



## Factors affecting picker capacity, area harvested and harvesting cost of cotton

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### Abstract

In this study an attempt has been made to determine the factors affecting the efficiency (capacity) of a cotton picker owned by a cotton producers group and their implications upon the cotton area harvested and the harvesting cost. For that purpose, a given machine with certain specifications has been employed and a model incorporating the relevant factors, stochastically and deterministically, has been developed and used to simulate the harvesting process and calculate the cotton area and cost, by using average weather and other relevant data. Beyond that by employing the sensitivity analysis the response of the model to systematic changes in parameter values and/or input variables over some range of interest were studied. The results showed that picker efficiency is primarily affected by weather conditions (precipitation and rainfall amount) and secondarily by crop moisture content, harvesting season length, machine reliability, traveling time between fields, etc.

**Key words:** Simulation, harvesting cost, capacity, cotton area, cotton picker.

### Introduction

In recent years the importance of machinery management decisions has substantially increased. This is particularly true for high capacity machines as cotton pickers, combine harvesters, sugar beet harvesters etc.<sup>14, 15, 23</sup>. Cotton growers have to answer questions regarding the type of cotton pickers and transport systems they need, the factors relating to picker performance and their interrelationships in order to maximize picker capacity and minimize harvesting costs<sup>10</sup>. Cotton producers have to make these decisions in an uncertain environment as adverse weather conditions and other factors may delay harvesting and reduce yield or quality of cotton. A standard procedure should be developed to help farmers make their critical management decisions for optimizing their returns.

It is widely known that a precise estimate of cotton harvesting cost requires accurate knowledge of the variables that influence it. This is not easy to achieve, as most of the cost calculations are based on "guesstimates" only. The actual cost of using a farm machine is never known until the machine is sold or worn out. The situation is further aggravated due to the rapid changes in price and technology. However, an estimation of the area harvested and the corresponding harvesting cost, should be a useful guide for determining the maximum acreage handled by a cotton picker at the minimum harvesting cost<sup>10, 26</sup>.

Simulation technique has been widely used in many disciplines such as aerospace, electronics, business studies, economics etc. by many researchers for solving various complex problems<sup>25, 31, 38, 53</sup>. In agricultural economics simulation technique is increasingly used covering many types of farming, various crops and harvesting operations, cotton harvesting, grain harvesting etc., particularly when uncertainty is involved. Jones *et al.*<sup>29</sup>, developed and used a model to simulate the harvesting management decisions on an individual farm basis and to determine harvested area and cost. Jones *et al.*<sup>30</sup> used a simulation model to determine the optimum

time for cotton harvesting when all bolls in the field, open and not open, were harvested for getting the higher gross return. Baskin and Sistler<sup>5</sup> used also a computer model to estimate the harvest cost as a function of the number of trailers needed for cotton transporting. Chen *et al.*<sup>9</sup> developed a cotton harvesting and ginning model for a farming community, while McClendon *et al.*<sup>37</sup> used also a model for scheduling harvesting operations for maximum returns. Other researchers<sup>48</sup> developed a model for cotton harvesting decisions based on fixed annual use of the equipment aiming at estimating net revenues for three weather scenarios, while Ozkan *et al.*<sup>40</sup> used a simulation model to determine field machinery timeliness cost in corn production. Chen *et al.*<sup>10</sup> developed a simulation model of cotton harvesting and handling systems, consisted of a number of harvesters, module builders and boll buggies, to study the interactions of harvesting and handling requirements with machinery costs, weather and cotton quality.

De Toro and Hansson<sup>14, 15</sup> used simulation models for field machinery operations to determine total costs for seven machinery sets and to quantify timeliness costs and their annual variations for machinery co-operatives. Many other researchers have used simulation models for machinery selection<sup>2, 12, 16, 17, 41, 43, 49, 51-53</sup>.

The objective of the present research was the development and use of a simulation model to study cotton harvesting process, based on daily status of crop and soil workability for a series of years, and to determine the least cost area handled by a cotton picker, owned by a cotton producers group, under weather conditions prevailing in the study area of Greece.

To fulfill the former objectives, the following boundaries-assumptions were considered relevant for the model: 1) The harvested period is 52 days, from 25<sup>th</sup> of September to 15<sup>th</sup> of November. 2) The harvesting process commences in the morning when crop moisture content falls below 10 percent and stops in the afternoon when it reaches again the above level. 3) The number

of group cotton fields range from 10 to 50 and vary in their size and distance from one another, while the cotton acreage varies from 30 to 110 hectares. 4) Cotton fields are harvested once or twice if the yield remaining in the field, after the first picking, is above the level of 170 kg/ha.

### Material and Methods

**System description:** The cotton harvesting system consists of four components: 1) the machine component, 2) the cotton in the field, 3) the weather and soil and 4) the harvested area and cost.

1) The machine component consists of a cotton picker model of certain specifications regarding machine horsepower, harvesting width, basket capacity, etc. The studding harvesting machine in this article is a two-row cotton picker, 155 h/p with a basket capacity of 1.5 tons of seed cotton.

Mechanical cotton picking involves a set of separate activities, such as machine travelling down the row picking cotton, turning and travelling across the row ends, travelling to and from the cotton trailer, dumping seed cotton from the picker basket into the trailer, cleaning out the picker, servicing the picker and miscellaneous activities (counting the rows, filling the water tank, talking to farmers and other workers etc.). Only the first of the above activities is that of accomplishing picking cotton. The other entire activities, although essential for harvesting, are considered as non-productive ones. Management of machine operation can have a significant influence upon the rate of work achieved in the field, the cotton acreage and yield harvested, and of course upon the cost of cotton harvesting

2) The cotton plants in the field range from 100,000 to 150,000 per hectare in rows of 97 cm apart and a plant height of 70-90 cm. Cotton fields are harvested twice during the harvesting season. The first picking takes place when 70-80 per cent of bolls are open, while the second picking occurs when all bolls are open. Beside that seed cotton moisture content must be lower than 10% to prevent quality deterioration, if cotton is going to be stored for some days before ginning. Harvesting season starts normally from 25<sup>th</sup> of September and finishes at 15<sup>th</sup> of November, when farm machinery and manpower is needed for cereals sowing, before heavy rains and snows take place.

3) Weather and soil conditions during the harvesting season play a very important roll. Precipitation occurrences and rainfall amounts prevent harvesting process for a time period depended upon the amount of rain, the type of soil, the temperature, the wind velocity etc. Thus, within the harvesting season the days suitable for harvesting are restricted more or less every year according to the rainfall occurrence affecting the machine capacity. Moreover, wet crop results very often in the clogging of the machine causing damages and delays in harvesting. Additionally, wet ground causes wheel slippage, destroying the synchronization between picking speed and machine velocity and this in turn leads to stripping of unopened bolls and to excessive damage of the cotton plants<sup>28</sup>.

4) The area harvested constitutes the model output for every working day and for the total area harvested at the end of the season along with the corresponding total harvesting cost, cost per hectare and per hour based on the data used. By carrying out a sensitivity analysis the cotton area with the minimum harvesting cost could be determined.

**Formulation of the model:** The purpose of modeling the cotton harvesting system is to facilitate the determination of the optimum area of cotton to be handled by a harvester machine in a farming group, as well as the investigation of alternative strategies in cotton harvesting under various circumstances.

Having defined the boundaries of the system modeled and specified the objectives to be achieved through the study of the system; the next step is the construction of the model to represent the real system. Symbolically the model can be presented as follows:

$$\text{Minimize } C = f(X, Y) \quad (1)$$

where  $C$  = the value to the decision-maker of supplementing a particular policy,  $X$  = the controllable variables of the system,  $Y$  = the non-controllable variables,  $f$  = the relationship between the casual factors  $X$  and  $Y$  and the response variable  $C$ , the harvesting cost. The minimization of  $C$  is constrained by the requirement that  $X \geq 0$  and  $Y \geq 0$ <sup>2</sup>.

The model is a simplification of the complex real situation showing the performance of the system and used as a means by which the value  $C$ , harvesting cost, can be estimated for any given combination of  $X$  and  $Y$ . In other words, it can be considered simply as a procedure presented in a symbolic form and programmed for a computer to carry out prediction processes for any level of the controllable variables<sup>12</sup>. According to Mihram<sup>38</sup>, "a simulation model may be viewed as an input-output device which produces a response (output), corresponding to a given set of environmental conditions (input)". The term "environmental conditions" comprises various sets of elements, initial conditions and policies that are applicable to the actual system, which the model is mimicking. Therefore, different harvesting policies and cotton areas can be evaluated in terms of harvesting cost to determine the level of acreage, which gives the minimum cost.

The overall research procedure of the model used in this study is outlined in Fig. 1. As can be seen the model simulates the annual harvesting operation, which is the central feature of this research technique based on a sequence of daily operations. These operations make the model operate in a manner similar to an actual cotton harvesting system.

The program first reads the initial conditions of the system: number of machines used, information about machine costs, number of harvests per field, the level of crop moisture content, picker basket capacity, selling price of the crop, yield losses, penalty charge, number of years to be simulated, the range of fields, harvest starting and finishing dates etc. Subsequently, the program reads a number of tables about the acreage, yield level, row length, rainfall amount, working or not days etc. The model assumes that harvesting commences on the 25<sup>th</sup> of September each year, if this day has been classified as working day. If not the program advances to the next day and so on, until a working day arrives when the harvesting starts and continue until the 15<sup>th</sup> of November.

The model goes from day to day estimating the crop loss for the yield unharvested and determines the time for starting and ending harvesting for the day and commences the harvesting process for the first selected field. The harvesting procedure continues unless the field is completed or a breakdown occurs. In the first case a new field is selected and harvesting continues, while in the second one a time interval for repairs is generated and the harvesting



harvesting which would optimize (minimize) the objective of the function.

Thus, the use of this model permits some insight into the interaction of the components of the harvesting system and allows alternative input data or policies to be evaluated. Within this framework, an attempt to evaluate the effects of weather (rains), plots distances, length of harvesting season, machine breakdowns and crop moisture content level has been undertaken.

**Machine component:** The progressive decrease of day length from September to November, the machine move from field to field during the day, the machine breakdowns, and the time needed for unloading the cotton into the trailers, the time spent turning at the rows end, the cleaning and servicing the machine time etc. are some of the factors affecting also the picker capacity and have been included in the model.

The day length at the beginning of harvesting (25<sup>th</sup> of September) is about 12 hours and progressively reduces to 5 hours at the end of the harvesting season (15<sup>th</sup> of November). This decrease of day length has been included in the model deterministically, based on the relevant equation derived from empirical data stem from the study area.

The machine moves from field to field during the day accounting for 10 percent loss of the time, along with the time loss for machine breakdowns and repairs amounting for another 10 percent, which are two important factors affecting machine efficiency and have incorporated in the model stochastically. Field data from cotton pickers operating in the area were collected and used for a period of twenty years to construct the relevant formulas introduced in the model<sup>39</sup>.

Additionally the cotton unloading time, the machine turning time at the end of the rows, the servicing and cleaning time were also included in the model in a stochastic way.

**Crop component:** Seed cotton harvest is accomplished when 70-80 percent of bolls are open and a second harvest occurs when the remainder of the crop is open. Cotton that is not harvested soon after the bolls are open is exposed to the environmental conditions that occur during the harvesting season, humidity and rainfall, with adverse results upon the yield and quality of the crop<sup>3,42,50</sup>. As found by Stapleton *et al.*<sup>42</sup> in a four year study, the average loss of cotton yield was 0.3 percent per day beginning 20 days after 50 percent of the bolls opened and reached up to 15 percent. Williford<sup>51</sup> reported that rainfall and delay in harvest significantly reduce lint grade and color. Hathorn *et al.*<sup>24</sup>, using eight year records of cotton classification, were able to determine a grade index loss for each day of delay in harvesting. They found a grade index loss of 0.028 index points per day for the first 6 weeks from the beginning of harvesting and 0.187 index points per day thereafter. Thus the trend in cotton production today is toward early maturing varieties and timely harvest for maximizing the farmer's returns.

**Weather component:** Weather is a major factor affecting many aspects of the agricultural production. It affects many physical operations in farming by restricting the time available for carrying out specific tasks and the degree of efficiency achieved. These lead to uncertainties and render farm decision-making very complex. This is particularly true for harvesting operations, as weather

conditions determine the number of days available for harvesting within a limited period of harvesting time. Thus harvesting machinery should correspond to the expected number of days available to perform field operations on a specific level of crop acreage. It is the weather uncertainty and the unknown number of days available for harvesting, which pose a risk for the machine performance and the decision-makers regarding the area harvested and the harvesting cost each year. For this reason a number of researchers have contacted extensive studies on machinery selection based on climatic conditions of specific geographical areas<sup>11, 12, 16, 17, 19, 21, 41, 43, 46, 49, 51-53</sup>.

To incorporate weather variations into a simulation model, information concerning the climatic conditions of the area under consideration is needed. The simplest way of putting weather into the cotton harvesting simulation model is to use historical data readily available<sup>6,45,49</sup>. However, the use of actual weather data in simulation models has been criticised as unnecessary restriction simulating the past and used to predict the likely performance of the system under consideration<sup>47</sup>. For the purpose of this study, a simple simulation model, which includes frequency of occurrence and amount of rain stochastically, has been used<sup>20,29,30</sup>. Additionally, crop moisture content due to night dew, which prevents harvesting early in the morning and late in the afternoon, has also been included in the model.

**Cost component:** Costs associated with cotton harvesting fall into two main categories, i.e. machine costs and crop loss or timeliness costs<sup>26, 32, 35</sup>. *Machine costs* are further divided into ownership or fixed costs and variable or operating or running costs<sup>4,34,35</sup>. *Ownership or fixed costs* comprise those costs, which remain the same per year irrespective of a machines usage. They include: depreciation, interest, housing and taxes. Fixed costs may be either cash (taxes, insurance etc.) or non-cash (depreciation) and are fixed in total but decline per hectare or per ton, as the annual use of the machine is increased<sup>4,34,35</sup>. Fixed machine cost is given by equation (1):

$$FMCOST = CDEP + CINT + CINS + CSHALT \quad (1)$$

where *FMCOST* = machine fixed cost, *CDEP* = depreciation, *CINT* = interest, *CINS* = insurance, *CSHALT* = shelter.

*Variable or operating costs* include expenditure on repair and maintenance, fuels, lubricant and labor wages<sup>8,26</sup>. As they are directly related to machine use, it is possible for some high-use machines to have variable costs greater than fixed costs.

Estimation of variable costs is based on the period of machine use. Thus, it is necessary first to determine the hours of use for a machine. Then, information on the labor wage rate, fuel and oil prices is used to estimate total variable costs. The remaining costs, repair and maintenance, are considered together and are usually determined as a percentage of the initial cost a machine<sup>7</sup>. Equation (2) gives the variable machine costs:

$$VRMCST = CREP + CFUEL + CLUR + CFLBR \quad (2)$$

where *VRMCST* = machine variable cost, *CREP* = repair and maintenance cost, *CFUEL* = fuels cost, *CLUR* = lubricant cost, *CFLBR* = labor cost.

*Crop loss costs or timeliness costs* are reductions in potential

return, arising because of an inability to complete a field operation within an optimum period of time<sup>26,33</sup>. Crop yield and quality are gradually reduced after ripening, due to the continuation of the biological processes, and the adverse weather, which may cause a complete loss of the unharvested portion of a crop. Timeliness costs include, therefore, costs due to yield loss and quality deterioration. In any case timeliness costs are of major importance to the machinery selection process and they must be evaluated quantitatively and considered as valid costs of field machinery operations<sup>4, 8, 26, 33</sup>.

However, the large number of factors involved in crop losses makes it very complicated. For our own purposes it is assumed that cotton yield loss commences 30 days after boll opening and the rate of loss or crop loss factor (CLOSF) is equal to 0.002 of the crop remaining in the field unharvested, for each day of delay. Thus, yield loss per day and for a particular field is given by equation (3):

$$YLOS = CLOSF * MATRTE(IDAQ) * (ACS - HACS) / ACS \quad (3)$$

where  $YLOS$  = yield loss per day,  $CLOSF$  = crop loss factor,  $MATRE$  = percentage of cotton open on a particular day,  $IDAQ$  = number of days counted 30 days after boll opening,  $ACS$  = number of acres in a particular field,  $HACS$  = number of acres already harvested during current harvest.

All these daily losses when added together give the total yield loss during the harvesting season as:

$$TYLOS = \sum_{i=1}^n YLOS \quad (4)$$

where  $TYLOS$  = total yield loss of the season,  $n$  = number of days since yield loss started.

Multiplying total yield loss by selling price of cotton gives the yield loss cost for a particular harvesting season, that is:

$$CYTLOS = TYLOS * PRCOT \quad (5)$$

where  $CYTLOS$  = yield loss cost,  $PRCOT$  = selling price of cotton (0.79 €/kg).

Apart from the yield loss cost, there also exist a quality loss cost resulting from consistent reduction in grade of the crop as the harvesting season progresses, estimating by the following relationship developed by Hathorn *et al*<sup>24</sup>:

$$TOTFL = \frac{SLOPI * FABASP}{2} * TCNPI * CCOT + \frac{SLOP2 * SABASP}{2} * TCNP2 * CCOT / PE \quad (6)$$

where  $TOTFL$  = loss per season,  $SLOPI$  = grade index loss per day during period one, that is, the first 38 days of harvesting (0.028 index points),  $FABASP$  = number of days of exposure in period one, maximum 38 days,  $TCNPI$  = yield harvested during period one,  $SLOP2$  = grade index loss per day during period two following period one (0.187 index points),  $SABASP$  = number of days of exposure in period two,  $TCNP2$  = yield harvested during period two,  $PE$  = picker efficiency (90 percent of the available cotton in the field).

Furthermore, the cotton harvesting operation was assumed to

commence on 25<sup>th</sup> September and to continue until all fields were harvested or 15<sup>th</sup> November, whichever came first. In the second case a penalty charge is applied to the acreage remaining unharvested.

In the literature there is no general agreement as to the method of application and the magnitude of the penalty charge. Ryan<sup>44</sup> and Donaldson<sup>18</sup> have considered penalty charge in two stages. They assumed that contract combine harvesters could be employed to help a farmer in harvesting the remaining acreage for a certain time, at a penalty charge equal to the contract rate. If at the end of this period the harvesting was not complete, the remaining acres were charged at a penalty rate equal to the cost of contract combining.

Frisby<sup>22</sup>, by studying a corn harvesting machinery systems in Iowa, considered the crop left in the field unharvested after the end of the harvesting period, as completely lost. In this study Frisby's<sup>22</sup> assumption was followed and the yield ( $YA$ ) remaining unharvested in the fields after 15<sup>th</sup> of November was estimated and the penalty charge (cost) was calculated by using the following equation:

$$PENCST = \sum_{i=1}^n (ACS - HACS) * YA * PRCOT \quad (7)$$

where  $PENCST$  = penalty cost for the season,  $n$  = number of plots in consideration,  $YA$  = potential yield of the field.

Having estimated all harvesting cost components the cost of the harvest was then calculated from the cumulative sum of the fixed and variable machine costs, the yield and quality loss cost (timeliness loss), and the penalty cost, using the following equation:

$$THCOST = FMCOST + VRMCST + CTLOS + TOTFL + PENCST \quad (8)$$

where  $THCOST$  = total harvesting costs.

From the above equation the average total costs per kg for the crop harvested each year was determined as:

$$CSTPKG = THCOST / TCN \quad (9)$$

where  $CSTPKG$  = harvesting cost per kg,  $TCN$  = total yield harvested.

Finally, the mean average total costs over the 20 years of simulation were determined by the model using the formula:

$$AMTCST = \frac{1}{n} \sum_{i=1}^{j=n} CSTPKG_{ij} \quad (10)$$

where  $AMTCST$  = mean average total costs,  $n$  = number of years,  $CSTRKG_{ij}$  = average total costs in the  $i^{\text{th}}$  year and  $j^{\text{th}}$  acreage level.

In addition to that the minimum and maximum  $AMTCST$ , the standard deviation and the frequency of occurrence of the penalty cost, were estimated. Finally, the program tabulated the frequency distribution of the  $AMTCST$  within certain cost value intervals, the average cost value corresponding to each of the above intervals, and lastly the expected  $AMTCST$  for each acreage level using mathematical expectations<sup>1</sup>. All the above accounting identities and equations have been used in the model for estimating the cotton harvesting cost for each acreage level, harvesting policy, and environmental conditions. The experiments conducted and the results obtained for 20 years are discussed below.

**Verification and validation of the model:** Verification of the present model and the sub-programs, used in this study, was

carried out separately by running them with certain input data and comparing their observed behavior with that anticipated. First they were tested for the purpose of eliminating compilation and execution errors. Subsequently, the results printed were checked against manual calculations to determine and remove possible logical errors. These comparisons conducted by statistical tests, chi-squared and Kolmogorov-Smirnov tests, which show the correctness and the logical structure of the model and the sub-models<sup>13, 38</sup>.

Having satisfactorily completed the verification phase, the next important inquiry was the validation of the model that is the assessment of whether or not the model adequately serves its prescribed use or to ascertain the degree of comparability between the values of performance measures obtained by the model and the values observed by the actual system under study. According to Mihram<sup>38</sup>, "model validation is concerned with the comparison of the model's response with those of the modelled system, wherever the conditions producing each are essentially the same".

An obvious approach to validate it is to compare the model outputs against the recorded or historical data of the real system, or against a subjective judgement of what the outputs should be, given a broad understanding of the modelled system.

In the first case the model is run in the exact circumstances and time series of the existing real system records. The output obtained from the model over simulating time, are then compared with the measured outputs of the real system, using statistical tests, for the purpose of establishing the correspondence of the model output with the historical records, using various goodness-of-fit tests<sup>13, 38, 47</sup>.

A third stage associated with the model evaluation or testing is referred to as sensitivity analysis. Some authors consider it as separate stage in model testing while others as part of the validation process. Sensitivity analysis studies the response of the model to systematic changes in parameter values and or input variables over some range of interest<sup>47</sup>.

## Results and Discussion

The simulation model outlined so far used to evaluate alternative strategies for harvesting cotton mechanically. Experimentation using the model for a range of decision-rule alternatives provided an insight into the operation of the harvesting system and the means by which the system potential could be more efficient. Thus, the model was used as a tool for investigating changes made one-at-a-time. For that end, a series of runs using the model were made representing the various policies corresponding to changes in assumptions about the system when altering acreage levels. The alternatives considered the most important and promising ones for the existing system under study were the following: 1) weather effect (limiting working days within the harvesting season), 2) several cotton fields or one cotton field, 3) altering the duration of the harvesting season, 4) considering machine reliability and 5) varying the level of crop moisture content at start and end of daily harvesting.

To facilitate harvesting cost comparisons between various acreage levels for a given picker, it is convenient to consider the revenue losses occurring due to untimely operation and weather effects as additional cost associated with the machine used and the acreage harvested, as already has been done estimating harvesting costs. In this way, variation in revenue is removed,

and it becomes constant for any level of cotton acreage, while the average revenue curve, which equals marginal revenue, takes the form of a straight line. Considering the average revenue per hectare as constant, we could then disregard it and directly compare the harvesting costs for the successive acreage levels<sup>19, 27</sup>. For convenience the cost calculations are referred to as the cost per unit of crop harvested instead of the cost per unit of area harvested. Because of the stochastic nature of the number of variables in the model, the value of harvesting costs and at any given acreage level will vary from year to year. Consequently the position of the average cost curve will be different for each year. The nature of the harvesting cost curves and their variability under different harvesting regimes are discussed below.

**The effect of weather conditions (limiting working days):** Among the factors affecting harvesting operations, weather conditions are the most important. Rainfall occurrences during the harvesting season may cause losses in yield and quality of the standing crop on the one hand and limitations in the number of days suitable for harvesting on the other. This in turn results in restricted use of the cotton picker during the season causing a reduction in the acreage harvested and finally an increase in the harvesting costs.

In determining the effects of weather (rainfall) on the acreage handled by a cotton picker and on the harvesting costs, the program was run first on the assumption of no rainfall or yield and quality losses due to untimely operations, during the 52 days period. The results obtained are shown in Fig. 2.

Inspection of Fig. 2 reveals that the average total cost curve per kg of seed cotton is the normal L-shape curve falling continuously as the acreage harvested increases, becoming asymptotic to the horizontal axis<sup>4, 24, 27, 44</sup>. Due to the same reason the fixed cost curve also follows the same pattern. The variable cost curve, on the other hand, appears to decline gradually and steadily as the acreage increases, rather than staying constant<sup>4, 27</sup>. This is a weakness of the model in representing reality accurately for small acreages, due to large amount of cotton left in the field unharvested when the second picking follows the first in a very short time, not long enough for all the remaining bolls to open before harvesting begins again. Thus while the expenses for the second picking have been made, the amount of yield harvested is less than it should otherwise have been and therefore the variable cost per unit of output is higher than it should have been. As cotton area increases this loss of yield decreases and therefore the variable cost decreases.

Fig. 2 shows, the larger the cotton acreage the better, as the average harvesting cost per unit of crop harvested decreases continuously. This means that under these circumstances (no rains, no losses) the area harvested can be higher than 110 hectares and the mean value of the associated harvesting cost lower than 0.075 €/kg.

However, as the cost curves in Fig. 2 ignore weather (rainfall) constrains and crop losses resulting from untimeliness of the harvesting operation, they do not say anything about the least cost area harvested and the minimum harvesting cost. To determine the influence of those two factors upon the area and the cost the program was run using 20 years of generated rainfall data and the indices for yield and quality losses as well as the penalty charge reported before. The results obtained are presented in Fig. 3.

Fig. 3 shows that the fixed cost curve has the same pattern as

before, that is, it fails as acreage increases. The variable cost curve now consisting of the machine variable costs, the untimeliness loss costs and the penalty cost, starts rising from the beginning due to the influence of the two later factors. Subsequently it turns up sharply as the penalty cost - the cost (value) of the unharvested yield after 15<sup>th</sup> of November- becomes excessive and as cotton acreage increases beyond the point at which a picker can handle it. The average total cost curve, on the other hand, now shows the characteristic U-shape. It passes through the decreasing stage up to 50 hectares, as fixed cost is spread over more and more hectares, then flattens out and subsequently turns upward sharply due to the influence of the penalty cost. Comparison between the two figures (Figs 2 and 3) shows the market influence of weather (rains) constraints upon the harvested area and the associated cost. By ignoring weather and losses (Fig. 2) the area served increases beyond the 110 hectares and the associated harvesting cost decreases continuously reaching down to 0.075 €/kg. Consideration of these two factors reveals that the optimum cotton area is achieved at about the level of 50 hectares (Fig. 3), that is 55 percent lower than before, while the minimum harvesting cost increases now up to 0.15 €/kg, which means 100 percent higher.

**The effect of scattered fields:** So far the results obtained reflected the existing situation in central Greece, where the area harvested consists of a number of fields of various acreages scattered around the villages at various distances. The model determined field acreage and distance between them randomly by using the distribution found from the analysis of the relevant data. This scattered location of the plots implies a loss of time by the picker for traveling from field to field. To determine the influence of the fields dispersion upon the group area harvested and the harvesting cost, it was assumed that all plots constituting each successive acreage level were combined into a single plot or were contiguous, so that traveling time between them became negligible.

The program was run again after making this adjustment, while all other assumptions were kept the same as before. The results of this treatment are presented in Fig. 4. As can be seen from Fig. 4, pooling of land does not have any influence upon the least cost acreage and harvesting cost, which in both cases are the same, 50 hectares and 0.15 €/kg. However, as acreage level increases, pooling of land or contiguous cotton fields results in a progressive reduction of the harvesting cost, which becomes higher at the level of 110 hectares equals to 11.4 percent. This reveals the advantage of one single field - the main feature of the group farming system - for an efficient use of a cotton picker and other farm machinery.

**The effect of harvesting period length:** The results presented so far were based upon the assumption that the length of the harvesting period was 52 days, that is, commencing on 25<sup>th</sup> of September, the most frequent date, and ending on 15<sup>th</sup> of November. However, there are cases where harvesting starts before or after this date, depending on the crop maturity, which is influenced by a number of factors (particularly weather), affecting the length of the production season. This means that it should be worthwhile to investigate the effects of an early start to harvesting upon the optimum acreage level and the harvesting cost. Thus, it was decided to carry out a new treatment by increasing the harvesting

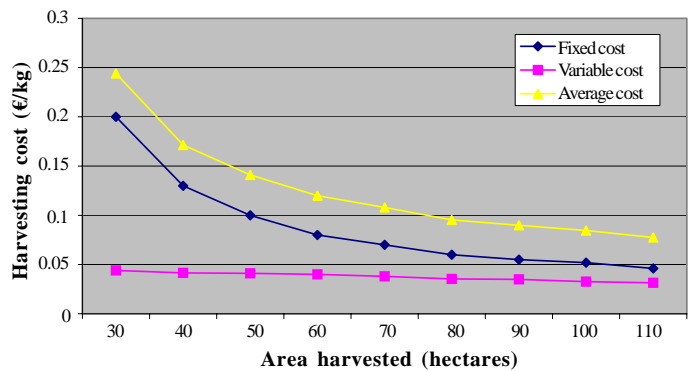


Figure 2. Cotton harvesting cost in relation to area harvested (assuming: no rains, no losses).

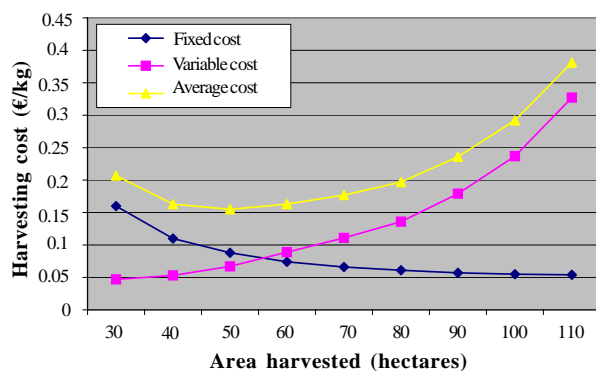


Figure 3. Cotton harvesting cost in relation to area harvested (assuming: rains, losses).

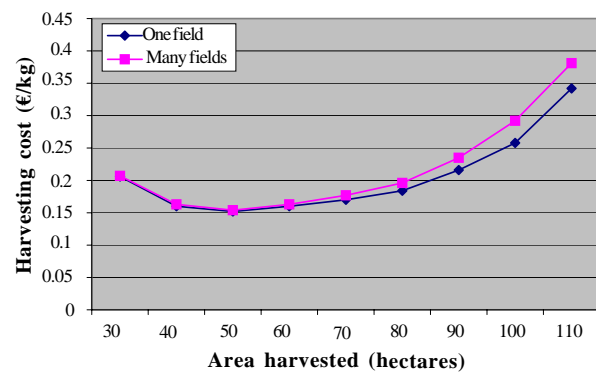
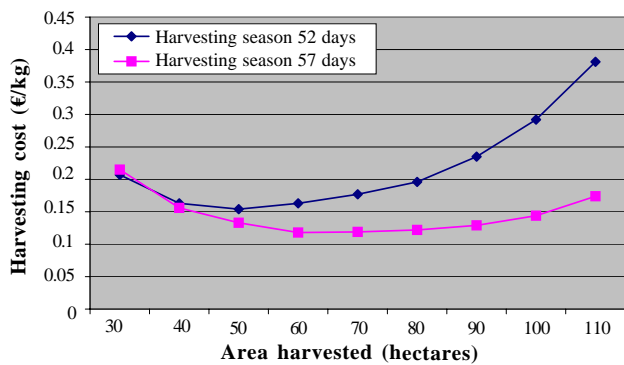


Figure 4. Cotton harvesting cost in relation to area harvested (assuming: one field and many fields).

period length from 52 to 57 days, i.e. by starting the harvesting at 20<sup>th</sup> of September, five days earlier than before.

The results of this treatment are presented in Fig. 5. As Fig. 5 shows, in small acreage levels, the 57-day period curve lies above the 52-day one, but as acreage increases it declines faster than the other, intersects it at about the 35 hectares level and continuously declining up to the level of 65 hectares.

Beyond that point it starts increasing a small amount but never approaches the 52-day period curve. The explanation of this pattern is that by starting the harvesting 5 days earlier than before, the proportion of bolls opened and therefore the yield harvested, when considering small acreages, is less than it would be if harvesting started 5 days later. Thus, while the total harvesting cost might be the same as before, the cost per unit, however, is higher as there is not enough time between the two harvests for



**Figure 5.** Harvesting cost in relation to area harvested (assuming: harvesting season 52 days and 57 days).

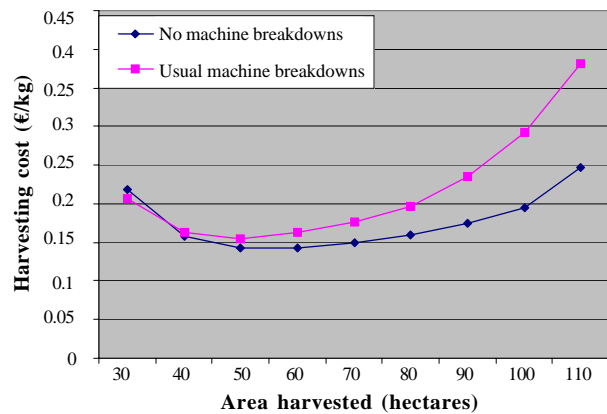
all bolls to open. In larger acreages the situation is different. Starting harvesting 5 days earlier it allows cotton picker to harvest a larger area and complete harvesting more frequently now than before. This entire means less pre-harvest yield and quality losses, as a larger proportion of the crop yield is harvested before the rainy period starts, penalty costs are smaller and less frequent, and completion of harvesting occurs more than before. Fig. 3 also shows that with a 52-day harvesting period the least cost area is 50 hectares as against 65 hectares in the case of 57-day period that is an increase of 30 percent. The corresponding harvesting cost values, on the other hand, are 0.15 €/kg for a 52-day period and 0.12 €/kg for a 57-day period, which means a cost reduction of 30.5 percent.

Thus, selection of early ripening variety combined with early planting and the relevant cultural practices, should lead to early crop maturity and this in turn to a more effective use of a cotton picker.

**The effect of machine reliability:** Machine reliability plays an important role in increasing picker efficiency and contributes to a reduction of the harvesting cost. This is true as machine breakdowns during the pick period of harvesting may result in costly repairs and delays in harvesting possibly lasting several hours and causing thus, substantial yield and quality losses, particularly when adverse weather conditions follow. As reported by Mygdakos and Gemtos<sup>39</sup>, machine breakdown occurs every 23.7 hours on average and requires 2.86 hours on average for repair. During the harvesting period each cotton picker undergoes on average 12.75 breakdowns, which correspond to an average idle time of 36.5 hours or about for days of work.

For that purpose an attempt was made to determine the influence of machine breakdowns upon the optimum acreage level and the corresponding harvesting cost. Thus, the program was run again assuming no machine breakdowns during the harvesting season and keeping all other assumptions the same. The results of this treatment were compared with those of a normal breakdowns machine. Fig. 6 shows the relevant information.

As can be seen from Fig. 6, the two curves are very close to each other in small acreage levels, but as acreage increases the difference between them become progressively larger. The curve corresponding to machine without breakdowns starts a bit higher than that of usual breakdowns, for the reason mentioned before, intercepts it again at the acreage level of 35 hectares and then lies



**Figure 6.** Effect of machine reliability (assuming: no machine breakdowns and usual breakdowns).

solely below that. The least cost acreage in the first case (usual breakdowns) is 50 hectares; while in the second one (no-breakdowns) is 65 hectares that is an increase of 30 percent. The harvesting cost, on the other hand, is 0.154 €/kg in the first case and 0.142 €/kg in the second case, which means a reduction of 8.5 percent.

All these mean that a reliable picker contributes substantially to an increase of the area served and to a reduction of the harvesting cost. High-level machine reliability depends largely on the operator's skill and motivation. Careful and responsible use of the machine, prevention of breakdowns before they occur, when possible, by repairing the worn-out parts and extensive repair and maintenance can maintain a high level of machine reliability.

**The effect of crop moisture content:** All the experiments so far, were conducted under the supposition that harvesting commences and ends every day when the crop moisture content is approximately at the level of 10 percent. This is a preposition to avoid seed-cotton degradation if the crop is to be stored for a period of time before ginning. If, however, wet cotton is to be ginned soon after harvesting, then it should be possible to start and finish harvesting at a higher moisture level. Thus, a 12 percent crop moisture content level was selected as an alternative harvesting policy. A 12 percent moisture content model allows an average increase of machine work up to about 3 hours per day or about 78 hours per harvesting season. This is a substantial amount of time, which could have a significant effect upon the cotton acreage harvested and the harvesting cost. For the purpose of determining this effect the program was run again under the same suppositions except that of moisture content, which is now 12 percent. The results obtained by comparing the cost curves for the two levels of crop moisture content are presented in Fig. 7.

Inspecting Fig.7, the following results can be drawn. The two curves follow a similar pattern as before. The 12 percent moisture content curve starts higher than that of 10 percent, for the same reason as pointed out before intersects it at the level of 50 hectares and thereafter lies lower than that. The above level of 50 hectares is the least cost acreage for the 10 percent moisture content curve while the corresponding level for the 12 percent curve is about 65 hectares, i.e. 30 percent higher. Similarly, the minimum harvesting cost value for the first case is 0.154 €/kg and for the second 0.14, which means a harvesting cost reduction of 10 percent.

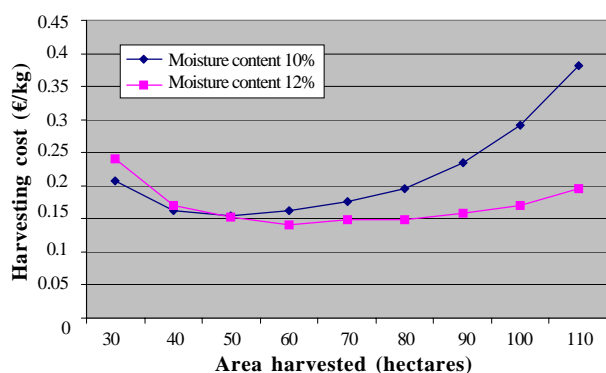


Figure 7. Effect of crop moisture content (assuming: moisture content 10% and 20%).

### Summary and Conclusions

In the present study a simulation model consisting of various stochastic and deterministic parameters has been used to investigate the most important factors affecting picker efficiency, area harvested and harvesting cost under Greek conditions.

Weather conditions and particularly rainfall occurrence and amount prevailing in the area during the harvesting season are the most important factors by reducing the number of days suitable for harvesting and subsequently the area served by a cotton picker, on the one hand, and by increasing yield losses and quality deterioration, on the other. Consideration of these two factors reveals that the optimum cotton area is reduced by 55 percent and the minimum harvesting cost is increased by 100 percent, compared to the case where no rains and losses are assumed.

The harvesting period length is another important factor affecting the area harvesting and the harvesting cost. Increasing the length of the period by 5 days, results in a 30 percent increase of the harvested area and a 24 percent decrease in the harvesting cost.

Crop moisture content for starting and ending cotton harvesting every day has also a significant effect upon the cotton area and cost. Increasing the level of crop moisture content for starting and ending harvesting from 10 percent to 12 percent, increases the area harvested by 30 percent and reduces the harvesting cost by 10 percent.

Machine reliability plays also an important role upon the area and the harvesting cost. Reliable picker harvests more than 30 percent cotton area compared to a picker with the usual breakdowns and contributes to a cost reduction up to 8.5 percent. Finally, pooling of cotton fields in one single field instead of many fields, has no any effect in small acreages harvested and the harvesting cost, but as cotton acreage increases it contributes positively to the area and the cost.

The findings of this study are very important for the cotton picker owners, cotton production groups, cooperatives and those who have the responsibility for the agricultural policy.

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