at much greater soil salinity than others. This is because of the fact that some are better able to make the needed osmotic adjustment enabling them to extract more water from saline soil. The ability of crop adjust to salinity is extremely useful. In areas where a build-up of soil salinity can not be controlled at an acceptable concentration for the crop grown, an alternative crop can be selected that is more tolerant of the expected salinity and can produce economical yield (Ayers and Westcot, 1976). Salt tolerance of crop was presented by Maas and Hoffman (1977) mathematically as:

$$Y_r=100-S(EC_e-C_t) \quad \text{for } EC_e >= C_t \quad (1)$$

$$Y_r=100 \quad \text{for } EC_e < C_t \quad (2)$$

Y_r represents relative crop yield, EC_e indicates the average electrical conductivity of soil water, C_t is the tolerance threshold and S is the tolerance slope.

Hoffman et al. (1983) conducted a field experiment to establish the salt tolerance of corn in the Sacremento-San Joaquin Delta in California. According to results of experiment they reported that the relative yield of corn grain was found to be related to soil salinity by $Y_r=100-14\,(EC_e-3.7)$ when $EC_e>=3.7$. They declared that to prevent loss in corn yield the salinity of applied water and management practices (including irrigation timing, irrigation amount, and leaching) must prevent EC_{sw} from exceeding 3.7 dS/m, on the average, during growing season. At the same way, Bahçeci and Kanber (1995) found that there was a close relationship between relative yield and electrical conductivity of soil water for field beans under Middle Anatolia conditions in Turkey. Beyond the salinity threshold value of Ece=0.81 dS/m, grain yields decreased approximately linearly as salinity increased; and at ECe=4 dS/m no yield was produced. Research results concerning crop salt tolerance showed that crop response to salinity might vary depending on fertiliser type and quantity, climatic and soil conditions, crop type as well as its stage of development. The relative salt tolerances of selected agricultural crops that are commonly tickle irrigated are given in Table 1. The literature on salinity indicated that, in general, crop yield decreased with increasing salinity (Hassan et al., 1970; Maas and Hoffman, 1977; Shalhevet and Yaron, 1973; Prunty et al., 1991, Bahçeci and Kanber, 1995).

Table 1. Salt tolerance of trickle irrigated crops as a function of the electrical conductivity of the soil water (EC_{ws}), and relative yield (Maas and Hoffman, 1977)

Crop	Threshold Value * dS/m	Yield Decline** %	Salt Tolerance ***	Crop	Threshold Value * dS/m	Yield Decline** %	Salt Tolerance***
Almond	1.5	19	S	Grapefruit	1.8	19	S
Apple	-	-	S	Lemon	-	-	S
Apricot	1.6	24	S	Lettuce	1.3	13	MS
Avocado	-	-	S	Okra	-	-	S
Bean	1.0	19	S	Olive	-	-	MT
Beet. Garden	4.0	9	MT	Onion	1.2	16	S
Bentgrass	-	-	MS	Orange	1.7	16	S
Bermudagrass	6.9	6.4	T	Peach	1.7	21	S
Blackberry	1.5	22	S	Peanut	3.2	29	MS
Boysenberry	1.5	22	S	Pepper	1.5	14	MS
Broadbean	1.6	9.6	MS	Plum	1.5	18	S
Broccoli	2.8	9.2	MS	Potato	1.7	12	MS
Cabbage	1.8	9.7	MS	Radish	1.2	13	MS
Carrot	1.0	14	S	Raspberry	-	-	S
Cotton	7.7	5.2	T	Ryegrass	5.6	7.6	MT
Cowpea	1.3	14	MS	Spinach	2.0	7.6	MS
Cucumber	2.5	13	MS	Strawberry	1.0	33	S
Date Palm	4.0	3.6	T	Sugarcane	1.7	5.9	MS
Fescue. Tall	3.9	5.3	MS	Sweet Potato	1.5	11	MS
Grape	1.5	9.6	MS	Tomato	2.5	9.9	MS

*The threshold value is the mean soil salinity at initial yield decline.
**Percent yield decline is the rate of yield reduction per unit increase in salinity beyond the threshold,
***Qualitative salt tolerance ratings are sensitive (S), moderately sensitive (MS), moderately tolerant (MT) and tolerant (T).

1.2. Plant Growth CharacTeristics

Soil salinity distribution within a field is typically so variable that one area of a field can show distinctively different salinity symptoms from another area. Bare spots, poor spotty stands, and severely stunted plants are all signs of high salinity. However, moderate salinity levels often restrict plant; growth without any obvious injury symptoms. Salt-affected plants usually appear normal although their growth is stunted. Salt-affected leaves may be smaller and may have a darker blue-green color than normal leaves. Chlorosis (the yellowing or blanching of green plant parts) is not a typical characteristic of salt-affected plants.

Wilting is` not a regular characteristic of salt-affected plants because it typically occurs when water availability decreases rather abruptly, as in a drying soil. Under saline conditions, moderately low plant water potentials are always present and water potential changes are usually gradual. Plants are, therefore, hardened by the continual stress and are less apted to exhibit abrupt changes in turgor.

Acute injury symptoms, such as marginal or tip burn of leaves, occur as a rule only in woody plants in which these symptoms indicate toxic concentrations of chloride or boron. Most nonwoody plants do zot exhibit such leaf injury symptoms although some accumulate as much chloride or boron as woody species that shows injury. In rare instances, excess sodium may cause calcium deficiency symptoms.

1.3. Crop Growth Stages

The behaviour of various crops as well as their varieties is different under irrigation with waters of different degrees of salinity. It is important to know the critical limits of the degree of salinity of irrigation water which may not effect adversely the germination of particular crop species or variety (Gupta, 1979). Germination of seeds is, in general, slightly delayed under saline conditions, the emergence of seedlings, however may be much more delayed and even prevented under unfavourable soil and weather conditions (van Hoorn, 1971). Although percent germination which determines final stand and yield is a survival parameter, emergence rate and seedling elongation rate are more typical rate parameters of initial growth stages than percent germination (Meiri, 1984).

Hamdy (1988) studied the seed germination percentages for ten field crops having variable salt tolerance degree under saline irrigation water. According to data obtained from experiment, he ranged corn as third crop after barley and wheat to tolerate to salinity. The author added that saline water up to 4 dS/m could be used safely for the majority of tolerant and moderately tolerant crops without deterioration in terms of reduction in germination. Experimentally, the three grain plants, barley, wheat and corn showed lowest reduction in germination with increasing salinity and even at the highest salinity level of 16 dS/m, more than half of the seeds germinated. The tolerance of varieties of particular crops is judged on the basis of mean yield obtained at different degrees of salinity of irrigation water. Many crops may be more salt-sensitive at early rather than later growth stages. However, as indicated by Maas and Hoffman (1977), the separation between growth stages and duration of salinization in experiment conducted to evaluate the growth, stages effect, is not always clear

Hoffman et al (1986) reached the same results obtained in a greenhouse by Maas et al. (1983) indicating that corn can tolerate to increase values of EC of irrigation water (EC_w) late in the season without suffering further yield reductions. Researchers concluded that crop management under saline irrigation practices requires identifying the critical growing stages at which water stress leads to a notable reduction in the final crop yield.

1.4. Factors Influencing Salt Tolerance

Many crops seem to tolerate salinity equally well during seed germination and later growth stages. Germination failures that occur on saline soils are not normally caused by crops being especially sensitive during germination, but rather to exceptionally high concentrations of salt where the seeds are planted. These high salt concentrations, near the soil surface are a consequence of upward water movement and evaporation in the absence of water applications. This can be a serious problem in fields previously irrigated with a trickle system where salinity is a hazard and provisions have not been made to leach the salts concentrated in the seed bed at the edge of the wetting front. The salt tolerance of some crops, particularly cereals, does change with growth stage.

Differences among varieties of a given crop, while it is not common, must also be considered in evaluating crop salt tolerance. Most known varietal differences are among grass species and legumes, but differences among varieties are expected to increase in the future as new varieties are developed.

Rootstock is also an important factor affecting the salt tolerance of tree and vine crops. Varieties and rootstock's of avocado, grapefruit, and orange that differ in their ability to absorb and transport chloride have different salinity tolerances. Similar effects of rootstock on salt accumulation and tolerance have been reported for stone fruit trees and grapes.

Environmental factors such as temperature, atmospheric humidity, and air pollution markedly influence crop salt tolerance. Many crops seem less salt tolerant when grown in hot, dry environments than in cool, humid ones. High atmospheric humidity alone tends to increase the salt tolerance of some crops, with high humidity generally benefiting salt-sensitive more than salt-tolerant crops. A strong interaction between salinity and ozone, a major air pollutant, has been found for alfalfa, bean, and garden beet.

1.5. Specific Solute Effects

Unlike most annual crops, trees and other woody perennials may be specifically sensitive to chloride, which is taken up with water, moves with the transpiration stream, and accumulates in the leaves. Crop, varietal and rootstock differences in tolerance to chloride depend largely upon the rate of transport from the soil to the leaves. In general, the slower the chloride absorption, the more tolerant the plant would be to this solute.

Leaf injury symptoms appear in chloride-sensitive crops when leaves accumulate about 0.3 to 0.5% chloride on a dry-weight basis. Symptoms develop as leaf burn or drying of leaf tissue, typically occurring first at the extreme tip of older leaves and progressing back along the leaf edges. Excessive leaf burn is often accompanied by defoliation. Chemical analysis of soil or leaves can be used to confirm probable chloride toxicity. The maximum permissible concentrations of chloride in the soil saturation extract or in plant leaves for several sensitive crops are given in Table 2.

Boron, although an essential minor element, is phytotoxic if present in excess. Toxicity arises from high boron concentrations in well waters or springs located near geothermal areas or geological faults. Concentrations as low as 0.5 g/m^3 in the irrigation can be detrimental to sensitive crops (Table 3). Few surface waters contain enough boron to cause toxicity. Sensitivity to boron is not limited to woody perennials, but to a vide variety of crops. Boron toxicity symptoms typically appear as yellowing, spotting, or drying of leaf tissue at the tip and along the edges of older leaves.

Table 2. Maximum permissible chloride concentration if leaf injury is to be avoided for fruit crops depending on various rootstock and varieties (Prepared from Hoffmann, 1986)

Crop	Maximum Permissible chloride Concentration	
	Soil Saturation Extract mol/m^3	Plant Leaf Analysis kg of Cl per kg dry leaf
Citrus	10-25	0.7
Stone Fruit	7-25	0.3
Avocado	8	0.25-0.50
Grape	10-40 (as varieties)	0.5
Olive	-	0.5
Berries	5-10	-
Strawberry	5-8	-

The damage gradually progresses interveinally toward the middle of. A gummosis or exudate on limbs or trunks is sometimes noticeable on boron-affected trees such as almond. Many sensitive crops show toxicity symptoms when boron concentrations in leaf blades exceed 250 mg/kg, but not all sensitive crops accumulate boron in their leaves. Stone fruits (e.g., peach, plum, almond) and pome fruits (pear, apple, and others) do not accumulate boron in leaf tissue so that leaf analysis is not a reliable toxicity indicator.

A wide range of crops has been tested for boron tolerance in sand cultures. The results of these tests are summarised in Table 3. The crops have been grouped according to their relative tolerance to boron in the irrigation water. These data are based on the boron level at which toxicity symptoms were observed and do not necessarily indicate corresponding reductions in yield. Establishment of the relationships between boron concentration and crop yield must await further research.

Although the concentrations of some solutes in saline soils may be several orders of magnitude greater than concentrations of some essential nutrients, plant nutritional disturbances are not common in salt affected soils. In some instances, however, if the proportion of calcium to sodium becomes either extremely high or low, nutritional imbalances can occur that reduces crop yield below: that expected from osmotic effects alone. Bean plants cannot tolerate excess calcium even though it is accumulated in the plant tissue. In contrast, calcium deficiency under some saline conditions results in blossom-end rot of tomatoes, internal browning of lettuce, and reduced corn growth. Because soil salinity in the field normally involves a mixture of salts, the effects of specific solutes of crop nutrition tend to be minimised so that the osmotic effect usually predominates.

2. Irrigation Water Quality

The suitability of any water for trickle irrigation depends on the concentration and composition of the soluble salts present. Water quality for salinity evaluation is normally based on three criteria: (1) salinity, the general effects of dissolved salts on crop growth that are associated with osmotic stress; (2) sodicity the effect of an excessive proportion of sodium that induces a deterioration of soil permeability; and (3) toxicity, the effects of specific solutes that damage plant tissue or cause an imbalance a plant nutrition.

Table 3. Relative tolerance of trickle irrigated crops to boron[a] (Hoffmann, 1986)

Tolerant [b] (4.0-2.0 g/m^3)	Medium Tolerant [b] (2.0-1.0 g/m^3)	Low Tolerant [b] (1.0-0.3 g/m^3)	
Asparagus	Sunflower	Pecan	Persimmon
Date palm	Potato	Walnut	Cherry
Gardenbeet	Cotton	Jerusalem	Peach
Broadbean	Tomato	artichoke	Apricot
Onion	Radish	Navy bean	Thornless
Turnip	Rield pea	Plum	blackberry
Cabbage	Olive	Pear	Orange
Lettuce	Pumpkin	Apple	Avocado
Carrot	Bell pepper	Grape	Grapefruit
	Sweetpotato	Katota fig	Lemon
	Lima bean		

[a] Relative tolerance is based on the boron concentration in irrigation water at which boron toxicity symptoms were observed when plants were grown in sand culture. It does necessarily indicate a reduction in crop yield.
[b] Tolerance decreases in descending order in each coloumn between the state limits.

Irrigation water, however, has no inherent quality independent of the specific conditions under which it is to be used. Thus, only a generalised guide for evaluating irrigation water quality is presented because site-specific conditions may alter the suitability of particular irrigation water.

2.1. Composition of Irrigation Water

The predominant cations in irrigation water are calcium, magnesium, sodium, and potassium; the typical anions are bicarbonate, sulfate, and chloride. Significant concentrations of other solutes, such as nitrate, carbonate, and minor elements are not common in natural waters. Nitrate, present in some localised areas, is beneficial to crop production unless it causes excessive vegetative growth or delays crop maturity. Appreciable amounts of carbonate occur only infrequently when the pH of the water exceeds 8.5. Trace elements (molybdenum, cadmium, selenium, arsenic, chromium, vanadium, beryllium, etc.) are not common in natural waters, but when present in only minute concentrations can severely limit production of certain crops. Any high concentration of minor elements (copper, zinc, etc.) may be a problem in wastewaters used for irrigation.

To assess the sodium hazard of water, the sodium adsorption ratio (SAR) must be calculated. The defining equation for SAR is

$$SAR = (Na)/(Ca + Mg)^{1/2} \qquad (3)$$

where all ion concentrations are in mol/m^3.

The quantities and types of salts present in irrigation water vary widely. The major sources of irrigation water are rivers and ground waters, but the use of brackish and wastewater will increase as supplemental irrigation as land disposal of municipal and industrial wastewaters increase. Irrigation is usually practiced in arid climates, and the rivers associated with such areas generally contain more salt than the average river water. Ground waters are generally more saline than surface waters, and usually contain higher proportions of sodium, boron, and nitrate

2.2. Salinity Assessment

Most irrigation waters do not contain enough salt to cause immediate injury to trickle-irrigated crops. However, the concentration of the soluble salts in the soil increases as evaporation and transpiration, leaving the salt behind removes water. Without leaching, salt accumulates in the soil with successive irrigations. With leaching, the accumulation of soluble salts in the soil is controlled by the fraction of the applied water that drains below the crop root zone (leaching fraction). Hence, salinity assessment must be made in view of the salt tolerance of the crop and the leaching fraction. The fraction of salt in the irrigation water that will precipitate is a further consideration if the leaching fraction is less than about 0.1.

A generalised appraisal of the salinity hazard of irrigation water can be made based upon proper water management and the ability of the soil to meet or exceed the minimum-leaching fraction required to maintain full crop production termed the leaching requirement (LR). The leaching requirement as a function of the salinity of the applied water and crop salt tolerance is given in Figure 2.

The salinity of water is the weighted average of the salt concentrations of the irrigation water and rainfall based on the amounts applied. The relationships in Figure 2 allows the prediction of the minimum leaching fraction required for the particular water and crop combination for avoiding possible loss in yield.

2.3. Sodicity Assessment

Another consideration in evaluating irrigation water quality is the potential for soil structural deterioration caused by excess builds up of sodium in the soil. When calcium and magnesium are the predominant cations adsorbed on the soil exchange complex, the soil tends to have a granular structure that is easily tilled and readily permeable. When the amount of adsorbed sodium exceeds about 10 percent of the total cation exchange capacity of the soil, however, soil mineral particles tend to disperse causing water penetration to decrease. Excess sodium becomes a problem when the rate of infiltration is reduced to the point that the crop is not adequately supplied with water or when the hydraulic conductivity of the soil profile is too low for adequate drainage. Sodium may also add to cropping difficulties because of crusting seed beds, temporary saturation at the soil surface, and/or possible disease, weed, oxygen, nutritional, and salinity problems. The type of clay minerals present in the soil influences the sodium adsorption ratio (SAR). In general, however, no permeability problem should be expected if the SAR is below 10 $(mol/m^3)^{0.5}$ providing the irrigation water is not too low in salt content.

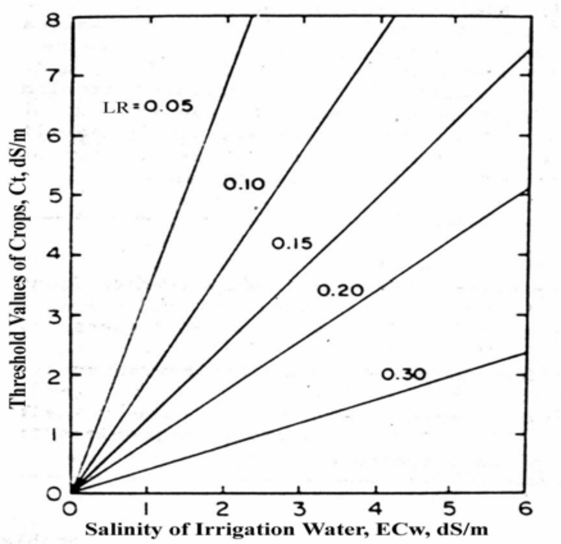

Figure 2. Graphical solution for the leaching requirement as a function of irrigation water salinity and crop threshold values (after Hoffman and van Genuchten, 1983)

Water of very low salt content can aggravate a permeability problem because it allows a maximal swelling and dispersion of soil minerals and organic matter, and because it has a tremendous capacity to dissolve and remove calcium. This problem can arise if the electrical conductivity of the irrigation is less than 0.2 dS/m. Irrigating with such a this water may cause problems on soil with potential permeability problems. The addition of amendments to the dilute irrigation water in parts of the this water is a common practice to improve infiltration. The addition of amendments of low solubility, such as gypsum, into waters to be applied through a trickle system is not recommended because of the serious threat of plugging emitters. To avoid this problem, amendments with low solubility should be applied directly to the soil.

3. Management of Salt-Affected Soils

With trickle irrigation, salinity control is influenced by the quality and quantity of the applied water, the irrigation system and its management, drainage conditions and agronomic techniques. These factors are often interrelated so that the solution to a salinity problem may not be obvious without proper diagnosis. The key to salinity control is a properly integrated total water management system.

3.1. Irrigation management

The primary objective of any irrigation method is to supply water to the soil so that it will be readily available at all times for crop growth, but soil salinity is definitely an influencing factor. The soil salinity profile that develops as soil water is decreased through water uptake by roots or soil evaporation depends in part on the water distribution pattern inherent with the irrigation method. Distinctly different salinity profiles develop for various irrigation methods, and significantly different profiles can develop for each method within a given field because of differences in soil properties or in the management of the system.

Trickle irrigation systems provide water through perforated tubes or emitters spaced according to plant density. Their advantage is the maintenance of high soil water content in the root zone by frequent but small water applications. Plant roots tend to proliferate in the leached zone of high soil water content beneath the water sources. This allows water of relatively high salt content to be used successfully in many cases. Trickle irrigation is appropriate for orchards and for some widely spaced or valuable row crops (Hoffman, 1986).

The salinity profile under line sources, such as perforated or multi-emitter drip irrigation systems, has clearly recognisable lateral and downward components. The typical cross-sectional profile has an isolated pocket of accumulated salts at the soil surface midway between the line sources and a second, deep zone of accumulation, depending on the degree of leaching. Directly beneath the line source is a leached zone whose size depends on the irrigation rate and frequency, and the crop's water extraction pattern.

The distribution of chloride in the soil water is illustrated in Figure 3 for a line source for water having an electrical conductivity of 2.2 dS/m and a chloride content of 7.8 mol/m^3. While the salt distribution from line sources increases laterally and down- ward, the distribution from point irrigation sources such as microbasins and drip systems with widely spaced emitters increases radially in all directions below the soil surface. As the rate of water application increases, the shape of the salinity distribution changes. The salinity distribution in uniform, isotropic sand changes from elliptical (with the maximum movement vertical) to more circulars as the rate of water application increases. In isotropic and layered soils, the horizontal rate of water movement increases relative to the vertical, resulting in relatively shallow salt accumulations. For tree crops irrigated with several drips emitters per tree, the wetting patterns may overlap, thereby reducing the level of salt accumulation midway between emitters under a tree.

Subsurface irrigation is the least practiced of the various methods of trickle irrigation where salinity is a hazard. The continuous upward water movements from subsurface system results in rapid salt accumulation near the soil surface as water is lost by evapotranspiration. The extent of salt accumulation at shallow depths is a function of the depth of the subsurface system and the application rate; the more shallow the system and the larger the application rate, the smaller the amount of salts that accumulate above the system. Subsurface systems provide no means of leaching these shallow accumulations. Unless the soil is leached periodically by rainfall or surface irrigations, salt accumulations are a certainty.

3.2. Drainage Management

Without drainage, salinization is a foregone conclusion and irrigated agriculture is bound to fail. Fortunately, most soils have some degree of natural drainage to facilitate leaching, but supplementary drainage is often required. The need for supplementary drainage may be lessened or even avoided by an efficient management of irrigation water.

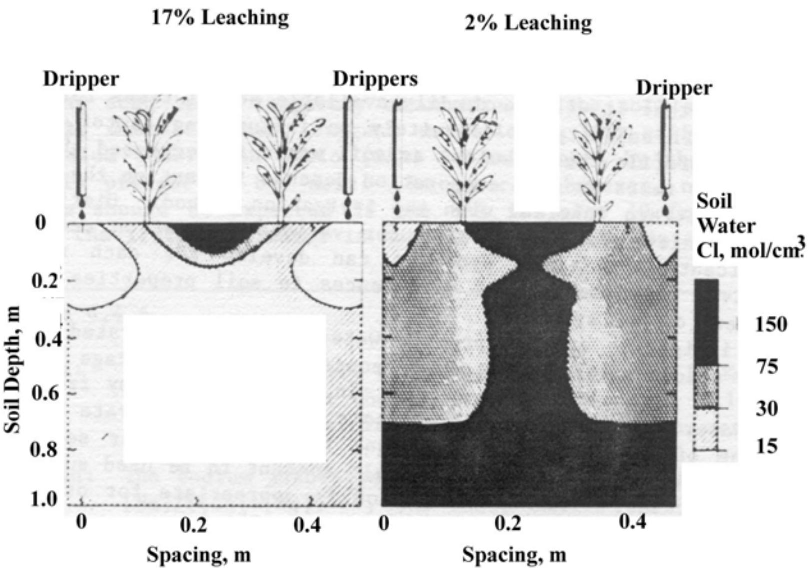

Figure 3. Soil-water chloride profiles for 17 and 2% leaching under a line source trickle irrigation system (Hoffman, 1986).

For salinity control, the leaching requirement establishes the minimum drainage requirement. Additional drainage, however, may be necessary to remove excess precipitation, seepage from adjacent irrigated areas or from water conveyance structures, nonuniform irrigation applications, and other sources of water that are not directly related to leaching. The drainage requirement for salt removal under steady-state conditions is given by Equations 4 and 5 (Hoffman, 1986).

$$D_d = LR \times D_{ET}/(1-LR) \quad (4)$$

Where D_d is the equivalent depth of drainage per unit land area, LR is the leaching requirement, and D_{ET} is the equivalent depth of evapotranspiration per unit land area. In terms of the electrical conductivities of the irrigation (EC_w) and drainage (EC_{DW}) waters,

$$D_d = EC_w \times D_{ET} /(EC_{DW}-EC_w)\cdot \quad (5)$$

Crop salt tolerance dictates the selection of the leaching requirement in one equation and the permissible value of ad in the other.

The value of D_d refers only to the minimum amount of water that must leave the root zone at any point of a field. It is not the total amount of water that must be removed. Furthermore, the actual amount will vary significantly with the crop.

Where a range of crops is grown in rotation, or where the cropping pattern changes over time, the effect of these changes on the drainage requirement must be considered. In planning a drainage system, the design should be based on the most demanding crop to be grown.

3.3 Agronomic Management

Many crop failures on salt-affected soils result from growing crops that have low salt tolerance. Approximately a ten-fold range in salt tolerance exists among agricultural crops (see Table 1). In areas where only saline irrigation water is available, where shallow, saline water tables prevail, or where soil permeability is low, achieving nonsaline conditions may not be economically feasible. In such areas, crops that produce satisfactory yields under saline conditions must be selected. Owing to the variations among cropping seasons and irrigation management, soils may tend to salinize during one crop and to desalinise during a following crop. Thus, by selecting an appropriate crop rotation, productivity can sometimes be maintained where, in the absence of a rotation, the soil would become unproductive.

Obtaining a satisfactory stand of trickle irrigated crops on saline soils or when using saline water is often a problem. Growers sometimes compensate for poor germination by planting two or three times as many seeds as normally required. In other cases, planting procedures are adjusted to ensure that the soil around the germinating seeds is low in salinity.

Summary and Conclusion

This paper discussed the use of drip irrigation systems for sustainable agriculture under saline water and soil conditions. The use of saline water is well pronounced and many management strategies were developed to minimise the negative effects of saline water on the crop yield and the soil as well as the environment. The management strategies aim at the reducing salt accumulation in the soil profile and matrix potential in the root zone. Drip irrigation systems that are known, as a modern irrigation method can be very effective on reducing the negative effects if it is properly laboured. In this paper, the managing principles of drip irrigation system were shown and emphasised their importance.

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