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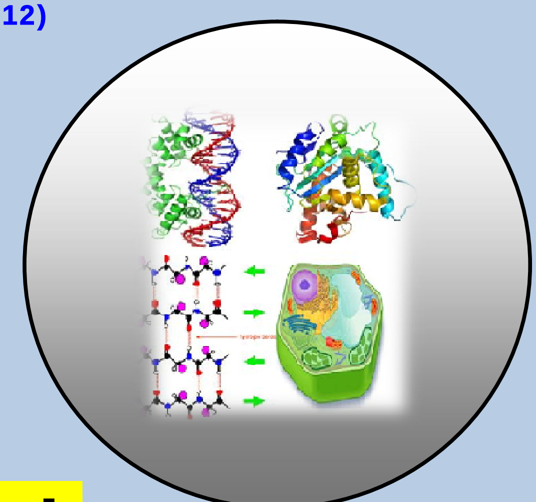

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RESEARCH PAPER

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Studies of the Different Levels of Salinity on Some Physiological Characteristics of Plants

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ABSTRACT

The salinity damages plants mainly through the osmotic effect , the effect of specific ion and subsequently.The salinityof water and soil decreases the growth and yield of agricultural crops. Salinity is one of the important issues in world's farmlands. Annually, millions of tons of salt enter the farmlands through irrigation. We observed that High concentrations of salt on the roots bring down the soil water potential and available water. The experimental laboratory had been fixed on the wheat and rice. In addition the results showed that the accumulation of proline and soluble sugars is a good indicator for salinity tolerance of wheat. Salinity stress leads to gradual reduction of magnesium ion concentration. We demonstrated that wheat is one of the more salt-tolerant crops, and rice is one of the more salt-sensitive crops.
Key words: Water Salinity, Soil Salinity and Salt Tolerant.

INTRODUCTION

In general, various mechanisms contribute to salt tolerance in plants, but commonly proposed mechanisms include compartment of ions in vacuoles, accumulation of compatible solutes in the cytoplasm, as well as genetic salt resistance.According to the FAO Land and Plant Nutrition Management Service, over 6% of the world's land is affected by either salinity or sodicity (Table 1). The term *salt-affected* refers to soils that are saline or sodic, and these cover over 400 million hectares, which is over 6% of the world land area (Table 1). Much of the world's land is not cultivated, but a significant proportion of cultivated land is salt-affected. Of the current 230 million ha of irrigated land, 45 million ha are salt-affected (19.5 percent) and of the 1,500 million ha under dryland agriculture, 32 million are salt-affected to varying degrees (2.1 percent).

Table 1. Regional distribution of salt-affected soils, in million hectares.

Regions	Total area	Saline soils		Sodic soils	
	Mha	Mha	%	Mha	%
Africa	1,899	39	2.0	34	1.8
Asia, the Pacific and Australia	3,107	195	6.3	249	8.0
Europe	2,011	7	0.3	73	3.6
Latin America	2,039	61	3.0	51	2.5
Near East	1,802	92	5.1	14	0.8
North America	1,924	5	0.2	15	0.8
Total	12,781	397	3.1%	434	3.4%

Source: FAO Land and Plant Nutrition Management Service

Salinity occurs through natural or human-induced processes that result in the accumulation of dissolved salts in the soil water to an extent that inhibits plant growth. Sodicity is a secondary result of salinity in clay soils, where leaching through either natural or human-induced processes has washed soluble salts into the subsoil, and left sodium bound to the negative charges of the clay.

A *saline soil* is defined as having a high concentration of soluble salts, high enough to affect plant growth. Salt concentration in a soil is measured in terms of its electrical conductivity, as described in the section below on measurements. The USDA Salinity Laboratory defines a saline soil as having an EC_e of 4 dS/m or more. EC_e is the electrical conductivity of the 'saturated paste extract', that is, of the solution extracted from a soil sample after being mixed with sufficient water to produce a saturated paste. However, may crops are affected by soil with an EC_e less than 4 dS/m. The moisture content of a drained soil at field capacity may be much lower than the water content of its saturated paste. Further, under dryland agriculture, the soil water content might drop to half of field capacity during the life of the crop. The actual salinity of a rain-fed field whose soil had an EC_e of 4 dS/m could be 8-12 dS/m. As described below, this would severely limit yield of most crops.

Types and Causes of Salinity

Natural or primary salinity

Primary salinity results from the accumulation of salts over long periods of time, through natural processes, in the soil or groundwater. It is caused by two natural processes. The first is the weathering of parent materials containing soluble salts. Weathering processes break down rocks and release soluble salts of various types, mainly chlorides of sodium, calcium and magnesium, and to a lesser extent, sulphates and carbonates. Sodium chloride is the most soluble salt. The second is the deposition of oceanic salt carried in wind and rain. 'Cyclic salts' are ocean salts carried inland by wind and deposited by rainfall, and are mainly sodium chloride (Table 2). Rainwater contains from 6 to 50 mg/kg of salt, the concentration of salts decreasing with distance from the coast. If the concentration is 10 mg/kg, this would add 10 kg/ha of salt for each 100 mm of rainfall per year. Accumulation of this salt in the soil would be considerable over millennia.

The amount of salt stored in the soil varies with the soil type, being low for sandy soils and high for soils contain a high percentage of clay minerals. It also varies inversely with average annual rainfall. For example, in Western Australia, the salt content of a 40 m profile ranges from 170 to 950 tonne/ha for rainfall averaging from 1000 mm to 600 mm per year.

Table 2: 'Cyclic salts' are ocean salts carried inland by wind and deposited by rainfall, and are mainly sodium chloride

Ion	rainwater (local)		seawater (global)	
	mg/kg (ppm)	(μmol/L) μM	g/kg (ppt)	(mmol/L) mM
Sodium (Na^+)	2.0	86	10.8	470
Chloride (Cl^-)	3.8	107	19.4	547
Sulfate (SO_4^{2-})	0.6	6	2.7	28
Magnesium (Mg^{2+})	0.3	11	1.3	53
Calcium (Ca^{2+})	0.1	2	0.4	10
Potassium (K^+)	0.3	8	0.4	10
Total	7.0		35.0	

Secondary or human-induced salinity

Prior to human activities, in arid or semi-arid climates, the water used by natural vegetation was in balance with the rainfall, with the deep roots of native vegetation ensuring that the water tables were well below the surface. Clearing and irrigation changed this balance, so that rainfall on the one hand, and irrigation water on the other, provided more water than the crops could use. The mobilised salt can also move laterally to water courses and increase their salinity. Irrigated lands of the world in 1987 totalled 227 Mha (Table 3). In many irrigated areas, the water table has risen due to excessive amounts of applied water coupled with poor drainage. In most of the irrigation projects located in semi-arid and arid areas, the problems of waterlogging and soil salinity have reached serious proportions even before the full potential of the irrigation project could be realised. Most of the irrigation systems of the world have caused secondary salinity, sodicity or waterlogging.

Table 3. Global estimate of secondary salinisation in the World's irrigated lands.

Country	Total land area cropped Mha	Area irrigated		Area of irrigated land that is salt-affected	
		Mha	%	Mha	%
China	97	45	46	6.7	15
India	169	42	25	7.0	17
Soviet Union	233	21	9	3.7	18
United States	190	18	10	4.2	23
Pakistan	21	16	78	4.2	26
Iran	15	6	39	1.7	30
Thailand	20	4	20	0.4	10
Egypt	3	3	100	0.9	33
Australia	47	2	4	0.2	9
Argentina	36	2	5	0.6	34
South Africa	13	1	9	0.1	9
Subtotal	843	159	19	29.6	20
World	1,474	227	15	45.4	20

Source: Ghassemi et al. (1995) compiled from FAO data for 1987.

Table 3 shows that the proportion of salt-affected irrigated land in various countries ranges from a minimum of 9% to a maximum of 34%, with a world average of 20%. In Australia, 2 Mha of land have been damaged by rising watertables due to land clearing, and another 15 Mha are at risk of salinisation by rising watertables over the next 50 years. (Data from National Land and Water Resources).

Soil sodicity and sub-soil salinity

Sodic soils have a low concentration of soluble salts, but a high percent of exchangeable Na^+; that is, Na^+ forms a high percent of all cations bound to the negative charges on the clay particles that make up the soil complex. Sodicity is defined in terms of the threshold ESP (exchangable sodium percentage) that causes degradation of soil structure. The negatively charged clay particles are held together by divalent cations. When monovalent cations such as Na^+ displace the divalent cations on the soil complex, and the concentration of free soluble salts is low, the complex swells and the clay particles separate (*'disperse'*). The USDA Salinity Laboratory defines a sodic soil as having an ESP greater than 15, but in theory, if sufficient salts accumulate, the threshold electrolyte concentration for flocculation will be exceeded and the clay will flocculate and take on pseudo-structure. Saline/sodic soils are widespread in arid and semi-arid lands of the world (Table 3), with a large component in Australia (over 250 million ha). Water infiltration is slow, and salts derived from rainfall or weathering reactions accumulate in saturated zones in the subsoil. The term '*transient salinity*' denotes the seasonal and spatial variation of salt accumulation in the root zone not influenced by groundwater processes and rising water table (Rengasamy, 2002). This transient salinity fluctuates in depth, due mainly to seasonal rainfall patterns. Transient salinity is extensive in many landscapes dominated by subsoil sodicity. Probably, two thirds of the agricultural area of Australia has a potential for transient salinity not associated with groundwater (Rengasamy, 2002).

2. Measuring soil salinity

Soil salinity is measured by its electrical conductivity. The SI unit of electrical conductivity (EC) is dS/m. Table 4 shows the relationship to other units of conductivity, and to NaCl concentration (10 mM NaCl has an EC close to 1 dS/m). Originally the conductivity was measured in a saturated paste extract (EC_e), but the method is tedious as first the saturated paste has to be made, second the water needs to be extracted by a powerful vacuum pump, and third a very sandy soil does not make a saturated paste. A more convenient and universal method is a '1:5 extract'. The electrical conductivity of irrigation or river water is measured with the same hand-held conductivity meter as above, but is expressed in units 1000 times magnified, as channel or river water would normally have a very low concentration of salts. River water quality is often expressed as dS/cm (1000 x dS/m). Irrigation water quality is often expressed as total soluble salts, an international convention being that 1 dS/m is equivalent to 640 mg/L of mixed salts (Table 4). Some data on the electrical conductivity of pure solutions relevant to saline soils or to seawater are given in Table 5. Soil salinity on a large scale is mapped with an electromagnetic (EM) conductivity meter. This instrument estimates the bulk electrical conductivity of the soil, which depends on the salinity of the soil solution, its water content, and the type and amount of clay in the soil. The output needs to be calibrated by chemical measurements of cores taken from the field. Fig 1 illustrates the heterogeneity of soil salinity as shown by the EM meter.

Table 4. Units for Measuring Salinity.

Measurement and units	Application	1 dS/m is equal to:	Equivalent units
Conductivity (dS/m)	soils	1	1 dS/m = 1 mS/cm = 1 mmho/cm
Conductivity (μS/cm)	irrigation and river water	1000 μS/cm	1 μS/cm = 1 μmho/cm
Total dissolved salts (mg/L)	irrigation and river water	640 mg/L (approx.)	1 mg/L = 1 mg/kg = 1 ppm
Molarity of NaCl (mM)	laboratory	10 mM	1 mM = 1 mmol/L

The solutions represent those of salts found in soils or in seawater. Data from the Handbook of Physics and Chemistry (CRC Press, 55th editition, 1975). (Note that 1 dS/m = 1 mmho/cm).

Table 5. Electrical conductivity (EC) of pure solutions at 20°C (dS/m).

Solution	EC (dS/m)
10 mM NaCl	1.0
100 mM NaCl	9.8
500 mM NaCl	42.2
10 mM KCl	1.2
10 mM CaCl2	1.8
10 mM MgCl2	1.6
50 mM MgCl2	8.1

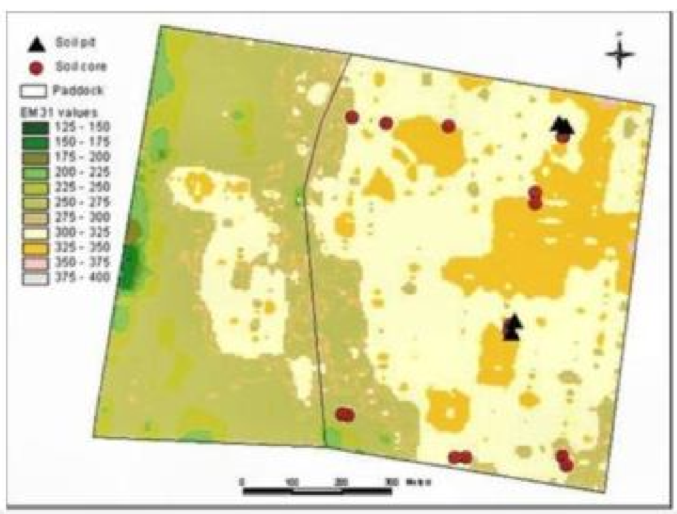

Fig 1. example of an EM survey taken on a paddock basis at groundlevel. (Image courtesy of P. Rampant, Department of Primary Industry, Bendigo, Australia).

The repercussions of salinity

The Effect of Salinity on Plants

This is referred to as the osmotic or water-deficit effect of salinity. Second, if excessive amounts of salt enter the plant in the transpiration stream there will be injury to cells in the transpiring leaves and this may cause further reductions in growth. This is called the salt-specific or ion-excess effect of salinity (Greenway and Munns, 1980). The definition of salt tolerance is usually the percent biomass production in saline soil relative to plants in non-saline soil, after growth for an extended period of time. As salinity is often caused by rising water tables, it can be accompanied by waterlogging.

Variation in Salt Tolerance between Species

Differences in the growth response of various species are shown in Fig. 2. Wheat is one of the more salt-tolerant crop species, and many cultivars that have been selected for yield in water-limited conditions do not suffer a 50% reduction in biomass until salinities reach 15 dS/m (approximately 150 mM NaCl). Rice is more salt-sensitive, and many cultivars suffer a 50% reduction in growth at half this concentration of salts. Maize falls in between these two species in terms of salt sensitivity.

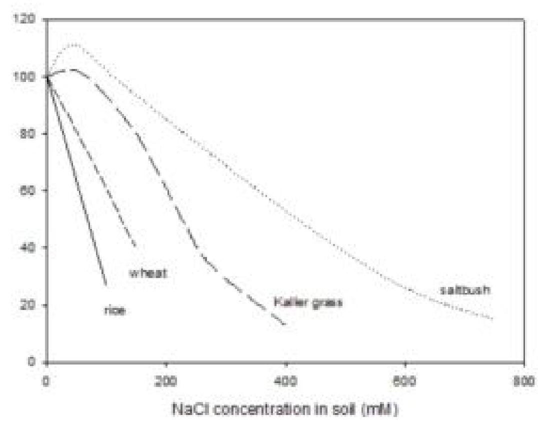

Figure 2. Biomass production of four diverse and important plant species in a range of salinities.

Wheat is one of the more salt-tolerant crops, and rice is one of the more salt-sensitive crops. Two halophytes: a saltbush species *Atriplex amnicola* and a grass *Diplachne* (syn. *Leptochloa*) *fusca* or Kallar grass. Both halophytes show outstanding salt tolerance with high growth rates and are being used in Australia and Asia for grazing on saline land. Another criterion of salt tolerance of crops is their yield in saline versus non-saline conditions. A survey of salt tolerance of crops, vegetables and fruit trees was made by the USDA Salinity Laboratory. This shows for each species a threshold salinity below which there is no reduction in yield, and then a regression for the reduction in yield with increasing salinity (Fig. 3). Full details are available on line. The data in some cases are for a single cultivar of the species, or a limited number of cultivars at a single site, so they are not necessarily representative of the species. Further, the data are related to an EC_e value, which is not an appropriate reference point for a sandy soil, or for many current soil salinity estimates that based merely on a 1:5 extract.

However, the data are useful in that they show the wide range of tolerance across species, and also show that yield has a different pattern of response than does vegetative biomass (compare with Fig. 2) Yield always shows a threshold in response to a range of salinities (Fig 3), but with young plants a threshold is rarely seen.

Causes of the Growth Reduction under Saline Conditions

The salt in the soil solution (the "osmotic stress") reduces leaf growth and to a lesser extent root growth, and decreases stomatal conductance and thereby photosynthesis (Munns, 1993). The cellular and metabolic processes involved are in common to drought-affected plants, and described under Drought Stress and Its Impact on this site.

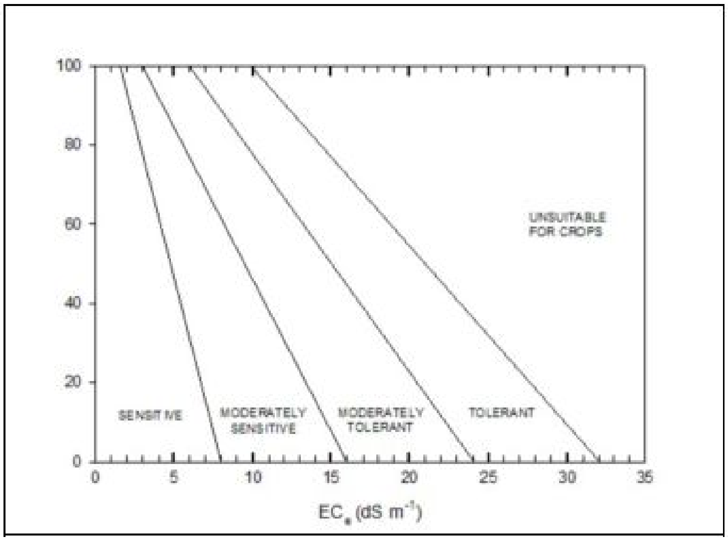

Figure 3. Categories for classifying crop tolerance to salinity according to the USDA Salinity Lab. Note that the ECe is more applicable to an irrigated than a rainfed field, in the latter the soil moisture content might be 2-4 time less than in a saturated pa.

So, the salt taken up by the plant does not directly inhibit the growth of new leaves. The salt within the plant enhances the senescence of old leaves. Continued transport of salt into transpiring leaves over a long period of time eventually results in very high Na^+ and Cl^- concentrations, and they die. The rate of leaf death is crucial for the survival of the plant. If new leaves are continually produced at a rate greater than that at which old leaves die, then there might be enough photosynthesising leaves for the plant to produce some flowers and seeds. However, if the rate of leaf death exceeds the rate at which new leaves are produced, then the plant may not survive to produce seed. For an annual plant there is a race against time to initiate flowers and form seeds, while the leaf area is still adequate to supply the necessary photosynthate. For perennial species, there is an opportunity to enter a state of dormancy, and thus survive the stress. The two responses occur sequentially, giving rise to a two-phase growth response to salinity. The first phase of growth reduction is quickly apparent, and is due to the salt outside the roots. It is essentially a water stress or osmotic phase, for which there is surprisingly little genotypic difference.

Then there is a second phase of growth reduction, which takes time to develop, and results from internal injury. The two-phase growth response is illustrated in Fig 4. The experiment was conducted with two genotypes with contrasting rates of Na^+ uptake, and known differences in salt tolerance; previous experiments had shown that the genotype with the low Na^+ uptake rate had a higher survival of high salinity. Fig 4 shows that during the first 3-4 weeks after the soil was salinised, there was a large growth reduction in both genotypes. This is called the 'Phase 1' response, and is due to the osmotic effect of the salt. Then after 4 weeks, the genotypes separated; the one with the low Na^+ uptake rate continued to grow, although still at a reduced rate compared to the controls in non-saline solution, but the one with the high Na^+ uptake rate produced little biomass and many individuals died. This is the 'Phase 2' response, and is due to genotypic differences in coping with the Na^+ or Cl^- ions in the soil, as distinct from the osmotic stress.

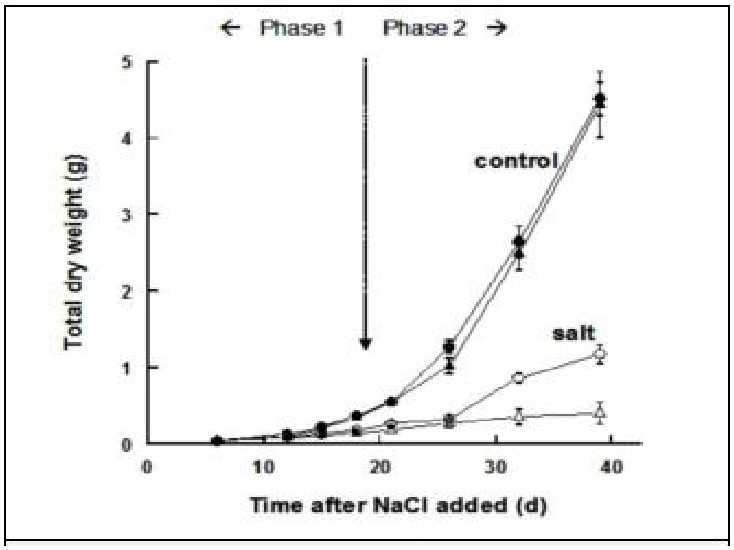

Figure 4. Two accessions of the diploid wheat progenitor *Ae. tauschii* grown in supported hydroponics in control solution (closed symbols) and in 150 mM NaCl (open symbols). Circles denote the tolerant accession, triangles the sensitive one.

The arrow marks the time at which symptoms of salt injury could be seen on the sensitive accession; at that time the proportion of dead leaves was 10% for the sensitive and 1% for the tolerant accession (Munns et al., 1995).

The Required Extent of Salt Exclusion

Roots must exclude most of the Na^+ and Cl^- dissolved in the soil solution or the salt will gradually build up with time in the shoot and become so high that it kills it. To prevent salt building up with time in the shoot, roots should exclude 98% of the salt in the soil solution, allowing only 2% to be transported in the xylem to the shoots. This value of 2% can be calculated from the following equation: The concentration at which NaCl accumulates in the shoot depends on the salt concentration in the soil solution, the percentage of salt taken up by roots, and the percentage of water retained in the leaves.

$$[NaCl]_{shoot} = [NaCl]_{soil} \times \frac{\%\ \text{salt taken up}}{\%\ \text{water retained}} \qquad \text{(Eqn. 1)}$$

Plants retain only about 2% of the water they transpire, ie they take up about 50 time more water from the soil than they retain in their shoot tissues. The percentage of transpired water that is retained in the shoot can be calculated from the product of the water use efficiency (*wue*; mass of shoot produced per mass of H_2O transpired) and the shoot water content (*wc*; shoot H_2O per shoot mass): Water use efficiency (WUE) of plants growing at moderate evaporation demand are usually in the range of 3-6 mg g^{-1}, the variation due to extremes of evaporative demand, rather than a peculiarity of the species. For a water use efficiency of 4 mg g^{-1} and a shoot H_2O:DW ratio of 5:1, about 20 mg of water is retained in the shoot for every g of water transpired (Eqn. 2). That is, the shoot retains only 2% of the water transpired. In order to prevent the salt concentration in the shoot increasing above that in the soil, then only 2% of the salt should be allowed into the shoot, *i.e.* 98% should be excluded.

$$\% \text{ water retained} = wue \times wc \times 100 \qquad \text{(Eqn. 2)}$$

A soil salinity of 100 mM NaCl or 10 dS m^{-1} is about as high as most crops will tolerate without a significant reduction in growth or yield (see Figs. 2 and 3), and a concentration of 100 mM NaCl on a whole shoot basis is about as high as is desirable because it will include some old leaves with much higher salt concentrations, as well as younger leaves or other tissues with lower concentrations. So for plants to grow for extended periods of time in soils with salinity of this order of magnitude, roots should ensure that no more than 2% gets to the shoots.

The Relationship between Transpiration and Salt Uptake

NaCl does not move passively with the transpiration stream, neither is its movement entirely independent of it, at least in some species, or over certain ranges of transpiration. Fig. 5 shows the relationship between water and salt flow in the xylem of barley plants (Munns, 1985). As water flow increased from a very low to a moderate rate, there was an increase in Cl^- flux, showing that the movement of the ion through the root was enhanced as water flow started to increase. However, when the water flow increased from moderate to high rates, there was little or no further increase in Cl^- flux, showing that the movement of the ion was independent of further increases in water flow. This relationship also holds for Na^+ and K^+. An effect might be seen more with species that are very poor excluders, such as lupin as mentioned above, and rice, which carry much more salt in an apoplastic or transpirational "bypass" pathway than other species. In rice, the percentage of water moving through a bypass pathway from roots to shoots was estimated as 5.5% of the total water transpired, and could account for all the Na^+ transported to the shoots, whereas in wheat only 0.4% of the water moved along a bypass pathway and could not account for most of the Na^+ transported (Garcia et al., 1997).

Mechanisms of Control of Salt Transport

Here we look at differences between species in the ability to tolerate the salt-specific component of salinity.

Differences in tolerating the osmotic stress itself are in common with drought tolerance. The rate at which old leaves die depends on the rate at which salts accumulate to toxic levels.

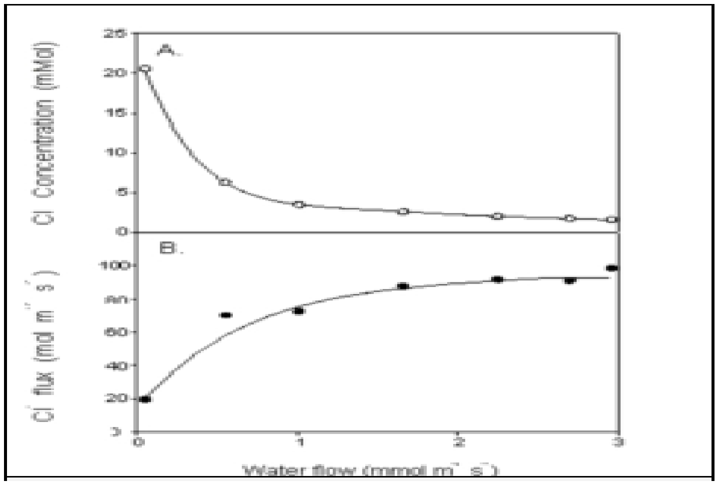

Figure 5. The relation between ion concentration in the xylem (A), ion flux to the shoot (B), and transpiration (water flow) (Munns, 1985).

Control at the whole plant level

Control of salt transport into and through the plant takes place at five sites in the plant (Fig. 6). Control occurs in the root cortex, at the loading of the xylem, at the retrieval from the xylem in upper parts of the roots. These three processes serve to reduce the transport to the leaves. Control in the shoot occurs by the exclusion of salt from the phloem sap flowing to meristematic regions of the shoot. An additional mechanism occurs in most halophytes: specialised cells to excrete salt from leaves. However, halophytes also rely on the first four mechanisms to reduce the flux of salt to the leaves – excretion is an additional backup for plants growing in very saline site, and for perennial species. Exclusion is particularly important for perennial species whose leaves may live for a year or more. For these species there is greater need to regulate the incoming salt load than for annual species whose leaves may live for only one month. There are contributory features that function to maintain low rates of salt accumulation in leaves. High shoot/root ratios and high intrinsic growth rates (Pitman, 1984), and absence of an apoplastic pathway in roots (Garcia et al., 1997) all will serve to reduce the rate at which salt enters the transpiration stream and accumulates in the shoot.

$$\text{Ion concentration in shoot (mol g}^{-1}\text{)} = \frac{\text{Ion uptake rate (mol g}^{-1}\text{d}^{-1}\text{)}}{\text{Relative growth rate (g g}^{-1}\text{ d}^{-1}\text{)}} \qquad \text{(Eqn 3)}$$

Control at the cellular level: ion compartmentation

That this occurs in most species is indicated by the high concentrations found in leaves that are still functioning normally, concentrations well over 200 mM, which are known to completely repress enzyme activity *in vitro* (Munns, 2002) Generally, Na^+ starts to inhibit most enzymes at a concentration above 100 mM. The concentration at which Cl^- becomes toxic is even less well defined, but is probably in the same range as that for Na^+. If Na^+ and Cl^- are sequestered in the vacuole of the cell, K^+ and organic solutes should accumulate in the cytoplasm and organelles to balance the osmotic pressure of the ions in the vacuole. The ion channels and transporters that regulate the net movement of salt across cell membranes were described in several recent reviews (see under Salinity Stress).

Summary

Roots do most of the work in protecting the plant from excessive uptake of salts, and filter out most of the salt in the soil while taking up water. Even so, there are mechanisms for coping with the continuous delivery of relatively small amounts of salt that arrive in the leaves, the most important being the cellular compartmentalisation of salts in the vacuoles of the mesophyll cells. This strategy allows plants to minimize or delay the toxic effects of high concentrations of ions on important and sensitive cytoplasmic processes. The rate at which leaves die is the rate at which salts accumulate to toxic levels, so genotypes that have poor control of the rate at which salt arrives in leaves, or a poor ability to sequester that salt in cell vacuoles, have a greater rate of leaf death.

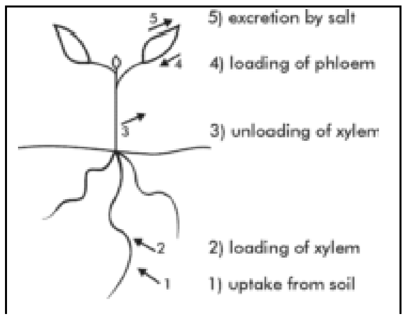

Figure 6. Control points at which salt transport is regulated. These are: 1. selectivity of uptake from the soil solution, 2. loading of the xylem, 3. removal of salt from the xylem in the upper part of the plant, 4. loading of the phloem and 5. excretion through salt glands or bladders. For a salt tolerant plant growing for some time in a soil solution of 100 mM NaCl, the root concentrations of Na^+ and Cl^- are typically about 50 mM, the xylem concentration about 5 mM, and the concentration in the oldest leaf as high as 500 mM (Munns et al., 2002).

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