Greenhouse Lighting Optimization for Tomato Cultivation Considering Real-Time Pricing (RTP) of Electricity in the Smart Grid

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Abstract: Nowadays, the human food needs is one of the important concerns of life science researchers. The scientific and technological agriculture can significantly help to reduce this concern. The movement from traditional agriculture to advanced and modern agriculture is quickly taking place. In this regard, usage of artificial light as the supplemental light in greenhouse cultivations is one of the most common techniques to increase greenhouse productions. Greenhouse is a part of the Smart Grid, where the activation of electricity energy market is applied. By Real-Time Pricing (RTP) of electricity energy, finding the optimum values of supplemental light for various cultivations and conditions in the greenhouse environments is very important. In this paper, by modelling and using the measured and presented data of cherry tomato in the greenhouse cultivation, the optimum amounts of supplemental light and required electrical energy for HPS lamps in the greenhouse environment are simulated and calculated. For this aim, two optimization techniques are considered which they are Iterative Search (IS) and Genetic Algorithm (GA). The simulation results verify the advantages of each method.

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1. Introduction

Today, usage of new sciences and technologies has been increasingly considered to solve the human life problems. According to the reports of the Food and Agriculture Organization (FAO), the food crisis is one of the most serious and most important crises of twenty first century. Insufficient financial resources, limitation of freshwater resources and agricultural land, incompatible climates, deficiency of required and suitable light for photosynthesis and so on are some of the most important development barriers of agricultural productions. Usage of industrial greenhouses can significantly help to solve or reduce of the mentioned problems. The ability of greenhouse climate control causes significant improvement of efficiency and performance of agriculture.

Greenhouse economic optimization is one of the key aims in today's advanced agriculture (Pasgianos et al.,2003). Greenhouse climate, a complex, nonlinear and uncertain system, consists of several major environmental factors such as temperature, humidity, light, co_2 concentration, etc (Hu et al., 2011). Due to many reasons, usage of industrial greenhouses in the agricultural science is increased significantly. Industrial greenhouses allow certain crops to be grown during all of the year. Greenhouses are very important in the food supply and food security in the most regions of the world especially in the high latitude countries. The most important factor in plant growth is light. Without enough light, photosynthesis in plants is impossible.

Nowadays, usage of artificial lighting and supplemental lighting in the greenhouses is very prevalent. Electrical lamps have been used to grow plants for nearly 150 years (Brazaityte et al., 2010). Optimal control of greenhouse lighting is one of the key techniques in digital agriculture. Due to many reasons, lighting sources installation in the greenhouse environments is justified extensively. Some of these reasons are Increment of crops quantity and quality, heat production, natural fight with plants pests, usage of surplus energy in the power system and smart grid, effective help to decreasing of carbon dioxide amount and increment of oxygen production, and ability of effective help to the smart grid in various directions such as voltage stability, oscillation damping and power quality improvement, etc.

Tomatoes have been grown in greenhouses for nearly 100 years (Anderson, 2002). Using artificial lighting for tomato cultivation has a big influence on tomato growth process (Dorais, 2003).

In the traditional power grid with the constant or quasi-constant tariffs, computation of costs and benefits for using artificial lighting in greenhouse environment is not very difficult and complex. By passing of traditional power grids era and beginning of the smart grid era, the situation will be changed quickly.

Smart grid is an advanced and developed electrical grid for delivering electricity from suppliers to consumers. Smart grid is a type of traditional electrical grid that efforts to forecast and intelligently respond to the behaviour and actions of all electric power users. The smart grid could be contain of some concepts such as power system stability, power system reliability, self healing, renewable energies, privacy and security, energy storage, flexibility in network topology, efficiency, sustainability, marketing, peak curtailment, price levelling and dynamic pricing (Biabani et al., 2011)

In the smart grid, the electricity market will be highly active. In this context, electricity tariffs could be different at any moment (Roozbehani et al., 2012). On the other hand, electricity tariffs in the smart grid will be a function of market rules and internal and external grid conditions. In these circumstances, the smart grid needs the smart loads definitely (Kumar et al., 2011). With proper control of electric energy in the bulbs, the most performance and efficiency in the greenhouse lighting system could be achieved (Zareipour et al., 2011). In case of neglecting the periodic prices in the electricity market in the smart grid, employing the artificial lighting in greenhouse environment could even be associated with financial losses (Motamedi et al., 2011). On the other hand, in case of inappropriate use of artificial lighting in greenhouse environment in smart grid, Performance and efficiency of system could be decreased to an amount less than its amount in conditions without using artificial lighting (Vijayapriya et al., 2010).

Nowadays, energy cost consideration has a particular importance in engineering economy. In advanced agriculture, requiring of supplemental light usage in greenhouse environments is unavoidable. Optimization of electrical energy consumption in greenhouse environments causes increasing of efficiency and performance in crop production (Ferentinosand and Albright, 2005). In this paper, greenhouse lighting optimization for cherry tomato cultivation is considered based on real-time pricing of electricity in the smart grid. The ultimate target is reaching to maximum possible amount of crop with minimum electrical energy cost. In this regard, two approaches are used. In one approach Iterative Search (IS) and in another one Genetic Algorithm (GA) are employed (Ferentinos et al., 2000). In this research, MATLAB software is used as one of the most common and most powerful engineering and programming software tool for implementation of mentioned approaches.

Next section describes the growth process of tomato. The modelling of the sunlight and HPS lamps are discussed in Section III. The electricity pricing in smart grid, Real-Time Pricing (RTP) and its modelling are presented in Section IV. The objective function for greenhouse lighting optimizing is presented in section V. The computer simulation results are presented in Section VI. Finally, Section VII concludes this paper.

2. Tomato Greenhouse Cultivation

The tomato is one of the most common global greenhouse productions. The growth of tomato is related to many factors and parameters. One of the most important factors is the light. The photosynthesis phenomenon has a strong direct relationship with light. Since long years ago, many models for modeling the relationship between photosynthesis and light are presented (Aalderink and Jovin, 1997). Some of these models are simple, while some others are sophisticated. Also employing of each of these models can bring some advantages and some disadvantages. Some of these models are expressed as shown in equations (1)-(6).

$$P\ (I) = \begin{cases} P_m \left(\frac{I}{I_s}\right) & I \le I_s \\ P_m & I > I_s \end{cases} \quad \mathit{Blackman}\,(1905)\ (1)$$

$$P\ (I) = P_m \frac{\left(\frac{I}{I_s}\right)}{1+\left(\frac{I}{I_s}\right)} \quad \mathit{Baly}\,(1935)\ (2)$$

$$P\ (I) = P_m \frac{\left(\frac{I}{I_s}\right)}{\sqrt{\left(1+\left(\frac{I}{I_s}\right)^2\right)}} \quad \begin{cases} \mathit{Smith}\,(1936) \\ \mathit{Talling}\,(1957) \end{cases} (3)$$

$$P\ (I) = P_m \left(\frac{I}{I_{opt}}\right) \exp\left(1-\frac{I}{I_{opt}}\right) \mathit{Steele}\,(1962)\ (4)$$

$$P\ (I) = P_m \left[1-\exp\left(\frac{I}{I_s}\right)\right] \mathit{web\ et\ al.}\,(1974)\ (5)$$

$$P\ (I) = P_m \tanh\left(\frac{I}{I_s}\right) \mathit{Jessby\ and\ Platt}\,(1976)\ (6)$$

It is worthy to mention that P (I), P_m, I, I_s and I_{opt} are photosynthesis amount, maximum photosynthesis amount, light amount, light saturation constant and optimal light amount, respectively.

Among of the presented models and due to selection of tomato cultivation as the study case in this paper, the equation (4) is selected as one of the photosynthesis models which it has an acceptable adaptation with tomato growth process and is shown in equation (7). This model has more flexibility and more adaptation for the case study of this research in comparison with other mentioned models. The graph of this model is shown in Figure 1.

$$P\ (I) = P_m \left(\frac{I}{I_{opt}}\right) \exp\left(1-\frac{I}{I_{opt}}\right) \mathit{Steele}\,(1962)\ (7)$$

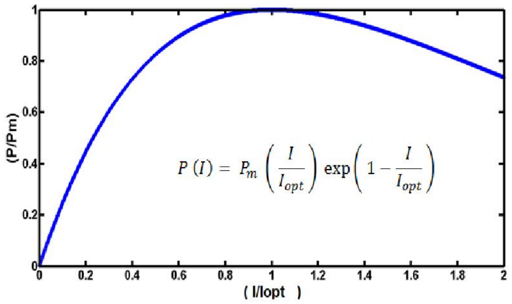


Figure 1. Steele photosynthesis model graph

In an accomplished practical research (Krumbein and Schwarz, 2013), cherry tomato bushes were cultivated in the greenhouse environment from 4 February to 4 June. The mean day length for place of research (Germany) can be considered approximately from 8AM to 4PM. In this research, the mean temperature was tuned 19.6 ± 1.89 ◦C and the relative humidity was tuned 74.8 ± 8.52% and the CO_2 concentration was tuned 391 ± 45.6 µmol mol. Also the plants were cultivated and fed according to the commercial practices. According to the mentioned research, the below table is extracted.

Table 1. Tomato production per plant based on amount of light during 120 days

Light (PAR) (mol/m2 day)	Fresh Tomato (Kg/Plant)
20.4	4.27
10.2	1.78

It is worthy to notice that Photosynthesis Active Radiation (PAR, measured in micromole/sec) is essential for plant growth, where 1 mole means $6*10^{23}$ photons. Also the plant density approximately is about 2 plants per square meter, so Table 1 is modified to Table 2.

Table 2. Tomato production per square meter based on amount of light during 120 days

Light (PAR) (mol/m2 day)	Fresh Tomato (Kg/m2)
20.4	8.54
10.2	3.56

By using values of table 2 in equation (7), the model of tomato production based on emitted light would be obtained. The model is illustrated by equations (8)-(9).

$$P\,(I) = 0.222\, I \exp\left(1-\frac{I}{56.1}\right) \left(\frac{Kg}{m^2}\right) \quad (8)$$

$$P\,(PAR_t) = 0.222\, PAR_t \exp\left(1-\frac{PAR_t}{56.1}\right) \left(\frac{Kg}{m^2}\right) \quad (9)$$

$$PAR_t = PAR_n + PAR_s \left(\frac{mol}{m^2\, day}\right) \quad (10)$$

It is noteworthy that PAR_t, PAR_n and PAR_s are the total amount of light, natural light (sunlight) and supplemental light, respectively.

3. Modeling of Light Resources

3.1. Sunlight Modeling

Sunlight is the best and costless kind of the light resources. The sunlight consists of continuous perfect spectrum of all wavelengths. The sunlight after passing through the earth atmosphere reaches to the earth surface in frequency domain of 250 nm-2500 nm which it consists of visible light domain (380 nm-720 nm) and invisible light domain. The photosynthesis frequency domain of plants is between 250 nm-750 nm. By extracting the sunlight radiation values in mentioned paper (Krumbein and Schwarz, 2013) for a real practical experiment and using MATLAB software, the model of sunlight could be obtained and formulated. It is worthy to notice that the peak of sunlight radiation occurs at solar noon time when the sun attains its greatest height above the horizon. The extracted values, result of modelling and model equation are shown in table 3, figure 2 and Gaussian equation (11), respectively.

Table 3. Sunlight at different time of the day

Time (Hour)	Sunlight (PAR) (mol/m^2 day)
0	0
6	0
8	1.42
12	31.2
16	1.42
18	0
24	0

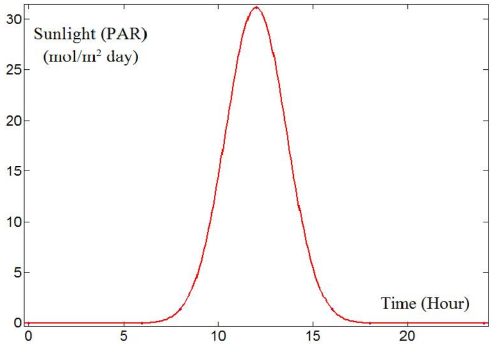


Figure 2. Model of the sunlight radiation

$$PAR_n = 31.2 \exp\left(-\left(\frac{Time-12}{2.273}\right)^2\right) \left(\frac{mol}{m^2\, day}\right) \quad (11)$$

Based on equation (10), the equating (12) can be written.

$$PAR_s = PAR_t - PAR_n \quad (12)$$

By combination of equations (10) and (12), model of the sunlight radiation can be expressed as equation (13).

$$PAR_s = PAR_t - 31.2\exp\left(-\left(\frac{(Time-12)}{2.273}\right)^2\right)$$

(13)

3.2. HPS Lamp Modeling

The most commonly used lamp type in the tomato cultivation is High Pressure Sodium (HPS) due to its favourable (PAR/Watt) value, low early and mid life failure rate. The HPS lamps range from some companies such as General electric (GE) has specially optimized spectra for greenhouse use, by enhancing the red portion of its light output. This means that HPS lamps designed for the greenhouse market can have lower light level (lumen) in the visible spectral range compared to HPS lamps designed for street lighting. Some technical data for HPS lamps which manufactured by GE are presented in Table 4. It is worthy to notice that the values of PARs (supplemental light) in the last column are calculated by using PAR values in the third column (General Electric Company, 2010).

Table 4. Technical data for GE HPS lamps (General Electric Company, 2010)

Lamp Type	Power (Watt)	PAR_s (μmol/m^{2}s)	PAR_s (mol/m^2 day)
LU250W/PSL	250	430	37.15
LU400W/PSL	420	710	61.34
LU600W/PSL	615	1080	93.31
LU750W/PSL	755	1320	114.05
LU400V/600W/PSL	620	1120	96.77
LU400V/750W/PSL	765	1390	120.1

By using curve fitting technique for data of Table 4, the relationship between PAR and lamp power could be modelled. By using MATLAB software (version 7.12.0) several models are obtained. The simulation results are shown in figure 3 and figure 4.

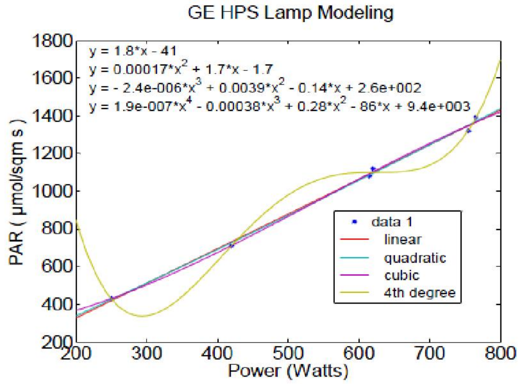


Figure 3. Several models for GE HPS lamps

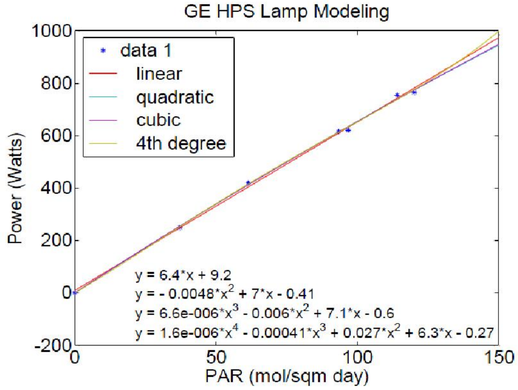


Figure 4. Different models for GE HPS lamps

By comparison of the models and by accepting an insignificant amount of error, the quadratic model is rewritten and is shown in equation (14) and (15).

$$PAR_s = 0.14688\left[\frac{(Power)^2}{10000} + (Power) - 1\right]$$

(14)

$$Power = \left[\left(\frac{-48}{10^4}(PAR_s)^2\right) + 7(PAR_s) - 0.41\right]$$

(15)

Where the Power is total wattage amount of HPS lamps.

4. The Electricity Pricing in the Smart Grid

4.1. Electricity Market and Electricity Price in the Smart Grid

In the smart grid, the electricity market is highly active. In this context, electricity tariffs could be different at any moment. On the other hand, electricity tariffs in the smart grid are a function of market rules and internal and external grid conditions. The price of electricity in the network could be calculated by smart grid every a few hours or minutes based on all conditions that they should be considered by the system. Then, the final net price of electricity would be informed to end users (Roozbehani et al., 2012). The period time of electricity price informing in smart grid determines based on power system and peripheral systems conditions. The real time electricity pricing creates a closed loop feedback between physical layer and market layer in the system. One of the important issues in the smart grid is dynamic pricing of electricity. In fact, by dynamic pricing of electricity, the customers such as greenhouse lighting could adjust and adapt their consumptions with the market conditions (Kumar et al., 2011). Various methods of electricity pricing such as Critical Peak Pricing (CPP), Time-of-Use Pricing (TUP), Real-Time Pricing (RTP) and so on are presented but one of the best of them is RTP method (Motamedi et al., 2010).

4.2. Modeling of Electricity Price in the Smart Grid

Modelling of electricity price in smart grid is one of the key features in the smart grid. An appropriate model for electricity price in the smart grid could be helping the Decision Makers (DMs) in all of the power network parts. DMs in power generation part, transmission part and consumption part could be increasing their abilities to make better decisions. The demand and price of electricity varies widely from moment to moment, hour to hour, day to day, and month to month. Figure 5 shows us the levels of demand (load) at different times of a day for a real and practical case. In fact, this graph presents the Real-Time Demands (RTDs) in the smart grid. Based on figure 5, figure 6 displays the Real-Time Prices (RTPs) of electricity during the 24-hour period (Joskow, 2012).

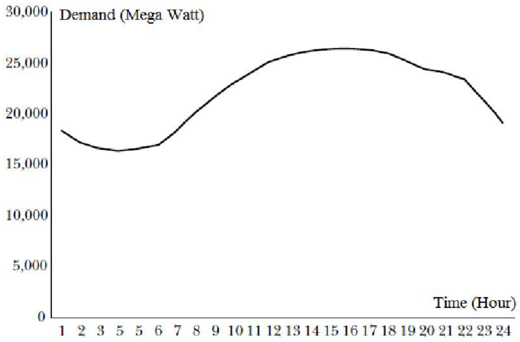


Figure 5. Real-time demands (RTDs) for electricity in the smart grid (Joskow, 2012)

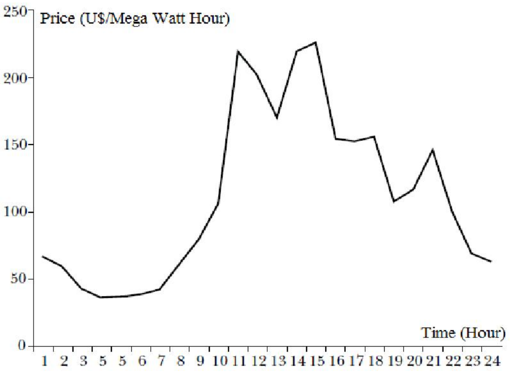


Figure 6. Real-time prices (RTPs) for electricity in the smart grid (Joskow, 2012)

By extracting the key spots of mentioned price curve and usage MATLAB software, an acceptable model can be obtained. This model presents the relationship between price of electricity and time. The simulation result is shown in figure 7.

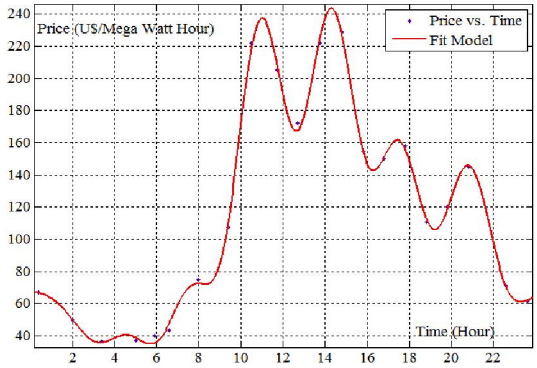


Figure 7. Curve fitting for 21 hot spots by using MATLAB

The Fourier equation (16) presents model of RTP for electricity in the smart grid.

$$Price = a_0 + \sum_{n=1}^{8}\left(a_n \cos\frac{n * Time}{3.879} + b_n \sin\frac{n * Time}{3.879}\right) \quad (16)$$

Where

a_0=114.3, a_1=-65.25, b_1=-48.16, a_2=26.08, b_2=-0.341, a_3=-12.33, b_3=2.064, a_4=-4.652, b_4=-1.629, a_5=4.869, b_5=12.62, a_6=-7.953, b_6=-1.68, a_7=16.71, b_7=11.76, a_8=-4.902, b_8=-9.571.

The goodness fitting values for this model are shown in table 5.

Table 5. Goodness fitting values for the proposed model

Index	Value
Sum Square Error (SSE)	142.6
R-Square	0.9984
Adjusted R-Square	0.9893
Root Mean Square Error (RMSE)	6.893

5. Greenhouse Lighting Optimization

5.1. Objective Function

The ultimate goal here is maximization of tomato cultivation profit by considering to several factors such as tomato price and electricity price in the market and photosynthesis phenomenon. In fact, finding the optimal amounts of total light and supplemental light is considered. The objective function can be written in the general form of equation (17).

$$Objective\ Function = (Income - Cost) \quad (17)$$

The Income function can be written as equations (18)-(20).

$$Income = (Amount\ of\ Tomato) * (Price\ of\ Tomato) \quad (18)$$

Where, the amount of Tomato is specified in equation (9).

$$Income = \left[\frac{P(PAR_t)}{(120 * 24)}\right] * 5 \left(\frac{US\$}{m^2 Hour}\right) \quad (19)$$

It is noteworthy that the mean price of cherry tomato is intended about 5 US$ per Kg [18]. Also the number 120 is the duration of tomato cultivation experiment and the number 24 is the hours of day and night.

Finally, by combining equations (9) and (19), Income function can be written as equation (20).

$$Income = \left[\frac{0.222\ PAR_t\ \exp\left(1 - \frac{PAR_t}{56.1}\right)}{576}\right]$$

$$(20)$$

By considering to electricity cost as the main factor in total cost in tomato cultivation, the Cost function can be written as equation (21).

$$Cost = (Consumed\ Power) * (Price\ of\ electricity) \quad (21)$$

Where, consumed power is specified in equation (15) and price of electricity is specified in equation (16). It is worthy to notice that the variable (PAR_s) in equation (15) is specified in equation (13). Based on equations (9), (10), (13) and (14), the Cost function could be written as equations (22).

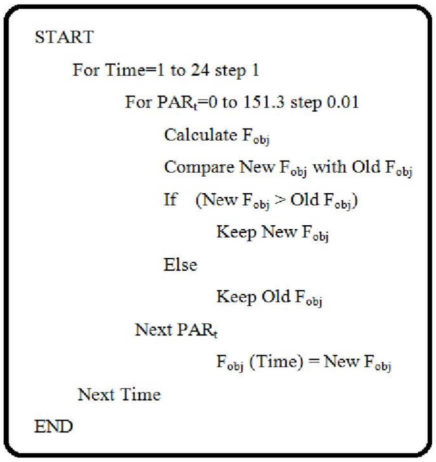
$$Cost = [\ (10^{-6}(([\ (-\frac{48}{10^4}(PAR_t - (31.2\exp\ (-\left(\frac{(Time-12)}{2.273}\right)^2)))^2) + 7(PAR_t - (31.2\exp\ (-\left(\frac{(Time-12)}{2.273}\right)^2))) - 0.41]))) (a_0 + \sum_{n=1}^{8} (\left(a_n \cos\frac{n * Time}{3.879} + b_n \sin\frac{n * Time}{3.879}\right)))] \left(\frac{US\$}{m^2 Hour}\right) \quad (22)$$

Finally based on equations (20) and (22), the objective function is presented in equation (23).

$$Objective\ Function = [\left[\frac{0.222\ PAR_t\ exp\left(1 - \frac{PAR_t}{56.1}\right)}{576}\right] - [\ (10^{-6}(([\ (-\frac{48}{10^4}(PAR_t - \Bigg(31.2\ exp\Bigg(-\left(\frac{(Time-12)}{2.273}\right)^2)))^2\Bigg)\Bigg) + 7(PAR_t - (31.2\exp\ (-\left(\frac{(Time-12)}{2.273}\right)^2))) - 0.41]))) (a_0 + \sum_{n=1}^{8} (\left(a_n\ cos\frac{n * Time}{3.879} + b_n\ sin\frac{n * Time}{3.879}\right)))] \left(\frac{US\$}{m^2\ Hour}\right) \quad (23)$$

By maximization the objective function, the profit of supplemental light usage for cherry tomato cultivation in the greenhouse environment will be placed at highest possible amount.

5.2. MATLAB Programming and Genetic Algorithm



```
START
    For Time=1 to 24 step 1
        For $PAR_t$=0 to 151.3 step 0.01
            Calculate $F_{obj}$
            Compare New $F_{obj}$ with Old $F_{obj}$
            If   (New $F_{obj}$ > Old $F_{obj}$)
                Keep New $F_{obj}$
            Else
                Keep Old $F_{obj}$
        Next $PAR_t$
                $F_{obj}$ (Time) = New $F_{obj}$
    Next Time
END
```

Figure 8. Pseudo code of iterative search

In this study, the MATLAB Software version 7.12.0 (R2011a) is used as one of the best and powerful analysis software. For this aim, two programs are written and employed with IS and with GA to find the best values for supplemental light in the greenhouse environment. In this regard, a desktop computer (Intel Core i3-2.4 GHz, 4 MB RAM, Windows 7 as 64-bit Operation System) is used.

For the first program Iterative Search (IS) technique is used. The program is expressed as pseudo program in figure 8.

For the second program, Genetic Algorithm (GA) is applied by using MATLAB toolbox.

It is worthy to notice that the Genetic Algorithm Procedure is:

i.[Start] Generate random population of n chromosomes

ii.[Fitness] Evaluate the fitness of each chromosome in the population

iii.[New population] Create a new population by repeating following steps until the new population is complete

iv.[Selection] Select two parent chromosomes from a population according to their fitness

v.[Crossover] With a crossover probability cross over the parents to form a new offspring (children). If no crossover was performed, offspring is an exact copy of parents.

vi.[Mutation] With a mutation probability mutate new offspring at each locus (position in chromosome).

vii.[Accepting] Place new offspring in a new population

viii.[Replace] Use new generated population for a further run of algorithm

ix.[Test] If the end condition is satisfied, stop, and return the best solution in current population

[Loop] Go to step ii.

Genetic Algorithm (GA) is a stochastic global search method. It is one of the most common used approaches for optimization. In fact, GA is a search technique used in computing to find problem solutions. Genetic Algorithm consists of four important steps. Evaluation, selection, crossover and mutation are these steps.

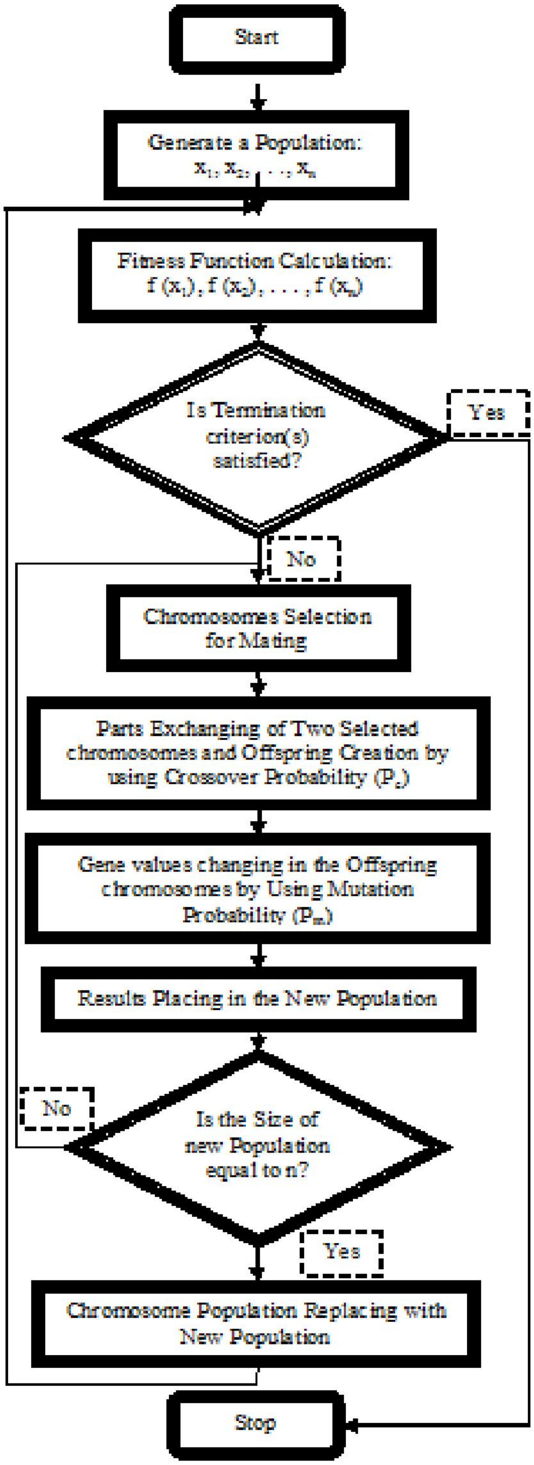


Figure 9. Flowchart of genetic algorithm procedure

In evaluation step, GA measures the fitness of each individual solution in the population and assigns to it a score. In selection step, the GA randomly selects individuals of the current population for development of the next generation. In crossover step, the GA takes two selected individuals and combines them about a crossover point thereby creating two new individuals. And finally in mutation step, the GA randomly modifies the genes of an individual subject to a small mutation factor and introducing further randomness into the population. This iterative process continues until one of the possible termination criteria is accepted. Figure 9 shows us a proposed GA flowchart.

6. The Simulation Results

In previous sections, the greenhouse cultivation for cherry tomato is considered. Although, the usage of supplemental and artificial lighting in greenhouse environments is for production increment but finding the optimum amount of required supplemental light is very important, especially when the electricity pricing is done by RTP method. By using obtained objective function and using MATLAB software, the amounts of optimum supplemental light and wattage of HPS lamps in the greenhouse environment have been obtained in two separated approaches. One approach is MATLAB programming with using GA toolbox and another approach is MATLAB programming with using IS. Figure 10 shows us the graph of optimum supplemental light with using IS.

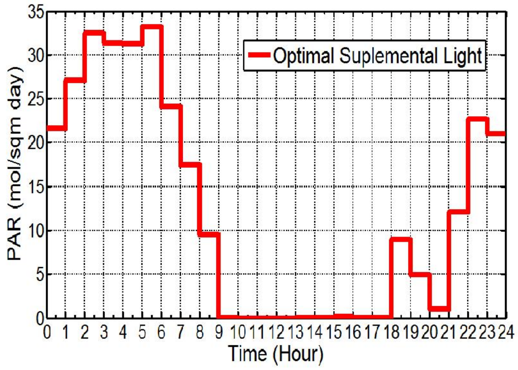


Figure 10. Optimum supplemental light with IS

Figure 11 shows us the graph of optimum supplemental light and HPS lamps wattage with using GA.

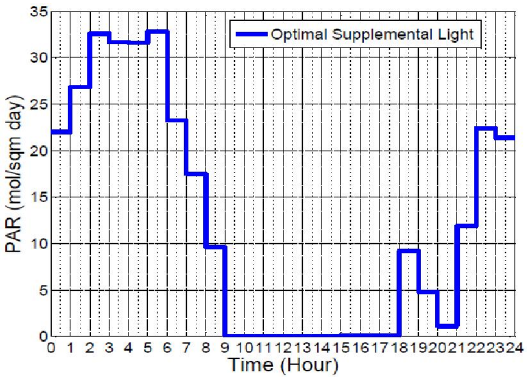


Figure 11. Optimum supplemental light with GA

It is worthy to notice that the setting parameters of GA toolbox are displayed in table 6.

Table 6. Setting parameters of GA in MATLAB toolbox

Setting Parameters of GA Toolbox	
Parameter	Setting
Population Type	Double Vector
Population Size	20
Parent Creation Function	Constraint Dependent
Scaling Function	Rank
Selection Function	Stochastic Uniform
Crossover Function	Two Points
Crossover Probability (P_c)	0.8
Mutation Function	Constraint Dependent
Mutation Probability (P_m)	0.2
Number of Generation	100

This is worthy to notice on termination criterion of the GA in MATLAB toolbox. Based on the performed setting, the program runs at least 50 generations. After passing of the 50th generation, if the difference value of 10 consecutive generations is less than 10^{-6}, the program running will be stopped. Otherwise the program runs for 100 generations and then stop.

It is worthy to mention that the termination criterion of GA can be adjusted through the parameters setting of GA toolbox.

Moreover, the numerical values for optimum supplemental light and HPS lamps wattage during the hours of day and night are displayed in Table 7. In this table, simulation results with IS and with GA are compared and evaluated.

Table 8. Comparison of computation times for simulation results

Simulation Subject	Approach	Computation Time (seconds)
Supplemental Light	**With** IS	6346.12
	With GA	937
HPS Lamps Wattage	**With** IS	6817.24
	With GA	984

Table 7. Optimum amounts of supplemental light, lamp wattage, income, cost and fitness value

Time (Hour)	Supplemental Light (mol/m^{2}day)		HPS Lamps Wattage (watt/m^2)		Income (US$/m^2 Hour)		Cost (US$/m^2 Hour)		Fitness Value (US$/m^2 Hour)	
	With IS	With GA	With IS	With GA	With IS	With GA	With IS	With GA	With IS	With GA
0-1	21.62	22	148.6864	151	0.0154	0.0156	0.0096	0.0097	0.0058	0.0059
1-2	27.13	26.8	185.9670	184	0.0175	0.0174	0.0095	0.0094	0.0080	0.0080
2-3	32.51	32.6	222.0869	223	0.0191	0.0191	0.0084	0.0084	0.0107	0.0107
3-4	31.32	31.7	214.1215	217	0.0188	0.0189	0.0084	0.0085	0.0104	0.0104
4-5	31.27	31.6	213.7835	216	0.0188	0.0188	0.0085	0.0086	0.0103	0.0102
5-6	33.19	32.8	226.6324	224	0.0193	0.0192	0.0084	0.0083	0.0109	0.0109
6-7	24.13	23.25	165.7052	160	0.0165	0.0162	0.0099	0.0096	0.0066	0.0066
7-8	17.43	17.5	120.1417	121	0.0141	0.0141	0.0088	0.0089	0.0053	0.0052
8-9	9.54	9.6	65.9131	67	0.0120	0.0121	0.0056	0.0056	0.0064	0.0065
9-10	0.026	0.015	0	0	0	0	0	0	0	0
10-11	0	0	0	0	0	0	0	0	0	0
11-12	0	0	0	0	0	0	0	0	0	0
12-13	0	0	0	0	0	0	0	0	0	0
13-14	0.027	0.015	0	0	0	0	0	0	0	0
14-15	0.046	0.035	0	0	0	0	0	0	0	0
15-16	0.113	0.09	0	0	0	0	0	0	0	0
16-17	0.057	0.05	0	0	0	0	0	0	0	0
17-18	0.064	0.07	0	0	0	0	0	0	0	0
18-19	8.98	9.2	62.0629	64	0.0080	0.0082	0.0067	0.0069	0.0013	0.0013
19-20	4.91	4.8	33.8433	33	0.0047	0.0046	0.0043	0.0042	0.0004	0.0004
20-21	1.02	1.1	6.7250	7	0.0010	0.0011	0.0008	0.0009	0.0002	0.0002
21-22	12.07	11.9	83.3807	82	0.0102	0.0095	0.0082	0.0075	0.0020	0.0020
22-23	22.68	22.4	155.8810	154	0.0159	0.0157	0.0099	0.0098	0.0060	0.0059
23-24	20.97	21.4	144.2692	147	0.0151	0.0153	0.0095	0.0097	0.0056	0.0056
Average					0.0086	0.008575	0.0048542	0.0048333	0.0037458	0.0037417

Moreover, computation times of these simulations for the both mentioned approaches are displayed and compared in table 8.

7. Conclusion

In this study, the optimization of a greenhouse supplemental lighting based on RTP in the electricity energy market is investigated. Greenhouse efficiency increment is one of the key aims in the advanced agriculture. The control of greenhouse climate is one of the most important issues in the industrial agriculture. Greenhouse climate, a nonlinear and uncertain system, consists of several major environmental factors such as temperature, humidity, light, co_2 concentration, etc. Controlling and tuning of a greenhouse parameters such as light has a majority role in increasing the greenhouse efficiency and increasing the crops cultivation performance. Among all of the mentioned parameters, the light is the most important parameter. Plants are related to light for photosynthesis phenomenon and the key parameter in photosynthesis process is the light. Optimal supplemental light determination and then greenhouse lighting control based on that can increase the economic efficiency of greenhouses.

For this aim, an appropriate model for cherry tomato plant is selected. Also a model for sunlight radiation based on measured data in considered greenhouse, a model for HPS lamps according to the manufacture's data (GE) and a model for Real-time Pricing (RTP) of electricity in the smart grid are simulated and obtained. By using the mentioned models and other data together, the objective function is obtained.

MATLAB software toolbox is used for maximum values calculation of the objective function during the specified time periods. In this regard, the simulation is obtained with Iterative Search and with GA. The simulation results show us that the optimum values for supplemental light and required electrical power for HPS lamps during various hours are different in both mentioned approaches. Also the optimal values of supplemental light in various greenhouse environments, cultivations, climates, geographic locations, and seasons and so on can be different. The obtained optimum values of electrical power for HPS lamps maximize the economic efficiency and performance of considered cherry tomato greenhouse cultivation in the electrical energy section.

Also the simulation results show us that each of the considered approaches has some advantages and disadvantages. The main advantage of the first approach (Iterative Search) is high computational precision and its main disadvantage is low computational speed. Vice versa, the main advantage of the second approach (with GA) is high computational speed and its main disadvantage is low computational precision. However, it is worthy to notice that according to this argument, employing GA approach in the mentioned application is justified. On the other hand, the simulation results verify usage of GA for computation method.

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