Productivity optimization of screen house layout design

G. Vitner[1], A. Bechar[2]

(1. *Ruppin Academic Center*, *School of Engineering*, *Emek-Hefer* 40250, *Israel*;
2. *Institute of Agricultural Engineering*, *Agricultural Research Organization*, *Bet-Dagan* 50250, *Israel*)

Abstract: The study investigated the optimization of the screen house design to improve the growth productivity of green ornamentals. It focused on the labor-intensive handling operations in order to minimize the time invested in these operations and to maximize the total revenue. The research was performed during 2006–2007 in two modern farms in the central part of Israel. The farms contained 7 and 11 ha of Pitosporum and Aralia screen houses. The various stages of harvesting on each farm were subjected to work studies and time measurements, and a computer simulation model was developed with the ARENA 7™ to find an improved screen house layout. The main goal was to determine the time per stem and hourly output per worker as functions of length of row and cart location. Results show that for the examined cultivars and the present working methods, the best outcome was reached when the row length was the shortest of those examined. There was a decrease of 35% in output when row length increased from 24 to 200 m. Simulation results showed that the best length of a screen house was 24 m. Furthermore, the optimal location of the cart used to transfer the crops to the packaging house was determined.

Keywords: Pitosporum, Aralia, work methods, screen houses, layout, productivity, simulation

Citation: G. Vitner, A. Bechar. 2011. Productivity optimization of screen house layout design. Agric Eng Int: CIGR Journal, 13(1): —.

1 Introduction

Pitosporum represents one of the major plant exports from Israel worldwide. The farmer's goal is to maintain continuous year-round sales, and the growing cycle extends through the entire year, with peaks in the growth rate from February through June and September through November.

Aralia has been grown in Israel since the late 1990 s; it started as a specialized ornamental plant for German-speaking countries, but it has spread widely to other European countries because of aggressive marketing and climatic considerations.

Green ornamental plants are grown in screen houses, which are agriculture structures covered with high-density plastic netting, and providing protection from the sun, insects, and other pests. The netting may be in various colors, such as black, white, red, etc. to provide various levels of shading, to reduce heat intensity during the day, and to control the spectrum of the light that penetrates the nets. Screen houses in various farms may differ in their geometric dimensions, sizes of gables, number and location of service paths, and screen colors (Figure 1). Furthermore, various working methods are possible.

Figure 1 An example of a screen house with red nets

Received date: 2010-08-02 **Accepted date:** 2011-02-18
Author's email: G. Vitner's, gadiv@ruppin.ac.il.; **A. Bechar's,** avital@volcani.agri.gov.il.

Work methods analysis is a commonly employed technique designed to improve productivity (Globerson, 2002). The determination of standard times for agricultural work processes, such as harvesting, is essential to enable efficient labor management (Luxhoj and Giacomelli, 1990; Bechar et al., 2007). Bochtis et al. (2007) discussed the issue of field operations planning for agriculture vehicles. Implementing the vehicle routing problem (VRP) in agriculture may support efficient management of machine routing during harvesting (Bochtis and Sorensen, 2009).

Finding the optimal solution for a given operational scenario is a classic industrial engineering problem. By definition optimal solutions (Taha, 2003) supplied the best results, but implementing such solutions may be complicated. Also, optimization was not often applied in agricultural operations because of the lack of complete database, high variability and low accuracy of the operational, marketing, and environmental parameters (Vitner, Giller and Pat, 2006). Therefore we used simulation to support the analysis of operational variables associated with growing crops in a screen house.

The present study aimed to improve crop productivity in screen houses and to develop recommendations that could support the design and construction of new screen houses. The putative recommendations would cover: improvement of work methods, increasing the efficiency of work processes, and improving screen house design. Improvement of work processes is achieved by using industrial engineering methods, such as are common in various industries. The methods used in the present study were: work study and time measurements (Vitner et al., 2007), layout design, and simulation techniques (Cros et al. 2003; Igbadun et al. 2006). The article is based on a study conducted during 2006 - 2007.

2 Materials and methods

2.1 Farm data

Data were collected on two modern farms in the central part of Israel. The farms have 7 and 11 ha of various green ornamentals in screen houses, and employ 14 and 13 workers, respectively. Work studies and time measurements were performed during the harvesting period. Working processes, layouts and geometries of the screen houses were examined. The green ornamental species under investigation were Pitosporum and Aralia, whose annual yield is 700 000 - 800 000 stems/ha.

2.2 Screen house layout

The design of a screen house encompasses: geometric dimension (length, width, and distance between gables), screen type (density, mesh, and color), and service path characteristics (location, and width). The present study aimed to improve productivity of the harvesting phase. Figure 2 is a schematic depiction of a typical screen house layout with six plots.

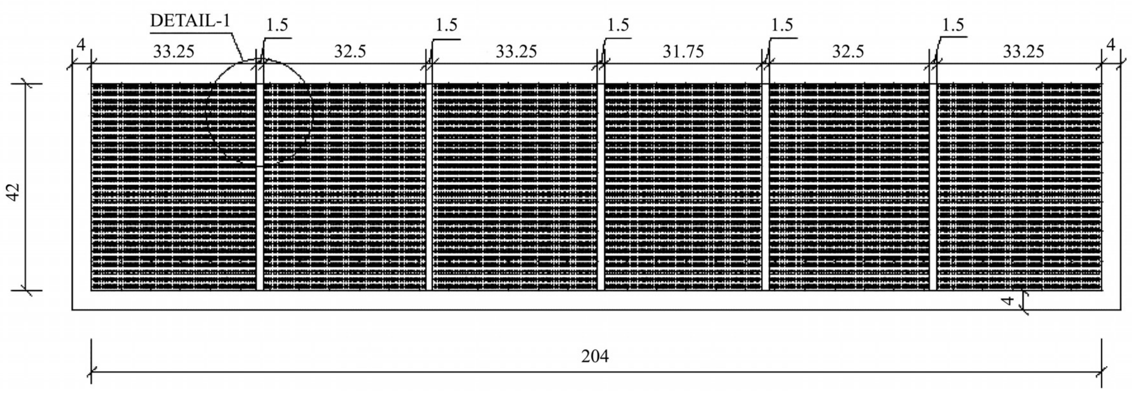

Figure 2 Typical screen house layout scheme. (Unit dimension is m)

2.3 Work methods

The harvesting processes of both cultivars are similar except that Pitosporum is harvested selectively.

Aralia – harvesting work elements in both farms are as follows: 1) harvest a stem; 2) move the stem from the picking hand to the other hand; 3) band a group of stems with a rubber band lay the bundle on the ground and continue harvesting; and 4) at the end of the process the bundles are picked up loaded onto a cart outside the screen house and transferred to the packing house.

Pitosporum – a selective procedure is conducted. 1) Identify and harvest an appropriate stem according to the farmer's instructions; 2) move the stem from the picking hand to the other hand; 3) band a group of stems with a rubber band lay the bundle on the ground and continue harvesting; and 4) at the end of the process the bundles are picked up loaded onto a cart and transferred to the packing house.

2.4 Work and time measurements

Work studies were conducted by means of direct measurements and work sampling techniques (Meyers and Stewart, 2001). Time measurements were made using work study software developed for handheld computers (Bechar et al., 2005).

2.5 Simulation

Detailed graphical simulation models for working processes with green ornamentals in screen houses were developed in ARENA 7 software – a simulation environment that uses a graphical flowchart presentation; the models simulate all work processes. The time distribution of the worker's operations is determined by using work study results.

The model starts with a worker selecting a row, conducting the harvest and loading the bundles or nets onto the cart.

The simulation inputs were: number of rows in the screen house, row length, number of plants in a row, operating time per plant, cart location, and the number of workers. The outputs of the simulation were: total working time per row, net working time (the worker's productive time), yield and the optimal cart location.

3 Results

The results are based on data collected and measured on the farms under study; they represent a typical production process of green ornamentals in screen houses.

3.1 Work study

Work processes were divided into elements as described in the Work Methods section. In addition to the described elements two more elements that are not directly related to the harvesting process were defined: 'service' – any auxiliary operation that supports the regular process; and 'other' – any other activities.

Tables 1 and 2 present time study results for the Aralia harvesting elements in the two farms under study.

Table 1 Time study results for Aralia harvesting elements in farm A

Element	Harvest a stem	Move to other hand	Banding	Pick and Load	Other	Service
Avg. time/s	1.88	2.33	9.95	29.86	39.50	40.75
Standard deviation/s	1.73	1.58	4.55	36.65	32.84	27.39
Total observations	7,180	2,003	118	14	10	8
required sample size	1,307	706	321	2,316	1,063	695
Total time/s	13,512	4,672	1,175	418	395	326
Percentage of total work	65.9	22.8	5.7	2.0	1.9	1.6

Table 2 Time study results for Aralia harvesting elements in farm B

Element	Harvest a stem	Move to other hand	Banding	Other	Service
Avg. time/s	1.6	1.5	8.1	17.4	14.5
Standard deviation/s	1.7	1.1	2.9	19.3	11.4
Total observations	7,651	2,180	106	14	17
required sample size	1,703	848	192	1,894	951
Total time/s	12,499	3,230	860	243	247
Percentage of total work	73.0	19.0	5.0	1.0	1.0

The results for Aralia reveal that the dominant working elements are: harvesting (66%-73%) and moving bundles to the other hand (19%-23%). Nonproductive elements account for 2%-3.5% of the total working time. The times for the various elements are similar in both farms. Table 3 presents time study results for the Pitosporum harvesting elements.

Table 3 Time study results for Pitosporum harvesting elements

Element	Harvest a stem	Move to other hand	Banding	Pick and Load	Other	Service
Avg. time/s	2.93	1.487	13.24	89.36	34.00	10.62
Standard deviation/s	4.1	0.9	5.8	54.1	51.0	13.2
Total observations	2,971	1,687	96	25	7	16
required sample size	3,030	522	294	563	3,453	2,367
Total time/s	8,713	2,508	1,271	2,234	238	170
Percentage of total work	57.6	16.6	8.4	14.8	1.6	1.1

The results for Pitosporum show that the dominant work elements are: harvesting (58%) and handling activities ('move to other hand' and 'pick and load' – about 32%). Nonproductive elements account for 3% of the total working time.

3.2 Simulation

The simulation model simulates the working activities in the screen house. It enables a sensitivity analysis to be applied in order to determine the productivity of various combinations of the relevant variables and to compare several different work methods. The model uses the data (distributions of the work elements) collected during the work study phase. The main goal was to determine the time per stem and hourly output per worker as functions of row length, distance between rows, distance between plants, work pace, and number of workers. The model contains two basic parts: harvesting (Figure 3) and 'pick and load' (Figure 4).

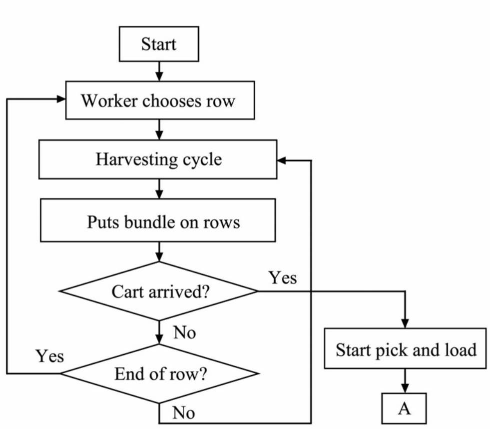

Figure 3 Harvesting process flow chart

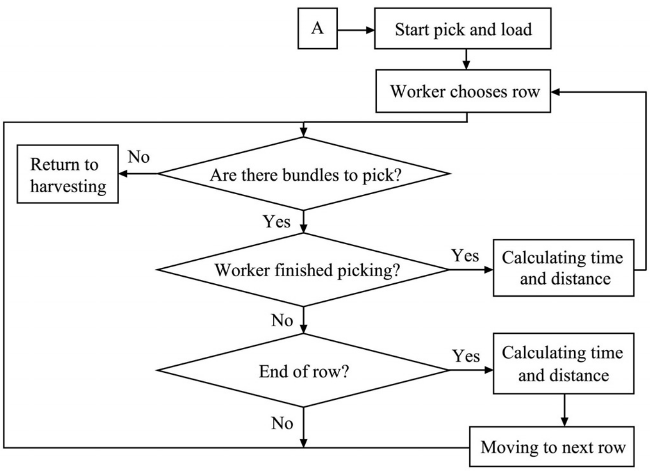

Figure 4 Pick and load process flow chart

Based on the work study data of the working elements, statistical distributions of the dominant elements were calculated using the input analyzer tool of the ARENA. The statistical distributions were used as inputs to the simulation and are given in Table 4.

Table 4 Statistical distributions of the dominant working elements

Element	Harvest a stem	Move to other hand	Banding
Aralia farm A	log*N*(2.27, 1.33)-0.5	14*β(1.1, 9.26)+0.5	*N*(11.8, 4.36)
Aralia farm B	-0.5+20*β(4.17, 34.3)	0.5 + exp(1.04)	*N*(8.54, 2.47)
Pitosporum	exp(2.96)	17*β(0.84, 14.4)+0.5	3.5+*WEIB*(12.8, 2.62)

A validation process was conducted to verify that the model simulated the real infrastructure.

All combinations of the various variables were examined. The range and resolution of the variables are shown in Table 5.

Table 5 Range and resolution of the variables

Variable name	Unit	Range	Resolution
Row length	m	200-24	8
Cart locations	---	a, b, c*	

* see Figure 6.

3.2.1 Picking cart locations

Figure 5 presents a schematic layout of the screen house and the picking cart location. There are various options for locating the cart.

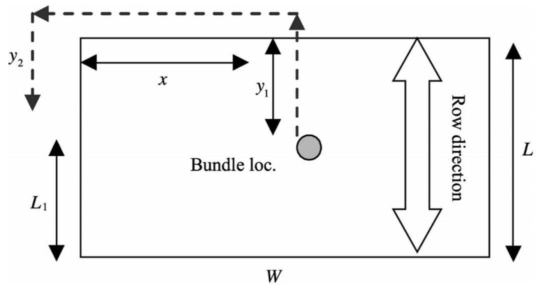

Figure 5 Schematic layout of the screen house and the picking cart location

The layout variables are: L and W – screen house length and width respectively; L_1 – cart location along the length axis; y_1 – walking distance along the row from bundle to end of row; x – distance between row end to screen house edge; y_2 – distance from screen house edge to cart (y_2 = L – L_1); and D – walking distance from bundle to cart, i.e. $D = y_1 + x + y_2$;

The examined cart locations are presented in Figure 6. In cases *B* and *C* the cart is located outside the screen house in the middle of the width and length of the screen house respectively.

Walking distances for each case are $D = x + Y_1$ (Figure 6a), $D = Y + \left| \frac{W}{2} - X \right|$ (Figure 6b) and $D = X + MIN(Y + L_1, 2L - Y - L_1)$ (Figure 6c).

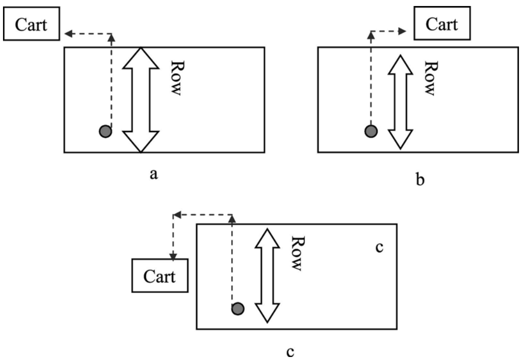

Figure 6 Three examined cart locations

3.2.2 Worker yield

Figure 7 presents worker yield as a function of row length and cart location. Results show a monotonic decrease of worker yield with increasing row length (decrease of 35% as the row length increases from 24 to 200 m). The best yield is achieved with a row length of 24 m (the minimal screen houses row length). As the row length increases, the worker's walking time increases because of the limited amount of bundles that can be carried; the worker returns to the same row several times in order to collect all bundles. The best solution for all combinations was with the cart located as illustrated in Figure 5b. The most unsuitable location of the cart was as illustrated in Figure 5c. The density of plants (i.e., distances between rows and plants) do not influence the quality of the simulation results but the production rate value. However, since this cultivar is very dense the practical influence is neglected.

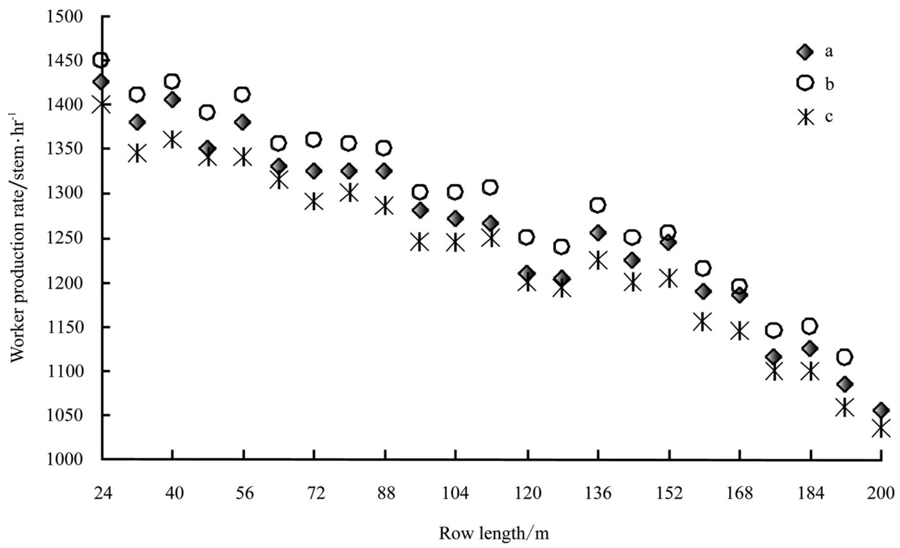

Figure 7 Worker yield as a function of the row length and cart location

4 Conclusions

The objectives of the study are to improve work methods in farms that grow green ornamentals, to increase productivity and to develop an optimal screen house layout. The research began by subjecting the various operational processes to work study and time measurement. Then, a simulation model based on the Arena software was developed. This model was used to determine the best location of the picking cart. The results show that better outputs were obtained with shorter rows: output decreased by 35% when the row length increased from 24 to 200 m.

The optimal dimensions of a one-hectare screen house are: row length 24 m; house width 420 m. Use of short rows (24 m) eliminates need for intermediate paths, because for longer rows there is a need for a 1.45-m-wide intermediate path to facilitate material handling. Thus, intermediate paths will reduce the total plot yield because of reduction of the net production area. In the case of adjacent screen houses, there should be a wide path between them for tractors and heavy machinery pass. Use of suitable conveying carts for in-row use might increase the optimal row length, but it would necessitate increasing the distance between rows and therefore also affect total plot yield.

Acknowledgments

We would like to thank David Harel, Dor Fine and Kobi Refael for their contributions to the measurements and data analysis.

[References]

[1] Bechar, A., D. Dayan, S. Schmilowotch, Y. Moskovitch, and Y. Edan. 2005. A Pocket-Pc-Based Platform for Agricultural Work Study Measurements. The 35th International Conference on Computers and Industrial Engineering, at Istanbul, Turkey.

[2] Bechar, A., S. Yosef, S. Netanyahu, and Y. Edan. 2007. Improvement of work methods in tomato greenhouses using simulation. Transactions of the ASABE, 50(2): 331–338.

[3] Bochtis, D., S. Vougioukas, C. Tsatsarelis, and Y. Ampatzidis. 2007. Field Operation Planning for Agricultural Vehicles: A Hierarchical Modeling Framework. Agricultural Engineering International–The CIGR Ejournal IX.

[4] Bochtis, D. D., and C. G. Sorensen. 2009. The vehicle routing problem in field logistics part I. Biosystems Engineering, 104(4): 447–457.

[5] Cros, M. J., F. Garcia, R. Martin-Clouaire, and J. P. Rellier. 2003. Modeling Management Operations in Agricultural Production Simulators. Agricultural Engineering International – The CIGR Ejournal V.

[6] Globerson, S. 2002. Operation Management and Performance Improvement. Tel-Aviv: Dionon.

[7] Igbadun, H. E., H. F. Mahoo, A. K. P. R. Tarimo, and B. A. Salim. 2006. Irrigation Scheduling Scenarios Studies for a Maize Crop in Tanzania Using a Computer-based Simulation Model. Agricultural Engineering International – The CIGR Ejournal VIII.

[8] Luxhoj, J. T., and G. A. Giacomelli. 1990. Comparison of labor standards for a greenhouse production system: A case study. International Journal of Operations and Production Management, 10(3): 38–49.

[9] Meyers, F. E., and J. R. Stewart. 2001. Motion and Time Study for Lean Manufacturing. 3rd ed. New Jersy: Prentice Hall.

[10] Taha, H. A. 2003. Operations research: An introduction. New Jersey: Prentice Hall.

[11] Vitner, G., A. Bechar, A. Kiryati, O. Eshet, and O. Shental. 2007. Quality and Productivity Improvement of Wax Flowers. Agricultural Engineering International – The CIGR Ejournal IX.

[12] Vitner, G., A. Giller, and L. Pat. 2006. A proposed method for the packaging of plant cuttings to reduce overfilling. Biosystems Engineering, 93(3): 353–358.