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Interlighting in the Production of Greenhouse Cucumber: Economic Comparison Using the Simulation Model

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Summary

A new supplementary lighting technique, interlighting, has been devised for greenhouse cucumber production. A prerequisite for the adoption of the new lighting technique is the ability to provide economic benefit for the producer. Thus, the aim of this study was to compare the economics between conventional top lighting (TL), in which all of the high pressure sodium (HPS) lamps were mounted above the canopy, and two treatments of interlighting: slight interlighting in which the top lamps (HPS) covered 76 % and the vertically mounted interlighting lamps (HPS) 24 % (T+IL24) of the lighting, and intense interlighting in which the top lamps covered 52 % and the vertically mounted interlighting lamps 48 % (T+IL48) of the lighting. Economic comparison was made using a static deterministic discrete-event simulation model, and a sensitivity analysis was conducted. In yearly level, both interlighting treatments proved to be relatively more profitable than top lighting: the addition to relative profit was 18.51 € m^{-2} for T+IL24 and 16.25 € m^{-2} for T+IL48. However, the advantage of interlighting turned up only in periods when the amount of natural light was low, in autumn-winter and in spring. Sensitivity analysis indicated that interlighting required high management skills because already an 11 % yield reduction caused interlighting to be no longer relatively profitable. External shocks, such as reduction of cucumber price or increase of electricity price affected interlighting more strongly than top lighting, but interlighting still remained relatively more profitable than top lighting after a 50 % change.

Key words. annual costs – *Cucumis sativus* – gross margin – relative profit – sensitivity analysis – supplementary lighting

Introduction

A new supplementary lighting technique, interlighting, has been devised for greenhouse vegetable production in several countries, e.g. Iceland (Gunnlaugsson and Adalsteinsson 2006), the Netherlands (Heuvelink et al. 2006) and Finland (Hovi et al. 2004). In interlighting, some of the lamps, which are conventionally mounted at the top of the canopy, are mounted lower between the plant rows, providing a more even distribution of artificial light throughout the canopy and thus more efficient use of lighting. In Finland, interlighting has been shown to increase the yield and improve the efficiency of the electricity consumption of greenhouse cucumber (Hovi et al. 2004) and sweet pepper (Hovi-Pekkanen et al. 2006). In addition, interlighting has improved the external fruit quality of cucumber (Hovi-Pekkanen and Tahvonen 2008).

Despite the positive effects on the yield, a careful economic evaluation is needed before interlighting will be widely adopted in commercial production. The factors that will influence the adoption include perceived economic benefit for the producer, which is determined by the degree of improvement in the amount of marketable yield compared to changes in invested capital and input costs. Also the level of management skills needed to make effective use of the interlighting technique, the risk associated with the technique, and goals of the producer influence the adoption of interlighting.

Several economic assessments of greenhouse cucumber production have been made, such as studies of Kristoffersen et al. (1992), Koivisto (2004), and Hao and Papadopoulos (2005), concerning the economics of winter production of cucumber, and study of Engindeniz (2004) on the economics of soilless culture. The approaches applied in these were profitability or production cost evaluations. However, fewer economic comparisons of lighting techniques have been made, even though the use of supplementary lighting is a widely used and economically important method in greenhouse production in the northern latitudes.

The aim of this study was to compare relative profit between conventional top lighting and interlighting. The comparison was made using a static deterministic discrete-event simulation model. A sensitivity analysis was conducted to assess the parameter values with regard to changes in outputs and thereby evaluate the risk caused by the new lighting technique and the management skills needed.

Materials and Methods

The simulation model

Simulation models are commonly used to imitate the real-world processes. The processes are defined by a set of assumptions and these assumptions constitute a model. In simulation, a model is evaluated numerically and data are gathered in order to estimate the desired true characteristics of the model (LAW and KELTON 2000).

Simulations are applied in numerous areas; typically in manufacturing and material handling analyzes (BANKS 1998; LAW and KELTON 2000), but also several simulation applications concerning economic systems can be found. For example, simulation based approach for economic evaluation has been used in milking systems, storage technologies, and cow-calf production systems (COOPER et al. 1999; DIN et al. 2005; GUIMARÃES et al. 2006). A simulation model is a suitable tool also for the current research problem, because an experimental study of the financial effects of different supplementary lighting techniques in various configurations would require an extensive research effort.

Model structure

The model used in our study was a static deterministic discrete-event simulation model which simulates the yearly relative profit. Production economics varies remarkably between growers depending on the production scale and methods. Determining relative profit allows making farm-level comparisons, even though all revenue and cost items are not specified. Results of such comparisons do not show the absolute profit of the production but they indicate the relative economic superiority of lighting techniques.

Economically important parameters which illustrated the quantity aspects of output and inputs as well as price parameters were included to the model (Table 1). On the other hand, parameters whose value were or were assumed to be similar in each lighting treatment were excluded. Also the availability of suitable data restricted the parameters used.

The model simulated yearly relative profit of two interlighting techniques, slight interlighting (T+IL24) and intense interlighting (T+IL48), compared to conventional top lighting (TL). The simulation model was composed of three submodels that illustrated spring, summer and autumn-winter stands. In practice, stands represented different outdoor conditions, uppermost the amount of global radiation. The amount of global radiation during the cultivation was about 9 400, 17 400, and 2 300 kJ m^{-2} in spring, summer and autumn-winter stands, respectively (FINNISH METEOROLOGICAL INSTITUTE 2006).

The structure of simulation model is represented in Fig. 1 and in equation 1:

$$\begin{aligned} P_{T+IL24} &= M_{T+IL24} - M_{TL} - A_{T+IL24} + A_{TL} \\ P_{T+IL48} &= M_{T+IL48} - M_{TL} - A_{T+IL48} + A_{TL} \end{aligned} \qquad (1)$$

where M is the gross margin and A is the annual costs for lighting fittings and bulbs for the different lighting treatments (TL, T+IL24 and T+IL48).

Gross margin M_t is defined in equation 2:

$$\begin{aligned} M_t &= Y_t - E_t - F_t - L_t, \\ &= \prod_t \left[\sum_1^N (\bar{y}\bar{c} - \bar{e}\bar{p} - \bar{f}\bar{v} - 0.006\bar{y}s) \right], \qquad (2) \\ t &= TL, T + IL24, T + IL48 \\ N &= 1, 2, 3 \end{aligned}$$

where Y_t is the sales income of cucumbers, E_t is electricity cost, F_t is fertilizer cost, and L_t is harvesting labour cost for the lighting treatments t. In equation 2 $\bar{y} = (y_1, y_2, ..., y_n)$ is a vector of first class yield for week n, and similarly $\bar{c}$ is cucumber price, $\bar{e}$ is electricity consumption, and $\bar{p}$ is electricity price (electricity energy + transfer fees + energy taxes). $\bar{f} = (f_1, f_2, ..., f_n)$ is the vector of n types of fertilizers, and $\bar{v}$ is a price of fertilizer. Harvesting labour requirement was assumed to be linear combination of the yield, $0.006\bar{y}$ as reported by KOIVISTO (2004) and s is a scalar of labour cost (salary + social security). N is the stand getting values 1,2, and 3 which describe the spring, summer and autumn-winter stands.

Annual cost A_t is defined in equation 3:

$$\begin{aligned} A_t &= R_t + T_t + S_t + D_t, \\ &= \prod_t \left[\sum_1^N (0.03I_t + 0.05I_t + 0.005I_t + (g_t 6^{-1} + b_t 3^{-1})) \right] \\ I_t &= g_t + b_t \\ t &= TL, T + IL24, T + IL48 \qquad (3) \\ N &= 1, 2, 3 \end{aligned}$$

where R_t is maintenance and repair costs, T_t is interest costs, S_t is insurances costs, and D_t is depreciation for the lighting treatments t. I_t is the investment cost consisting of the investment cost of lighting fittings g_t and bulbs b_t. Costs of maintenance and repair, interest, and insurances were assumed to be linear combinations of the investment costs for the lighting treatments (I_t) and annual costs were estimated to be 3.0, 5.0 and 0.5 % of the investment costs, respectively. Depreciation, D_t, was defined using a straight-line depreciation without a salvage value, and the life time (technical duration) of lighting fittings was assumed to be six years and three years for the bulbs.

Data

The data for estimating the values of parameters were gained both from the experimental study and from the official statistics (Fig. 1). The experimental study was carried out in Southern Finland (Piikkiö 60 ° 23 'N, 22 ° 33 'E) in 2003–2004, where three cucumber (*Cucumis sativus* L. cv. 'Cumuli') stands (spring, summer and autumn-winter) were cultivated under three treatments of supplementary lighting. The lighting treatments included top lighting (TL) in which all of the lamps were mounted above the canopy, and two interlighting treatments: slight interlighting in which top lamps covered 76 % and vertically mounted interlighting lamps 24 % of the lighting (T+IL24), and intense interlighting in which the top lamps covered 52 % and vertically mounted interlighting lamps 48 % (T+IL48) of the lighting. Supplementary lighting was provided by high pressure sodium lamps (400 W in top lighting lamps and 250 W in interlighting

Table 1. Mean values of the parameters for each submodel. TL = top lighting, T+IL24 = top + interlighting 24 %, T+IL48 = top + interlighting 48 %.

Parameter		Unit	TL			T+IL24			T+IL48		
			Spring	Summer	Autumn-Winter	Spring	Summer	Autumn-Winter	Spring	Summer	Autumn-Winter
y	weekly yield[1)]	kg m^{-2}	2.44	2.08	1.77	2.82	2.21	2.25	2.83	2.19	2.27
c	weekly cucumber price[1)]	€ kg^{-1}	1.55	1.06	1.85	1.55	1.06	1.85	1.55	1.06	1.85
e	weekly electricity consumption[1)]	kWh m^{-2}	21.11	16.68	24.80	21.14	17.36	24.25	21.65	18.42	24.27
p	weekly electricity price[1)]	€ kWh^{-1}	0.048	0.050	0.054	0.048	0.050	0.054	0.048	0.050	0.054
f	fertilizers' consumption										
	NPK	kg m^{-2}	0.83	0.99	0.42	0.94	1.20	0.46	1.09	1.36	0.52
	HNO_3	l m^{-2}	0.02	0.02	0.01	0.02	0.03	0.01	0.02	0.03	0.01
	CaN	kg m^{-2}	0.59	0.71	0.30	0.67	0.86	0.33	0.78	0.97	0.37
	$MgNO_3$	kg m^{-2}	0.13	0.16	0.07	0.15	0.19	0.07	0.17	0.22	0.08
v	fertilizers' price										
	NPK	€ kg^{-1}	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04
	HNO_3	€ l^{-1}	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
	CaN	€ kg^{-1}	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43
	$MgNO_3$	€ kg^{-1}	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
s	labour price	€ h^{-1}	11.82	11.82	11.82	11.82	11.82	11.82	11.82	11.82	11.82
I	investment costs[2)]	€ m^{-2}	14.82	9.17	11.65	16.76	10.77	12.77	19.40	12.47	14.32
g	investment costs of lighting fittings[2)]	€ m^{-2}	11.25	6.96	8.84	12.98	8.34	9.89	15.21	9.77	11.23
b	investment costs of bulbs[2)]	€ m^{-2}	3.57	2.21	2.81	3.78	2.43	2.88	4.19	2.70	3.09

[1)]Mean of weekly mean values
[2)]Divided between submodels using their proportion of total electricity consumption

lamps) and the installed capacity in TL and T+IL was 170 and 163 W m^{-2}, respectively. Electricity consumption in lighting in each treatment was measured in weekly level and fertilizers' consumption in stand level. Fruits were harvested three times a week and graded according to the EU regulations. Annual first class yield in interlighting treatments was 15 % higher than in top lighting (87.9 in TL, 100.8 in T+IL24 and 100.9 kg m^{-2} in T+IL48). Besides yield, interlighting affected also fruit quality. It increased the total chlorophyll concentration of fruit skin in each stand; the higher the proportion of interlighting, the greener the fruits. The keeping quality of the fruits was also slightly better in interlighting treatments. The more detailed information of the experimental study is reported in Hovi-Pekkanen and Tahvonen (2008).

The official statistics, which covered the price parameters, described the financial situation in Finland in 2005, without value-added taxes. Only the statistics of weekly energy price and labour price were public statistics provided by Finnish Energy Market Authority and Maaseudun työnantajaliitto ry, respectively. Statistics of cucumber and fertilizers prices were provided for research purpose by Finnish Glasshouse Grower's Association and greenhouse fertilizer suppliers, respectively. Price parameters as well as quantity parameters are mean values (Table 1). Mean values were used, because majority of the distributions of parameters were not available and no *a priori* assumptions were not wanted to do.

Verification, validation, and model testing

The base idea in testing is that the model is an abstraction of a system and perfect representation is never expected. The model credibility must be judged with respect to the study object (Banks 1998). Because a real data of the simulation object did not exist, the relative profit of different lighting treatments, the model verification, validation and testing was done using *Data analysis*-method. In *Data analysis*-method a *Data flow* which involves the assessment of model accuracy with respect to the use of model parameters, and a *Data dependency* which involves the determination of what parameters depend on what other parameters, are critically assessed (Banks 1998).

The parameters of the model has been widely used in corresponding economic analysis (D'Amico et al. 2003; Engindeniz and Tüzel 2003; Engindeniz 2004). Our model lacked some parameters that were assumed to get equal values between different lighting treatments (e.g. commonly used parameters of costs of plant protection, growing-media, seedlings, and greenhouse investment) and therefore reduced of relative profit definition. One missing parameter which might have had some economic effect is heating energy costs, which was excluded because of the lack of suitable data. The effect of heating energy costs was, however, assumed only to strengthen the magnitude, not to change the rank of relative profits of different lighting treatments.

In our study, the parameters dependencies were oversimplified, and there was hardly any horizontal connection between parameters (Fig. 1). The affects of horizontal connections were assumed to be insignificant for the sake of outcome. Overall, despite of the deficiencies, the model was considered as a valid for the purpose of economic comparison of different lighting treatments.

Sensitivity analysis

Sensitivity analysis is a process by which parameters are evaluated with regard to their effects on the simulation results. Sensitivity analysis is also a validation tool for the model, because it allows testing the direction of the output change after the change of input (BANKS 1998; PEART and CURRY 1998). In our study sensitivity analysis was also used to assess the risk of the adoption of the new lighting techniques and to evaluate the management skills needed to get economic benefit from the new technology.

The sensitivity of the yield was studied only in cases where the yield was lower than the original values of yield parameters, because higher yield would, in most cases, require higher installed capacity of supplementary lighting. In the analysis the yield of top lighting was kept constant at the original parameter value and only the yield of interlighting was reduced by one percentage unit at a time. The simulation of cucumber price was done only in price reduction cases, because yearly cucumber price has decreased by about 8 %, from 1.68 to 1.49 € kg^{-1} in 2000–2005 (FINNISH GLASSHOUSE GROWER'S ASSOCIATION 2006). At the same time, price of industrial electricity has arisen substantially, over 40 % from 3.78 to 5.32 Cents kWh^{-1}, (FINNISH ENERGY MARKET AUTHORITY 2006), and that made the simulation of energy price rise realistic.

Current investment costs for lighting treatments TL, T+IL24, and T+IL48 were 35.30, 39.90, and 46.20 € m^{-2}, which indicated that interlighting equipment increased the investment costs. Usually, after a new technology becomes more common, the investment costs begin to decrease. With a new technology real lifetime of lighting equipment as well as the exact maintenance and repair costs are difficult to define. It is possible that interlighting lamps have a shorter lifetime and higher maintenance and repair costs because of their location inside the canopy and the fact that they are more vulnerable to different nursing treatments of the canopy than top lamps. The effects of the investment cost reduction as well as uncertainty of lifetimes and maintenance and repair costs were simulated.

Results

According to the simulation model interlighting proved to be relatively more profitable than top lighting in yearly level: the addition to relative profit was 18.51 and 16.25 € m^{-2} for P_{T+IL24} and P_{T+IL48}, respectively. Increasing the proportion of interlighting did not increase the relative profit, instead, the relative profit was lower in P_{T+IL48} than in P_{T+IL24} (Table 2). Considering the different stands, interlighting was relatively more profitable in the periods when the amount of global radiation was low, i.e. during autumn-winter and spring. In the summer, when the amount of global radiation was high, interlighting P_{T+IL24} gave similar relative profit, or even lower with P_{T+IL48}, than top lighting. The relative profit of interlighting was highest during the spring when, in addition to low amount of global radiation, the price of cucumber was higher and the price of electricity lower compared to the other seasons.

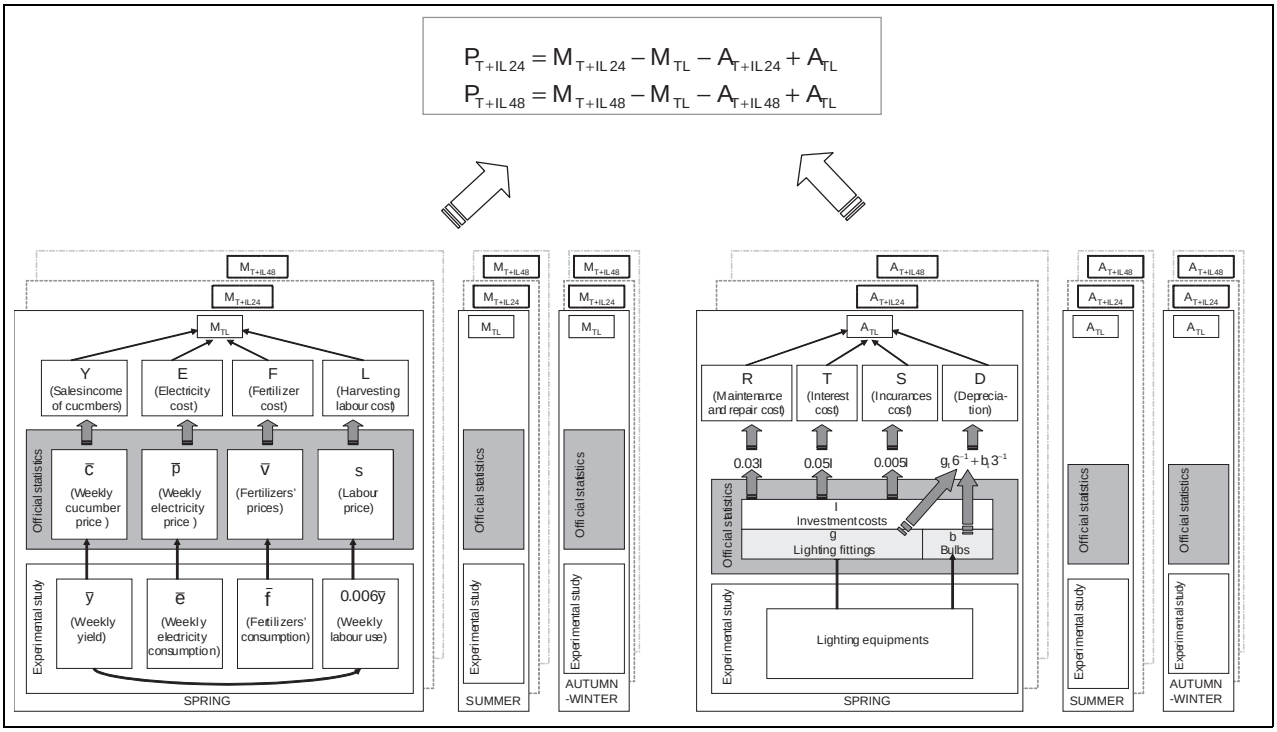


Fig. 1. Structure of simulation model. P = relative profit, M = gross margin, A = annual costs of lighting fittings and bulbs.

Table 2. Relative profits (€ m^{-2}) for the three submodels and for the yearly simulation model.

Period	P_{T+IL24}	P_{T+IL48}
Spring	9.54	9.09
Summer	0.37	−1.16
Autumn-winter	8.60	8.32
Whole year	18.51	16.25

Sensitivity analysis indicated that the yearly relative profit of P_{T+IL24} and P_{T+IL48} decreased dramatically as the yield decreased. Already an 11 % yield reduction caused P_{T+IL48} to be no longer relatively more profitable than top lighting, and a 13 % reduction did the same to P_{T+IL24}. Examination by submodels showed also that during the summer top lighting was relatively more profitable than interlighting, while in the spring and autumn-winter a yield reduction by 15 and 20 %, respectively, caused top lighting to be relatively more profitable than interlighting (Fig. 2).

Reduction in cucumber price caused a remarkable decrease in relative profit, even though both interlighting treatments remained relatively more profitable than top lighting after a 50 % price-reduction. The sensitivity was caused by the stands of spring and autumn-winter, in the summer stand price reduction changed the relative profit hardly at all (Fig. 2). The rise of electricity price affected only slightly the relative profit of interlighting treatments, because electricity consumption per m^{-2} in each lighting treatment was quite similar (Fig. 2). Moreover, sensitivity analysis indicated that each 10 % decrease in the costs of interlighting fittings caused a 0.29 € m^{-2} increase in relative profit in P_{T+IL24} and a 0.57 € m^{-2} increase in P_{T+IL48} (Table 3).

Table 3. Effects of the cost of interlighting fittings on relative profit.

	Reduction in cots of interlighting fittings (%)*	Investment cost (I), (€ m^{-2})	Addition to relative profit (€ $year^{-1}$)
P_{T+IL24}	0	39.90	0.00
	−10	38.80	0.29
	−20	37.70	0.58
	−30	36.50	0.87
	−40	35.40	1.16
	−50	34.20	1.45
P_{T+IL48}	0	46.20	0.00
	−10	43.90	0.57
	−20	41.60	1.15
	−30	39.30	1.72
	−40	37.00	2.30
	−50	34.70	2.87

*Cost of top lighting fittings and bulbs does not change.

The analysis indicated that a one year cut off the lifetime of interlighting fittings caused a 0.38 € m^{-2} reduction in relative profit in P_{T+IL24}, and 0.76 € m^{-2} in P_{T+IL48}, respectively. Two years' cut caused a 0.96, and three years' cut a 1.92 € m^{-2} reduction in relative profit in

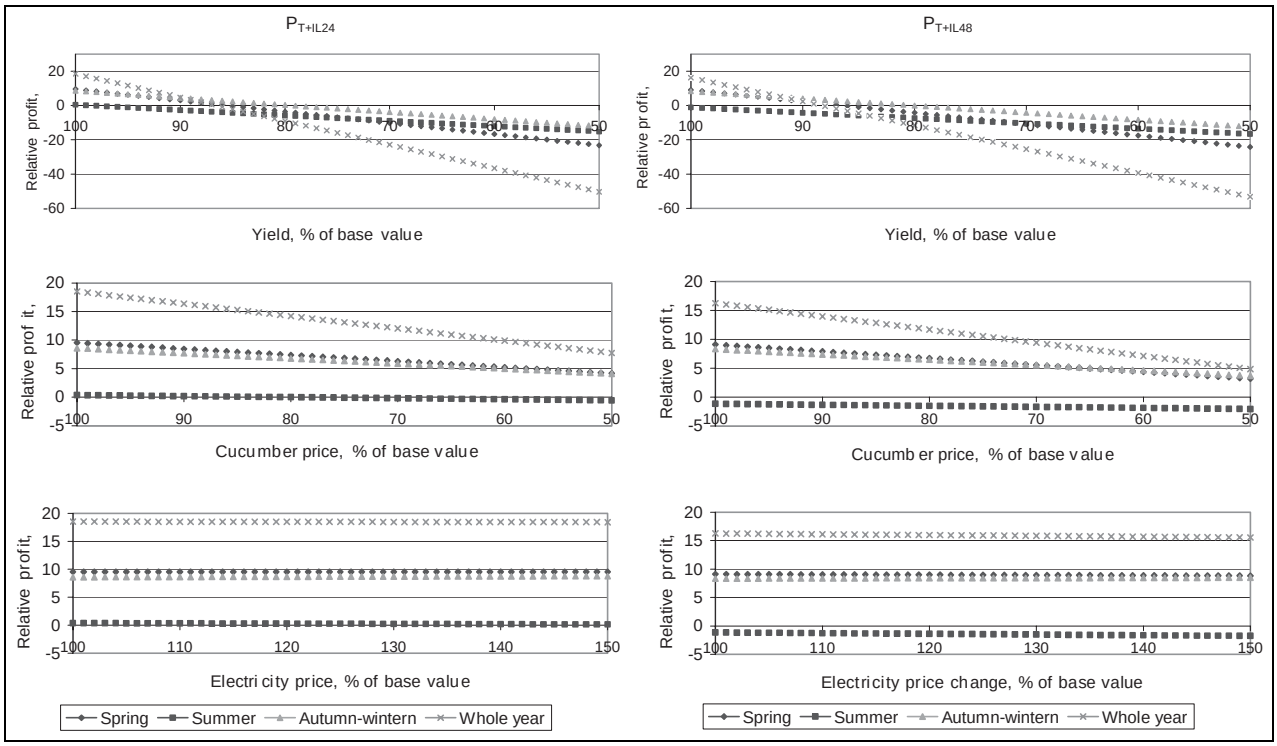


Fig. 2. Effects of amount of yield, cucumber price, and electricity price on relative profit according to sensitivity analysis.

P_{T+IL24} and 1.90 and 3.81 € m^{-2} in P_{T+IL48}, respectively. Similarly, one-year cut in the lifetime of interlighting bulbs caused a 0.47, and two years' cut a 1.90 € m^{-2} reduction in relative profit in P_{T+IL24} and 0.94 and 3.76 € m^{-2} in P_{T+IL48}, respectively. Moreover, each additional percentage unit of maintenance and repair costs reduced relative profit 0.05 € m^{-2} in P_{T+IL24} and 0.10 € m^{-2} in P_{T+IL48}, respectively.

Discussion

Interlighting proved to be an economically feasible lighting technique. According to this study slight interlighting (24 %) as well as intense interlighting (48 %) were both relatively more profitable than conventional top lighting in the yearly level. However, the advantage of interlighting turned up only in periods when the amount of global radiation was low, in autumn-winter and spring. In addition to the low amount of global radiation, also the angle of the sun altitude in Finland was extremely low during autumn-winter and spring (6 ° at lowest), and this emphasized the poor penetration of natural light into the lower part of the canopy. In autumn-winter and spring also the environmental conditions in the greenhouse were easier to control due to the lower outdoor temperatures. Thus the growth conditions were closer to the optimum than in the summer and light inside the canopy could be used more effectively, which made interlighting in the autumn-winter and spring time relatively more profitable.

Exogenous shocks, such as decreasing cucumber price or increasing electricity price, affected interlighting more strongly than top lighting, because interlighting treatments had relatively higher yield and they used higher quantities of electricity, respectively. However, even a 50 % change would not make top lighting relatively more profitable than interlighting.

The prospective investment cost reductions increased relative profit and made the adoption of interlighting more attractive. Even a four-year shortening of the lifetime of lighting fittings, and two-year shortening in the lifetime of bulbs, or 20 % higher repair and maintenance costs of interlighting did not solely make top lighting relatively more profitable than interlighting.

The adoption of interlighting turned out to be economically fairly risky; high management skills are needed for successful production, because only slight reduction of the yield makes interlighting no longer relatively more profitable than top lighting. Whether to use interlighting is, however, also dependent on the goal of the producer. Earlier studies have shown that interlighting improves cucumber fruit quality (Heuvelink et al. 2006; Hovi et al. 2004; Hovi-Pekkanen and Tahvonen 2008) and the grower may prefer producing better quality by using interlighting to maximising the profit.

In Finland's climate conditions interlighting provided economic benefit for the producer. However, the relative profit of interlighting seemed to be strongly affected by the light conditions, which means that geographic location probably had a similar effect, making interlighting a relatively more profitable lighting technique in northern latitudes compared to regions closer to the equator with better natural light conditions. Heuvelink et al. (2006) reported that in the Netherlands climatic conditions interlighting with fluorescent tubes did not substantially improve the yield and hence did not provide similar advantages than in Finland. However, further research with more alternative lighting techniques would be needed in order to find economically best lighting techniques. Also, more detailed assessment of the effects of natural light conditions on the economics of supplementary lighting are needed, before supplementary lighting techniques can be taken to use on the economically reliable basis.

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