



Deliverable n. 9

**Cascade cropping systems as a tool for
increasing water use efficiency in protected horticulture**



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INTRODUCTION

In the last years, the spread of soilless culture techniques has been increasing in the Mediterranean countries with the main purpose of saving labour and avoiding soil-borne diseases. It is well established that for reducing environmental impact and for saving water and fertilisers, the closed-loop system should be adopted. Indeed, in some countries, such as The Netherlands and France, the law has imposed at the growers to recycle the drainage solution (van OS 1998).

In closed-loop hydroponics the control of crop mineral nutrition generally relies on the recirculation of a feeding solution with relatively high nutrient concentration, that is maintained by injecting stock-solutions on the basis of the readings of electrical conductivity (EC). This procedure is efficient only when it is available an irrigation water with low concentration of ions that are not or scarcely absorbed by the crop, such as Na and Cl.

On the contrary, when a saline water is used, as it occurs frequently in the Mediterranean countries, there is a build-up of salts and this makes it necessary to replace more or less frequently the solution with consequent waste of water and fertilisers. Generally, the nutrient solution is completely or partially replaced when the values of EC and/or the concentration of ions such as Na or Cl exceed a given threshold, which is dependent on crop tolerance to salinity.

The amount of nutrient solution run-off is related to the crop transpiration and to the water quality; in particular, the use of rain water or reverse-osmosis purified water can reduce hardly the need of leaching. Nevertheless, in Mediterranean areas rainfall is quite scarce and reverse osmosis treatment is not economically sustainable due to the small dimensions of farms.

Drainage solution not only contains non-essential ions, but also nutrients that may be exploited by other crops. Indeed, the practice to feed soil cultures with drainage water is quite common. This paper illustrates the possible application of cascade cropping system, performed with crops of different salt tolerance grown in semi-closed hydroponic systems, in order to reduce the environmental pollution related to the production of drainage exhausted nutrient solution.

CROP SALT TOLERANCE

Maas and Hoffmann introduced in the 1977 a general linear model to describe the general salt tolerance of a crop in terms of reduction of relative yield (Y) versus the EC of Soil Saturated Extract (SSE):

$$Y = 100 - s (EC_{SSE} - EC_{SSE-TR}),$$

therefore salt tolerance can be adequately measured on the basis of only two parameter: a) the threshold (EC_{TR}), that is the maximum salinity without yield reduction and b) the slope (s), that is the percentage yield decrease per unit increase in salinity above the threshold (fig 1).

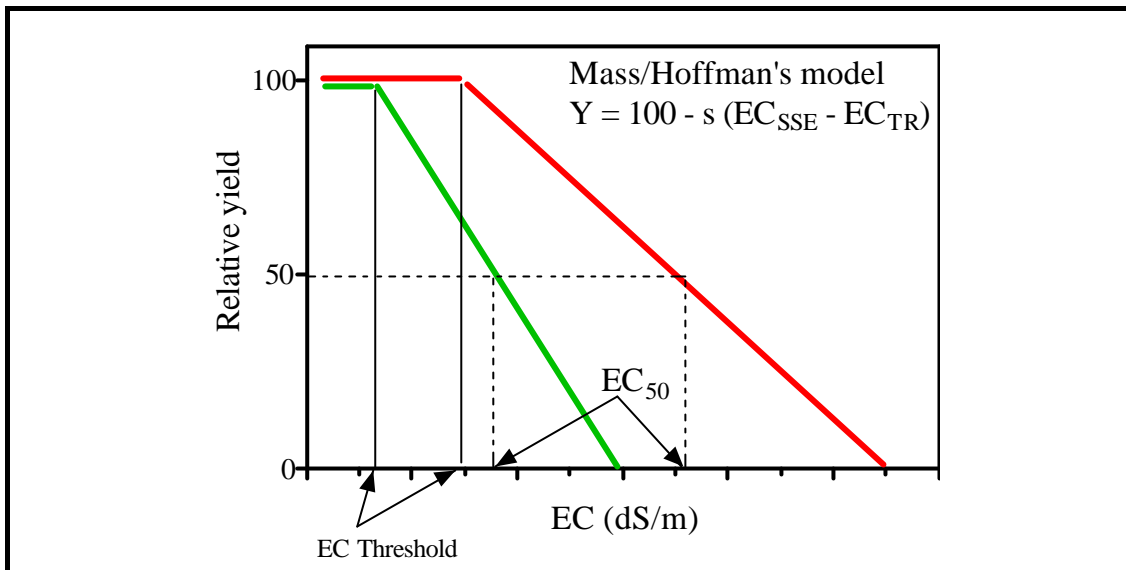


Fig 1. Schematic representation of the linear Mass/Hoffman's model. The green and red line represent the yield- EC_{SSE} relationship of a moderately sensitive crop and a moderately salt resistant crop respectively.

Many authors have studied the salt tolerance of different crops, and often the results obtained for the same species are quite different due to the great number of ways to measure and describe salt tolerance and to the complex interactions of both climatic and genetic factors that are listed below:

- ? supply of water and nutrients;
- ? methods of water supply;
- ? air temperature and humidity;
- ? evaporation rate;
- ? CO_2 supply;
- ? light intensity.
- ? crop time of saliniton

Despite these conflicting results, some reviewers have tried to summarise data of crop reaction to salinity: the most extensive reviews on crop salt tolerance classification are the work of Maas and Hoffman (1977), of Maas (1986) and of Shannon and Grieve (1999). According to these and some others experimental works, a classification of salt tolerance of many greenhouse crop are reported in table 1.

The data reported here must be considered as only indicative for describing the crop's tolerance to salinity when grown in hydroponics, since these are based mainly on outdoor experiments and on the Soil Saturated Extract (SSE) EC values. Often in hydroponic culture the EC of substrate solution or the recirculating nutrient solution is most used than the SSE.

Table 1. Salt tolerance of the main vegetable and cut flower species grown under greenhouse. See text for abbreviations. SS was calculated according to Sonneveld (1990): $EC_{(SS)} = 1.6 EC_{(SSE)} - 0.18$.

	EC_{SSE} (mS/cm)		EC_{SS} (mS/cm)		References
	EC_{TR}	Slope	EC_{TR}	Slope	
Salt sensitive crop					
Bean	1.9	19.0	2.9	11.9	Maas and Hoffman, 1977
Carrot	1.0	14.0	1.4	8.7	Maas 1986
Chrysanthemum	0.9	8.7	1.3	5.4	Barbieri and De Pascale, 1992
Eggplant	1.1	6.9	1.6	4.3	Maas 1986
Fennel	1.2	14.0	1.7	8.8	Graifenberg et al. , 1996
Lettuce	1.3	13.0	1.9	8.1	Shannon and Grieve, 1999
Onion	1.4	17.0	2.1	10.6	Shannon and Grieve, 1999
Pepper	1.5	14.0	2.2	8.7	Maas 1986
Radish	1.2	13.0	1.7	7.9	Shannon and Grieve, 1999
Rose	1.5	9.7	2.2	6.1	Barbieri and De Pascale, 1992
Strawberry	1.0	33.0	1.4	20.6	Maas and Hoffman, 1977
Moderately salt sensitive crop					
Broccoli	2.8	9.2	4.3	5.8	Shannon and Grieve, 1999
Cabbage	1.8	9.7	2.7	6.1	Shannon and Grieve, 1999
Carnation	2.5	3.9	3.8	2.4	Barbieri and De Pascale, 1992
Celery	1.8	6.2	2.7	3.9	Maas 1986
Cucumber	2.5	13.0	3.8	8.1	Maas and Hoffman, 1977
Melon	2.2	7.3	3.3	4.6	Maas and Hoffman, 1977
Spinach	2.0	7.6	3.0	4.7	Maas and Hoffman, 1977
Tomato	2.5	9.9	3.8	6.2	Maas and Hoffman, 1977
Moderately salt tolerant vegetables					
Artichoke	4.9	10.7	7.7	6.7	Graifenberg et al, 1993
Asparagus	4.1	2.0	6.4	1.25	Maas, 1986
Cherry tomato	6.0	5.8	9.4	3.6	Gough & Hobson, 1990
Garden orach	6.4	4	10.0	2.5	Shannon and Grieve, 1999
Purslane	6.3	9.6	9.9	6.0	Shannon and Grieve, 1999
Rocket salad	3.5	9.0	5.4	5.6	Shannon and Grieve, 1999
Swiss chard	7.0	9.1	11.0	5.7	Shannon and Grieve, 1999
Table beet	4.0	9.0	6.2	5.6	Shannon and Grieve, 1999
Turnip	3.3	4.8	5.1	3.0	Shannon and Grieve, 1999
Zucchini squash	5.1	11.6	8.0	7.2	Graifenberg et al, 1996

Sonneveld *et al.* (1990) reported the following relationship between the EC of solution in the soil or in the substrate (SS) and SSE:

$$EC_{(SS)} = 1.6 EC_{(SSE)} - 0.18$$

In conclusion, data from table 1 must be considered as a basis to establish salt tolerance of glasshouse crops in hydroponics. These figures are likely to underestimate salt

tolerance value, as the typical growing conditions under greenhouse tend to improve the crop's response to salinity.

THE CONCEPT OF CASCADE CROPPING SYSTEM.

An interesting system has been already developed for open-field crops in San Joaquin Valley of California in order to reduce the volume of disposal water (Rhoades, 1989; Grieve and Suarez, 1997; Shannon et al. 2000). These authors have been proposed a system where fresh water is used for irrigating salt sensitive species (melons, onions, almonds) and the drainage water is then used for crop of higher salt tolerance (i.e. sweet corn, wheat, cotton, sugar beet). The drainage water becomes progressively more saline and the sequence ends with a very tolerant species, generally the alophytic plants such as purslane, beet or garden orach.

A similar approach, aimed to reduce the run-off of hydroponics, could be the development of a drain nutrient solution reuse system (DRS), which is based on the cultivation of plants with increasing salt tolerance. In a cascade cropping system, salt-tolerant species (user crop) would be cultivated with salt-enriched nutrient solutions flushed out from growing systems with less tolerant species (donor crop) and finally the drainage nutrient solutions would be discharged when the salinity is too high for cultivating, but the nutrient content (in particular that of nitrate and phosphate) is low and, therefore, environmentally-safe.

The best user crop is a species that has the highest EC_{TR} and the lowest slope coupled with good value of its production. The choice of the best salt tolerant crops as user crop could be easily determined by plotting EC_{TR} versus the slope (fig 2).

For applying the cascade cropping systems, two main problems are encountered: the risks of root pathogen spread and the presence of phytotoxic organic compounds in the exhausted nutrient solution.

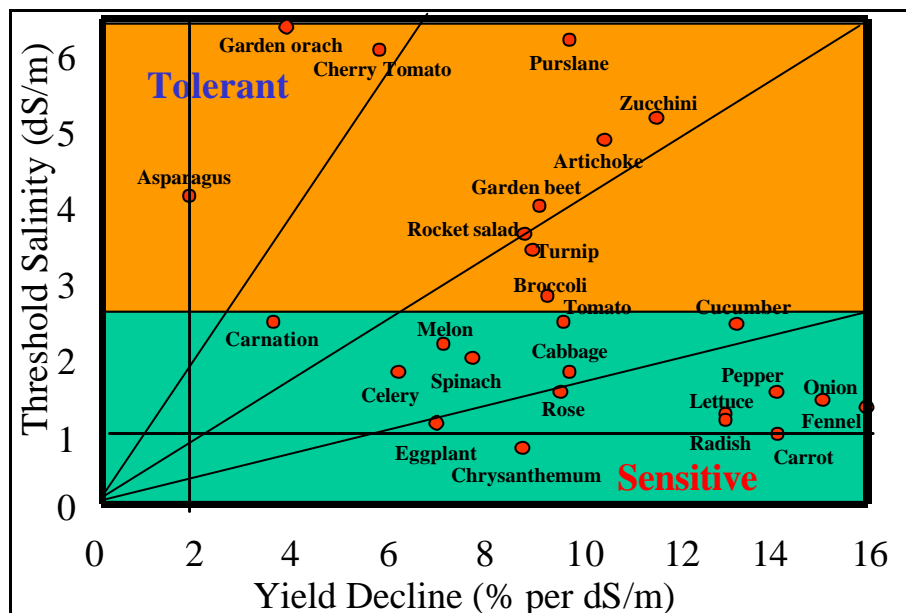


Fig. 2. The main classification of greenhouse crop to salinity resistance. In the right-down part of the graph area are present the sensitive species (donor crop), while in the left-upper area the more resistant. Data are based on Soil Saturated Extract See table 1 for more specific information.

THE MAIN SYSTEMS FOR DISINFECTING THE NUTRIENT SOLUTION

The main risks in DRS is the spread of soil-borne pathogens. Therefore, the disinfection methods of recirculating nutrient solution could be adopted. Several methods provide acceptable combination of effectiveness and cost. According to Van Os *et al.* (2003), the means of disinfecting solution could be classified as physical, chemical (oxidising) and physical-biological methods. Currently, only heat treatment assure a total elimination of all pathogens, but, for its high investment cost, it is not sustainable for farms with an area of less than 1 ha. Actually, the UV-method, coupled with a pre-filtration, provide results similar to those of heat treatment. Nevertheless, sometimes there are unreliable results due to a poor light transmission in the drainage nutrient solution or to the presence of particles that could shade the pathogens from UV-light.

Chemical methods (hydrogen peroxide treatment, and chlorination) are not very used since it's difficult to find the effective dosage against pathogens without phytotoxic effects.

The use of ozone is effective, but it is not very popular due to high cost and the needs of pre-treatment and precautions.

Finally, slow sand filtration appears to be an effective sustainable disinfection method that is feasible for the low technology greenhouses of Mediterranean countries. A more complete review of these disinfection methods is give in table 2.

Many growers are currently using grafted plants for avoiding root disease when recirculating of drained nutrient solution or reuse of cultivated substrate are adopted. Generally grafted plants are used for tomato and melon cultivations, but recently new rootstocks for cucumber, pepper, eggplant and water-melon have been proposed. (Morra *et al.*, 2003)

Table 2. The advantage and disadvantage of most popular nutrient solution disinfection methods (from van Os et al., 2003 and Runia, 1996).

Disinfection method	Doses	Advantages	Disadvantages
Heat treatment (physical method)	95°C for 30 s 85°C for 3 min	Complete destruction of all pathogens;	High investment and gas costs (only for farm > 1 Ha);
Ultra-violet radiation (UV) (physical method)	100-250 mJ/cm ² UV-C	Good control of pathogens; medium investment cost	Sometimes unreliable results; need to pre-filtration; iron chelate break down
Membrane filtration (physical method)	Pores size: 0.05 μm for <i>Fusarium</i> ; 0.1 μm for <i>Verticillium</i>	Complete elimination of pathogens	Very expensive; Low filter membrane life,
Ozone treatment (oxidising method)	10 g m ⁻³ h ⁻¹	Complete destruction of all pathogens;	Expensive system; need to pre-filtration, pre-acidification; iron chelate break down

Chlorinating (oxidising method)	2 ppm di Cl per 1' for <i>P. Cinnamomi</i>	Low investment costs; Clean pipers and drippers.	Difficulties to establish the efficacy doses. Acidity and organic compound influence the efficiency
Hydrogen peroxide (oxidising method)	100 ppm for <i>Fusarium</i> spp.	Low investment costs	No kill completely the nematodes; break down a part of iron chelate
Slow filtration (physical-biological method)	Flow rates: 100–300 L m ² hour ⁻¹ Sand grain size: 0-2 mm	Low investment cost; suitable for low technology greenhouse and for small farm surfaces.	Eliminate completely zoosporic fungi, but only partly <i>Fusarium</i> , viruses and nematodes

THE PRESENCE OF PHYTOTOXIC SUBSTANCES IN THE EXHAUSTED DRAINED NUTRIENT SOLUTION

When an exhausted nutrient solution is used to feed an other user crop grown in closed-loop system, an important point to evaluate is the progressive enrichment in that of organic compounds. The main sources of these in a nutrient solution are the irrigation water used to balance the system evapotranspiration, the roots (exudates and losses of damages roots), the microorganisms (the cells and their metabolites) and organic growing medium (Waechter-Kristensen *et al.* 1999). The second and the third components are the most important sources of organic compounds in the recirculating nutrient solution.

In particular, plant roots release a diverse range of organic compounds depending on the species and cultivar and on crop stage. Many of these low molecular weight compounds (such as sugars, aminoacids, carboxylic acid) are rapidly metabolised by root microorganisms, while higher molecular weight organic compounds, derived by the secondary metabolism pathways, could be attached slowly and could be represent molecules with some biological activities. Some of these plant and microbial metabolites may have beneficial effects for plant growth, but it is well established that some substances have a phytotoxic effects on the same and/or other species. These substances represent a big group of allelopathic substances. Main of these compounds are simple water-soluble organic acids, straight chain alcohols, fatty acids, complex quinones, simple phenols, phenolic acids, cinnamic acid and its derivatives, alkaloids, cyanogenic glycosides (Seigler 1996).

Indeed, Jung *et al.* (2001) reported a significant decrease in root and shoot weight when tomato seedlings were irrigated with a fresh nutrient solution containing a low concentration (10 μ M) of some phenolic compounds (i.e. benzoic, chlorogenic, vanillic and ferulic acids), while Caspersen (1997) noticed on a growth reduction of hydroponically-grown lettuce induced by a low concentration of ferulic acid (200 μ M).

Recent studies have demonstrated that, if oxygen and nutrient content, pH, and temperature are optimised in the recirculating nutrient solution, the risk of damage by phytotoxic substances is minimal, as the microbial metabolism and extracellular root enzymes activity reduce the concentration of potentially-phytotoxic substances (Waechter-

Kristensen et al., 1999; Alsanius et al 2003)

Hortimed experimental results obtained on DRS with cherry tomato as user crop and round-type tomato as donor crop, further support the absence of risks related to the presence of allelopathic substances (Incrocci *et al.*, 2003).

SOME EXAMPLES OF CASCADE CROPPING SYSTEMS

When cascade cropping systems are applied, some considerations should be kept in mind:

- a) usually, the greenhouse farms present a good level of specialisation, as they produce only few different crops. Therefore, when a cascade cropping system is proposed, similar plants, from the commercial viewpoint, must be chosen. For example, in farm specialised in ready-to-use leafy vegetables (lettuce, chicory, corn salad) interesting user crops are rocket salad, leafy beet, spinach and purslane. Other possible example of crop combination are reported in table 3.
- b) In order to facilitate the renewal of nutrient solution, hydroponic system should have a low volume of recirculating water, such NFT and aggregate culture with low water retention substrate (pumice instead of rockwool).
- c) In general, plant salt tolerance is higher when occurred in the late developmental stage. Some cut leafy vegetables show higher salinity tolerance after the first harvest, such spinach and purslane (Shannon and Grieve, 1999). Therefore, to reduce yield loss late salinisation could be adopted.
- d) In order to minimise the environmental impact and to observe the current legislation as well, the nutrient solution drained out from the user crop must contain very low concentration of both nitrate and phosphate. This means that growers have to monitor the concentration of these ions, eventually by means of quick test kits, and allow the crop reduce the nutrient concentration after the fertigation system has been switched off.

Table 3. Examples of some cascade cropping systems with the maximum value of EC (dS/m) in the recirculating nutrient solution.

Donor Crop		User crop	
1) Round Tomato	6	Cherry Tomato	10-12
2) Lettuce	2.5	Rocket	4-6
3) Pepper	2.5	Zucchini	8.0
4) Strawberry	2.0	Melon	4-5
5) Roses	2.5	Japanese Limonium	8.5
6) Gerbera	2.5	Lisianthus	6.0

RULES OF THUMB

- ✍ In closed soilless culture, when a saline water is used, there is a build-up of salts and this makes it necessary to replace more or less frequently (in dependence on crop evapotranspiration and salinity tolerance as well as on water quality) the nutrient solution with consequent waste of water and fertilisers.
- ✍ Cascade cropping system is a combination of crops where a salt sensitive crop (donor crop) produces exhausted nutrient solution that is reused to feed a more tolerant species (user crop).
- ✍ A disinfection method of nutrient solution or the use of resistant grafted plants is advised when cascade crop is applied. Sand filtration is an effective sustainable disinfection method that is feasible for the low technology greenhouses of Mediterranean countries.
- ✍ If oxygen and nutrient content, pH, and temperature are optimised in the recirculating nutrient solution, the risk of root damage due to root organic exudates is minimal.
- ✍ Cascade cropping systems should be include crops in the same market category (such as round tomato and cherry tomato, cut leafy vegetables).
- ✍ The nutrient solution drained out from the user crop will must contain nitrate and phosphate concentration that are lower than the limits established by EU (Nitrates Directive).

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ANNEX 1: DESCRIPTIVE FOLIOS OF SOME POSSIBLE USER CROP


Species: ARTICHOKE (*Cynara scolymus* L.; Asteraceae)

Yield response Maas's equation	EC* _{SSE} (dS/cm)	EC** _{SS} (dS/m)		
	Threshold	4.9		7.7
	Slope	10.7		6.7
	Zero-yield EC***	14.2		22.6
	50%-yield EC***	9.6		15.1
Notes				

Species: ASPARAGUS (*Asparagus officinalis* L.; Liliaceae)

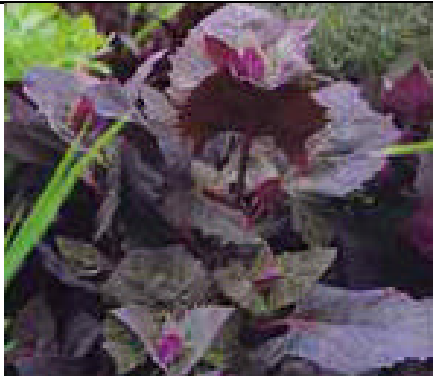
Yield response Maas's equation	EC* _{SSE} (dS/cm)	EC** _{SS} (dS/m)		
	Threshold	4.1		6.4
	Slope	2.0		1.25
	Zero-yield EC***	54.1		86.4
	50%-yield EC***	29.1		46.4
Notes	It has been considered the most salt tolerant vegetable crop.			

Species: CHERRY TOMATO (*Lycopersicon Esculentum* Mill., var. *cerasiforme*; Solanaceae)


Yield response	EC* _{SSE} (dS/cm)	EC** _{SS} (dS/m)		
	Threshold	6.0		9.4
	Slope	5.8		3.6
	Zero-yield EC***	23.2		37.0
	50%-yield EC***	14.6		23.2
Notes	Cherry tomato in soilless culture could be tolerate EC of nutrient solution until 12-15 dS/m, with a less yield reduction but with a higher improvement of fruit quality			

Species: GARDEN ORACH (*Atriplex hortensis* L.; Chenopodiaceae)


* Soil saturated extract. ** Soil Solution, calculated from SSE data applying the Sonneveld's equation. *** Figures calculated on the basis of threshold and slope.

Yield response Maas's equation	EC* _{SSE} (dS/cm)	EC** _{SS} (dS/m)		
	Threshold	6.4		10.0
	Slope	4.0		2.5
	Zero-yield EC***	31.4		50.1
	50%-yield EC***	18.9		30.0
Notes				


Species: PURSLANE (*Portulaca oleraceae* L.; Portulacaceae)

Yield response Maas's equation	EC* _{SSE} (dS/cm)	EC** _{SS} (dS/m)		
	Threshold	6.3		9.9
	Slope	9.6		6.0
	Zero-yield EC***	16.7		26.6
	50%-yield EC***	11.5		18.2
Notes	The fresh leaves and stem are used as salad; the shoot is a rich source of ? -3 fatty acids, tocopherols, ascorbic acids and ? -carotene.			


Species: ROCKET (*Eruca sativa* L.; Cruciferae)

Yield response Maas's equation	EC* _{SSE} (dS/cm)	EC** _{SS} (dS/m)		
	Threshold	3.5		5.4
	Slope	9		5.6
	Zero-yield EC***	14.6		23.2
	50%-yield EC***	9.1		14.3
Notes	Also wild rocket (<i>Diplotaxis</i> spp.) is cultivated in the Mediterranean country			


Species: SWISS CHARD (*Beta vulgaris* (L.) Koch, Cicla group; Chenopodiaceae)

Yield response Maas's equation	EC* _{SSE} (dS/cm)	EC** _{SS} (dS/m)		
	Threshold	7.0		11.0
	Slope	9.1		5.7
	Zero-yield EC***	18.0		28.6
	50%-yield EC***	12.5		19.8
Notes	Very resistant to Chloride (untill 120 mM)			

Species: TABLE BEET (*Beta vulgaris* L.; Chenopodiaceae)

Yield response Maas's equation	EC* _{SSE} (dS/cm)	EC** _{SS} (dS/m)		
	Threshold	4		6.2
	Slope	9		5.6
	Zero-yield EC***	15.1		24.0
	50%-yield EC***	9.6		15.1
Notes				

Species: ZUCCHINI (*Cucurbita pepo* L.; Cucurbitaceae)

Yield response Maas's equation	EC* _{SSE} (dS/cm)	EC** _{SS} (dS/m)		
	Threshold	5.1		8.0
	Slope	11.6		7.2
	Zero-yield EC***	13.7		21.8
	50%-yield EC***	9.4		14.9
Notes				