

HARVESTING FREQUENCY IMPACT ON THE ECONOMICS OF A SWEEPER BASED MECHANICAL NUT HARVESTING SYSTEM

A. T. M. Ziauddin*

ABSTRACT

A sweeper based Macadamia nut, (*Macadamia Integrifolia*) harvesting model for machine harvest was developed to determine an optimal harvesting schedule. The total cost including nut spoilage was used as optimization criterion. Nut spoilage as a function of soil moisture was modeled. The optimal harvesting interval with a policy of uniform harvest interval and with a policy of non-uniform harvest interval were found to be at 10 days and 12-7-12 days, respectively.

Key Words : Nut, Harvesting, Economics, Model and System

INTRODUCTION

Traditionally Macadamia nuts (*Macadamia Integrifolia*) are harvested from ground by hand after falling naturally from the tree. A large portion of the crop continues to be harvested in this fashion, but mechanical harvesting of naturally fallen nuts by a combination of sweepers and collectors is also used. Still a third method to harvest naturally fallen nuts is the use of nets suspended beneath the trees (Liang and Lopez-Madrado, 1973). The normal harvest period is about 7 months, from August through February in the northern hemisphere and from about March through September in the southern hemisphere, during which time essentially the entire crop is harvested. Length of the harvest season varies between cultivars, with some cultivars having a peak season but some production throughout the year.

Macadamia nut falling on the ground must be picked at proper time to prevent quality deterioration. Nuts on wet ground are soon lost due to rot, mold and germination. This loss is significant if harvesting is not performed in proper time. The amount of nut damage due to rot or mold largely depends on soil moisture and the length of nut exposure time to the high soil moisture. The frequency of harvesting depends a great deal on the falling pattern of nuts and the nut spoilage characteristics. Frequent harvest of nuts cuts down nut spoilage but increases the harvesting cost. On the other hand, delay of harvest increases the nut spoilage. The question about the optimal time of harvest becomes difficult to answer. A quantitative management model integrating adequately the relevant

*Professor, Department of Farm Power & Machinery Bangladesh Agricultural University, Mymensingh, Bangladesh

variables of nut harvest into a cost criterion can help determine the optimal course of action. The objective of the study was to develop a sweeper based mechanical nut harvesting system model.

METHODOLOGY

Tree nuts on the ground are sometimes harvested mechanically. A sweeper based nut harvesting system can be represented as a process of interrelated operations. Pattern of natural fall of nut, soil moisture content, labour cost, nut spoilage, farm productivity and farm area have highly significant effects on this process. Evaluation of the overall system response to any activity of the harvesting system is very difficult to conduct without a model. The following assumptions have been made in modeling the system.

1. The effect of unfavourable weather on nut harvesting system is neglected.
2. The harvesting season is approximately equally divided into three sections—early harvest, peak harvest and late harvest periods.

The Model :

The model consists of two major components, namely, Harvesting Cost Submodel and Nut Spoilage Submodel. The total harvesting cost of the entire harvesting season is calculated by the Harvesting Cost Submodel. The Nut Spoilage Submodel simulates the value of total nut spoilage for the entire harvesting season. Since the total harvesting cost and the value of total nut spoilage depend on harvesting frequency, the two major components are modeled as functions of harvest interval. The overall criterion for selecting optimal harvesting schedule is defined in expression (1).

$$\begin{array}{l} \text{Minimize } Z = \sum_{j=1}^N [(H_j + P * S_j) / (T * Y)] \\ \text{with respect to } \Delta t_j \end{array} \quad \dots \dots \dots (1)$$

Where,

H_j = Machine harvest cost at jth harvest, \$ / ha

Δt_j = Harvest interval at jth harvest, day

N = Total number of harvest in the season

P = Price of nut, \$ / kg-inshell

S_j = Nut spoilage at jth harvest, kg-inshell / ha

Z = Average harvesting cost, \$ / kg-inshell

T = Number of productive trees per hectare

Y = Yield, kg-inshell / tree

1. Harvesting Cost Submodel :

The purpose of this cost model is to simulate nut harvesting cost incurred at each harvest. For mechanical harvest, fixed and operating cost constitutes the harvesting cost. The operating cost component includes repair and maintenance, wages of skilled laborer, fuel and oil expense. The fuel and oil consumption of the harvester were modeled as a function of the nut density on the ground. The harvesting cost is affected by nut falling pattern, harvesting interval, productivity of the farm, nut density on the ground, wage, nut price and the price of nut harvester. The model components are described as follows :

i) Harvest Date and Harvest Interval : The relationship between harvest date and harvest interval can be described by expression (2).

$$X_j = X_0 + \sum_1^j \Delta t_j \quad \text{for } j = 1 \text{ to } N \quad \dots \dots \dots (2)$$

Where,

X_j = Harvest date of jth harvest, julian date

X_0 = Beginning date of harvesting season, julain date

ii) Natural Fall of Nuts : The amount of nuts on the ground at anytime depends on the falling pattern, yield per tree, variety of nut and productive area of the farm. Expression (3) shows how G_j are affected by.

$$G_j = \frac{g_j * Y * T}{100} \quad \text{for } j=1 \text{ to } N \quad \dots \dots \dots (3)$$

Where,

G_j = Accumulated nut on the ground on date X_j
(i. e. at the jth harvest), kg-inshell / ha

g_j = Accumulated ground nut on date X_j , % of yield ; (= $\alpha + \beta X_j + \gamma X_j^2$)

α, β, γ = Parameters

The following model for g_j that adequately fits the data of Liang, (1976) has been used to simulate the natural fall of nuts.

$$g_j = -223.45 + 1.296 X_j - 0.00116 X_j^2$$

(0.342) (0.00056)

($R^2 = 0.9625$, $F = 166.86$, $S_{yx} = 7.254$)

The fixed cost per harvest is calculated as (Hunt, 1979)

$$FC = \frac{f * P_m}{A * N} \quad \dots \dots \dots (4)$$

Where,

A = Total productive area of the nut farm, ha

f = Annual fixed cost, decimal of purchase price of harvester.

FC = Fixed cost of harvester per harvest, \$ / ha / harvest

P_m = Purchase price of the nut harvester, \$

The operating cost (OC_j) of the harvester per harvest per hectare is calculated as (Hunt, 1979):

$$OC_j = \frac{10}{V_j W e} (r_m + L + O + F_j) \quad \text{for } j = 1 \text{ to } N \dots \dots \dots (5)$$

where,

e = Field efficiency of the harvester, decimal

F_j = Fuel cost at jth harvest, \$/hr; (= 2 - 0.009 d_j)

d_j = Nut density on the ground at jth harvest, kg-inshell/tree

L = Wage for harvester operator, \$/hr

O = Oil cost, \$/hr

r_m = Repair and maintenance cost, \$/hr

V_j = Speed of harvester at jth harvest, km/hr; (= 2 - 0.01 d_j)

W = Size (width) of the harvester, m

Thus, the harvesting cost for jth harvest, using the method of mechanical harvest is:

$$H_j = FC + OC_j \quad \text{for } j = 1 \text{ to } N \quad \dots \dots (6)$$

2. Nut Spoilage Submodel :

The Nut Spoilage Submodel simulates the amount of nut spoilage during a harvest interval. It has been observed that the soil moisture largely contributes to the quality deterioration of the nuts. In some cases, quality deterioration of nuts may also be occurred due to insect infestation. A simple nut spoilage model based on soil moisture content, developed by Liang and Ziauddin (1985) has been used to simulate the amount of nut spoilage. The nut at jth harvest is calculated as;

$$S_j = \frac{(s_j - s_{j-1}) * (G_j - G_{j-1})}{100} \quad \text{for } j = 1 \text{ to } N \quad \dots \dots (7)$$

(s_{j-1} = 0 & G_{j-1} = 0 for j = 1)

where,

s_j = Cumulative nut spoilage at jth harvest, %

(= b₀ + b₁ M_d + b₂ M_d²)

b₀ b₁ and b₂ = Constants

M_d = Moisture-day, (= $\sum_{i=1}^n (m_i - K) / 100$)

m_j = Soil moisture content on day i, % by volume

K = A constant (= 9)

n = Number of days nuts remain in contact with soil

The following nut spoilage model developed by Liang and Ziauddin (1985) was used to simulate the percent of nut spoilage at jth harvest.

$$r_j = -1.5231 + 0.6443 M_{j1} + 0.0108 M_d^2 \quad ; \text{ for } M_d \geq 2.28$$

$$(0.07887) \quad (0.0339)$$

$$(R^2 = 0.9596, F = 724.19, S_{yx} = 1.13)$$

The total cost per hectare at jth harvest as a result of mechanical harvest is;

$$C_j = H_j + P * S_j \quad ; \quad \text{for } j = 1 \text{ to } N \quad \dots \quad \dots \quad \dots \quad (8)$$

Thus, the average nut harvesting cost, \$/kg-inshell nut, can be modeled as :

Minimize $Z = \sum_{j=1}^N (H_j + P * S_j) / (T * Y) \quad \dots \quad \dots \quad \dots \quad (9)$
 with respect to Δt_j

The model was coded in the BASIC language on a Tandy Microcomputer. The computational flow diagram of the harvesting system model is shown in Figure 1.

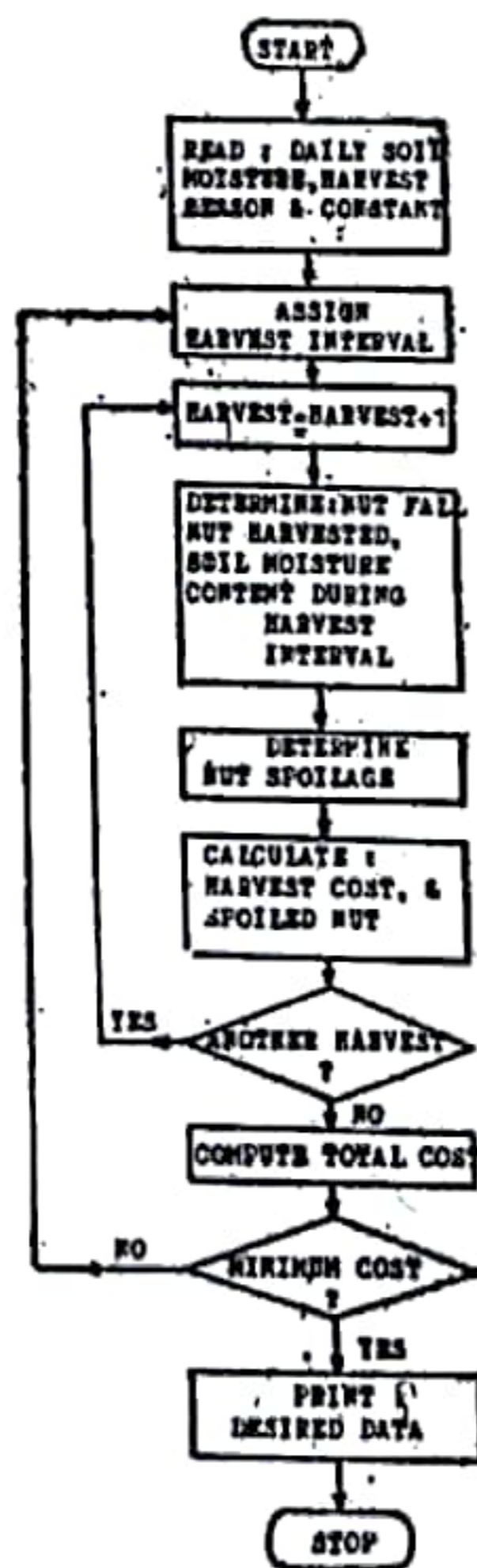


Fig. 1. A flow diagram of a sweeper based nut harvesting system model

RESULTS

Since simulation does not provide any optimization power, searching for the optimal harvesting pattern was performed in an iterative manner. The daily soil moisture content (% by volume) of entire harvesting season, beginning and end of the harvesting season (in Julian data), number of days in the harvesting season, price of macadamia nut, labor cost, average nut yield per tree, price of nut harvester, productive area of the farm and the number of productive tree per hectare are the important input data of the model. The necessary data were gathered from the Macadamia nut farm of the University of Hawaii Agricultural Experiment Station in Oahu, Hawaii.

To get the optimal harvesting pattern, initially, a reasonable value of harvest interval was chosen. The words "optimal harvesting pattern" has been defined here as the harvesting pattern where total harvesting cost is a minimum. The computer program of the model was run for different values of harvest interval until the minimum total harvesting cost was reached. The optimal harvesting pattern was obtained to the corresponding minimum value of total harvesting cost. Two optimal harvesting patterns were determined for two possible strategies of nut harvest. The two harvesting strategies are i) mechanical harvest with a uniform harvest interval and ii) mechanical harvest with a non-uniform harvest interval. Figure 2 and Figure 3 show the results of the two harvesting strategies. Each figure shows the total harvesting cost, labor, operating cost and the amount of nut spoilage at different levels of harvest interval. The figures reveal the fact that the harvesting interval increased as the total amount of nut spoilage increased. On

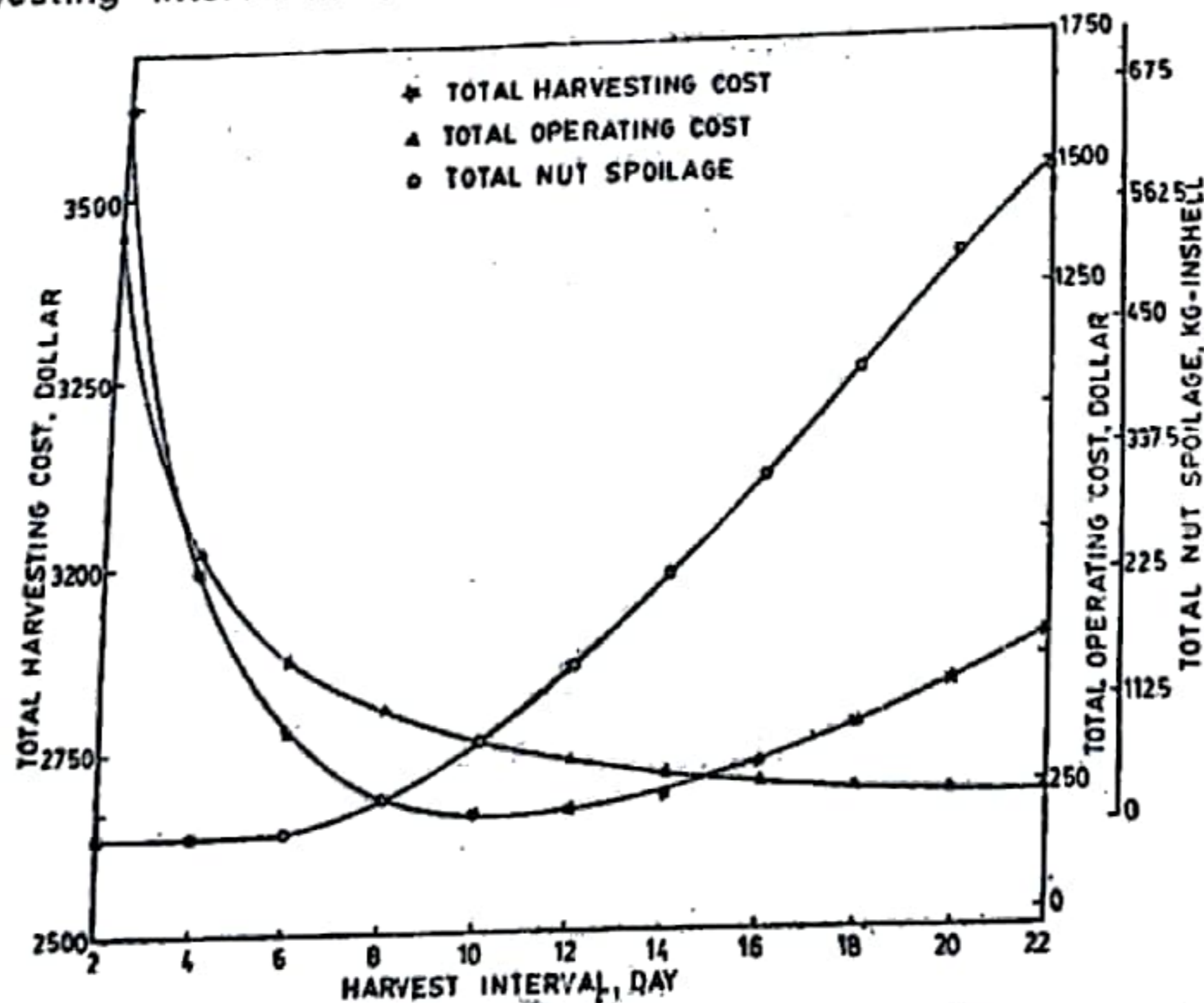


Fig. 2. Harvesting cost, operating cost and nut spoilage versus a uniform harvest interval during a harvest season.

the other hand, the total operating cost decreased as the harvesting interval increased. The figures also indicate that the total harvesting cost decreased as the harvesting interval increased until the optimal harvesting interval were reached. The total harvesting cost decreased due to the decrease of operating cost. On the other hand, the total harvesting cost increased beyond the optimal harvesting interval. This was due to the increase of nut spoilage. The optimal harvesting interval for mechanical harvest with a uniform harvesting interval was obtained at 10 days. (Figure 2). While, the optimal harvesting pattern for mechanical harvest with a non-uniform harvesting interval was found at 12-7-12* days (Figure 3).

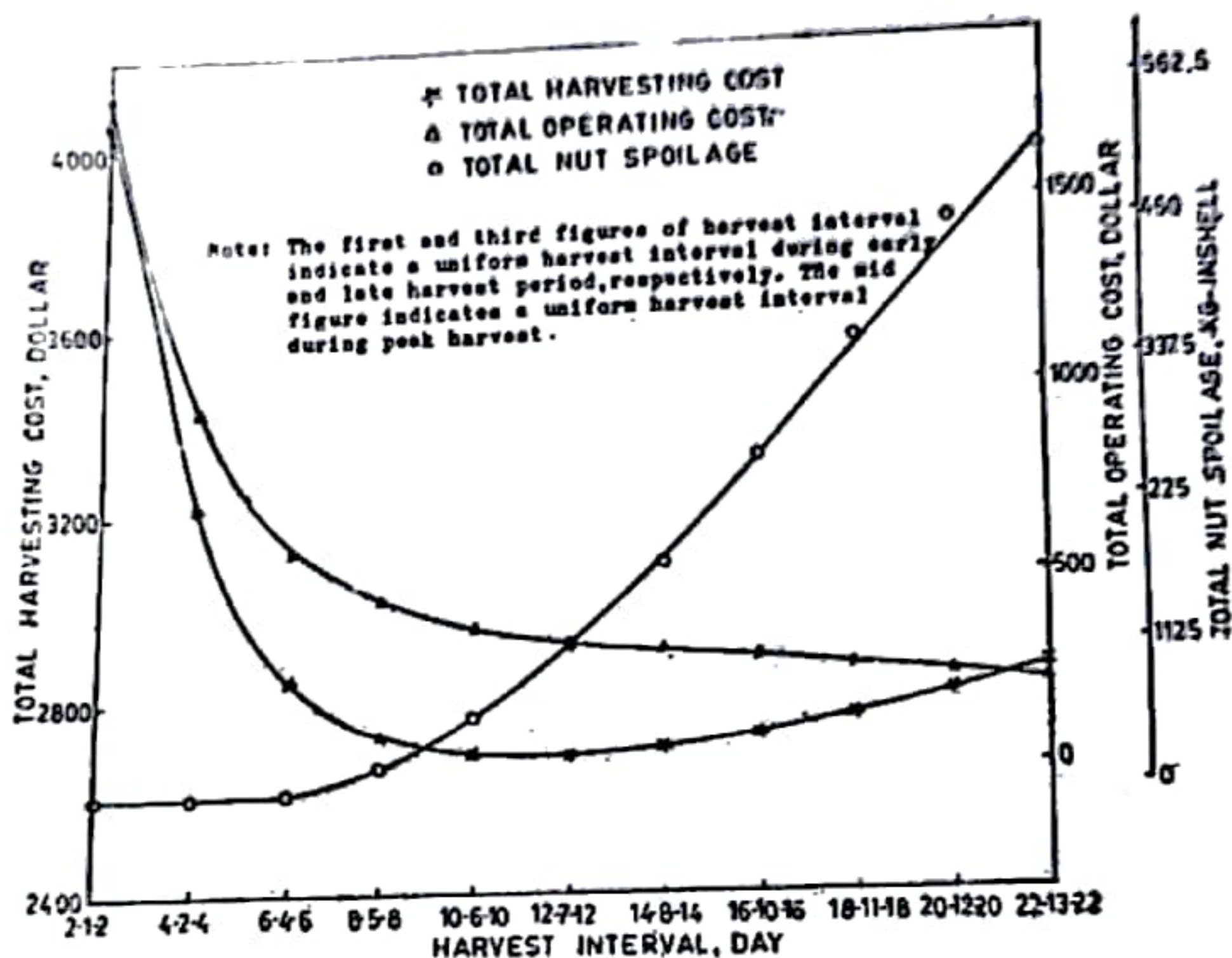


Fig. 3. Harvesting cost, operating cost and nut spoilage versus a non-uniform harvest interval during a harvest season

Sensitivity Analyses on Optimal Harvest Schedule

Sensitivity analyses of the model were performed with respect to three important uncontrollable variables of the system. The effects of change of wage, price of macadamia nut and soil moisture content were studied. The results are shown in Table 1, Table 2 and Table 3.

The effects of change of wage on optimal harvesting pattern were evaluated for

* The first and the third figures indicate a uniform harvesting interval during early and late harvest periods, respectively. The mid figure represents a uniform harvesting interval during peak harvest period.

seven different levels of wage (Table 1). The results reveal the fact that as the wage decreased the optimal harvesting interval decreased and vice versa.

The change of macadamia nut price also had significant effects on the optimal harvesting pattern (Table 2). The optimal harvesting interval increased as the nut price decreased and vice versa. The results show that the nut should be harvested more frequently when there is a higher market price of nut.

The most important uncontrollable variable affecting decision and operation of a sweeper based nut harvesting system is the soil moisture content, because it plays a significant role on nut spoilage. Table 3 shows the effects of change of soil moisture

Table 1 Effects of Change of Wage on Optimal Harvest Pattern

Percent increase of wage rate	Policy of uniform harvest interval (day)	Policy of non-uniform harvest interval (day)
-75	9	11-7-11
-50	9	11-7-11
-25	9	11-7-11
0	10	12-7-12
+25	12	12-7-12
+50	12	13-8-13
+75	13	13-8-13

Note : The first and third figures under policy of non-uniform harvest interval indicate a uniform harvest interval during early and late harvest period, respectively. The mid figure represents a uniform harvest interval during peak harvest period.

Table 2 Effects of Change of Nut Price on Optimal Harvest Pattern

Percent increase of nut price	Policy of uniform harvest interval (day)	Policy of non-uniform harvest interval (day)
-75	16	18-11-18
-50	14	17-10-17
-25	13	13-8-13
0	10	12-7-12
+25	9	11-7-11
+50	9	9-5-9
+75	9	9-5-9

Note : The first and third figures under policy of non-uniform harvest interval indicate a uniform harvest interval during early and late harvest period, respectively. The mid figure represents a uniform harvest interval during peak harvest period.

Table 3 Effects of Change of Soil Moisture on Optimal Harvest Pattern

Percent increase of soil moisture content	Policy of uniform harvest interval (day)	Policy of non-uniform harvest interval (day)
-60	31 (-100.00)*	37-22-37 (-100.00)
-40	14 (-96.14)	20-12-20 (-89.26)
-20	11 (-71.30)	17-10-17 (-54.45)
0	10 (0)	12-7-12 (0)
+20	9 (66.40)	9-5-9 (122.47)
+40	9 (320.57)	7-4-7 (936.63)
+60	7 (1474.93)	7-4-7 (1545.36)

Note : The first and third figures under policy of non-uniform harvest interval indicate a uniform harvest interval during early and late harvest period, respectively. The mid figure represents a uniform harvest interval during peak harvest period.

* The figure inside the parenthesis indicates percent increase of nut spoilage.

content on optimal harvesting pattern. The frequency of nut harvest decreased as the soil moisture content decreased. This was due to the decrease of nut spoilage. The opposite phenomena were also observed in case of increase of soil moisture content.

DISCUSSIONS AND CONCLUSIONS

The macadamia nut harvesting system was analyzed and abstracted into an operational, flexible and general simulation model for determining the optimal harvesting pattern at a minimum cost. The results of the study indicate that the model adequately represents a sweeper based nut harvesting system. The optimal harvesting interval for mechanical harvest with a uniform harvesting interval was obtained at 10 days. While, the optimal harvesting pattern for mechanical harvest with a non-uniform harvesting interval was found at 12-7-12 days. The results of the study indicate that the optimal harvesting pattern was very sensitive to the soil moisture content, wage and market price of the nut.

The accuracy of the simulated nut harvesting system performance depends a great deal on the precision and adequacy of the input data. The model did not consider the

soil moisture variation due to weather (rainfall) uncertainty. However, the program is flexible enough to accomodate a subprogram for simulation of soil moisture content with weather uncertainty.

Not only the harvesting system of macadamia nut but also the harvesting system of other similar tree nuts may be analyzed using the model for successful harvesting, operating and management with a minor modification of the model.

REFERENCES

- Hunt, D. 1979. Farm Power and Machinery Management. 7th edition, Iowa State University Press, Ames, Iowa.
- Liang, T. 1979. Determining macadamia nut ripening patterns for developing efficient harvesting methods. Unpublished report, Agricultural Engineering Department, University of Hawaii, Honolulu, Hawaii 96822.
- Liang, T. and Lopez-Madrado, L. 1973. Systems approach to the designing of suspended net harvesting systems for macadamia nuts. TRANSACTIONS of ASAE 16 (6) : 1064-1067. 1071.
- Liang, T. and Ziauddin, A. T. M. 1985. Determining tree nut (macadamia) spoilage for developing efficient harvesting pattern. Unpublished report, Agricultural Engineering Department, University of Hawaii, Honolulu, Hawaii 96822.