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Effects of Salinity on Vegetable Growth and Nutrients Uptake

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1. Introduction

Irrigation of vegetables during both air and soil-born drought has very positive effect on growth, development and yield. The impact of irrigation on the metabolism of plants is very complex because the increase in soil moisture affects plant physical, chemical and biological properties. Increasing the amount of water in the soil increases its heath capacity. Irrigated (wet) soil is cooler in summer and warmer during the cold weather in comparison with dry soil. Irrigation increases heat conduction in soil and relative humidity of ground layers of the atmosphere. These changes reduce the temperature fluctuations of ground layers of the air and soil during the day and night. Therefore, irrigation suppresses harmful effects of the weak spring and autumn frosts. The water in the soil acts as a solvent and as an environment in which chemical reactions take place. With increasing soil moisture concentration of soil solution is diminishing and the power of water to dissolve different substances is increasing. The CO_2 dissolved in the water contributes significantly to this process by lowering the pH value of soil solution. In weak acidic solution mineral elements present in the soil become more soluble, which may alter plant nutrition. However, if there is any excess of water in the soil, than easily soluble salts of potassium, nitrogen and phosphorus from the upper layers of soil can be leached into deeper soil layers, even outside the zone of the root system, which is very undesirable. In general, irrigation increases soil pH, which should be borne in mind because optimum acidity (pH) for cultivation of most vegetables is between 6.0 and 6.5. Irrigation has a positive effect on microbial processes in the soil which in turn affects nutrient availability to plants. Moreover, irrigation stimulates aerobic processes that may be temporarily slowed down or replaced by anaerobic if the soil is too wet.

In agricultural practice it is not always possible to provide sufficient quantities of irrigation water of good quality. Often more mineralized water and processed waste waters are used (Kalavrouziotis et al., 2010). Therefore, by irrigation the soil can be enriched with useful or harmful salts and various other compounds, depending on water quality. In the irrigation water too high concentration of ions that make it saline is present very often (Table 1).

Salinity of arable land is a problem that is becoming more and more important in many areas where irrigation is a regular agro-technical measure, and in semi-arid and arid regions in the world where atmospheric precipitations are not sufficient to flush the salts from the root zone. When irrigation water is of inadequate quality, the occurrence of chlorosis between leaf veins is commonly observed, leaf tissue necrosis often develops and flowering

may not happen at all. Very great importance is ascribed to the time during which the plants were exposed to different concentrations of salts. As explained by Munns (2002), effects of salinity on salt-tolerant plants are the same as effects of water deficiency. Within minutes and hours of exposure to salinity salt-specific effects are not visible. If the exposure to salts lasts many days, salt-induced injuries become apparent on older leaves of salt-sensitive plants, in addition to reduced rate of leaf emergence and heavier impact on leaves than on roots, which are symptoms typical for water-stress. After weeks of exposure to salts older leaves of sensitive genotypes die and if exposure lasts several months younger leaves die and the whole plant may die before seed maturation. Differences between short-term/temporary effects of salinization vs. long-term effects (either single irrigation seasons or multiple years) are often overlooked (Maggio et al., 2011).

Water designation	Total dissolved salts (ppm)	EC (dSm⁻¹)	Common name	Botanical name	Threshold EC (dS m⁻¹)	Rating*
Fresh water	< 500	< 0.6				
Slightly brackish	500–1000	0.6–1.5	Bean	*Phaseolus vulgaris* L.	1.0	S
			Carrot	*Daucus carota* L.	1.0	S
			Muskmelon	*Cucumis melo* L.	1.0	MS
			Eggplant	*Solanum melongena* L.	1.1	MS
			Onion	*Allium cepa* L.	1.2	S
			Radish	*Raphanus sativus* L.	1.2	MS
			Lettuce	*Lactuca sativa* L.	1.3	MS
			Pepper	*Capsicum annuum* L.	1.5	MS
Brackish	1000–2000	1.5–3.0	Garlic	*Allium sativum* L.	1.7	MS
			Potato	*Solanum tuberosum* L.	1.7	MS
			Cabbage	*Brassica oleracea* L.	1.8	MS
			Celery	*Apium graveolens* L.	1.8	MS
			Spinach	*Spinacia oleracea* L.	2.0	MS
			Cucumber	*Cucumis sativus* L.	2.5	MS
			Tomato	*Lycopersicon esculentum* L.	2.5	MS
Moderately saline	2000-5000	3.0–8.0	Pea	*Pisum sativum* L.	3.4	MS
			Red beet	*Beta vulgaris* L.	4.0	MT
			Asparagus	*Asparagus officinalis* L.	4.1	T
Saline	5000-10000	8.0–15.0				
Highly saline	10000-35000	15.0–45.0				

Table 1. Classification of waters with respect to total salt concentration and salt tolerance of selected vegetables (after Maas 1990, Francois & Maas, 1994 & Hillel, 2000). Asterix (*) marks the level of tolerance: sensitive (S), moderately sensitive (MS), moderately tolerant (MT), tolerant (T).

Stress caused by lack of water has similarities with the stress caused by excess salt in the soil solution, although there are differences (Munns, 2002). The stress caused by the presence of salts is one of the biggest problems that accompany agricultural production (Francois & Maas, 1994). Vegetables are not immune to the increased concentration of salts and therefore their presence significantly affects their quality and yield. According to FAO (1997) saline soil is the soil whose soil solution electrical conductivity (ECE) is 4 dS m^{-1} and higher, whereas soils whose ECE exceeds 15 dS m^{-1} are considered highly saline. Cations that are most commonly associated with saline soils are Na$^+$, Ca^{2+} and Mg^{2+}, accompanied by anions Cl$^-$, SO$_4^{2-}$ and HCO$_3^-$. However, major ions are considered to be Na$^+$ and Cl$^-$ since both are toxic to plants (Dudley, 1992, Hasegawa et al., 2000). Sulfates, which are usually involved in metabolic processes of plants as an integral part of proteins and enzymes, can also disrupt the metabolism of plants. They are usually more toxic than chlorides.

Stress caused by increased concentrations of salts effect the metabolism of plants and the final outcome of crop production in many ways. Excess salt has an osmotic effect, which means that the presence of salts reduces the amount of water accessible to plants. Some ions may be toxic to some processes in plants. Increased salt concentrations can lead to disturbances in mineral nutrition of plants, the plant hormone imbalances, and to the formation of reactive compounds such as different types of oxygen and other free radicals that damage cell membranes (Marschner, 1995). Plant cells, tissues, organs, individuals and entire ecosystems can have and/or can develop mechanisms by which they protect themselves against adverse effects of elevated salt concentrations (Pitman & Läuchli, 2002).

2. Effect of excess salinity on plant growth

Response of vegetables to the presence of increased amounts of salts is primarily stunted growth (Romero-Aranda et al., 2001). The ultimate impact of excess salts is of course very dependent on the other environmental factors such as humidity, temperature, light and air pollution (Shannon et al., 1994). The accumulation of salts in the leaves cause premature aging, reduces the supply of plant parts with nutrients and products of carbon assimilation of the fastest-growing plant parts and thus impair the growth of the entire plant. In the more sensitive genotypes salts accumulate more rapidly and because cells are not able to isolate the salt ions in vacuoles to the same extent as more tolerant genotypes, the leaves of more sensitive genotypes usually die faster (Munns, 2002). Neumann (1997) suggests that growth inhibition due to excessive salt concentration in the leaves reduces the volume of new leaf tissue in which excess salts can accumulate and therefore, in combination with the continuous accumulation of salts, it can lead to an increase in salt concentration in the tissue. It is often difficult to determine the relative influence of osmotic effect and the effect of the toxicity of specific ions on vegetable yield. In any case, yield losses due to osmotic stress can be very significant even before symptoms of toxicity on leaves become noticeable. Under the influence of salt stress growth of many species of vegetables is reduced, such as tomato (Romero-Aranda et al., 2001, Maggio et al., 2004), pepper (De Pascale et al., 2003b), celery (De Pascale et al., 2003a) and peas (Maksimovic et al., 2008, Maksimovic et al ., 2010). There are significant differences in salt tolerance between plant species and genotypes and similar goes for the ability to tolerate water deficiency (Munns, 2002; Lukovic et al., 2009). Table 1 shows in parallel the classification of waters with respect to the total concentration of salts and tolerance of selected vegetable species to salts. Salinity causes anatomical changes in

leaves of many plant species. For example, the epidermis and mesophyll leaves of beans, cotton and *Attriplex* become thick, length of palisade mesophyll cells and diameter of spongy mesophyll cells increase and thickness of palisade and spongy layers and increasing as well (Longstreth & Nobel, 1979). In some other plant species were recorded adverse effects. In spinach leaves the presence of salt reduces the intercellular spaces (Delfine et al., 1998) and stomatal density in tomato (Romero-Aranda et al., 2001), but it increases stomatal density in pea (Maksimović et al., 2010) (Fig. 1).
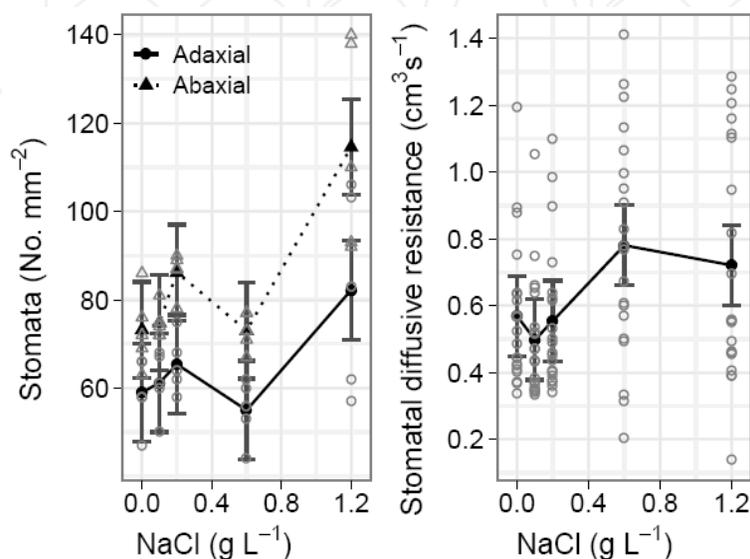

Fig. 1. Stomatal density and stomatal diffusive resistance in the presence of 0, 0.1, 0.2, 0.6, or 1.2 g NaCl L[-1] in the nutrient solution (Maksimovic et al. 2010).

3. Effect of excess salinity on the water regime of plants

The main cause of reduced plant growth in the presence of salt can be impairment of water regime. Increasing the salt concentration in the soil increases the osmotic pressure of the soil solution and plants can not uptake the water as easily as in the case of relatively non-saline soils. Therefore, as the concentration of salt i.e. soil EC increases, water becomes less accessible to plants, even if the soil contains significant amounts of water and looks wet. Osmotic pressure depends on the number of particles contained in the solution and the temperature. Osmotic pressure (OP) of extracted soil solution can be expressed by the following empirical formula: OP = 0.36 x EC (dS m^{-1}). At a pressure of about 1.44 bar, corresponding to the EC of 4 dS m^{-1}, the plants start to show signs of physiological stress caused by water shortage. Therefore, in saline soils, despite the fact that water can be physically present, it becomes inaccessible to plants and the phenomenon is known as physiological drought (Ayers & Westcot, 1994).

The first effects of soil salinity, especially when it comes to low and moderate salt concentrations, can be attributed to the increase of osmotic value of the soil solution (Munns & Termaat, 1986). With the increasing salinity of soil solution, uptake of water through the root system becomes more difficult which leads to decreased evapotranspiration and yield. There are several reasons why evapotranspiration decreases with increase in soil salinity. Due to decreased accessibility of water to the root system root growth is reduced wich leads

to a reduction in the total absorption area for water uptake. At the same time, total leaf area e.g. transpiration surface is reduced. As one of the mechanisms by which plants protect their cells from harmful effect of high concentration of salts is dilution, then increasing of water retention in the tissues of the plant further reduces transpiration. These factors reduce the efficiency of water usage and ultimately result in reduction of vegetable growth and yield. The vegetation period is shortened, water regime of plants is disrupted and the uptake and distribution of essential elements in both semi-controlled and field conditions is altered (Maksimovic et al., 2008, Maksimovic et al., 2010).

At very low soil water potential, the uptake of water and maintenance of turgor pressure in the tissues becomes very difficult. Water potential of leaves of plants well provided with water ranges from -0.2 to about -0.6 MPa, but the leaves of plants in arid regions can have significantly lower values, from -0.2 to 5 MPa even in extreme conditions (Taiz & Zeiger, 2006). Since the uptake of water is spontaneous process, the water potential of root cells must be more negative than potential of soil solution. If, due to increased salt concentration, the difference between water potential of soil solution and of root cells differs very slightly, plants may adapt osmoticaly by accumulation of so-called compatible osmolites in their cells. In that way, water potential of plant cells is kept more negative in relation to the soil solution water potential, thus permitting continuous uptake of water (Guerrier, 2006; Ghoulam et al., 2002).

Increasing the concentration of salt in a medium in which is the root leads to a reduction in the osmotic potential of leaves (Sohan et al., 1999, Romero-Aranda et al., 2001). Reduced osmotic potential of leaves is reflected in many processes in plants. Several authors have reported that water and osmotic potential of plants become more negative with increase in soil salinity, while turgor pressure concomitantly increases (Meloni et al., 2001, Romero-Aranda et al., 2001). Ashraf (2001) found that leaf water potential and evapotranspiration significantly decreased with increasing salt concentration in six species of the genus *Brassica*. At 200 mM NaCl *B. campestris* and *B. carinata* held a significantly higher water potential of leaves than other species in their experiment and therefore can be considered more tolerant to stress caused by salts. According to Sohan et al. (1999), the decrease in water potential can be explained by: 1) the influence of high concentrations of salts due to which plants accumulate more NaCl in the leaves than usual, and 2) by the reduced flow of water from root to aboveground organs due to the reduction of water conductivity, causing water stress in the tissues of leaves.

After Katerji et al. (1997), a decrease in RWC indicates loss of turgor which occurs due to disturbances in the increase in the area of individual leaves, in other words in leaf expansion. The connection between the impact of salt on gas exchange in leaves and growth is not completely understood. Many experimental results indicate that gas exchange in leaves of plants remains unchanged under the influence of soil water potential, until it reaches a certain threshold value (Ritchie, 1981). Results of Shalhevet (1994) suggest that the expansion of leaves is the most affected by osmotic stress and that there was a linear relationship between transpiration and the synthesis of organic matter in different agro-ecological conditions. The slope of this function represents the efficiency of water utilization by plants (water use efficiency, WUE). More recently, stomatal traits have been proven to critically affect WUE. In absence of stress, it has been demonstrated that low stomatal density reduces transpirational water fluxes (Zhang et al., 2001) and improves water use efficiency (Masle et al., 2005).

4. Accumulation of compatible osmolites increases vegetable tolerance to osmotic stress

One of the ways plants can adapt to conditions of osmotic stress is the accumulation of salt ions, if these salts are isolated in individual cell compartments by which their involvement in metabolism is prevented. The ability to regulate the concentration of salts through compartimentation is an important aspect of tolerance to increased salt concentrations (Romero-Aranda et al., 2001). In the presence of salts plants often accumulate low molecular weight substances which are called compatible osmolites. These substances do not interfere with normal biochemical reactions in cells (Hasegawa et al., 2000, Ashraf & Foolad, 2007). Compatible osmolites are low molecular weight molecules such as proline and glycine betaine (Ghoulam et al., 2002, Ashraf & Foolad, 2007). It is believed that under conditions of stress, proline has a role in osmotic adjustment of cells, enzymes and membrane protection and also as a source of nitrogen for a moment when conditions of stress are over (Ashraf & Foolad, 2007). The role of glycine betaine is also in maintaining pH of the cells, cell detoxification and binding of free radicals. Conditions of salt stress also lead to the accumulation of the other nitrogen compounds such as amino acids, amides, proteins and polyamines, which is often correlated with tolerance to salt (Mansour, 2000). Another group of compatible osmolytes are carbohydrates, both simple sugars (glucose, fructose, sucrose, fruktani), and starch. Their most important roles, beside in osmotic adjustment, is carbon storage and neutralization of free radicals (Parida et al., 2002). A similar role is attributed to the polyols that may accumulate under conditions of salt stress as well (Bohnert et al., 1995).

Ionic status of plants is highly correlated with tolerance to salts so that it can serve as a selection criterion in breeding to help create genotypes more tolerant to excess salt (Ashraf & Khanum, 1997).

5. Effect of excess salinity on mineral nutrition of plants

Increased salt concentration in the vicinity of the root system can interfere with mineral nutrition of plants and limit vegetable yield due to salinity or osmotic value of the soil solution. Salinity affects nutrient availability to plants in many ways. It modifies binding, retention and transformation of nutrients in the soil and affects the uptake and/or absorption of nutrients by the root system due to antagonism of ions and reduced root growth. It disrupts the metabolism of nutrients in the plant, primarily through water stress, thus reducing the efficiency of utilization of nutrients. In the presence of increasing concentrations of salts some species-specific symptoms may be present, such as necrosis and burns of leaf edges due to the accumulation of Na^+ and Cl^- ions (Wahome, 2001). The high concentration of ions can disrupt the structure and function of cell membranes. Mineral nutrition of plants depends on the activity of membrane transporters which participate in the transfer of ions from the soil into the plant and regulate their distribution within and between cells (Marschner, 1995; Tester & Davenport, 2003, Epstein & Bloom, 2005). Changes in membranes may finally lead to disturbances in chemical composition of cells and can therefore be displayed as symptoms of deficiency of some essential elements, similarly as it happens in the absence of salts (Grattan & Grieve, 1999).

High concentrations of NaCl act antagonistically to the uptake of the other nutrients, such as K^+, Ca^{2+}, N, P (Cramer et al., 1991, Grattan & Grieve, 1999). Increased concentrations of

NaCl increase concentrations of Na^+ and Cl^- and reduce concentrations of Ca^{2+}, K^+ and Mg^{2+} in many plant species (Bayuelo-Jimenez et al., 2003). In the presence of NaCl, the concentration of K^+, Ca^{2+} and P in vegetative parts decreased and in pods and grains increased (Fig. 2A). Ratios between concentrations of essential cations is changed as well (Fig. 2B). It was found that deleterious effects of salinity on tomato biomass production can be ameliorated by an enhanced supply of calcium. Similarly to the effect on the uptake of macroelements, salt stress can exert stimulatory and inhibitory influence on the uptake of some trace elements (Grattan & Grieve, 1999).

Irrigation waters sometimes contain increased concentration of boron, which can lead to reduced yields of crops (Nable et al., 1997; Kastori et al., 2008). Numerous studies have been done in order to find suitable methods for early assessment of tolerance to excess boron and finding sources of tolerance to high concentrations of this element (Nable et al., 1997, Yau & Ryan, 2008; Brdar-Jokanovic et al., 2010).

It is often considered that the use of fertilizers may aggravate problems that exist due to the presence of excessive amounts of salts in the soil. However, the lack of essential elements in accessible forms is a very common reason for poor productivity on such soils. When the saline soils are for the purpose of remediation washed with large quantities of water, some essential elements may concomitantly be washed away. Therefore, the application of fertilizers in appropriate doses is necessary to attain higher yields.

5.1 Effect of excess salinity on nitrogen, phosphorus and potassium uptake and metabolism

Under the conditions of salt stress, the uptake of nitrogen is often disrupted and numerous studies have shown that excess salts can reduce the accumulation of nitrogen in plants (Pardossi et al., 1999, Silveira et al., 2001, Wahid et al., 2004). Increase in uptake and accumulation of Cl^- is accompanied by a reduction in the concentration of NO_3^- in eggplant (Savvas & Lenz, 2000). There are authors who have attributed this reduction to the antagonism between Cl^- and NO_3^- (Bar et al., 1997) and those who explain it by reduced water uptake (Lea-Cox & Syvertsen, 1993). The rate of nitrate uptake or interactions between NO_3^- and Cl^- is associated with tolerance of examined plant species to salts. Kafkafi et al. (1992) found that tomato and melon varieties tolerant of salts have a higher flow rate of NO_3^- ions than more sensitive varieties.

Nitrogen fertilization on saline soils is often necessary because in such soils there is a lack of accessible nitrogen and also because losses of nitrogen due to leaching typical for nitrate form (Yin et al., 2007, Abdelgadir et al., 2010). In addition, rate of nitrification of ammonia is often significantly reduced due to the large direct toxic effects of Cl^- and the total amount of salt on the activity of nitrifying bacteria (Stark & Firestone, 1995).

Level of salinity does not affect necessarily the overall uptake of nitrogen by plants which may continue to accumulate nitrogen in the presence of excess salts despite a reduction in yield of dry matter. With the increase in soil salinity, total removal of nitrogen through the yield often decreases. Reduction in nitrogen fertilizer use efficiency is primarily a result of reduction of plant growth rate rather than the reduction of nitrogen uptake rate.
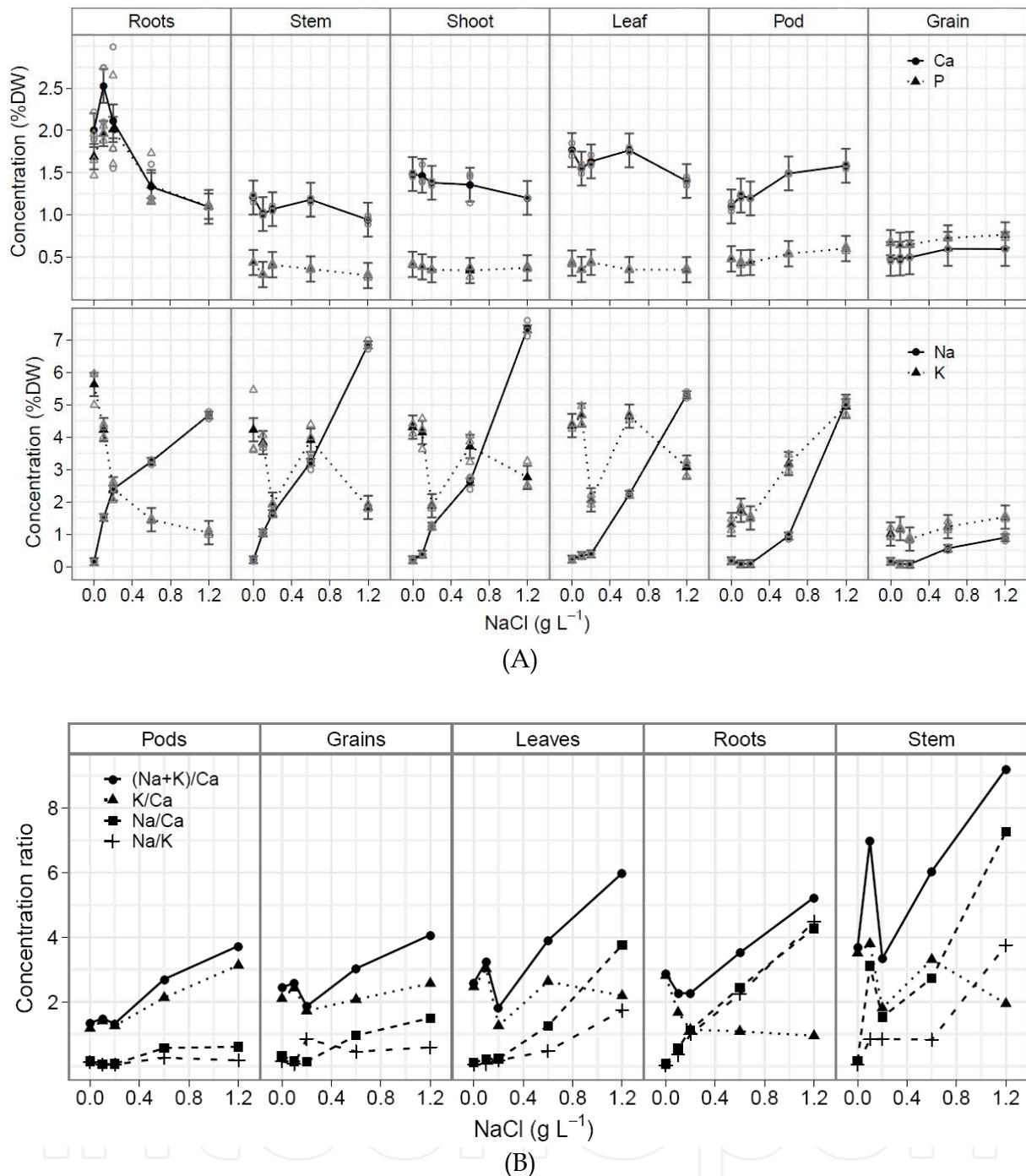
Fig. 2. Concentration of Ca^{2+}, P, Na^+ and K^+ (% in dry weight) (A) and ratios between concentrations of cations in different tissues of peas ((K^++Na^+)/Ca^{2+}, K^+/Ca^{2+}, Na^+/Ca^{2+}, and Na^+/K^+, in relative units) (B) grown in the presence of 0, 0.1, 0.2, 0.6, or 1.2 g NaCl L^{-1} in the nutrient solution (Maksimović et al., 2010).

Excess water and poor aeration that lead to anaerobic conditions can reduce the accessibility and absorption of nitrogen through the root system. In anaerobic conditions the intensity of reduction of NO_3^- to NO_2^- is higher. Woodruff et al. (1984) concluded that poor soil drainage, associated with high levels of the water table, led to a lack of nitrogen and the crop grown on such soils require more nitrogen fertilizer. Similarly, after the heavy rains

that cause water retention and the appearance of anaerobic conditions, plants are often chlorotic, which is symptom characteristic of nitrogen deficiency. Such plants require the application of high doses of fertilizers in order to neutralize the effect of water lodging.

Nitrogen fixing bacteria affect nitrogen nutrition as well. Due to the toxic effects of salts on rhizobium the metabolism of nodulating bacteria can drastically alter (Hua et al., 1982) and number and activity of root nodules may be reduced (Singleton et al., 1982). Graham & Parker (1964) found that the highest EC that can tolerate *Rhizobium* strain compatible with pea is of 4.5 dS m^{-1}. On the basis of tolerance to salt concentration, Elsiddig & Elsheikh (1998) proposed the division of strains of bacteria from the genera *Rhizobium* and *Bradyrhizobium* in four groups: sensitive strains, 0-200 mM; moderately sensitive, 200-500 mM; tolerant, 500-800 mM; and highly tolerant, more than 800 mM. Such a classification should be considered with precaution, as a great influence on the overall tolerance to salts has pH value of the soil solution, temperature and carbon source that bacteria use.

Water stress, that is the result of high osmotic pressure of the soil solution, leads to the disturbance of nitrogen metabolism in plant tissues. In the presence of excess salts the synthesis of proteins is disturbed as well. Nightingale & Farnham (1936) found that with increase in osmotic pressure the amount of soluble organic nitrogen and proteins in sweet peas decreased, while the nitrate form of nitrogen accumulated. Similar results were obtained in the works of Ben-Zioni et al. (1967) and Kahane & Poljakoff-Mayber (1968) who concluded that the lack of water through a salt stress caused may result in slowing down the metabolism of plants grown on saline soils. It is considered that the fact that the because of the impact that disruption in water supply has on the total plant nitrogen status, this indicator (the total amount of nitrogen in plants) does not accurately reflect the impact of excess salts on plants. Protein nitrogen, but not total nitrogen, is therefore the appropriate indicator of plant nitrogen status in the soils in which salinity is increased. In plants tolerant to salts synthesis of proteins is mainly undisturbed. In general, on saline soils, the effects of nitrogen application were observed at lower doses than on normal and alkaline soils. Sharma (1980) found that the yield of eggplant fruits grown on saline soils in Yemen increased from the application of 40 kg N ha^{-1}, while higher doses, up to 120 kg N ha^{-1}, did not significantly affect the increase of yield.

Besides the dose, form of nitrogen, time and method of application significantly affect the efficiency of fertilization on saline soils. Foliar application of nitrogen fertilizers (e.g. 3% solution of urea, 20 kg N ha^{-1}) along with the application to the soil is very economical and effective on saline soils. This also saves irrigation, which would otherwise be necessary to carry out in order to dissolve and distribute well the fertilizer, and it is very important wherever the quality of water is not sufficiently good. Sharma (1980) found that application over the soil (75%) followed by foliar application (25%) gives better results than the application of total amount of nitrogen fertilizers in one of the two ways. Regarding the form of nitrogen in the fertilizer, urea gives better results than CAN and $(NH_4)_2SO_4$ in the soils of low to moderate salinity. However, on the more mineralized soils, it is better to use fertilizers containing NO_3^- than NH_4^+.

In some parts of the world, for example in parts of India, California, Pakistan and Egypt, saline ground water that is used for irrigation already contain significant amounts of NO_3^-. While this may be beneficial for plants, it is not always the case because these waters are sometimes toxic to plants. Long-term irrigation with such waters stimulates the

development of vegetative tissues, ripening may be delayed and effect on seed filling may be adverse. Grains are often empty and of poor quality. In such regions, at least two irrigations have to be done with non-saline canal water, and production of forage crops is preferable to production of grain crops.

The final impact of salinity of soil solution on the concentration of phosphorus in plants depends heavily on plant species, phase of ontogenesis, the type and level of salinity and concentration of phospohorus that is already present in the soil (Grattan & Grieve, 1999). In most cases, excess of salts in soil solution leads to a reduction in phosphorus concentration in the tissues of plants, but the results of some studies show that salinity may increase but that does not affect the uptake and accumulation of phosphorus (Sonneveld & de Kreij, 1999, Kaya et al. 2001). Kochian (2000) suggests that the reduction of the availability of phosphorus in saline soils is the result of the activity of ions-antagonists, which can reduce the activity of phosphate and phosphate transporters of both high and low affinity, which are necessary for the uptake of phosphorus (Kochian, 2000). Reduced uptake of phosphorus can also be a consequence of the strong influence of sorption processes that control the concentration of phosphorus in the soil and low solubility of Ca-P minerals (Marschner, 1995).

In the saline soil phosphorus availability is to a greater extent dependent on the length and area of the root system (which is limited due to salinity) and antagonistic effects of excess phosphorus chloride on the uptake of phosphorus by the root system. Plant response to phosphorus fertilizers depends on the degree of soil salinity. In general, the use of phosphorus fertilizers in saline soils helps to increase vegetable yields directly by adding phosphorus and by reducing absorption of toxic elements such as chlorine Cl^- (Chabra et al., 1976) and fluorine F^- (Singh et al., 1995). Therefore, it is usually necessary to apply phosphorus fertilizers on saline soils.

In conditions of high salinity plants may show signs of potassium deficiency due to antagonistic effects of Na^+ and Ca^{2+} on K^+ absorption and/or abnormal Na^+/K^+ or Ca^{2+}/K^+ ratio (an example is given in Fig. 2). In such circumstances, the application of potassium fertilizers can increase the yield of plants. There is evidence that sodium in the aboveground parts of plants influences the transport of potassium from the roots to aboveground parts, or at least the concentration of potassium in leaves (Song & Fujiyama, 1998). It has been shown that increased concentrations of Na^+ block channel protein used for the uptake of K^+, AKT1, and in this way reduce the uptake of K^+. Inhibitory effect of Na^+ on transport of K^+ through channels in the membranes is probably more important in the phase of uptake of K^+ from the soil solution than in the phase of K^+ transport to the xylem (Qi & Spadling, 2004). The degree of tolerance of plants to the salinity is higher if they have a more efficient system for the selective uptake of K^+ instead of N^+ (Ashraf, 2004, Carden et al., 2003).

6. Effect of excess salinity on photosynthesis

Since plant growth directly depends on photosynthesis, stress factors that affect plant growth, affect the photosynthesis as well (Taiz & Zeiger, 2006). The effect of irrigation on production of organic matter and yield of vegetables is irreplaceable, as illustrated in Table 2. The capacity of the photosynthetic apparatus is reduced in the presence of excess salts (Ashraf, 2001, Romero-Aranda et al., 2001). However, the intensity of photosynthesis and

yield are not correlated in the same way in different plant species. In asparagus and cotton a positive correlation was found (Pettigrew & Meredith, 1994; Faville et al., 1999), while in wheat there was practically no correlation (Hawkins & Lewis, 1993). In any case, the ultimate effect of salts on photosynthesis depends on the concentration of salts and plant species. It is possible that low salinity increases photosynthesis while high salinity reduces it. Connection between photosynthesis and stomatal conductivity is not obvious because stomatal conductivity may remain unchanged both in the case of low and high salinity (Parida et al., 2004).

Biological yield (t ha^{-1})		Yield of tubers (t ha^{-1})				Harvest index (%)		Dry matter in tubers (%)			
		Young		Mature				Young		Mature	
NI	I	NI	I	NI	I	NI	I	NI	I	NI	I
29.30	40.16	13.14	17.09	21.13	28.27	42.73	46.88	17.74	19.01	22.65	20.66
Starch content (%)				NO$_3$ concentration (mg kg^{-1})				NO$_2$ concentration (mg kg^{-1})			
Young		Mature		Young		Mature		Young		Mature	
NI	I	NI	I	NI	I	NI	I	NI	I	NI	I
15.10	15.09	19.41	19.35	338.2	281.2	213.7	235.8	0.81	0.78	0.65	0.67

Table 2. Effect of irrigation in the three year trial with potato. Sprinkling irrigation was employed at the technical minimum of 70% FWC and irrigation norm of 40 mm. Mean values are given for 11 fertilization treatments: unfertilized, manure, manure+NPK(80:80:80), manure+NPK(120:80:80), NPK(80:80:80), NPK(120:80:80), NPK(160:80:80), NPK(200:80:80), NPK(120:80:120), NPK(120:80:160), and NPK(120:80:200). Young and Mature stand for young and physiologically mature tubers, NI stands for not irrigated and I for irrigated potato. Adapted from Ilin (1993).

According to Iyengar & Reddy (1996) reduction of the intensity of photosynthesis in the presence of salts may be a result of dehydration of cell membranes which reduces their permeability to CO_2. Osmotic stress, caused by reduction of water potential, ultimately inactivates photosynthetic electron transport by reducing intercellular spaces. Salt toxicity is primarily caused by the Na^+ and Cl^- ions themselves. Ion Cl^- inhibits photosynthesis by inhibiting the uptake of NO_3^- form of nitrogen by the root system (Fisarakis et al., 2001). Reduced uptake of nitrate in combination with osmotic stress may explain the inhibitory effect of excess salts on photosynthesis. The presence of salt leads to the closure of stomata (Fig. 1). Reduced stomatal conductance results in a decrease in uptake of CO_2 that can be used in carboxylation reactions (Brugnoli & Bjorkman, 1992). Closure of stomata in the presence of increasing concentrations of salts is a way for plants to reduce water losses in the process of transpiration. This, however, affects the antenna system of chloroplasts, the biochemical reactions that take place in them and the entire system of energy transformation in chloroplasts (Iyengar & Reddy, 1996). Higher stomatal conductance in plants increases the diffusion of CO_2 in the leaves and thus increases the intensity of photosynthesis. However, the results which for net assimilation rate and stomatal conductance reported Ashraf (2001) for six different *Brassica* species have shown that between these two phenomena there is no connection. There are also experimental data on inhibition of photosynthesis in the presence of excess salts that are not accompanied by changes in the

functioning of stomata. Iyengar & Reddy (1996) found that the cause of the non-stomatal inhibition of photosynthesis is actually increased resistance to diffusion of CO_2 through the liquid phase of mesophyll cell walls to the point of reduction of CO_2 in the chloroplast, and reduced efficiency of the enzyme RuBPC/O. In addition to these reasons, reduction of the intensity of photosynthesis in the presence of excess salts may be explained by the rapid aging of leaves, and changes in activities and actions of other enzymes, beside RuBPC/O, that are involved in photosynthesis, which leads to changes in the structure of the entire cell cytoplasm of photosynthetic tissues. At the same time, slower transport of the products of photosynthesis from the source to the sink also leads to a slowing down of photosynthesis (Iyengar & Reddy, 1996). Although salt stress reduces the intensity of photosynthesis, the results of several studies show that this is not a cause of reduced expansion rate of leaf cells. According to Alarcon et al. (1994) growth of the leaf is reduced more rapidly than photosynthesis at lower concentration of sodium. This means that in plants may happen a certain loss of intensity of photosynthesis without any effects on the cell growth itself.

In the presence of large amounts of salts in the soil, in plants occur many changes that lead to increased tolerance to salts and preservation of photosynthetic activity. Such changes are necessary for plants to maintain a balance between photosynthesis and growth. These mechanisms are not fully understood and may be somewhat specific to the species/genotype. Some plants can adapt to higher salinity by biochemical changes in the photosynthetic pathway. For example, facultative halophyte *Mesembryanthemum crystallinum* instead of the usual C3 uses CAM pathway (Cushman et al., 2008), while another species is tolerant of salts due to property that photosynthetic path runs along the C4 instead of C3 biochemical pathway (Zhu & Meinzer, 1999). Understanding the mechanisms by which salinity affects photosynthesis would help to improve conditions for growing vegetables and increase their yield, and would provide a useful tool for future genetic engineering.

7. Effect of excess salinity on amino acid composition, hormonal balance, antioxidant system and quality of vegetables

Changes in electrical conductivity of water, the sodium adsorption ratio (SAR) and the concentration of boron in water can affect the amino acid composition of plants. Totawat & Saxena (1974) in the greenhouse experiment found that with increasing SAR and/or boron, regardless of the electrical conductivity of water, significantly decrease the synthesis of amino acids for the species *Vigna catjang*. Synthesis of arginine, histidine, aspartate, glutamine, methionine and phenylalanine decreased, and the synthesis of lysine and valine increased. In addition to the synthesis of amino acids, which was reduced two to three times, in this experiment excess salts reduced the total amount of nitrogen in plants. Both phenomena can be explained by inhibition of the synthesis of RNA and DNA.

Salts affect the level of hormones in plants. The responses of tomato to salt stress conditions are largely determined by the concentration of endogenous ABA (Chen et al. 2003; Mulholland et al. 2003). However ABA is only one component of composite hormonal control (Ross & O'Neill, 2001; Nemhauser et al., 2006). It was found that the concentration of ABA and cytokinins increase with increasing in salt concentration (Aldeuquy & Ibrahim, 2001, Vaidyanathan et al., 1999). Abscisic acid may modify the expression of genes affected by salts, and these genes likely play a significant role in the mechanisms of tobacco tolerance

to excess salts (Boussiba & Richmond, 1976). Itai et al. (1968) have noted a significant reduction in the concentration of cytokinins in the exudates of plants exposed to elevated concentrations of salt. In tissues exposed to stress, the incorporation of L-leucine into proteins decreased. Also, kinetin pretreatment can partially neutralize the effect of salts on leucine incorporation into proteins, suggesting that in tissues exposed to salt stress concentrations of endogenous cytokinins, essential for normal metabolism of above-ground plant parts, are lower. Treatment by cytokinins can lighten the effect of stress caused by insufficient nitrogen supply (Stoparić & Maksimović, 2008). Inhibitory effect of NaCl on photosynthesis, growth and transport of the products of photosynthesis may be reduced under the influence of ABA. In tomato, different levels of endogenous GA3 and ABA on water fluxes may reduce or enhance plant salt tolerance (Maggio et al., 2010). Although the nature of the ABA receptor is unknown, there is evidence that ABA is involved in reversible protein phosphorylation and modification of pH and concentration of Ca^{2+} in the cytosol (Leung & Giraudat, 1998). Increase in the concentration of ABA results in the uptake and increased concentration of Ca^{2+} which contributes to preservation of membrane integrity during longer periods of time and allows the plant to regulate uptake and transport of ions. Genotypes that are tolerant of salt in the presence of salts also accumulate jasmonates (Pedranzani et al., 2003) which mainly affect the transmission of signals. Similar to other types of stresses, salt stress leads to the formation of free radicals which activate antioxidant system of plants. The ability to survive under conditions of salt stress is largely dependent on the efficiency of this antioxidant system (Spychalla & Desborough, 1990, Gossett et al. 1994a,b). A mild salt stress may also improve both lypophilic and hydrophilic antioxidant activities. Exposure to moderate salinity (4.4 dS m^{-1}) can increase up to 40% the concentration of carotenoids in tomato fruits (De Pascale et al., 2001). After Garratt et al. (2002), the most important antioxidant enzymes are catalase (CAT), glutathione reductase (GR), superoxide dismutase (SOD) and glutathione S-transferase (GST). The mechanism through which excess salts affect antioxidant response of plants is not completely understood. Meneguzzo et al. (1999) found that it the most likely occurs over the toxic effects of Cl$^-$ on photosystem II or through changes that occur in the membranes under the influence of higher Na^+/Ca^{2+} ratio.

8. Irrigation with treated municipal wastewaters in vegetable production

Treated municipal wastewaters, in addition to being a source of water, are a source of nutrients for plants (Jimenez-Cisneros, 1995) and heavy metals (Alloway, 1995). The use of such water often enriches the soil with heavy metals and thereby stimulates their accumulation in the soil-plant system (Kalavrouziotis & Arslan-Alaton, 2008). In principle, there is a positive correlation between the concentration of metals in the soil and in plant tissues (Kabata-Pendias & Pendias, 1995). The concentration of metals in plants is affected by many factors and one of the most important is the genetic basis of plants, i.e. genotype (Woolhouse, 1983). Heavy metals can affect the anatomy and uptake and distribution of essential elements in plants (Maksimovic et al., 2007). The impact of treated wastewaters on growth, yield and metabolism of vegetables intensively studied Kalavrouziotis. Particular attention is devoted to the study of accumulation of essential elements and heavy metals in soil and in plant tissues. This question is important because it is directly related to food safety and health of consumers. Also, the results of his research should also be used to determine limits for the concentration of certain elements in treated municipal wastewaters.

It was found that irrigation of broccoli and brussel sprouts with treated municipal wastewater contributed differently to nutrition of different plant parts (roots, stems and sprouts) and that interaction of elements is quite complicated. However, the authors finally concluded that these differences between the control (deionized water irrigated plants) and plants irrigated with treated wastewater were not statistically significant and that such waters can be used for irrigation of vegetables which is very important because of the limited availability of high quality fresh water for irrigation and the importance of irrigation for vegetable production. A particular risk is the presence of heavy metals such as Co, Ni and Pb in these waters. Irrigation of broccoli with treated wastewater increased synergism between Ca and Fe, K, P and Fe and Ni in the roots and because of that plants accumulated large amounts of Fe, P and Ni (Kalavrouziotis et al., 2009). At the same time, in the roots, leaves and flowers an interaction between Ni and Zn and P and Zn were found, in roots and leaves between Ca and Ni, K and B and P and K, and in the bud and blossom between Fe and Ni, Mn and B, and Fe and Ca. In general, in the roots of broccoli higher concentration of nutrients in relation to the leaves and flowers have accumulated, and especially higher concentration of Fe (1200 mg g^{-1}) was found, which indicates that this vegetable species is accumulator of Fe. The lowest accumulation of nutrients under the influence of treated municipal waste water was found in the blossom, the plant part used in diet.

9. Conclusion

Irrigation is often conducted by using to certain extent mineralized water and treated municipal waste waters. In this way, various beneficial or harmful salts and various other compounds can enter into the soil. The final outcome of the influence of impurities in the water for irrigation on the metabolism of vegetables depends on the nature of the substance, the time of exposure and the ability of plants to adapt. This ability is genetically determined but also depends on the combination of agro-ecological conditions in which the plant develops.

The stress provoked by excess salts in the soil solution has similarities with the stress caused by lack of water, although there are differences. Excess salt has an osmotic effect, which means that the amount of water accessible for plants is reduced. Yield losses due to osmotic stress can be very significant before toxicity symptoms on plants become apparent. Increased salt concentrations can lead to a reduction in evapotranspiration, disturbances in mineral nutrition of plants, the plant hormone imbalances, and to the formation of free radicals that damage cell membranes. Expansion of leaves may be impaired and their anatomical properties altered. The high concentration of salts in the soil solution may reduce the removal of nitrogen, phosphorus and potassium so it is necessary to add these elements in the form of fertilizers.

Understanding the mechanisms by which salinity affects photosynthesis and other physiological processes would help to improve conditions for growing vegetables and increase their yield and quality, and would provide a useful tool for future genetic engineering.

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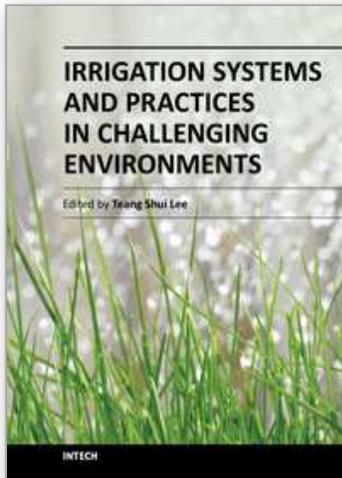
Irrigation Systems and Practices in Challenging Environments
Edited by Dr. Teang Shui Lee

The book Irrigation Systems and Practices in Challenging Environments is divided into two interesting sections, with the first section titled Agricultural Water Productivity in Stressed Environments, which consists of nine chapters technically crafted by experts in their own right in their fields of expertise. Topics range from effects of irrigation on the physiology of plants, deficit irrigation practices and the genetic manipulation, to creating drought tolerant variety and a host of interesting topics to cater for the those interested in the plant water soil atmosphere relationships and agronomic practices relevant in many challenging environments, more so with the onslaught of global warming, climate change and the accompanying agro-meteorological impacts. The second section, with eight chapters, deals with systems of irrigation practices around the world, covering different climate zones apart from showing casing practices for sustainable irrigation practices and more efficient ways of conveying irrigation waters - the life blood of agriculture, undoubtedly the most important sector in the world.

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