Hortimed

Deliverable n. 3

Salt response of protected horticultural crops

MARCH 2001

Table of contents

Introduction

A study was conducted on the response of horticultural crops to salinity with particular emphasis on crop yield and produce quality under saline conditions. In particular, the work aimed to distillate from the existing literature i) how the response to salinity in selected protected horticultural crops is influenced by genotype (variety and cultivar), crop stage, type of ions (e.g. Na, Cl, SO4, and macronutrient), growing system (soil, substrate, water culture, etc.), crop transpiration (ET) and irrigation regime; ii) the factors responsible for yield reduction in saline environment (e.g. reduced fruit growth and/or fruitset, shorter growing cycle due to enhanced plant senescence, higher incidence of fruit and/or leaf disorders, etc.); iii) strategies and methods to counteract or reduce the negative effects of saline water on crop performance (ET reduction, improvement of mineral nutrition, use of growth regulators, CO_2 enrichment); iv) what species are positively influenced by moderate salinity (salinity as resource, not as a constraint) and/or could be used in a cascade cropping system (salt-tolerant crop grown with salt-enriched nutrient solution flushing out from culture with sensitive crop; see task 3.3.).

The work was bibliographic in nature, but it *did not intend* to produce a paper, as so many excellent reviews have been published in scientific journals or as book chapter, recently too (e.g. Sonneveld, 1999 - *Effect of salinity on substrate grown vegetables and ornamentals in greenhouse horticulture).* Rather, an effort was done to produce a sort of salt-response data sheet (folio) that could be used in DSS1-2.

The study concerned the six horticultural crops that were selected at the meeting in Cairo on the basis of their economic importance in the Mediterranean Regions.

Information were collected by electronic searching in CAB ABSTRACT (1973-present), BIOLOGICAL ABSTRACT (1995-present) and CURRENT CONTENTS (1996-present) databases. Some data were also derived from the experiments conducted during the first year by several partners University of Pisa and from publications provided by other AUA and IMAG.

Modelling plant response to salinity

Current literature reports two mathematical models: linear or Mass/Hoffman's model and non-linear or Van Genuchten/Hoffman's model.

The first model has been developed to predict the effect of salt stress on crop (figure 1). The model has the following form:

Y = 100 – B(EC-A),

where Y is the relative yield, A is the threshold, that is the maximum salinity (saturated-paste soil extract, or irrigation water) without yield reduction, and B the slope B, that is the percentage yield decrease per unit increase in salinity above the threshold.

Salinity response of some horticultural crops (Maas and Hoffman, 1977; ; Barbieri and De Pascale, 1992; Botrini et al., 1996). Values of EC of the saturated soil extract.

Crop	*Threshold (mS/cm)*	*Slope (% per mS/cm)*
Artichoke	4.8	10.9
Asparagus	4.1	2.0
Bean	1.9	19.0
Celer	1.8	6.2
Cucumber	2.5	13.0
Eggplant	1.1	6.9
Lettuce	1.3	13.0
Melon	1.0	8.4
Radish	1.2	13.0
Spinach	2.0	7.6
Tomato	2.5	9.9
Zucchini squash	5.1	11.6
Carnation	2.5	3.9
Chrysanthemum	0.9	8.7
Rose	1.2	10.9

The model developed by Van Genuchten and Hoffman (1983) is the following (Figure 2):

Van Genuchten/Hoffman's model

$Y = 100 / [1+ (EC/EC_{50})^{P}]$

where EC_{50} is the value of EC which reduce yield to 50% of maximum yield and p is an empirical constant (generally p = 3).

The model provides a convenient analysis of experimental data by coupling a salt tolerance model with least squares optimization procedure.

The models are relatively simple and useful to interpret experimental data, but do not seem suitable for commercial application. The fundamental parameters of the models, i.e. the salinity threshold value (the maximum salinity without any significant reduction in growth or yield) and the salinity yield decrease (the percentage yield decrease per unit increase in salinity above the threshold) are influenced by many cultural and environmental factor, as also demonstrated by some results of the experiments conducted by some Hortimed partners.

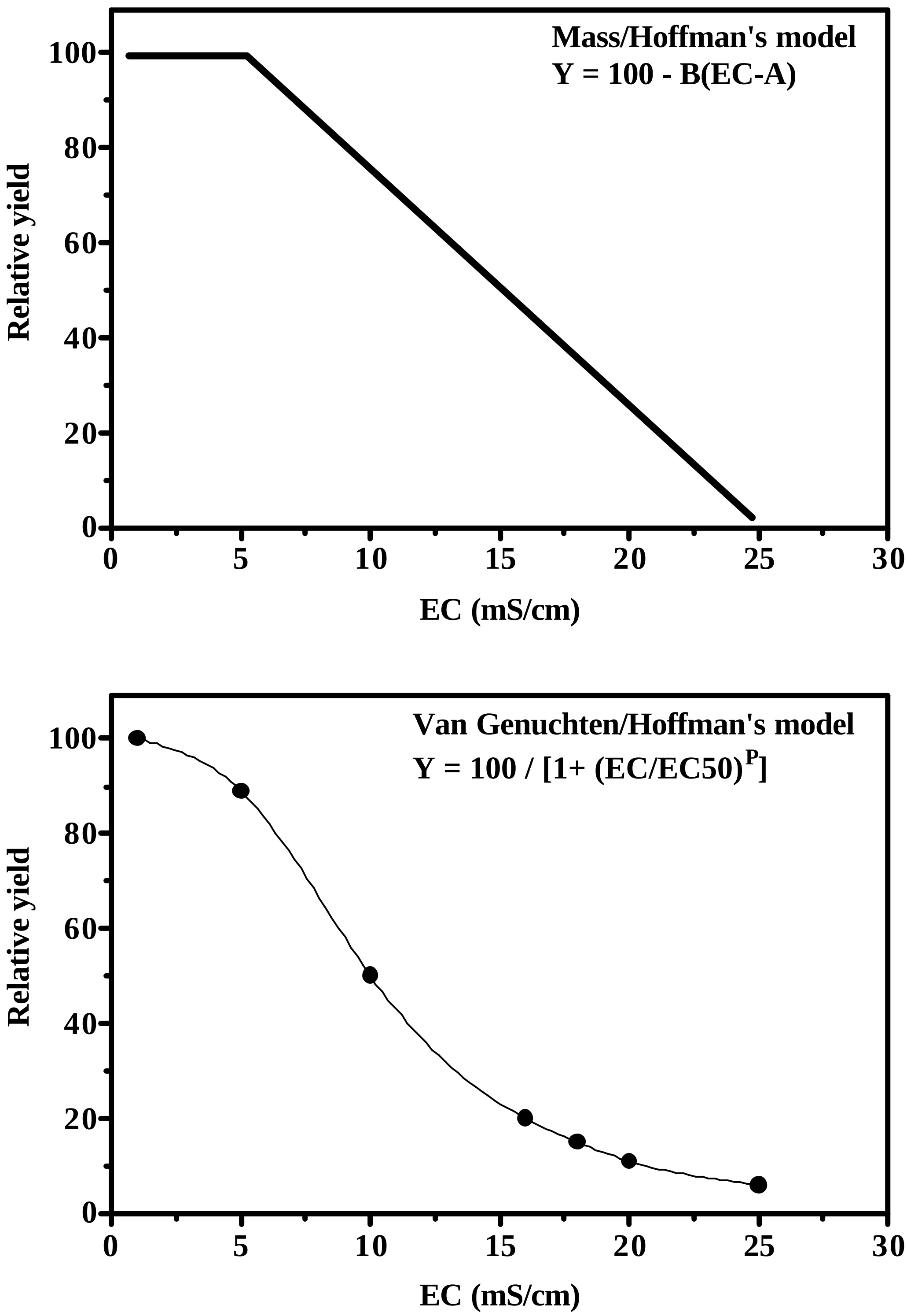

Figure 1. The linear and non-linear model for crop response to salinity.

Moreover, the influence of salinity on produce quality and the incidence of specific physiological disorders that are responsible, at least in part, for yield reduction (e.g. blossom-end rot in tomato), is difficult to be described by simple mathematical models. Even if it is assumed that the relationship between quality parameters (dry matter or sugar content, texture, acidity, colour) can be described by some (simple) equation, there is the problem to evaluate the overall effect. In most vegetables, market quality does not depend only on one or two measurable quantities, but on an array of parameters that recently began to be assessed following the sophisticated and expensive approach of "panel test" derived from the food industry. Moreover, the quality has to certified and recognised by the consumers, if higher price is expected. Of course, the problem is not easier to resolve in flower crops.

Therefore, it has been proposed to develop a descriptive model to be used in an expert system (IF/THEN type) for supporting growers in strategical, tactical and operational decision. In DSS a sub-routine will be included to estimate the yield response to root zone salinity on the basis of the two parameters of Mass/Hoffmann's model that will be distilled from existing literature and new experimental data provided by different Hortimed partners.

The folios developed for cucumber, melon, pepper, rose, strawberry and tomato have been reported in the annex 1, together with some tables reporting useful data concerning saline water and micronutrient toxicity.

Conclusions

Modelling crop response to salinity is a difficult task, since many factors related to climate, growing techniques and plant genotype as well affect how yield and product quality are affected by salt stress. Nevertheless, some mathematical models on salinity response of crop species have been developed and they can be used in DSS as a tool to predict the gross effect of increasing salinity in the root zone of a given crop; DSS will allow the user to update the fundamental parameters of the model, also on the basis of on-farm experience. On the other hand, descriptive folios may help growers in developing cultural techniques that may reduce the deleterious effect of salinity and exploit its positive influence on produce quality.

ANNEX 1: Descriptive folios for the selected crops

Species: CUCUMBER (*Cucumis sativus* L., Cucurbitaceae)

RESPONSE		
Yield response		
Maas/Hoffman's equation	SSE* EC (mS/cm)	
Threshold	2.5	
Slope	13.0	
Zero-yield EC**	10.2	
50%-yield EC**	6.3	4.3
Causes of yield reduction		
Fewer fruits	Yes	
Smaller fruits	Yes	
Worse fruits	Yes	
Degree of tolerance	Moderately sensitive	
Most sensitive stage	Seedling	
Most tolerant stage	Fruit ripening	
B-tolerance	Moderate to sensitive	
Physiological response		
Prevailing effect	Osmotic, nutritional	
Early senescence	Yes	
Disorders	Leaf necrosis, fruit pillowness	
Beneficial effects	Reduced vegetative growth; higher fruit content of dry matter and sugar, better taste of fruit.	
REMEDIES		
Genotype selection	Yes	
Cultural techniques		
Osmotic effect	Drip irrigation; use of organic matter;	
Ionic effect	Grafting on resistant rootstocks of *Benincasa hyspida (until 100 mM of NaCl in nutrient solution), Lagenaria siceraria and Cucurbita spp..*	
Nutritional effect	+ N-NO_3^-; + K,+ Ca, + Mg.	
ROLE IN DWRCS***	Donor crop; in NFT system it can tollerate until 60mM NaCl	
LITERATURE	>100 papers; quite recent literature (>1990, about 50 papers); most works were conducted in Mediterranean countries (E, IL, G, SP), in Japan, UK and NL with plants grown in greenhouse.	

* Soil saturated extract. ** Figures calculated on the basis of threshold and slope. *** Drainage water reuse cropping system.

Species: MELON (*Cucumis melo*, Cucurbitaceae**)**

RESPONSE	
Yield response	
Maas's equation	SSE* EC (mS/cm)
Threshold	2.2
Slope	7.3
Zero-yield EC**	15.9
50%-yield EC**	9.0
Causes of yield reduction	
Fewer fruits	Yes
Smaller fruits	Yes
Worse fruits	Yes
Degree of tolerance	Moderately sensitive
Most sensitive stage	Seedling
Most tolerant stage	Fruit ripening
B-tolerance	Moderate
Physiological response	
Prevailing effect	Osmotic, nutritional
Early senescence	Yes
Disorders	Fruit vitrescence
Beneficial effects	Hardening, increased fruit sugar content
REMEDIES	
Genotype selection	Yes
Cultural techniques	
Osmotic effect	Drip or subsurface irrigation
Ionic effect	Grafting on resistant rootstocks of *Cucumis melo* or *Cucubita spp.*
Nutritional effect	+ $N\text{-}NO_3^-$; + $N\text{-}NH_4^+$; + Ca
ROLE IN DWRCS* **	Donor and/or user crop
LITERATURE	>100 papers; recent literature (>1990); most works were conducted in Mediterranean countries (E, IL) with plants grown in greenhouse and in open field.

* Soil saturated extract. ** Figures calculated on the basis of threshold and slope. *** Drainage water reuse cropping system.

Species: PEPPER (*Capsicum annum*, Solanaceae**)**

RESPONSE	
Yield response	
Maas's equation	SSE* EC (mS/cm)
Threshold	1.5
Slope	14
Zero-yield EC**	8.6
50%-yield EC**	5.1
Causes of yield reduction	
Fewer fruits	Yes
Smaller fruits	Yes
Worse fruits	Yes
Degree of tolerance	Moderately sensitive
Most sensitive stage	Seedling
Most tolerant stage	Fruit ripening
B-tolerance	Moderate sensitive
Physiological response	
Prevailing effect	Osmotic, nutritional
Early senescence	Yes
Disorders	Blossom-end rot (BER)
Beneficial effects	Decrease of skin cracking; increase fruit quality
REMEDIES	
Genotype selection	Yes
Cultural techniques	
Osmotic effect	Drip irrigation
Ionic effect	
Nutritional effect	+ K; + Ca
ROLE IN DWRCS* **	Donor crop
LITERATURE	>100 papers; recent literature (>1990); most works were conducted in Mediterranean countries and NL with plants grown in greenhouse and in open field.

* Soil saturated extract. ** Figures calculated on the basis of threshold and slope. *** Drainage water reuse cropping system.

Species: ROSE (*Rosa* spp., Rosaceae**)**

RESPONSE	
Yield response (total floral weight)	
Maas's equation	SSE* EC (mS/cm)
Threshold	1.5
Slope	9.7
Zero-yield EC**	11.8
50%-yield EC**	6.6
Causes of yield reduction	
Fewer flowers	Yes
Smaller flowers	Yes, reduced stem length
Worse flowers	Yes
Degree of tolerance	Sensitive
Most sensitive stage	
Most tolerant stage	
B-tolerance	
Physiological response	
Prevailing effect	Osmotic, nutritional
Early senescence	Vase life reduction
Disorders	Leaf necrosis, Fe and/or Cu deficiency
Beneficial effects	
REMEDIES	
Genotype selection	Yes
Cultural techniques	
Osmotic effect	Reducing fertilization input, use of good fertilizers (low impurity content)
Ionic effect	Drip or subsurface irrigation
Nutritional effect	Grafting on resistant rootstocks of *R. rubiginosa, R. damascena, R. canina*
ROLE IN DWRCS* **	Donor crop
LITERATURE	>50 papers;

* Soil saturated extract. ** Figures calculated on the basis of threshold and slope. *** Drainage water reuse cropping system.

Species: STRAWBERRY (*Fragaria x ananassa* Duch, Rosaceae)

RESPONSE	
Yield response	
Maas's equation	SSE* EC (mS/cm)
Threshold	1.0
Slope	33.0
Zero-yield EC**	4.0
50%-yield EC**	2.5
Causes of yield reduction	
Fewer fruits	Yes, reduction of inflorencescences
Smaller fruits	Yes
Worse fruits	
Degree of tolerance	Very sensitive
Most sensitive stage	Young plants
Most tolerant stage	Fruit ripening
B-tolerance	Sensitive
Physiological response	
Prevailing effect	Chlorine tossicity; osmotic, nutritional
Early senescence	Yes
Disorders	Leaf scorch and abscission
Beneficial effects	Better flavour and taste and higher sugar content of fruits
REMEDIES	
Genotype selection	Yes
Cultural techniques	
Osmotic effect	Drip or subsurface irrigation
Ionic effect	
Nutritional effect	Si addition to nutrient solution; no KCl + N-NO_3^-; + N-NH_4^+; + Ca
ROLE IN DWRCS* **	Donor crops
LITERATURE	About 50 papers quite recent; most works were conducted in North Europ countries (UK, NL), USA and URSS with plants grown in greenhouse.

* Soil saturated extract. ** Figures calculated on the basis of threshold and slope. *** Drainage water reuse cropping system.

Species: TOMATO (*Lycopersicon esculentum*, Solanaceae**)**

RESPONSE	
Yield response	
Maas's equation	SSE* EC (mS/cm)
Threshold	2.5
Slope	9.9
Zero-yield EC**	12.6
50%-yield EC**	7.5
Causes of yield reduction	
Fewer fruits	Yes
Smaller fruits	Yes
Worse fruits	Yes
Degree of tolerance	Moderately tolerant
Most sensitive stage	Seedling
Most tolerant stage	Mature fruit
B-tolerance	Tolerant
Physiological response	
Prevailing effect	Osmotic, nutritional
Early senescence	Yes
Disorders	Blossom-end rot (BER)
Beneficial effects	Better quality of fruit (higher sugar content, acidity nd shelf-life)
REMEDIES	
Genotype selection	yes
Cultural techniques	
Osmotic effect	Drip irrigation; measures to reduce transpiration
Ionic effect	Reduced transpiration may reduce the incidence of BER
	4 – 6 trusses are raccomended (upper infiorescences are particularly sensitive to salt)
	+ Ca; + K; + P
Nutritional effect	
ROLE IN DWRCS*	Donor and/or user crop
LITERATURE	>300 papers; recent literature (>1990); most works were conducted in Mediterranean countries and NL with plants grown in greenhouse and in open field.

* Soil saturated extract. ** Figures calculated on the basis of threshold and slope. *** Drainage water reuse cropping system.

ANNEX 2: TABLES

Micronutrient toxicity in plants (Marschner, 1995).

Element	*Critical concentration (mg/kg, dry weight basis)*
Iron	> 500
Manganese	> 500
Copper	> 20-30
Zinc	> 300
Nickel	> 10-50
Molybdenum	> 10-50
Boron	> 100-150
Chlorine	> 10-40

Note: critical concentration varies with species

Boron toxicity in vegetables: maximun soil concentration without yield reduction (Barbieri, 1992)

Crop	*Threshold (g/m^3)*
Very sensitive	
Onion	0.50 - 0.75
Garlic	0.75 - 1.0
Strawberry	0.75 - 1.0
Bean	0.75 - 1.0
Sensitive	
Pepper	1.0 - 2.0
Pea	1.0 - 2.0
Carrot	1.0 - 2.0
Potato	1.0 - 2.0
Cucumber	1.0 - 2.0
Moderately tolerant	
Lattuce	2.0 - 4.0
Celery	2.0 - 4.0
Artichoke	2.0-4.0
Melon	2.0 - 4.0
Tolerant	
tomato	4.0 - 6.0
Very tolerant	
Asparagus	10.0 - 15.0

Micronutrient toxicity for tomato and lettuce greenhouse crops (Bould et al., 1983)

Crop	*Element*	*mg/kg (dry weight)*
Tomato	Fe	> 300
	Mn	> 1000
	Cu	> 30
	Zn	> 350
	Mo	> 10
	B	> 150
Lettuce	Mn	> 300
	Cu	> 25
	Zn	> 500
	B	> 80

Water Quality Guidelines for crops (Styer and Koranski, 1997)

Element	*mg/l*
Iron (Fe)	< 5
Manganese (Mn)	< 2
Copper (Cu)	< 0,2
Zinc (Zn)	< 5
Nickel (Ni)	< 0,2
Molybdenum (Mo)	< 0,02
Boron (B)	< 0,5
Chlorine (Cl)	< 80

Quality of irrigation water (Tesi, 1987)

Water quality	*E C (mS/cm)*	*Salt concentration (mg/l)*	*Sodium (% total)*	*Boron (ppm)*
Very good	< 250	<175	< 20	< 0.33
Good	250-750	175- 525	20- 40	0.33- 0.67
Mediocre	750-2000	525- 1400	40- 60	0.67- 1.25
Inadequate	> 2000	> 1400	> 60	> 1.25

References

1. Barbieri G., De Pascale S. (1992). Salinità dell'acqua di irrigazione e colture ortofloricole". Colture Protette 2.
2. Botrini L., Lipucci Di Paola M., Temperini O., Giustiniani L., Graifenberg A. (1996). Stress salino: risposta di specie orticole e suggerimenti di tecnica colturale. L'Informatore Agrario 22, 41-46.
3. Bould C., Hewitt E.J., Needham P. (1983). Diagnosis of mineral disorders in plants. Volume 1-3. Her Majesty's Stationary Office, London.
4. Maas E.V., Hoffman G.J. (1977). Crop salt tolerance: current assessment. Journal of Irrigation and Drainage Division 103, 115-134.
5. Marschner H. (1995). Mineral Nutrition of Higher Plants. Academic Press.
6. Styer R.C., Koranski D.S. (1997). Plug and transplant production: A growers's guide. Ball Publishing, new York.
7. Tesi R. (1987). Principi di Orticoltura. EdAgricole, Bologna.
8. Van Genuchten M.T., Hoffman G.J. (1984). Analysis of crop salt tolerance data. In Shalhevet Ed. Soild Salinity under Irrigation – Processes and Management, Springer-Verlag, Berlin, 258-271.