

## **6. Potassium chloride management in fertilization and irrigation**

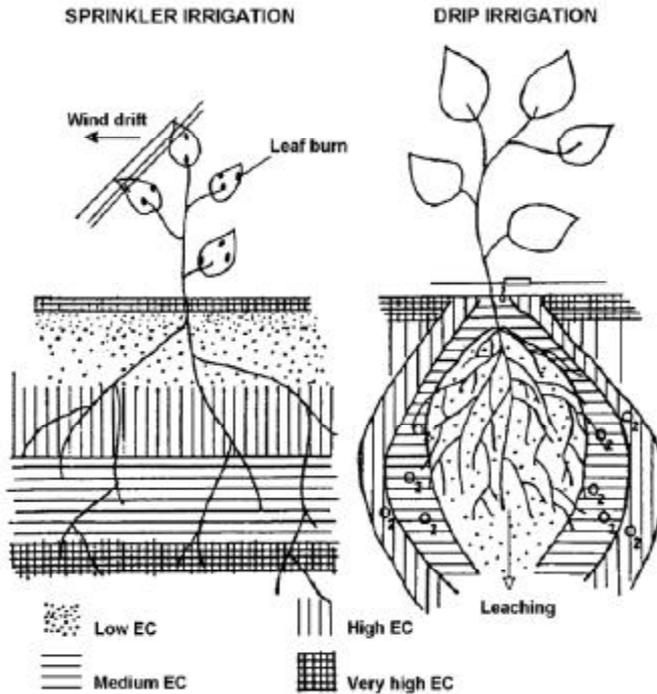
### **6.1. Salt accumulation in irrigated soils**

The concentration of total salts and of each specific ion present in the soil solution are a consequence of several factors: quality of irrigation water, irrigation method, fertilization practices, rate of water uptake by the plants, evaporation from the soil surface, soil type, and rainfall amount and distribution. Excessive salts may accumulate in low-lying, poorly drained soils and when irrigation water contains large amounts of salts. In soils with a shallow underground water table, the draining water may create a continuous wet zone with the groundwater level, leading to the upward flow of capillary water and salinization of the soil surface as a result of water evaporation and salt accumulation on the soil surface.

Irrigation methods can be used to control the concentration of soluble salts in the soil solution (Rhoades, 1993). In level basin irrigation, salt accumulation is minimal, although problems of aeration and crust formation may occur. Furrow irrigation is used for row crops where the slope is unsuitable for level basin irrigation. Uniformity of water distribution is important to avoid the accumulation of water and salts in areas with low water infiltration rates. Reduction of furrow length (Worstell, 1979) or the use of surge irrigation (Bishop *et al.*, 1981) may increase the uniformity of water distribution.

Sprinkler irrigation allows a good control of salt accumulation in the soil when the water distribution in the field is uniform. When water distribution is regular, there is an uniform leaching of the salts out from the root zone, and there are no areas with lower soil moisture where salt concentration in the soil solution is high. In sprinkler irrigation there is a potential hazard of salt absorption through the foliage and risk of foliar injury.

Drip irrigation allows a close control of salt accumulation in the soil solution, also under high salinity conditions. With this method, a high uniformity of water distribution is achieved thus avoiding the formation of areas with water excess or deficit. The salt distribution pattern depends on the evaporation rate from the soil surface, the water uptake by the roots, the location of the wetting front, the total amount of applied irrigation water and the distance between drip lines (Yaron *et al.*, 1973; Dasberg and Bresler, 1985). Soil salinity under the drip emitter itself is the place with the lowest salinity. The roots grow mainly inside this restricted, fully leached soil volume, and the salts are accumulated outside this soil volume and on the soil surface (Fig. 6.1) (Pasternak and De Malach, 1994). Drip irrigation under plastic mulch is safer with saline water as direct evaporation from the soil surface is prevented and no surface salt accumulation is observed.



**Fig. 6.1.** Schematic EC distribution in the weeting front under sprinkler and drip irrigation system (Based on Pasternak and De Malach, 1994; reprinted from Ref. 01-151, p. 613 by courtesy of Marcel Dekker Inc.).

Water quality classifications should consider the effect of the irrigation regime (amount of applied water and the interval between irrigations) and plant root distribution. Most of the threshold values of total salt concentration in the soil or specific toxicity of a given ion (Cl, Na and B) were determined according to their concentrations in saturated soil paste extracts. Under field conditions, however, the soil moisture level usually varies between field capacity and permanent wilting point, and the ions concentration in the soil solution will be higher than under saturation conditions. Salt concentration in the soil solution increases as more water is taken up by the plant and when the soil moisture level approaches the permanent wilting point. High irrigation frequency implies irrigating even when the soil moisture content is relatively high, thus salt concentration remains relatively low. Due to the relatively low water content difference from saturation point, the salinity threshold values can be higher (as measured in the saturated paste extract). Plants can tolerate water with a high

salt concentration when the soil moisture level is high and when the high salt concentration zone is located in deeper soil layers with lower a root density (Rhoades, 1993).

## **6.2. Irrigation and leaching of chloride salts in the root zone**

The use of water containing Cl must be accompanied by appropriate practices to keep Cl levels in the soil within the limits of crop tolerance. The amount of Cl salt added to the soil with the irrigation water depends on the salt concentration in the water, the evaporation level and the amount of irrigation water (which varies with the physiological development of the plant).

With 500 mm of irrigation water containing Cl at 100-200 g m<sup>-3</sup> (low to medium saline water, Table 2.1), the amount of Cl applied is 500-1000 kg ha<sup>-1</sup>, equivalent to the application of 1000-2000 kg ha<sup>-1</sup> KCl. In practice, the recommended amounts of KCl fertilization ranges from 75 to 150 kg ha<sup>-1</sup> for field crops and 300-500 kg ha<sup>-1</sup> for horticultural crops. This suggests that the addition of Cl in KCl fertilizer is relatively small for most agricultural crops, especially when the rainfall during the rainy season leaches excess Cl accumulated during fertilization and irrigation.

Irrigation with saline water is managed by an excess of irrigation to meet the leaching requirement for avoiding salt accumulation in the crop root zone (Richards, 1954). There is a risk that the advantages gained from salt leaching may be lost with the onset of temporary oxygen shortage due to water logging (Stevens and Harvey, 1995). Steven and Harvey (1995) report that grapevines suffered salinity damage even when the EC of the irrigation water during 15 years was less than 0.5 dS m<sup>-1</sup>. This was because the excessive irrigation led to water draining below the root zone forming a temporary water table, where the leached salts were mobilized and carried back into the root zone by the capillary rise of the water.

The irrigation system influences the distribution of salt in the soil profile and on its surface. Keller and Bliesner (1990) presented a detailed calculation of the efficiency of Cl leaching by different irrigation methods. In drip irrigation, small amounts of water are applied at short intervals, keeping the salinity of the soil close to that of the irrigation water. The quantity of water needed for leaching the salts out from the root zone (LR) is defined as the ratio between the water required for leaching and that required to satisfy crop and leaching demands.

Keller and Bliesner (1990) define the maximum salinity (expressed as EC) that can be obtained in the saturated soil extract (EC<sub>emx</sub>), as the value at which the yield is zero (0). If the whole root-zone has a value similar or higher than EC<sub>emx</sub>, the yield will be reduced to 0. Similarly, the EC<sub>emi</sub> value

can be defined as the electrical conductivity of the saturated soil extract at which there is no yield reduction.

When the salt concentration in the irrigation water is low, and a LR of 0.1 or more is applied by drip irrigation, then the crop's expected potential yield is achieved:

$$\text{When } EC_w \leq EC_{emi}, \text{ then } Y_r = 1.0$$

Where:

$Y_r$  = relative crop yield

$EC_w$  = Electrical conductivity of the irrigation water ( $dS\ m^{-1}$ )

In cases when  $EC_w$  is higher than  $EC_{emi}$  and lower than  $(EC_{emx} + EC_{emi} / 2)$ , then:

$$Y_r \approx (EC_{emx} - EC_{emi}) / (EC_{emx} - EC_w) \quad [1]$$

The leaching dose required for washing salts out of the root zone is defined as the ratio between the water height applied for leaching and the irrigation water height applied for satisfying crop and leaching demands. The leaching requirement can be calculated by the following equation:

$$LR = L_n / (d_n + L_n) = L_N / (D_n + L_N) = EC_w / EC_{dw} \quad [2]$$

Where:

$d_n$  = Net water height applied in each irrigation according to the crop demand (mm)

$D_n$  = Seasonal water height applied according to the crop demand (mm)

$L_n$  = Water height applied for salt leaching in each irrigation (mm)

$L_N$  = Water height for seasonal salt leaching (mm)

$EC_{dw}$  = Electrical conductivity of the water drained below the root-zone ( $dS\ m^{-1}$ )

The LR value represents the minimum water amount (as a fraction of the whole irrigated water) that should pass through the root-zone to avoid salt accumulation. The  $L_n$  and  $L_N$  values constitute water amounts needed to avoid salt accumulation. These values can be determined by controlling soil moisture salinity. In order to achieve the relative yields expected according to Equation 1 for drip irrigation with frequent applications (every day or every other day), Keller and Bliesner (1990) assumed that:

$$EC_{dw} = 2\ EC_{emx} \quad \text{Therefore, } LR_t = EC_w / 2\ (EC_{emx})$$

For example, the leaching requirement for drip irrigation of tomatoes is calculated as follows:

$$EC_w = 2.5\ dS\ m^{-1} \text{ and } EC_{emx} = 12.5\ dS\ m^{-1}, \text{ therefore,} \\ LR_t = EC_w / 2\ (EC_{emx}) = 2.5 / 2\ (12.5) = 0.1$$

In sprinkler or surface irrigation the EC of the soil solution is different from that of the irrigation water. This difference stems from longer intervals in

which the salt concentration in the soil solution gradually increases due to the water uptake by the roots and the evaporation from the soil surface. Before the next irrigation, salt concentrations on the soil surface reach relatively high values. The equation for calculating the leaching requirement in sprinkler or surface irrigation is (Keller and Bliesner, 1990):

$$LR = EC_w / (5 EC_e - EC_w) \quad [3]$$

Where  $EC_e$  = mean EC of the saturated soil extract at which no yield reduction occurs.

For example, the leaching requirement for tomatoes irrigated by sprinkler or surface irrigation is calculated as follows:

When  $EC_w = 2.5 \text{ dS m}^{-1}$  and utilizing the  $EC_e$  value of  $2.5 \text{ dS m}^{-1}$  at which no yield reduction occurs,  $LR = EC_w / (5 EC_e - EC_w) = 2.5 / [5 (2.5) - 2.5] = 0.25$ .

According to the above example, when the water requirement of tomato is 700 mm the actual quantity of water required by drip irrigated plots would be 770 mm. Comparatively, the water height required for plant consumption and salt leaching when irrigation was by sprinkler or surface irrigation would be 875 mm. These values do not consider the irrigation efficiency of each method.

Irrigation with sprayers (wetted diameter approximately 2 m) constitutes an intermediate situation between sprinkle and drip irrigation. As in drip irrigation, a partial soil volume is wetted and lateral water movement occurs due to differences in water potential between the wet and the dry zone. Consequently, a zone with salt concentration is formed in the borders of the wetting front around the wetted zone, as observed in drip irrigation. The concentration of salts in the soil solution is related to the irrigation interval. When the irrigation intervals are short as in drip irrigation, the soil solution concentration will remain relatively low, and oppositely, long irrigation intervals as those applied in sprinkler irrigation will cause a high salt concentration in the soil solution in the days previous to the next irrigation.

### 6.3. Monitoring chloride concentration in the soil

Correct management of irrigation requires periodic soil solution monitoring to ensure that the salt concentration remains below the threshold value for the crop, particularly Cl concentration (see Table 3.6). Chloride concentration can be determined directly in the saturated soil extract or in the soil solution extracted with suction cups. Chloride testing methods have been reviewed by Johnson and Fixen (1990) and discussed in Chapter 2.4.2.

Five methods are generally used for monitoring soil salinity (Rhoades and Oster, 1986): (A) laboratory extraction of field soil samples; (B) sampling

the soil solution in the field (in situ), generally by suction pumps; (C) using porous sensors buried in soil, which are saturated and in equilibrium with the soil solution; (D) using four electrodes probe directly in the soil; (E) remote sensing by using electromagnetic methods. The reliability of the results is influenced by soil variability, the position of the suction cups relative to the pattern of water and salt accumulation in the soil profile and the type of porous sensors (Rhoades and Miyamoto, 1990). The irrigation method and salt distribution in the wetted zone can lead to areas of excessive salt accumulation especially at the edges of the seedbed in furrow irrigation, or at the edge of the wetting front in drip irrigation. The number of samples and their spatial distribution will affect the reliability of the data. The total concentration of soluble salts in the soil solution is generally estimated by measuring the electrical conductivity of the saturated paste extract or by sampling the soil solution. Laboratory tests can determine the concentration of each single ion in the soil extracts (Richard, 1954).

#### **6.4. Sprinkler irrigation and chloride induced foliar injury**

Sprinkler irrigation of field crops can cause leaf injury when the irrigation is applied to the whole plant canopy. In orchards where sprinklers are placed below the canopy, direct leaf injury due to excessive chloride is unlikely.

Chloride can be directly absorbed by crop leaves and cause foliar injury when its concentration in the sprinkler water is high (Maas *et al.*, 1982). Leaf scorching due to excessive Cl accumulation varies with species and depends on leaf properties. Temperature, relative humidity and water stress have marked effects on the degree of injury. Absorption of Cl continues as long as the leaf is wet. Evaporation from the leaf surface increases the salt concentration in the solution and consequently the degree of scorching.

Deciduous trees, such as almond, apricot and plum, readily absorb Na and Cl through the leaves and partial leaf abscission occurs after a 50-h sprinkler irrigation with water containing 10 mM  $\text{CaCl}_2$  or NaCl (Ehlig and Bernstein, 1959). Leaf Cl concentrations causing injury in plum, almond and orange are 4.3-7.1, 6.4-10.6 and 7.1-10.6  $\text{mg g}^{-1}$  DM, respectively. No visual foliar injury was observed in grapevines sprinkled with water containing 5 or 10 mM Cl (Francois and Clark, 1979). In avocado, where the thick waxy layer of the leaves limits absorption of ions present in the sprinkling water, Cl accumulation in the leaves is very low and no visual injuries are observed (Ehlig and Bernstein, 1959). Therefore, although avocado is known to be sensitive to salt in the growing medium, there is no risk of direct foliar absorption of Cl because of the leaf surface characteristics. Chloride accumulation in leaves depends mainly on the time of watering (Francois and Clark, 1979).

Field and vegetable crops are not especially sensitive to salt accumulation in the leaves (Ehlig and Bernstein, 1959). Strawberry is highly sensitive to Cl in the soil solution, but is less affected by absorption through the leaves (Ehlig, 1961). The rate of foliar absorption of Cl increases in the following order: sorghum << cotton, sunflower < cauliflower < sesame, alfalfa, sugar beet < barley, tomato < potato, safflower (Maas *et al.*, 1982). However, the above order does not apply to foliar injury.

The relative values of crop sensitivity to foliar injury due to Cl in the sprinkling water are summarized in Table 6.1. Because both crop and environmental conditions influence the level of injury, these data are only a guideline to possible effects of irrigation during daytime hours.

**Table 6.1.** Foliar injury by chloride in different crops irrigated by sprinklers.

Cl concentration in irrigation water (mM)	Crops exhibiting foliar injury
< 5	Almond, apricot, citrus, plum
5-10	Grape, pepper, potato, tomato
10-20	Alfalfa, barley, corn, cucumber, safflower, sesame, sorghum
> 20	Cauliflower, cotton, sugarbeet, sunflower

Based on Maas *et al.* (1982).

Sprinkler irrigation of crops that are less sensitive to Cl is possible provided that steps are taken to avoid or minimize foliar injury. Such measures might include the use of mobile sprinklers, uniform water distribution, night irrigation, and the scheduling of longer intervals between irrigations (Maas, 1985).

### 6.5. Fertilization under conditions of chloride salinity

With the increasing use of saline and recycled sewage water for agriculture, fertilizer application under saline conditions has become a subject of considerable interest (Feigin, 1985). Sodium chloride salinity disrupts mineral nutrients acquisition by plants in two ways (Grattan and Grieve, 1992): (1) total ionic strength of the soil solution, regardless of its composition, can reduce nutrient uptake and translocation; and (2) competition with Na and Cl ions can reduce nutrient availability. These interactions may lead to Na-induced Ca and/or K deficiencies (Volkmar *et al.*, 1998) and Cl-induced inhibition of NO<sub>3</sub> uptake (Kafkafi *et al.*, 1982). The internal K concentration was a major factor in maintaining the growth of

cultured cells of the orange cultivar Shamouti at increasing NaCl and CaCl<sub>2</sub> concentrations (Ben Hayyim *et al.*, 1987). The salinity tolerance of crops can be improved by the suitable use of nutrients (Kafkafi, 1987).

Most of the reported studies on NaCl salinity effects do not separate those of Na from Cl (Volkmar *et al.*, 1998). EC values of about 3.0 dS m<sup>-1</sup> (with Cl as the dominant anion) are common in the wetted volume of irrigated soils growing field crops like tomatoes and melons, (Kafkafi *et al.*, 1992). However, Cl concentrations above about 10 mM in the irrigation water are generally considered problematic for plant growth (Ayers and Westcott, 1985). Salinization with NaCl or KCl inhibits the net uptake of NO<sub>3</sub> by citrus (Cerezo *et al.*, 1997) causing N deficiency (Embleton *et al.*, 1978). Nitrate competes with Cl for uptake by the plant, as discussed in section 3.4.5. Therefore, when irrigation water contains NO<sub>3</sub> at about 8-16 mM, even sensitive plants like avocado (Bar *et al.*, 1997) can survive at Cl concentrations of 8-16 mM (Plate 3.1). Supplying NO<sub>3</sub> considerably relieved the suppressive effects of Cl salinity on the faba bean (*Vicia faba* L.) (Cordovilla *et al.*, 1995). Under high salinity and Cl conditions, K<sub>2</sub>SO<sub>4</sub> is the preferred source of K due to its lower salt index and absence of Cl (Zehler *et al.*, 1981; von Braunschweig, 1986).

Applying a large amount of K might increase the plant's capacity for osmotic adjustment in saline habitats (Cerdea *et al.*, 1995), because K is the most abundant cation in the cytoplasm of glycophytes (Marschner, 1995). In spinach, more K is required for shoot growth under high- than under low-salinity conditions (Chow *et al.*, 1990). Differences in salt tolerance among maize varieties appears to be related to greater K fluxes and cytoplasmic concentrations on one hand and lower Na and Cl fluxes and cytoplasmic concentrations on the other (Hajibagheri *et al.*, 1989). Potassium uptake is greater in salt tolerant barley cultivars than in salt sensitive ones (Sopandie *et al.*, 1993).

Ben Asher and Pacardo (1997) proposed a conceptual model which suggested that enhanced fertilization with KNO<sub>3</sub> under saline conditions might reduce the toxic effect of salinity even if KNO<sub>3</sub> increased soil osmotic potential. At two soil salinity levels (2 dS m<sup>-1</sup> and 8 dS m<sup>-1</sup>) application of KNO<sub>3</sub> was associated with a significant increase of the groundnut shoot dry weight up to 150-300 kg KNO<sub>3</sub> ha<sup>-1</sup>.

Both the growth and development of tomato plants irrigated with a saline solution of EC 5.5 dS m<sup>-1</sup> (with 50 mM NaCl), were improved by adding to the saline solution 2 mM KNO<sub>3</sub> and to a lesser extent by adding 20 mM Ca(NO<sub>3</sub>)<sub>2</sub> (EC = 7.5 dS m<sup>-1</sup>) (Satti *et al.*, 1994). However, an external K supply was not required for root growth of castor bean (*Ricinus communis* L.) under saline conditions (Jeschke and Wolf, 1988).

Increasing the K supply to maize did not prevent the decrease in growth caused by NaCl at 50 mM (Cerdea *et al.*, 1995). Tip-burn symptoms in

Chinese cabbage, induced by salinity with NaCl and CaCl<sub>2</sub>, were not alleviated by the addition of KNO<sub>3</sub> (Feigin *et al.*, 1991a).

Addition of adequate P can also help alleviate salt stress (Champagnol, 1979; Awad *et al.*, 1990). Adding P increased the yield of foxtail millet and clover grown in a saline soil (Ravikovitch and Yoles, 1971). As crops can differ greatly in their response to nutrition management under different combinations of environmental salinity (Feigin *et al.*, 1991a), crop specific information on the response to Cl under different situations is needed for optimal fertilization management.

### 6.6. Potassium supplement to fertigation through sewage treated waters

Waste water effluents usually contain large concentrations of several organic and inorganic components both in solution and suspended. Among these components, attention should be paid to the NaCl levels, as well as to the main nutrients - N, P, and K. There is more N, P and organic matter in recycled water than in fresh water, but there is little difference in the K concentration because K is not removed during sewage treatments.

Pettygrove and Asano (1985) gave ranges for the K concentration in different sources of waste water effluents and sewage waters (Table 6.2). The average K concentration in waste water effluents was 14.7 g m<sup>-3</sup> in New Mexico, 12 g m<sup>-3</sup> in Frankston (Australia) and 15-30 g m<sup>-3</sup> in Alberta (Canada) (Feigin *et al.*, 1991b). A value of 23.9 g K m<sup>-3</sup> in sewage water was reported in Israel (Noy and Feinmesser, 1977). Thus, the K concentration in effluents and sewage from domestic sources can range between 10 and 30 g m<sup>-3</sup>. These concentrations result, in part, from accumulation during domestic water use. There were reports on additions that amounted 7-15 g m<sup>-3</sup> in California (Tchobanoglous, 1979) and 18.8 g m<sup>-3</sup> in Israel (Noy and Feinmesser, 1977).

**Table 6.2.** Potassium concentration in waste water effluents and in sewage waters.

Water source	K concentration (g m <sup>-3</sup> )
Municipal waste water	13-20
Primary effluent	13-33
Secondary effluent	
Low-rate biological process: aerated lagoons and oxidation ponds	10-27
High-rate biological process: trickling filter or activated sludge	11-20
Selected advanced waste water treatment	12-18

Source: Pettygrove and Asano (1985).

There are two common situations where the K concentration in waste water effluents exceeds that typically found in domestic waste water effluents; (1) when K is used as a water softener in industry, (2) waste water containing effluents from treated dairy farm sewage.

In regions with hard water, softeners must be added in different domestic and industrial processes (dishwashers, water for steam generation systems, milk and fruit juice industry or refrigeration, etc.). Domestic and industrial water-softening processes are among the major contributors to the Na content of waste water. Potassium salts can replace Na salts (mainly NaCl) successfully in many water softening treatments. In Israel, the use of KCl to refresh the softeners has been tested as an alternative to NaCl, in order to reduce the amount of Na concentration in effluents used for irrigation (Avnimelech *et al.*, 1992). A similar solution was proposed in the USA to solve the problem of Na coming from softening processes (Elliot, 1993; Polizotto and Harms, 1993). Such replacement may lead to a decrease of exchangeable Na and to increase of exchangeable K percentage (EPP) in soils using recycled water. It is assumed that reduction of sodicity hazards in soils irrigated with waste water can be achieved by replacing Na salts with K salts.

A milking cow excretes about 38% of the dry matter content of the food intake. Over a year, a dairy farm with 1000 milking cows produces about 2000 t urine and faeces which contain 6830 kg K (Van Horn, 1992; Hutson *et al.*, 1996). Dairy cow urine and faeces contain 0.69% and 0.078% K respectively (Hutson *et al.*, 1996). Thus about 83% of the K which is excreted is in the liquid fraction obtained after the separation of liquids and solids. Therefore, waste water containing effluents from treated dairy farm sewage have a higher K content than domestic waste water effluents.

Waste water, such as from a sugar beet factory, can be recycled to agriculture up to a certain amount and can supply both K and lime (Paulsen *et al.*, 1997). Therefore, when irrigating crops with waste water effluents, the application of K fertilizer should be reduced accordingly. For example, if K concentration in the waste water effluent is  $20 \text{ g m}^{-3}$ , and the irrigation is  $5000 \text{ m}^3 \text{ ha}^{-1}$  (representative for field crops and orchards in the coastal plain in Israel), the irrigation water already provides about half of the recommended application of K and the rest should be added as fertilizer.

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## 7. Environmental issues relating to potassium fertilizers

### 7.1. Potassium and water quality

Potassium has no known deleterious effect on the quality of natural and drinking waters and it does not induce eutrophication in rivers and lakes (Mengel, 1997). Potassium ions leached into deeper soil layers and finally reaching the aquifers presents no ecological threat, and K in drinking water and/or food is no hazard for human health provided renal function is normal (Grossklaus, 1992). A diet high in K has no harmful effect and is recommended for people suffering from hypertension.

Most of the water sources used for human consumption are derived from surface waters (rivers and lakes) or from groundwater wells. Potassium ions not absorbed by the crop roots are adsorbed by the soil particles thus minimising the risk of K leaching (Beringer, 1992) and almost all exchangeable and non-exchangeable soil sites would have to be K-saturated before there is a serious risk of large amounts of K being leached from soil (Johnston and Goulding, 1992). Studies on cation migration in water draining through the soil profile showed that K is depleted relative to Na because K is liberated with greater difficulty from minerals and exhibits a stronger tendency to be retained in solid weathering products (Nativ, 1992).

Most of the drinking water regulations do not establish a threshold concentration for K (WHO, 1993; USEPA, 1991; Environmental Health Directorate of Canada, 1996). However, the European Community has established a maximum admissible concentration (MAC) value for K in water for human consumption of  $12 \text{ mg K L}^{-1}$  (Drinking Water Directive 80/778 EEC, 1980). This administrative threshold value has been criticized because it has no toxicological or physiological justification. In fact, many natural beverages have much higher K concentrations, for example, fruit juices contain up to  $2270 \text{ mg K L}^{-1}$  but beverages represent only 13.5% of the daily total K uptake and have little relevance in relation to the total K intake through solid foods (Grossklaus, 1992). The contribution of drinking water to the total K intake should be ignored from the viewpoint of nutritional physiology, as it contributes only 0.1% of total K intake. It is concluded, therefore, that the MAC value for K in drinking water is unnecessarily low from the nutritional and health aspects (Grossklaus, 1992). Johnston and Goulding (1992) reported that K concentrations in borehole water at three experimental stations in England ranged between  $0.9\text{-}4.4 \text{ mg K L}^{-1}$ , these and other water analyses were well below the EEC threshold level. Because K has no known pollution or health hazard, any decrease in K fertilizer use for ecological or health reasons is not justified.

## 7.2. Chloride and water quality

The presence of Cl in drinking water sources is attributed to the dissolution of salt deposits, salt used for de-icing of highways, effluents from chemical industries, oil well operations, sewage, irrigation drainage, refuse leachates, volcanic emanations, sea spray and seawater intrusion in coastal areas (Environmental Health Directorate of Canada, 1996). Each of these sources may result in local contamination of surface water and groundwater. Chloride ions are highly mobile in aqueous solution and are eventually transported into closed basins or to the oceans.

Chloride is an essential element for human beings and is the main extracellular anion in the body. Until recently, it had been assumed that the physiological role of the Cl ion was simply that of a passive counter ion. Over the past few years, however, several studies have suggested that the Cl ion may play a more active and independent role in renal function, neurophysiology and nutrition (Environmental Health Directorate of Canada, 1996).

Toxic effects of Cl are related to hypertension (Kurtz and Morris, 1983; Whitescarves *et al.*, 1984). Both Na and Cl are required for a hypertensive effect. There is no evidence that a high Cl concentration would be more toxic than a high Na concentration (Environmental Health Directorate of Canada, 1996).

Chloride concentrations in the body are well regulated through a complex interrelated system involving both nervous and hormonal systems. The body Cl balance is maintained, mainly by the excretion of excess Cl in the urine, even after intake of large quantities of Cl in food and water (ICRP, 1975). The daily body intake of Cl from water constitutes only about 0.25% of the average Cl intake from food (Environmental Health Directorate of Canada, 1998). In consequence drinking water is not considered to be a significant source of exposure to Cl, and a MAC has not been set for Cl in drinking water (Environmental Health Directorate of Canada, 1996).

The maximum Cl concentration as an *aesthetic objective* (based on organoleptic characteristics of the water) is 250 mg L<sup>-1</sup> (Environmental Health Directorate of Canada, 1996; WHO, 1993). At concentrations above the aesthetic objective, Cl imparts undesirable tastes to water and to beverages prepared from water and may cause corrosion in the distribution system (Environmental Health Directorate of Canada, 1996).

Increased levels of Cl in drinking water are associated with saline water intrusion to the aquifers in coastal areas or with increasing amounts of chloride in atmospheric deposition, but not due to increasing use of KCl as a fertilizer (Johnston and Goulding, 1992).

### 7.3. Potassium chloride and hazardous chemical elements

#### 7.3.1. Heavy metals in fertilizers

Potassium fertilizers do not contain any of the heavy metals which are considered toxic and environmentally hazardous (USEPA, 1980). However, reporting the individual metal levels in all fertilizers is a requirement, effective from July 1, 1999, by the Washington State Department of Agriculture (WSDA). In order to register a commercial fertilizer, the total concentration of each metal must be reported using USEPA analytical methods; and should not exceed the WSDA standards. Table 7.1 gives the metal analysis for KCl from two different producers, which meet appropriate WSDA standards (WSDA, 1999).

**Table 7.1.** Guaranteed analysis of KCl from two registrants at the Washington State Department of Agriculture.

Metals	Concentration in KCl fertilizer (mg kg <sup>-1</sup> )	
	PCS Sales Inc.	IMC Kalium
Arsenic	< 0.5	1
Cadmium	< 0.1	< 1
Cobalt	< 0.1	<
Mercury	< 0.05	0.2
Nickel	0.7	1
Lead	< 1.2	< 1
Selenium	< 5.5	< 5

< : minimum detection limit (the metal was not found at or above the minimum detection limit).

Source: WSDA (1999).

Raven and Loeppert (1997) gave the trace element and heavy metal composition of a wide variety of fertilizers and soil amendments, and found that commercial K fertilizers (KCl and K-Mg sulphate) had the lowest trace element concentrations. For KCl, the concentration of more than half of the heavy metals analyzed was less than 1 mg kg<sup>-1</sup>. Cadmium, arsenic and lead concentrations were very low: < 0.2, < 0.4 and < 0.4-1 mg kg<sup>-1</sup>, respectively.

#### 7.3.2. Heavy metals in soils

The evidences for possible effects of the addition of K fertilizers on the uptake of heavy metals by plants is contradictory. Grant *et al.* (1995) found that KCl tended to increase the Cd concentration in malted barley, while Mc Laughlin *et al.* (1995) reported that K fertilizer had little influence on Cd

concentration in potato tubers. These apparently conflicting results may stem from the fact that although fertilizers may desorb Cd from the soil, this Cd might not be taken up by the plants due to cation competition (Cd vs. K antagonism) in uptake (Jalil *et al.*, 1994).

The mobility of heavy metals in soils was found to be greater with KCl than with  $K_2SO_4$  (Khan *et al.*, 1996; Sparrow *et al.*, 1994) or  $KNO_3$  (Sakurai and Huang, 1996), due to the desorption of adsorbed cations. Greater desorption rate by KCl may be due to the formation of complexes between Cd and Cl, which are more mobile than Cd complexes with  $SO_4^{2-}$  or  $NO_3^-$  ions. Salardini *et al.* (1993) proposed that in a leaching environment, the use of KCl might help to remove Cd from the root zone.

Special care should therefore be taken when adding fertilizers in general and KCl in particular to soils receiving large inputs of animal manure, refuse compost or treated sludge which can add significant quantities of heavy metals to the soil.

### 7.3.3. Radioactive elements

Potassium fertilizers are not referred to as potential hazards in relation to radioactive elements (IFA-UNEP-UNIDO, 1998).

#### 7.3.3.1. KCl fertilization as an alleviation factor in radioactive contaminated soils - The Chernobyl case

In the former Soviet Union, the Chernobyl reactor accident in 1986 contaminated about 125,000 km<sup>2</sup> of land in Belarus, Ukraine and Russia with radioactive caesium (Cs) levels greater than 37 kBq m<sup>-2</sup>, and about 30,000 km<sup>2</sup> with radioactive strontium greater than 10 kBq m<sup>-2</sup>. About 52,000 km<sup>2</sup> of this total area were in agricultural use; the remainder was forest, lakes and urban areas (Richards, 1996).

Since July 1986, the dose rate from external irradiation in some areas has decreased by a factor of forty, and in some places, it is less than 1% of its original value. Nevertheless, soil contamination with <sup>137</sup>Cs, <sup>90</sup>Sr and <sup>239</sup>Pu is still high. In Belarus, the most widely contaminated Republic, eight years after the accident 2,640 km<sup>2</sup> of agricultural land are still excluded from use (NEA-OECD, 1996).

Potassium fertilizers have been used in the FSU since the Chernobyl event to decrease the content of radioactive elements in food crops grown on contaminated land. In laboratory experiments, the uptake of <sup>133</sup>Cs by wheat roots was depressed by K (given as KCl) and NH<sub>4</sub> (given as NH<sub>4</sub>Cl), probably due to a competitive inhibition by analogous ions and with K reducing Cs uptake more than did NH<sub>4</sub> (Shaw and Bell, 1991). Fertilization with KCl not only decreased the uptake of radioactive Cs by a factor of 2 to 14, but also increased crop yield (NEA-OECD, 1996).

**Table 7.2.** Effect of KCl application on  $^{137}\text{Cs}$  concentration in various crops on soddy-podzolic sandy soils in the Bryansk region.

K dose (kg $\text{K}_2\text{O}$ $\text{ha}^{-1}$ )	$^{137}\text{Cs}$ concentration ( $\text{Bq kg}^{-1}$ )					
	Barley (grain)	Oats (grain)	Potato (tubers)	Corn for silage (green mass)	Perennial grass (hay)	
					1 cut	2 cut
0	18.5	32.9	52.9	90.6	118.4	162.8
120	17.4	21.5	22.2	72.2	50.0	62.9
240	13.7	14.8	11.1	29.6	62.9	48.1
360	15.9	17.4	13.7	24.0	48.1	50.0

Source: Vorobyev (1999).

In a contaminated sandy podzol, KCl fertilization reduced the uptake of  $^{137}\text{Cs}$  by oats and when  $90 \text{ kg K}_2\text{O ha}^{-1}$  (as KCl) was applied to a fodder crop the  $^{137}\text{Cs}$  concentration was decreased by 35% and yield was increased (Tulin *et al.*, 1995). When K was applied with dolomite or  $\text{CaCO}_3$ ,  $^{137}\text{Cs}$  concentration was reduced by 41% and 54% respectively. Combining K with liming, especially with dolomite, was most effective in reducing  $^{137}\text{Cs}$  contamination through the improvement in the  $\text{K}/(\text{Ca}+\text{Mg})$  ratio in the soil. Potassium fertilizer also decreased  $^{137}\text{Cs}$  concentration in other crops, like lupin, rape, potato and rye (Table 7.2) (Tulin *et al.*, 1995; Vorobyev, 1999). Applying KCl reduced  $^{137}\text{Cs}$  uptake of peas and potatoes by 13 to 45%, respectively when applied to alluvial and leached chernozem soils and also increased yields (Pristchep, 1994).

## **7.4. Environmental aspects of the production of potassium chloride**

### **7.4.1. Disposal of salt residues**

The environmental impact of the potash industry is quite small so it is not mentioned in the most recent publications of the United Nations (IFA-UNEP-UNIDO, 1998; UNIDO-IFDC, 1998) as an environmental polluting industry.

The main concern is the potential contamination of ground and surface water by waste brines and by runoff from salt piles (Beringer, 1992). These saline constituents are present in the ore bodies and are separated from the potash product during processing (Anonymous, 1998). The main residue of potash fertilizer production is NaCl and also some  $\text{CaSO}_4$ ,  $\text{MgCl}_2$  and clay. The amount of these residues ranges between 60-86 t per 100 t of crude ore, depending on the grade of the ore. In Saskatchewan, production of 10 Mt of KCl generated 28 Mt of salt tailings and 11 million  $\text{m}^3$  of waste brine (Anonymous, 1998).

Only minor quantities of NaCl salt can be sold, and the bulk has to be disposed of either by backfilling into mine cavities, or by piling up on the surface. Industry wide, between 30 and 50% of the residues must be piled, and the soil underneath the pile is sealed off with clay or plastic to avoid leakage and seepage. In addition, the pile should be surrounded by a ring drainage system (Beringer, 1992).

The drainage water from the salt piles as well as the waste water from the manufacturing process is disposed finally into rivers (France and Germany) or into the sea (New Brunswick, Canada). In Saskatchewan (Canada), which is an arid zone, the regulations do not allow the disposal of brines into surface water. All waste brines must be disposed of by re-injection via deepwells (Anonymous, 1998). At the Dead Sea (Israel and Jordan), most of the waste brines are returned to the Dead Sea. Public authorities and the industry

itself are applying comprehensive and continuous controls to handle the tailings in environmentally acceptable ways in order not to exceed the permissible limits for salt disposal (Anonymous, 1998).

#### 7.4.2. Salt dust deposition

Salt dust is inevitably produced during processing and is deposited locally. This is harmless to humans, as no KCl dust related diseases are known, but there can be damage to the vegetation near the mine. Preventive measures consist of combinations of dust removal and filtering in order to keep the dust emissions below the present threshold value of 509 mg m<sup>-3</sup> air (Beringer, 1992).

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