Misr J. Ag. Eng., 25(3): 712-722 FARM MACHINERY AND POWER

MODELING AND SIMULATING OF OLIVE-TREE HARVESTING MECHANISM

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ABSTRACT

A simulation of olive-tree harvesting model was constructed using measured tree's physical properties. It has been found that top parts of olive-tree respond to higher frequency "22Hz, and displacement of 10cm", while bottom portion was not harvested easily and responded to relatively lower frequency "14Hz, and displacement of 15cm". Therefore, it is concluded that the harvester must be designed to apply various frequencies with the ability of changing shaking amplitudes. Simulation was verified using different harvesting cases. According to simulated harvesting model, it was found that bottom portion of olive-tree did not react as other tree parts and has less efficient fruit removal. In addition, other results indicated that shaking point at 40cm above ground is effective in exiting most of the tree branches and could enhance harvesting process.

Keywords: *Modeling, Simulating, Olive-tree, Harvesting, Finite element.*

INTRODUCTION

The olive tree features a characteristic fructification and dynamic behaviour. Its production is concentrated around last-year grown branches and it shows high damping values during the trunk shaking process (Gil et al., 2005). Erdogan *et al*. (2003) studied harvesting of apricots by mean of an inertia type limb shaker. They analyzed fruit damage and removal efficiency protecting fruit mechanical properties and harvesting parameters. Parameswarakumar and Gupta (1991) showed that, to obtain maximum fruit removal with minimum tree damage, the shaker should be operated in the range of 76–102 mm amplitude and frequencies of 11–13 Hz for 4 s. There have been a lot of test sessions on young olive trees (about 10 years old). Each one was carried out varying the frequency of the vibration in the range 10 – 30 Hz so to analyze clamp – trunk coupling in true operative conditions. Phillips et al. (1970) used finite element analysis to model arbitrarily oriented branches in space as uniform Euler-Bernoulli beam elements with lumped mass at nodal points.

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Upadhyaya and Cooke (1981)used finite elements analysis with modal analysis techniques to model and experimentally verify the dynamic behaviour of trees, and developed a finite element model for the dynamic representation of limb impact harvesting, and conducted experimental tests to verify the model.

MATERIAL AND METHODS

In investigation on wood mechanical properties by the resonance vibration method, Vobolis and Aleksiejunas (2002) described wood as polymeric materials and put them in the category of visco-elastic materials. So wood mechanical properties are defined in terms of elastic solids and viscous liquids. It was also found that dynamic vibrating system (Fig.1) may be expressed as (Sharkawy and Awady, 1970):

$$m\ddot{z} + kz + c\dot{z} = F.\sin\omega t$$

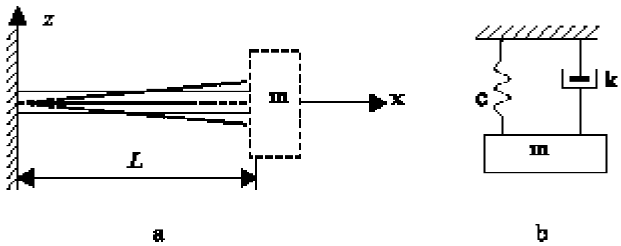

Fig.1: Scheme of the investigated specimen.

Where "*m*" is the mass of a specimen, "*F*" the applied shaking force, "*c*" the damping coefficient of the system, "*k*", mean resistance of the specimen The bar can be represented by a mechanical system with an infinite number of degrees of freedom. In this case, the mass of the bar is also distributed along its length, the basic frequency of free vibration is calculated as:

$$f = 3.52\sqrt{\frac{EI}{mL^3}}$$

Where "*E*" is the modulus of elasticity, "*I*" is the moment of inertia of the cross-section," *f* " is frequency of the mass free oscillations," *L*" is length of the specimen. The natural frequency of an olive tree system is determined according to the relationship:

$$f_n = \sqrt{\frac{k}{m}}$$

where "*k*" is the appropriate elasticity value (spring rate), "m" is the appropriate mass value (Fig.2). Simulating tree shaker harvester: sap2000 an "integrated finite element analysis and design of structures" computer software tool was used to represent, analyze, and simulate the olive-tree model structure as illustrated in Fig. (3).

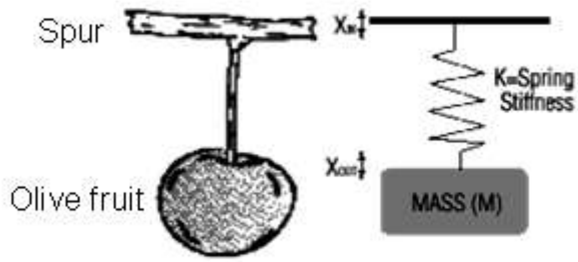

Fig.2: The model of olive-fruit vibratory system.

Data were entered according to simulation program procedure as: Wood material, Physical properties, geometric properties and section stiffness. Basic geometric properties are used, together with the material properties, to generate the stiffness of the section. Elements of the cross-sectional area and the moment of inertia are shown in Fig. (4). Formulae for calculating the shear areas of typical sections are given in (1) Tree frame-elements, representing trunk, branches, leaves, and fruit, (2)Joints that represent connections of tree elements, (3)Restraints and springs that support the joints,(4) Loads, including self-weight (wood, stem, leafs, and fruit mass), vibration force, and others. After analyzing tree skeleton, the model also includes displacements, stresses, and reactions due to the loads. Model descriptions (Fundamental Assumptions) Data were recorded over a short period of time"1sec" so that the properties of the limb were assumed constant throughout the test period. Tree structure was evaluated for steady-state forced vibration. Tree limb elements were considered to be truncated conic segments, with length and radius of curvature very large compared to their diameter. The tree was simulated by a number of elements that formulate a trunk with three branches for simplicity, each supporting secondary branches which support fruits in retrain. Un-damped mode shapes and natural frequencies were found using the "Eigenvector" analysis procedure, considering proportional damping Rotary inertia and shear effects can be neglected. Deflection and loads occurred in a three dimensional space. Olive-tree model considered Z-direction as the vertical axis, with (+) Z being upward. Local coordinate systems for joints, elements, and ground-acceleration loading are defined with respect to this upward direction. Self-weight loading (wood, leaves, and fruits) always acts down-ward.

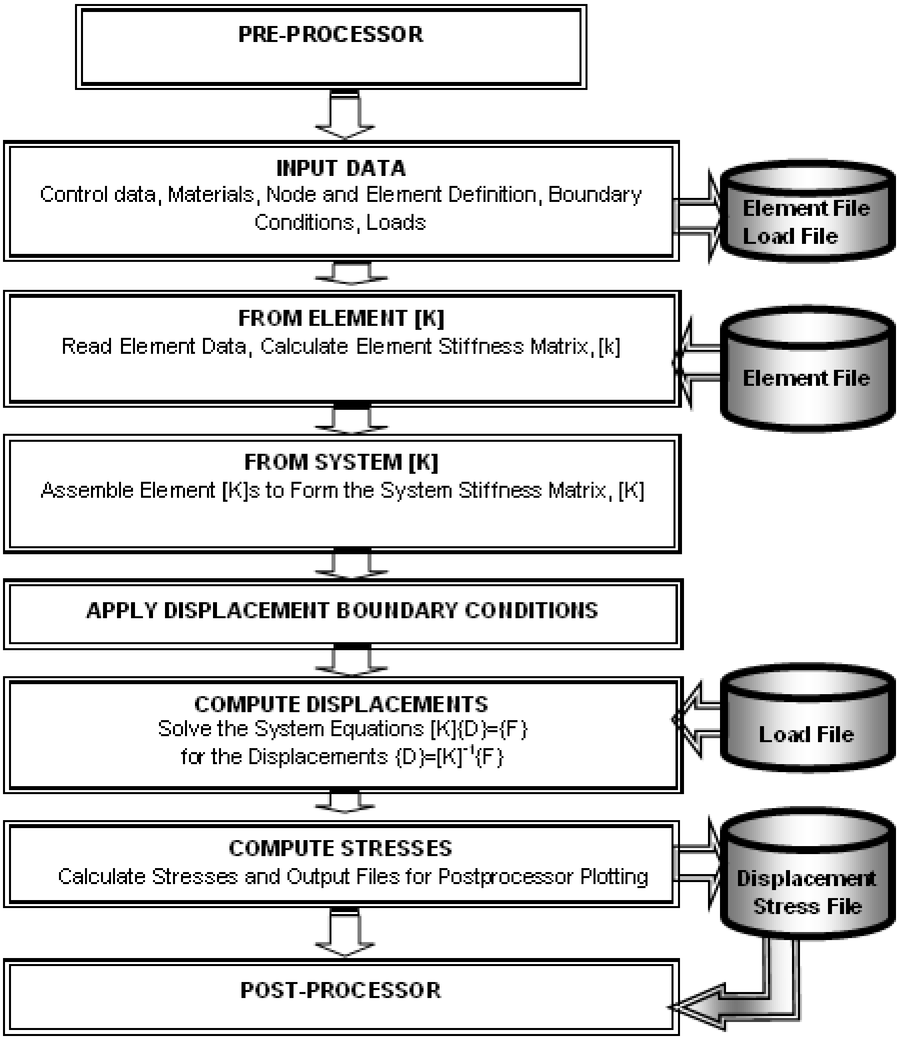

Fig.3: Finite-element computer program block diagram.

Solid circular section shear force from any direction.

$$Effective\ shear\ area = 0.9\pi\, r^2$$

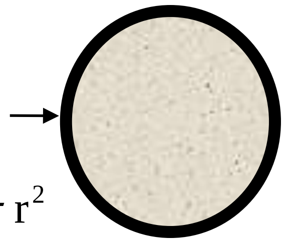

Fig.4: Corresponding bending stiffness of the Section.

Definitions are set to create named entities that are not part of the geometry of the model. These entities include: Material properties of olive-tree wood "olvwood", which are mainly: (a) mass per unit volume, and (b) modulus of elasticity. Mass density, w, that is used for calculating the self-weight "*Ws*" of the element. The total weight of the element is:

$$W_s = W \times V$$

where *V* is the volume of the element. This weight is apportioned to each joint of the element. Self-weight is activated using Self-weight Load and Gravity Load. Tree frame properties: Olive-tree frame and section properties: Data were added by defining the dimensions and or properties manually. Elements could be arranged at any convenient angle to create curved branches; Fig. (5). Model analysis: Completing structural model, used the operations above, to determine the resulting displacements, stresses, and reactions. However, before analyzing, options must be set up for the tree model including the following: Degrees of freedom: Model was assigned to 6 degrees of freedom. Translations are denoted U1, U2, and U3. The joint may also rotate about its two local axes (R1, and R2); Fig. (6). Model Damping Proportional modal damping is assumed with respect to the total stiffness matrix, *K*, which includes the effective stiffness from the nonlinear elements.

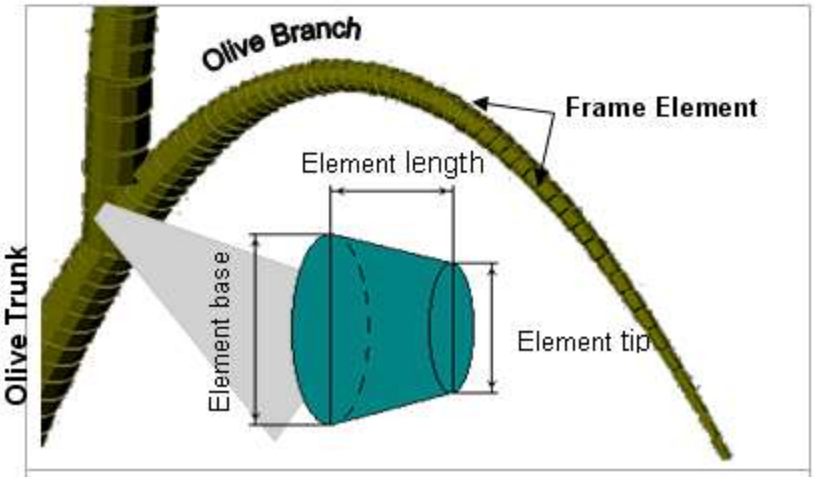

Fig.5: Frame section "truncated cone" definition. (SAP2000 Software)

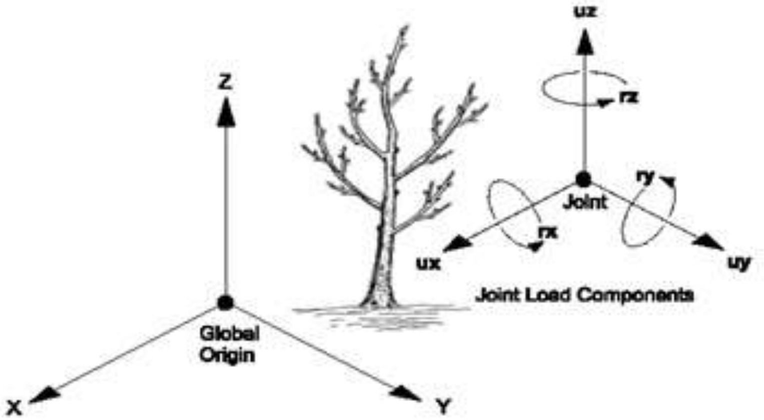

Fig.6: The six degrees of freedom in the joint local coordinate system.

Fig.(7) illustrates the fundamentals of finite element method analysis in one-dimensional spring system. When applying F force at node (3). To find the node displacement and spring forces, a general element must be formulated. Element p with nodes i and j, assumes positive displacement components of u_i, at node i and u_j at node j. the element spring constant k, and forces at node result, when these displacements occur. When force f_{ip} acts on node i due to the node displacements of element p it could be illustrated at equilibrium form:

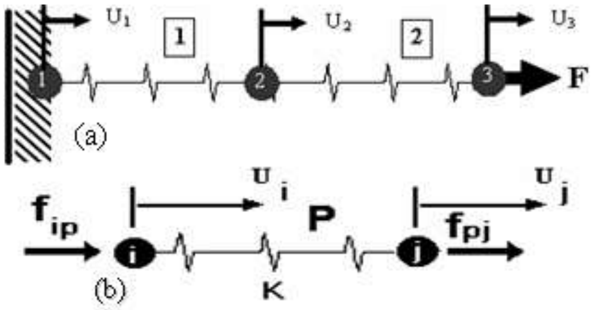

Fig.7:One-dimensional spring (a) Structure, (b) element.

$$f_{ip} = \pm k_p u_i - k_p u_j$$

$$f_{pj} = -k_p u_i \pm k_p u_j$$

And it could be solved according to matrix form as:

$$\begin{bmatrix} k_p & -k_p \\ -k_p & k_p \end{bmatrix} \begin{Bmatrix} u_i \\ u_j \end{Bmatrix} = \begin{Bmatrix} \pm f_{ip} \\ \pm f_{pj} \end{Bmatrix}$$, and

$$[k]\{d\} = \{f\}$$

where [*k*] is the element stiffness matrix, {*d*} is the element node displacement vector, and {f} is the element node internal force vector.

At node 1 Σ forces=0 $\Rightarrow$ -*f*11=F1
At node 2 Σ forces=0 $\Rightarrow$ -*f*21-*f*22=F2
At node 3 Σ forces=0 $\Rightarrow$ -*f*32=F3

Eigenvector analysis used by simulation software, determines the un-damped free-vibration mode shapes and frequencies of the system. These natural modes provide an excellent insight into the behavior of structures. They can also be used as the basis for response-spectrum analyses; Eigenvector analysis involves the solution of the generalized Eigenvalue problem:

$$[K - \Omega M]\Phi = 0$$

where K is the stiffness matrix, M is the diagonal mass matrix; **Ω** is the diagonal matrix of Eigenvalues, **Φ** is the matrix of corresponding eigenvectors mode shapes. The Modes are identified by numbers from 1 to 40 in the order in which the modes are found by the program. The Eigenvalue is the square of the circular frequency, ω for that Mode. The cyclic frequency, *f*, and period, T, of the Mode are related to ω by:

$$T = \frac{1}{f} \quad and \quad f = \frac{\omega}{2\pi}$$

RESULTS AND DISCUSSIONS

Data of olive-tree geometry, wood physical properties, masses of different tree parts, and load distribution are represented in Fig. (8). Simulation results (Fig .9), agreed with the results of field studies (Fig.10), and reviewed by El-Attar (2004). Analysis has indicated that: 1- it is impossible to determine a unique optimum applied frequency or even to choose a very narrow frequency range that is particularly effective in tree harvesting, 2- simulation results, also emphasize the tree clamping point to be at 40 cm above ground as indicated from Fig. (11), 3- tree must be trained and pruned in vase-shape to increase the harvest efficiency and avoid developed fruit near the ground. Tree harvesting electronic model and simulation is capable of similar different tree harvesting action for different tree types and analyses of the result establish roles of designing and constructing tree harvester mechanisms

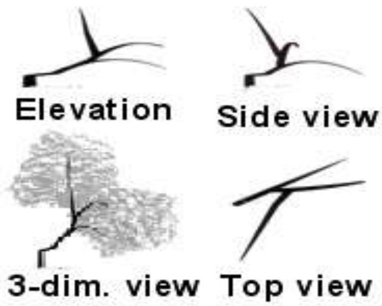

Fig.(8):Olive-tree geometry output by SAP2000 finite element analysis tool.

CONCLUSIONS

The developed simulation model of tree harvesting based on finite element analysis agrees with the field tests. Simulation models analysis showed that tree response varied with different shaking actions according to fruit location on the olive-tree due to differences in physical and mechanical properties. Concluded recommendations of simulating harvesting cases are: 1-Tree must be trained and pruned in vase-shape to limit the branches in the bottom portion of the olive-tree giving inefficient properties for fruit removal by shaking. 2-Attaching the clamping device of the tree shaker harvester at height 40cm above the ground gives good results of shaking olive-tree branches giving high fruit removal. 3-Using simulation model for other conditions of tree harvesting is foreseen by applying changes to values of physical properties, tree skeleton, stiffness, and mass distribution. This study iterates demand for further studies or simulating the changes in the physical properties for different tree developing stages by environmental, climatic, and biological factors, etc.

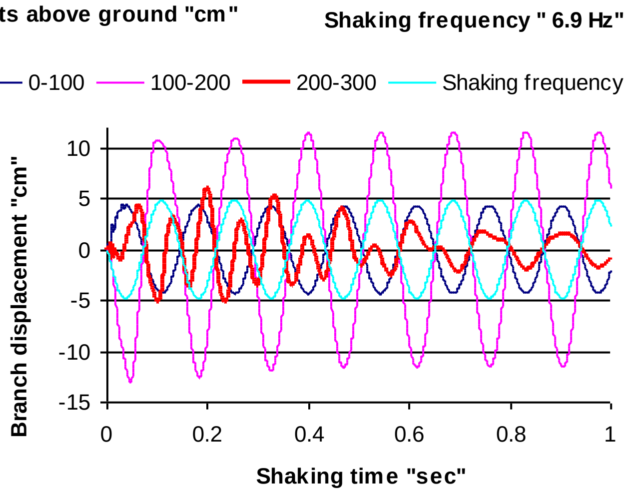

Fig.(9):Actual branch displacement compared with simulation output at shaking frequency of 6.9 Hz.

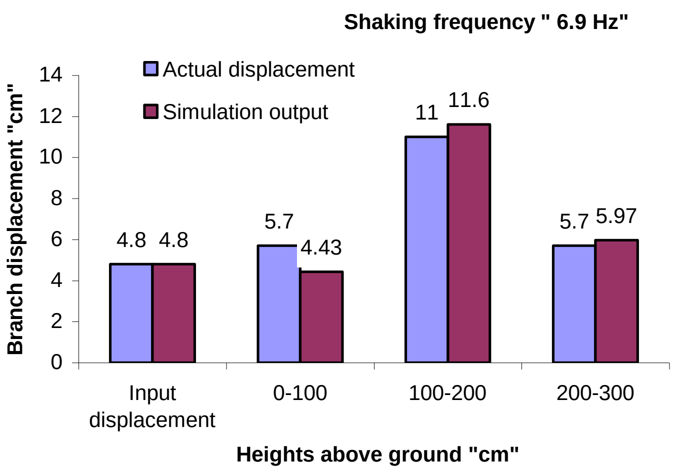

Fig. (10): Actual branch displacement compared with simulation output at shaking frequency of 6.9 Hz.

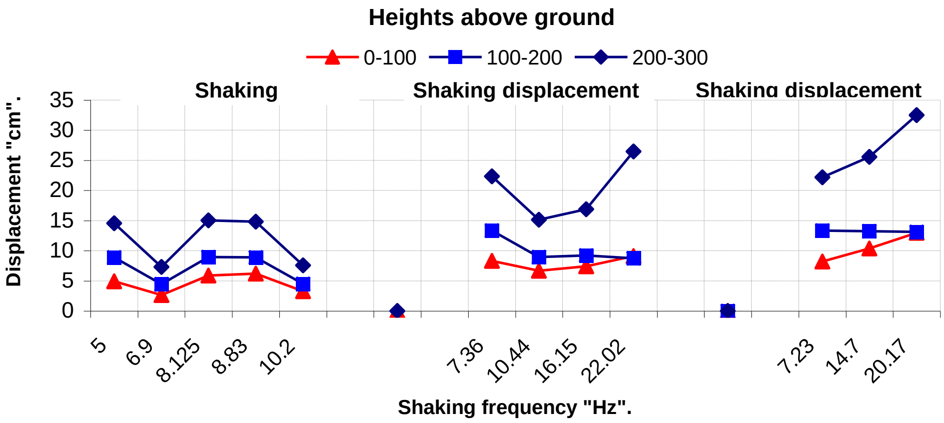

Fig.(11):Olive-tree branch displacement response to shaking point at 40 cm above ground.

REFERENCES

Amirante , P., P. Catalano, F. Giametta , A. Leone and GL. Montel. 2007. Vibration Analysis of an Olives Mechanical Harvesting System. Agric. Eng. International the CIGR journal. Manuscript PM 07 012. Vol. IX., pp10.

El-Attar, M. Z. 2004. Similtude Model for Tree Shaker Harvester Mechanism. PhD Thesis. Ain Shams Univ.pp178.

Erdogan D. M. Guner., E.Dursun and I. Gezer.2003. Mechanical Harvesting of Apricots. Biosystems Engineering, (85): 19–28.

Gil J.A., S. Castro, G.L. Blanco and J. Agüera.2005. Modal Testing of Trunk Shakers Used in Olive Mechanical Harvesting. Frutic05. 7th Fruit, Nut and Vegetable Eng. Prod. Symposium. Montpellier, France: 147-154.

Parameswarakumar M. and C.P. Gupta.1991. Design parameters for vibratory mango harvesting system. Transactions of the ASAE, 34(1): 14–20.

Phillips, A. L., J. R. Hutchinson and R. B. Fridley. 1970. Formulation of forced vibration of tree limbs with secondary branches. Trans. ASAE, 13(1) 138-142.

Sharkawy , M.K. and M.N. Awady. 1970. Theory of machine. Ain-Shams Press: 321-324.

Thomas L. Saaty. 2002. Decision-making with the AHP: Why is the principal eigenvector necessary. European Journal of Operational Research, 145 (1): 85-91.

Tsatsarelis, C.A. 1987. Vibratory olive harvesting: The response of the fruit-stem system to fruit removing action. J. Agric. Eng., 83:77-90.
Upadhyaya, S.K. and J. R. Cooke. 1981. Limb impact harvesting, Model studies. Trans. ASAE, 24(4): 868-871, 878.
Vobolis J. and M. Aleksiejunas. 2002. Investigation of wood mechanical properties by the resonance vibration method. Materials Scie. 9(1):139-143.

الملخص العربى

نمذجة و محاكاة لآلية حصاد شجرة الزيتون

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تم بناء نموذج محاكاة تفاعل شجرة الزيتون لتأثير فعل الحصاد بالهز والذى يعمل على المساهمة فى تصميم آلية حصاد مناسبة وفعالة.أستخدمت فيها قياسات الخواص الطبيعية كمدخلات لنظام النمذجة والمحاكاة .وقد أوضحت الدراسة وجود استجابات متباينة فى نسب حصاد الثمار الواقعة فى مختلف أجزاء الشجرة تبعا لتغير كلا من الترددات وأطوال الإزاحات المستخدمة أثناء عمليات الحصاد بالهزاز الآلى. وقد وجد أن تأثر حصاد الثمار الواقعة فى قمة الشجرة بالترددات المرتفعة (٢٢هرتز، إزاحة ١٠سم) بينما تستجيب الثمار الواقعة فى الأجزاء القريبة من سطح الأرض لترددات الحصاد المنخفضة نسبيا (١٤هرتز، إزاحة ١٥سم) مع انخفاض نسب الثمار المحصودة عموما،من هذا الجزء. وتركزت اعلى نسب لحصاد الثمار فى المنطقة الوسطى من الشجرة لمختلف الترددات والإزاحات المستخدمة. وطبقا لهذه النتائج يتضح وجوب تصميم هازات أشجار بساتين الفاكهة لتقوم بالعمل ضمن نطاق متغير من الترددات و الإزاحات المصاحبة، و التى يمكن تعديلها من وقت لأخر خلال عمليات الحصاد لتوجيه تأثير الترددات و الإزاحات لمناطق تأثيرها المختلفة على أشجار الزيتون. وطبقا لمخرجات نموذج المحاكاة لمعطيات مختلفة الإرتفاعات لجهاز شبك ماكينة الحصاد "المفترضة" على جذع الشجرة المعاملة، وجد أن أفضل تأثير لإزاحات فروع الشجرة المنمذجة كانت لمعاملة الشبك ذات ٤٠سم ارتفاعا عن مستوى سطح الأرض. . أظهرت النتائج أيضا ضعف تأثر الجزء السفلى من الشجرة بمختلف المعاملات المطبقة على النموذج الأمر الذى يتطلب معه إجراء تقليم لهذه الأجزاء لتتحسن الاستجابة، بالإضافة إلى إجراء عمليات الحصاد بالترددات المنخفضة ذات الإزاحات الكبيرة نسبيا كما أتضح من نتائج إجراء عمليات المحاكاة.

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