# What limits the application of wastewater and/or closed cycle in horticulture?

Cecilia Stanghellini[1], Alberto Pardossi[2], Nick Sigrimis[3]

[1]Plant Research International, Wageningen UR, Bornsesteeg 59, 6708 PD Wageningen, The Netherlands (cecilia.stanghellini@wur.nl)
[2]Dipt. di Biologia delle Piante Agrarie, Università di Pisa, Viale delle Piagge 23, 56124 Pisa, Italy
[3]Dept. of Agricultural Engineering, Agricultural University, Iera odos 75, Athens 11855, Greece

**Keywords:** water saving, yield response; brackish water; water price; salinity; pollution

## Abstract

**We determine the "optimal" management of a closed growing system with multiple sources of water, of price decreasing with quality. The management that balances marginal costs of water and fertilizers with marginal yield loss is determined. By using a number of yield response curves, in a couple of different cases (Holland and Mediterranean basin), we show that, with realistic prices both of resources and of produce, closed systems are financially viable only in two cases: 1. in regions with good water or 2. with high-value crops that offset the costs of ensuring good water (such as rain collection or desalinisation), so that there is no advantage for a grower to maintain a closed loop whenever the quality of irrigation water is poor. This means that a price structure of water resources that shifts the economic optimum towards poorer irrigation water has the consequence that the irrigation loop cannot be closed. In other words, there is no way that low-value crops using poor irrigation water may still be profitable under stricter environmental rules. We conclude that in view of the environmental impact, it would be advisable for irrigation and local authorities in horticultural areas either to provide good water at a relatively high price or to consider subsidizing investment costs of on-site desalinization plants, rather than stimulating use of poor quality water, or attempting to prevent pollution through unrealistic regulations. This means that local authorities, seriously planning to reduce agricultural pollution, should either provide incentives for growers to switch to less sensitive or more valuable combinations of crops, or contemplate developing other economic activities than agriculture.**

## INTRODUCTION

Socio-environmental impact of irrigation is two-fold: competition for scarce water resources and pollution of common resources. However, since agricultural pollution is very strictly linked to the amount of drain, which follows from amount of water application, there is little doubt that the agricultural sector must do with less water and anyhow must use water more efficiently. Application of lower quality water (either from brackish wells or partly cleansed waste water) is often stimulated, as well as reuse of drain (closed cycle) in soil-less cultures (including open-air container crops). It is commonly stated that the only way to ensure efficient use and decreased lixiviation is "pricing" irrigation water in such a way that application of lower quality water and/or of closed cycle is the most economical management. However, whenever irrigation water contains non-nutrient salts, these will accumulate in the root zone. It is well known that increased root zone salinity causes yield loss so that at some time leaching will become necessary. It can be shown that the fraction of water that is leached out of a closed cycle is nearly proportional to the ratio between the concentration of the critical salt of the irrigation water and the "ceiling" concentration at which the system is leached.

Since water use and leaching pollution are very strictly related, an increasingly fashionable line of thought (for instance: OECD, 1999; European Parlament & Council, 2000) is that the solution to both scarcity and environmental problems caused by over-irrigation, is to price irrigation water in such a way that saving water through closed systems and/or using water of lesser quality becomes optimal economic policy for growers. In this paper we analyze the feasibility of such an approach, in view of information collected and generated in the framework of a project co-financed by the European Union (HORTIMED, ICA3-1999-0009), aimed at methods for saving water in Mediterranean Horticulture.

## MATERIALS AND METHODS

Let's assume we deal with a crop that in optimal conditions generates a gross return $Y$ (€ $m^{-2}$ $year^{-1}$), and that return decreases by a fraction $a$, for each dS/m that the salinity $EC$ in the root zone environment increases.

$$Gross\ return = Y(1 - aEC) \qquad \text{€ m}^{-2}\ \text{y}^{-1} \quad (1)$$

Obviously, in a closed system fed with saline irrigation water, water use exceeds potential evaporation ($E_p$), since the water has to be periodically refreshed, as quantified by Carmassi et al., 2003. Stanghellini & Kempkes, 2004, have shown that if irrigation water has as salt concentration $EC_{in}$ and the system is flushed at a concentration $EC_{MAX}$, a good estimate of actual water use $W$ is:

$$W = \frac{EC_{MAX}}{EC_{MAX} - EC_{in}} E_p \qquad \text{m}^3\ \text{m}^{-2}\ \text{y} \quad (2)$$

The potential yield, $Y$ and $E_p$ are typical of the crop, and $a$ is a measure of the crop sensitivity to salinity (the higher is $a$, the faster is yield loss with salinity). Now, let's assume that irrigation water has a price structure that encourages use of saline water, in particular that:

$$water\ price = \max[\varepsilon, P(1 - b \cdot EC_{in})] \qquad \text{€ m}^{-3} \quad (3)$$

Where $P$ (€ $m^{-3}$) is the price of good quality water; $b$ is the fractional decrease of the price with salinity and $\varepsilon$ is a minimum cost of water, associated with pumping, maintenance, etc, (Fig. 1). Please observe that water of poorer quality carries a hidden cost that is the cost of fertilizers that are expelled with leaching. Accounting for this would simply result in a somewhat less steep trend than the "bare" cost. Therefore, in the following we will regard $b$ as a parameter incorporating both water and fertilizers cost. As Fig. 1 shows, the water cost to a grower does not decrease beyond a given EC (depending on the price structure: $P$ and $b$, and his own costs $\varepsilon$), and the steeper is the price decrease, the lower is this EC value. The "optimal" EC of the irrigation water, from a growers' point of view will never be higher than this, since there are no advantages to be got further.

Finally, let's assume that all other production costs are independent of the salinity of the irrigation water. A smart grower chooses the $EC_{in}$ of the irrigation water and the maximal $EC_{MAX}$ to allow in the root zone (that is, in fact, water use) in a way that his profit is the maximum possible. Considering only irrigation costs, that is:

$$Y\left(1-a\frac{EC_{in}+EC_{MAX}}{2}\right)-\frac{EC_{MAX}}{EC_{MAX}-EC_{in}}E_pP(1-bEC_{in})\Rightarrow \max \qquad € \text{ m}^{-2}\text{ y}^{-1} \quad (4)$$

The equation above cannot be solved in an analytical fashion. It is possible, however, to explore under which conditions the parameters of the price structure would ensure that it makes economic sense to use irrigation water with an $EC_{in}$ larger than zero. One can show that all possible solutions to eq(4) depend similarly from the ratio:

$$k=\frac{aY}{P\,E_p} \qquad \text{m dS}^{-1} \quad (5)$$

that is, the ratio between loss of return for each dS/m increase in salinity in the root zone and the “potential irrigation costs”, that is the costs when using irrigation water of good quality.

For instance, a reasonable return for Dutch glasshouses is about 50 € $\text{m}^{-2}$ $\text{y}^{-1}$ (Agri-Holland, 2004; Central Bureau for Statistics, 2004) whereas for unheated plastic houses in the Mediterranean basin it is 10 € $\text{m}^{-2}$ $\text{y}^{-1}$ (Caballero & De Miguel, 2002). Sonneveld (2000) has tabulated yield decrease with salinity for a number of greenhouse crops, ranging from 2-3% for tomato and carnation; 5-6% for sweet pepper, cucumber and rose to 10% for gerbera and most pot plants. At the lower end of the range we can add cherry tomato with a yield loss of less than 1% (in view of the quality-premium in price). Potential evaporation is about 1 $\text{m}^3$ $\text{m}^{-2}$ $\text{y}^{-1}$ in all cases, since heating in Dutch greenhouses, and winter cultivation cycle (and whitewashing) in the Mediterranean, tend to offset differences in climatic potential evaporation, Kempkes and Stanghellini, 2001. Table 1 shows the corresponding values of $k$, with a number of possible potential irrigation costs.

## RESULTS

Figure 2 shows the net income for a grower (eq(4), only irrigation costs are deduced from return), for all sensible combinations of salinity of the irrigation water and water use, eq(2), for the trends of price of the irrigation water indicated besides, $k$ = 0.5 in all cases. The white area represents all combinations with incomes less than 90% of the theoretical maximum (that is, irrigation costs and yield loss exceed together 10% of possible income), and each contour line is 2% of it. What Fig. 2 shows is that if price of water becomes negligible at a quality that is still acceptable (top panel), it does make economic sense to use water of lower quality. The consequence of a fast decreasing price is that there is little restraint with respect to quantity used. Observe that the economic optimum in the top panel is around 2.5 $E_p$, which is a leaching fraction of 60%, in the common definition of the latter as the ratio of amount of water leached to quantity of water applied. On the other hand, if water of lower quality is only slightly cheaper than good water (middle and bottom panel) then it is more efficient to have good water and pay for it.

Figure 3, on the other hand shows the effect of the crop type (increasing $k$, that is either the value of yield of the sensitivity to salinity, or both), at a given trend of water price. We see that as $k$ increases (top to bottom), the range of economically sensible salinities of irrigation water shifts towards a higher quality of the water, and lower water use.

## DISCUSSION

We have seen that whenever *k* is large enough (that is, the potential loss of return caused by salinity is large with respect to the “potential” irrigation costs), there is no way that it could be profitable for a grower to use irrigation water of lower quality. That is, it is always cheaper to “clean” the water beforehand, f.i. with a on-site reverse osmosis plant. Lower-value (and lower investment) crops could be more reasonably cultivated in closed loops fed with irrigation water of poor quality. How poor, however, can be debated. Indeed, looking at Figures 2 and 3, one can see that even when an irrigation water of EC around 1 dS/m would be acceptable, actual water use would be more than twice potential evaporation (a leaching fraction around 60%), which seems to be a poor definition of a closed system.

Therefore, incentives to apply water of low quality may well decrease pressure on good water resources, but may significantly improve pollution caused by leaching. Implicitly, this is acknowledged by the Dutch regulations. Indeed, after allowing for (quite benevolent) specie-specific ceilings on sodium concentration in the closed loop, above which leaching is permitted, there are limits on the amount of irrigation that may be applied yearly, Table 2. Since such limits are quite difficult to enforce, an additional item in the regulation is a detailed list of conditions that make (or not) a rain collection basin compulsory. In this respect, Holland has the obvious advantage of equilibrium between rainfall and potential evaporation, and a rather even distribution of rainfall. However, the shallowness of the ground water table makes it impossible to dig deep basins, which, in turn, increases occupation of [expensive] and potentially productive soil surface. Indeed, calculations of integral costs of rain basins (KWIN, 2003) show that in some cases cost of storage per cubic meter may exceed cost of desalinization.

A similar lesson can be drawn for semi-arid regions where greenhouses are presently expanding: the one way to prevent leaching is to have good water (Pardossi et al., 2004). Closed systems in greenhouses are the vegetable production system with the highest economic water use efficiency by far (Stanghellini et al., 2003) and thus can afford a relatively expensive irrigation water, Table 3. Expansion of such systems should, therefore, be welcomed, particularly in semi-arid regions.

## CONCLUSION

Economically optimal management of most closed-loop crops in greenhouses requires irrigation water of good quality. A price structure of irrigation water that shifts the economic optimum towards poorer irrigation water has the consequence that the irrigation loop cannot be closed. In view of the environmental impact, it would be advisable for irrigation and local authorities in horticultural areas either to provide good water at a high price or to consider subsidizing investment costs of on-site desalinization plants, rather than stimulating use of poor quality water, or attempting to prevent pollution through regulation that may be both un-economical and un-enforceable, since there is no way that low-value crops using poor irrigation water may still be profitable under stricter environmental rules. This means that local authorities, seriously planning to enforce such rules, should either provide incentives for growers to switch to less sensitive or more valuable combinations of crops, or contemplate developing other economic activities than agriculture.

## REFERENCES

AgriHolland, 2004a. Tuinbouw goudhaantje van Nederlandse economie. http://www.agriholland.nl/nieuws/art.html?id=41580

Caballero, P. & De Miguel, M.D., 2002. Costes e intensificación en la hortofruti-cúltura Mediterránea. In: J.M.Garcá (Ed), La Agricultura Mediterránea en el Siglo XXI. Instituto Cajamar, Almería: 222-244.

Carmassi G., Incrocci L., Malorgio M., Tognoni F., Pardossi A., 2003. A simple model for salt accumulation in closed-loop hydroponics. Acta Horticulturae 614, 149-154.

Central Bureau for Statistics (CBS), 2004. Landbouwtellingen 2003 http://www.cbs.nl/nl/cijfers/themapagina/landbouw/1-cijfers.htm

Colino, J. & Martinez, J.M., 2002. El agua en la agricultura del Sureste Español: productividad, precio y demanda. In: J.M.Garcá (Ed), La Agricultura Mediterránea en el Siglo XXI. Instituto Cajamar, Almería: 199-221.

European Parlament & Council, 2000. Directive 2000/60/EC establishing a framework for Community action in the field of water policy. Official journal of the EC, L327/1 22-12-2000.

Kempkes, F.L.K. & C. Stanghellini, 2001. A compilation of water use for protected cultivation in the Mediterranean, water resources and economics of storing and upgrading water. EU-HORTIMED, ICA3-1999-0009: Deliverable 7.

Kwantitatieve Informatie Glastuinbouw (KWIN), 2003. Praktijk Onderzoek Plant & Omgeving, Naaldwijk, Report PPO 580 154 pp + annexes.

OECD, 1999. Agricultural water pricing in OECD countries. Report no. 77608, 60 pp.

Pardossi A., Tognoni F., Incrocci L., 2004 Mediterranean greenhouse technology. Chronicla Horticulturae 44 (2), 28-34.

Sonneveld, C., 2000. Effects of salinity on substrate-grown vegetables and ornamentals in greenhouse horticulture. PhD dissertation, Wageningen University: 151 pp

Stanghellini, C.; F.L.K. Kempkes & P. Knies, 2003. Enhancing environmental quality in agricultural systems. Acta Horticulturae 609: 277-283.

Stanghellini, C. & F.L.K. Kempkes, 2004. A blueprint for optimal management of multiple-quality water-resources.EU-HORTIMED, ICA3-1999-0009: Deliverable 8.

| **Crop** | **Potential return** (€ $m^{-2}$ $y^{-1}$) | **Salinity Yield Decrease SYD, %** $(dS/m)^{-1}$ | **P·ETP** (€ $m^{-2}$ $y^{-1}$) | | |
|---|---|---|---|---|---|
| | | | *0.5* | *1* | *1.5* |
| Cherry tomato | 10 | 1 | 0.2 | 0.1 | 0.07 |
| Tomato, carnation | 10 | 3 | 0.6 | 0.3 | 0.2 |
| Sweet pepper, rose | 10 | 5 | 1 | 0.5 | 0.33 |
| Cherry tomato | 50 | 1 | 1 | 0.5 | 0.33 |
| Gerbera, pot plants | 10 | 10 | 2 | 1 | 0.67 |
| Tomato, carnation | 50 | 3 | 3 | 1.5 | 1 |
| Sweet pepper, rose | 50 | 5 | 5 | 2.5 | 1.67 |
| Gerbera, pot plants | 50 | 10 | 10 | 5 | 3.33 |

***Table 1.*** *Value of the ratio k for a number of typical greenhouse crops and costs of irrigation. The differences in potential return for the same crop refer to the growing system: it has been assumed that return in high investment glasshouses is fivefold the return in simple plastic houses.*

| **Crop** | **Ceiling Na concentration** (mmol $L^{-1}$) | **Maximal application** (mm $y^{-1}$) |
|---|---|---|
| Tomato | 8 | 1140 |
| Sweet pepper; cucumber; eggplant; melon; squash (zucchini); beans | 6 | 1140 |
| Lettuce | 5 | 860 |
| Rose; gerbera; carnation, amaryllis | 4 | 1140 |
| Strawberry | 3 | 860 |
| Anthurium, lilium, bouvardia, iris | 3 | 1140 |
| Orchid | 0 | 1140 |
| Others | 5 | 1000 |

***Table 2**. For each crop indicated in the first column: sodium concentration (crop specific) that has to be reached in a closed loop before leaching is allowed and maximum permitted yearly irrigation application, under current Dutch law*

| | **Productivity** (€ $m^{-3}$) | **$m^3$/man-hour** | **Break-even price of water** (€ $m^{-3}$) |
|---|---|---|---|
| Open field vegetables | 1.60 | 11.5 | 0.9 |
| Greenhouse vegetables | 6.12 | 4.2 | 3.7 |

***Table 3.** Average productivity (income per unit applied) of irrigation water in open field and greenhouse vegetable production in the region of Almeria (column 2); "social efficiency" (mean water use for man-hour), column 3; and break-even price of water, that is the price that would cancel out the net income of growers (Colino & Martinez, 2002).*

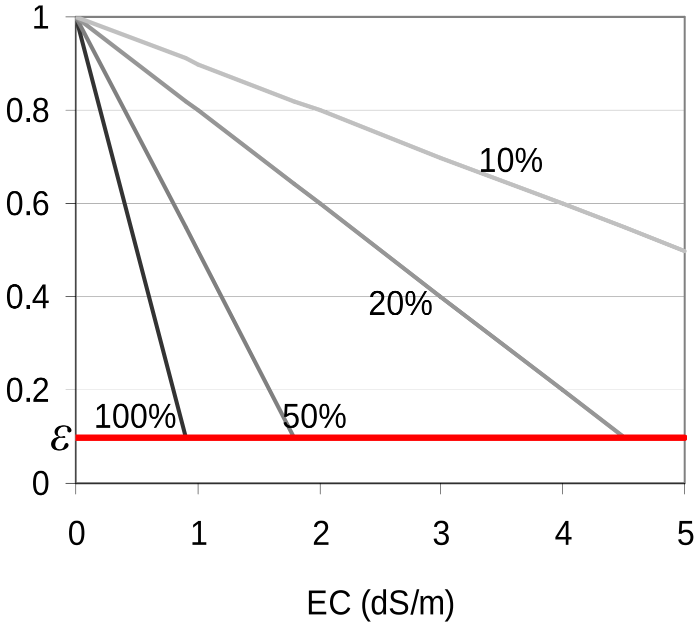

***Figure 1**. Hypothetical fractional decrease of cost of irrigation water with increasing salinity, eq(3). The four lines represent % decrease for each dS/m salinity, as indicated. Cost of irrigation is assumed to have a lower limit ε, in view of investment, maintenance and pumping expenses.*

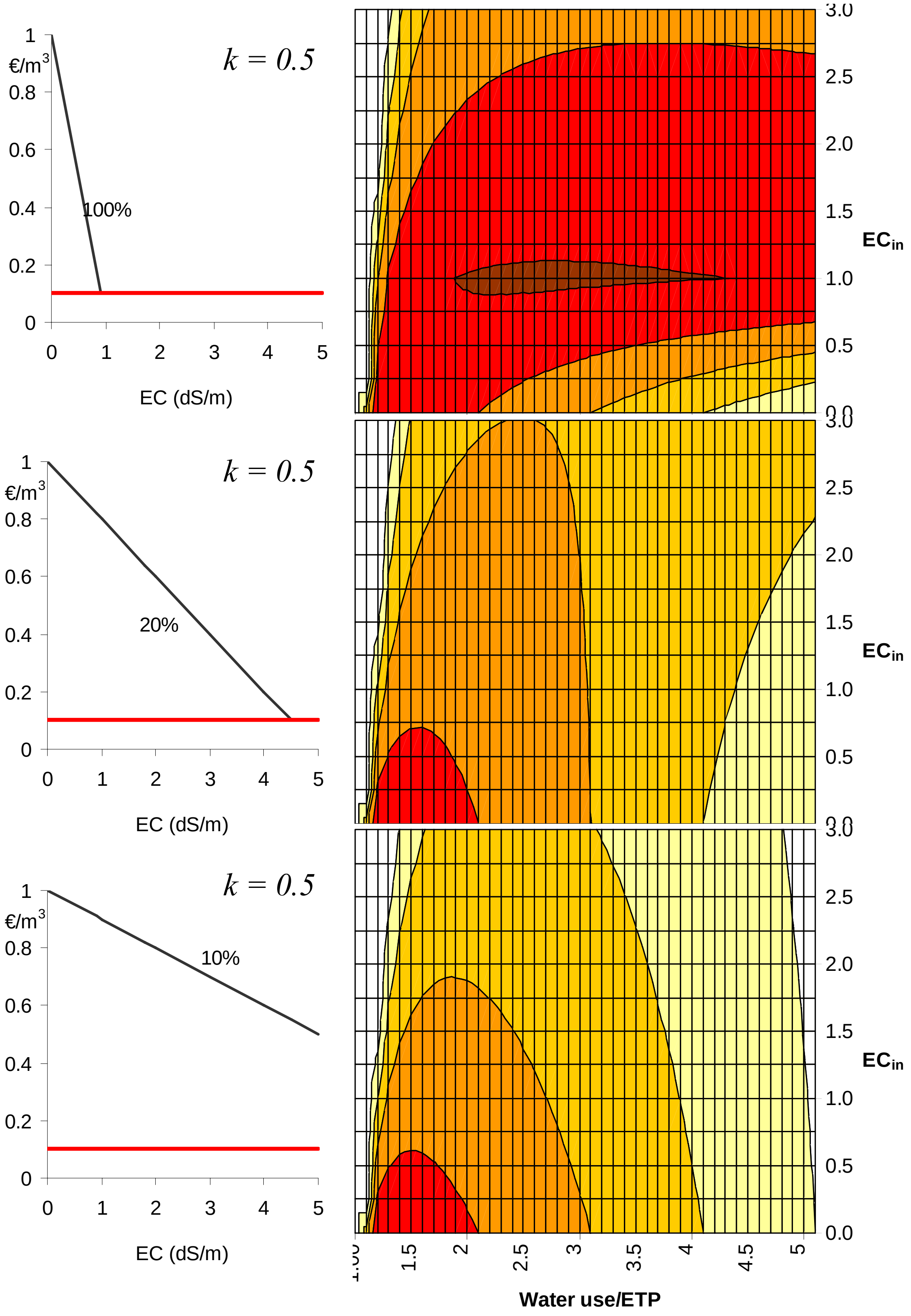

***Figure 2.*** *Net income (only irrigation costs are deduced from return) for a grower with a crop of k = 0.5, for all sensible combinations of salinity of the irrigation water ($EC_{in}$, dS/m, y-axis) and water use (as multiple of potential transpiration, x-axis), under the price trend in the corresponding panel on the left. The white area represents all cases with incomes less than 90% of the theoretical maximum, and each contour line is 2%.*

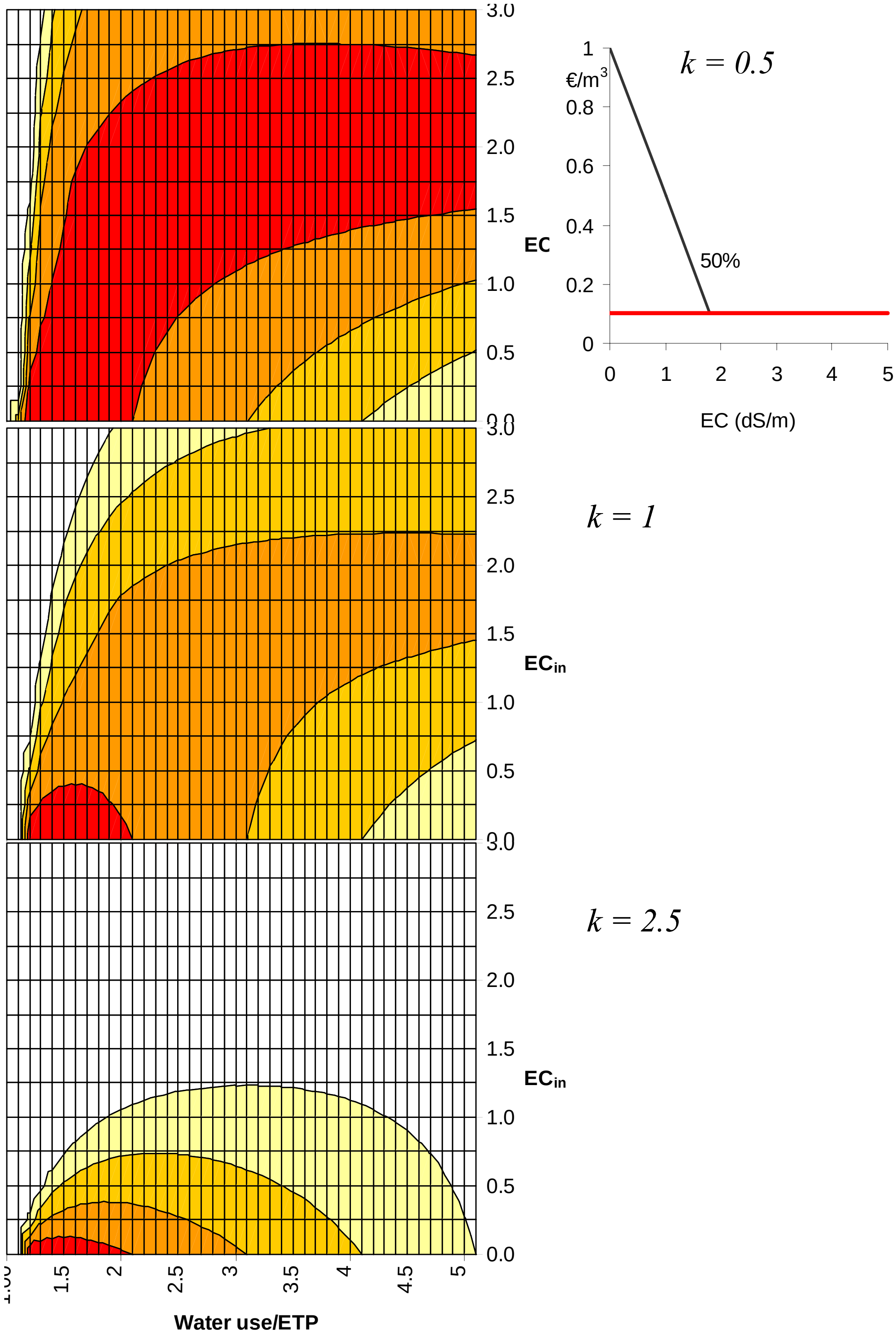

**Figure 3.** *Net income (only irrigation costs are deduced from return) for all sensible combinations of salinity of the irrigation water (EC$_{in}$, dS/m, y-axis) and water use (as multiple of potential transpiration, x-axis), under the water price shown at right and from top to bottom: k is respectively 0.5; 1 and 2.5. The white area represents all cases with incomes less than 90% of the theoretical maximum, and each contour line is 2%.*