Economic evaluation of mechanical harvesting of lemons

J. M. Brotons-Martínez[a*]; B. Martin-Gorriz[b]; A. Torregrosa[c]; I. Porras[d]

[a] *Departamento de Estudios Económicos y Financieros. Universidad Miguel Hernández, Avda. de la Universidad, s/n, 03292, Elche, Alicante*

[b] *Universidad Politécnica de Cartagena. Dpto. Ingeniería Alimentos y Equipamiento Agrícola*

[c] *Universitat Politècnica de València. Dpto. Ingeniería Rural y Agroalimentaria*

[d] *Departamento de Citricultura y Calidad Alimentaria, Instituto Murciano de Investigación y Desarrollo Agrario y Alimentario (IMIDA), Estación Sericícola, Calle Mayor s/n. 30150, La Alberca, Murcia*

[*]Corresponding author: jm.brotons@umh.es

Abstract

Several hypotheses regarding hand and mechanical harvesting have been analysed, in order to estimate the economic possibilities for the mechanical harvesting of lemons taking into account the current availability of technology. We considered several detachment options under experimental conditions; only yellow detachment has been considered for mechanical harvesting, because the sensitivity to the impacts is lower and mechanical detachment was high (80%). Price changes throughout the season were also considered. Total harvest cost is an average of the cost of mechanical harvesting (80%) and the cost of manually harvesting remaining fruit (20%), plus the cost of handling the mechanical harvested fraction. This cost ranges between 0.031 and 0.058 € kg^{-1} for outputs between 20 and 60 t ha^{-1}, respectively, which is always lower than harvesting by hand (0.065 € kg^{-1}). A Monte Carlo approach was used to study the sensitivity of the results, and Value at Risk (VaR) calculated. The analysis showed that the mechanical harvesting margin is *c*0.020 € kg^{-1} higher than the hand harvesting margin, and the output dispersion is higher in March. The VaR analysis showed that at 10% there was no risk that the hand margin is higher than the mechanical margin; at 5% the risk is very low and only for March harvesting. Mechanical harvesting represents a good economic option compared to hand harvesting, since it can increase farmer income by between 400 and 1200 € ha^{-1}.

Key words: Shaker; profitability; harvesting economic margin; Monte Carlo; VaR.

Introduction

The main use of Spanish lemons is for the fresh market. Harvesting starts when the fruit reach 58 mm in diameter (García-Lidón *et al.*, 2003; Porras, 2014). During the first harvesting period, lemons are still green in colour, and must be harvested with care, since any impact will lead to bruising during the de-greening process. The natural colour change on the tree takes place when the average temperature falls below 15º C (Manera *et al.,* 2012 a, b). After that, the fruits can be managed with less care because the skin is able to resist small impacts without the formation of spots, bruising and rot.

Lemon prices vary throughout the harvesting period and are influenced by the expected levels of production; they are generally high at the beginning of harvest (September-October), and then decrease progressively until April, when prices the usually recover. In years with more than 700,000 t of expected production, the price usually remains low (Brotons *et al.,* 2015). In these cases, one of the really important challenges facing agricultural producers is the choice of their product distribution channels (Mojaverian et al., 2014).

Mechanical harvesting of citrus fruit is used in countries such as the USA, where there is a shortage of labour and where the main market is the juice industry. Several types of equipment are used, mainly trunk and canopy shakers (Whitney, 1999; Sanders, 2004). In the Spanish region of Andalusia, mechanical harvesting with canopy shakers is being used in some citrus orchards for juice (Arenas-Arenas *et al.,* 2015; Bordas *et al.,* 2012). Although the surface area of citrus mechanically harvested globally is not high, in industrial zones such as Florida, research and development on mechanical harvesting continues to provide alternatives in the event of labour shortages (Roka and Hyman, 2012).

In South-East Spanish lemon orchards (Murcia, Alicante) trials on mechanical harvesting with trunk and branch shakers have been carried out combined with canvas collection of detached fruit to avoid impacts with the ground, in order to obtain a clean product and ease transfer to boxes. Detachment percentages of 80 % have been attained with trunk shakers (Torregrosa *et al.,* 2010). Hand-held branch shakers do not seem to be effective because they do not improve detachment and are less productive than trunk shakers; moreover, they are not ergonomic, with risks to the operator in managing machines that are heavy and which transmit noise and vibrations (Villalba *et al.,* 2016). The success of mechanical fruit detachment by vibratory methods depends, among other factors, on fruit detachment force. In this way, several chemical products have been tested to reduce such force, including ethephon and 5-chloro-3-methyl-4-nitro-1H-pyrazole (CMNP), but the low increases in detachment achieved in trials advise against their use, particularly in the present context of chemical reduction (Burns *et al.,* 2006; Torregrosa *et al.*, 2010 and Moreno *et al.*, 2015).

After December, the lemon skin is more tolerant to impact (Porras, 2014) so mechanical harvesting is an alternative to manual harvesting which can be used under two scenarios, (i) in years with excessive global production, low prices and all the yield is targeted to the juice industry, and (ii) as a simple alternative to hand harvesting to reduce costs. In this way the application of Auto-Regressive Integrated Moving Average (ARIMA) models for forecasting agricultural prices is becoming a very useful tool (Jadhav et al. 2017). In this study, several hypotheses for hand and mechanical harvesting were analysed, using as detachment percentages from experimental trials to estimate the economic possibilities for lemon harvesting using existing techniques.

Materials and methods

Experiments were carried out in a lemon orchard at the Instituto Murciano de Investigación y Desarrollo Agrario (IMIDA, La Alberca-Murcia), under full commercial production and controlled experimental conditions. The variety Fino 49 was used which is the most widespread in Spanish citriculture (Porras *et al.*, 2012). To determine the economic possibilities for mechanical harvesting, the following steps were followed:

1. Determination of harvesting costs per tree (€ $tree^{-1}$) comprising tractor costs and labour, as the product of the time used (h $tree^{-1}$) by the hourly cost (€ h^{-1});
2. Determining harvesting costs per kilogram of product (€ kg^{-1}) for every harvest date and yield (kg ha^{-1}). It is thus possible to compare costs between mechanical and hand harvesting on each date. Several yield scenarios were analysed and the costs per kilogram harvested calculated. It was assumed that the harvester is able to detach 80% of the fruit, based on previous studies from 2005 to 2009 (Torregrosa et al., 2010). The remainder is harvested by hand. Fruit selection and peduncle cutting costs are included;
3. Determination of income per kilogram. Weekly prices provided by the Spanish Agriculture Ministry (MAGRAMA, 2015) from the last 10 years were considered. On the tree and hand harvesting costs (0.065 € kg^{-1}) have been included. In this way, the farmer assumes the harvest costs. The percentage of fruit without calyx that exceeds 5% cannot be sold in the fresh market and is used for lower value uses such as the juice industry and animal feed.will be for industry.
4. Determination of the economical margin per kilogram of production, as the difference between income and mechanical harvesting costs. The costs for fruit selection and peduncle cutting carried out in the packing house also need to be included. The cost is then compared with the hand economic margin, the difference between incomes, and hand harvesting cost;
5. Sensitivity analysis using the Monte Carlo method. Although in some studies only the effect of changes in one variable on results have been analysed, such as the interest rate (Grafiadellis and Mattas, 2000), the Monte Carlo simulation allows the effect of several variables combined to be studied (Wagner, 1995). For calculation, an Excel spread sheet was used with 20000 iterations. The parameters considered were yield (kg ha^{-1}), detachment percentage, reduction of harvesting time, and prices.

In this study it was assumed that yield follows a probabilistic normal distribution as a function of the production in the previous years; the detachment percentage has a probabilistic uniform distribution as a function based on the trials conducted; the reduction in time necessary for harvesting has been considered as having a uniform probabilistic distribution, and price has been considered to follow a lognormal distribution.

The Value at Risk (VaR) can be defined as the lower value for a variable by a determined confidence level α, this is the value at which the α % of possible values for that variable is lower than that value, and the (1- α) % is higher (see for example, Saunders et al., 2003). Value at Risk ($VaR\alpha$) can be obtained in a parametric form, as the α-quantile of such a distribution.

Results

Evaluation of harvesting costs per tree

For mechanical harvesting, four operators working simultaneously are required to manage the catching canvases. For the remaining activities, one operator is sufficient. A summary of costs is given in Table 1. These are the calculated costs for medium sized trees; it was assumed that the time used for each tree is identical, independently of tree yield, because the time needed for the trunk shaker is independent. The operation to empty the fruit from the canvas to the ground is also independent of tree yield, but if lemons form the canvases are transferred manually to boxes, then this time will depend on tree yield. Each tree requires 0.044 h. The harvesting time was obtained using equipment without lateral motion, this means that more time per tree was needed to perform tree engagement manoeuvres than if a shaker with lateral movement was used. With a shaker provided with these adjustments, tasks 2 and 4 (Table 1) would be faster and the time estimated to harvest a tree would be 30% lower, which equates to 0.031 h tree^{-1}. The cost per tree (Table 2) is the cost of the tractor (including driver) plus the cost of the operators. The total cost was 2.99 € tree^{-1}.

Determining harvesting costs per kilogram

For the calculation of harvesting costs per kilogram (Table 3) a 1 ha orchard with 267 trees (frame 5 m x 7.5 m) was assumed. In order to take into account other alternatives, it was assumed that yield could vary between 30000 and 60000 kg ha^{-1}. Moreover, detachment percentages in this trial and previous trials ranged between 69 and 85% with an average 80%; this value was therefore used. Non-detached fruit (20%) must be harvested by hand, this cost was assumed to be 0.065 € kg^{-1}. The total harvesting cost is the cost that combines mechanical (80%) and manual (20%) unitary costs. The data from Table 3 is summarised in Figure 1a. As noted, the mechanical harvesting cost, and consequently, the total cost, is clearly lower than the manual costs, and the total cost decreases as yield per hectare rises. To these costs, it is necessary to add the cost of the selection and peduncle cutting that is carried out in the pack-house. In calculating these costs was assumed that approximately 50% of fruit must be managed by an operator in the pack-house line with one hand and to cut the peduncle with scissors with the other hand. It will be possible to manipulate 30 fruit min^{-1} (1800 fruit h^{-1}), and discounting downtime the efficacy would be over 1700 fruit h^{-1}. If the average weight of a lemon is 140 g, this means 7.14 lemons kg^{-1} and 238 kg h^{-1}; if the cost of labour in the pack-house is 8 € h^{-1} then this operation costs 0.033 € kg^{-1}. Table 4 shows the proportions of fruit harvested with calyx, without calyx and with peduncle (Torregrosa *et al*., 2010) and the costs of selection and conditioning of mechanically-harvested fruit per kilogram. This cost is independent of tree yield, because it is completed after harvest.

By combining the conditioning costs (Table 4) with harvesting costs (Table 3) the total costs per harvested kilogram were derived (Table 5). It must be highlighted that mechanical harvesting for the three selected periods was lower than hand harvesting. The mechanical cost is similar in January and February and significantly lower in March. This is due to the fact that the proportion of fruit with a peduncle, considering the peduncle itself or the same plus a portion of twig, is almost similar in the two first months (65 and 61%) with conditioning costs being similar, but the proportion of fruit with peduncles is much lower in March, so mechanical total costs are reduced.

Determining income per kilogram

From information provided by MAGRAMA (2015) the weekly trend in lemon prices from the beginning of January to mid-April for the last 12 years (2004-2015) is shown in Figure 2. These constitute the price (€ kg^{-1}) plus the costs of hand harvesting (0.065 € kg^{-1}) in order to obtain the fruit price in field, harvested and available to the buyer. In Figure 2 it can be seen that the average prices are quite stable between January and March and then tend to rise in the latter weeks (April-May). With the average weekly price data (Figure 1b) the prices for dates in which the trials were performed were calculated: 0.273 € kg^{-1}, 0.261 € kg^{-1} and 0.286 € kg^{-1} for 15th January, 14th February, and 15th March, respectively. For lemons harvested without a calyx, it was assumed that if the proportion was less than 5%, then they can be sold for fresh and if the proportion exceeds that limit they must be sold for industry (0.07 € kg^{-1}). From the percentages of fruit harvested with and without calyx (Table 4) and considering that all the fruits harvested by hand have a calyx, the income per hectare was calculated (Table 5). It is obvious that the production value increases with yield, although the increase by harvested kilogram does not vary, representing 0.273 € ha^{-1}, 0.261 € ha^{-1}, and 0.275 € ha^{-1} for harvesting in January, February and March, respectively. It should be noted that in the March harvesting, income per harvested kilogram does not coincide with the fruit price for that date, because part of the fruit will be sent to industry, which reduces the average income.

Economic harvesting margin

Economic harvesting margin is defined as the difference between the average selling price and the unit harvest cost in € kg^{-1}. The following two factors were considered to derive the harvesting margin, (i) only harvesting carried out after 15th January was considered, since before that date lemons are green and cannot be harvested mechanically (Porras, 2014), and (ii) the hand harvesting cost (0.065 € kg^{-1}) has been added to the market selling price to consider the harvested lemon price in the orchard. From the comparison shown in Table 5 and from incomes per harvested kilogram for each date, the economic harvesting margin by date was calculated as a function of yield (kg $tree^{-1}$) (Figure 3). The margins in hand harvesting were 0.208 € kg^{-1}, 0.196 € kg^{-1} and 0.221 € kg^{-1} for January, February, and March harvesting dates, respectively. As shown in Figure 3, the margin for mechanical harvesting (which depends on tree yield) is greater than the margin from hand harvesting. That margin is higher for higher yields, because the majority of the mechanical harvesting costs per surface area do not depend on yield. It should also be noted that the economic margin for mechanical harvesting rises with late harvesting, which is due to (i) the market price being slightly higher, and (ii) decreases in the cost of peduncle cutting, because the proportion of fruit with a peduncle is lower (the percentage falls from 60% in the first two dates to 34% in the last one). These two factors have a positive effect that overcomes the negative aspect of the fruit being harvested without calyx having to be sold at industry prices (0.07 € kg^{-1}).

Sensitivity analysis

A sensitivity analysis of the results has been undertaken using a Monte Carlo approach. The following variables have been used:

1. Yield, as a normal variable with 39,758 kg ha^{-1} on average and 7399 kg ha^{-1} standard deviation.
2. Detachment percentage oscillates between 69% and 85%.
3. The same procedure was adopted for improving harvesting time, ranging between 20% and 40%.
4. Prices on each date (15th January, 14th February, and 15th March) considered as a lognormal variable with averages of 0.273 € kg^{-1}, 0.261 € kg^{-1}, and € kg^{-1} and standard deviations of 0.158 € kg^{-1}, 0.14 € kg^{-1}, and 0.167 € kg^{-1} for January, February, and March harvesting, respectively.

After 20 000 iterations, the difference between the mechanical and hand harvesting margin was calculated. Figure 3a shows the probability to obtain each of the different intervals between the mechanical and hand harvesting margin (intervals considered were 0.002 €). The analysis shows that the probability of the difference between mechanical and hand margin is similar for January and February, but February has values slightly higher for all the curve. In fact, the higher probability values are 0.020 € kg^{-1} in January and 0.022 € kg^{-1} in February. In January the economic margin for mechanical harvesting is higher than for manual harvesting. It can therefore be concluded that mechanical and hand harvesting have similar margins, perhaps slightly higher in February. Conversely, March harvesting shows a different curve, with a central value of 0.022 € kg^{-1}, and higher dispersion , and left skewed (negative skewness)with the left queue longer than the right queue.. This means that small differences between both margins are also possible in March, in some cases making it more beneficial to hand harvest.

Figure 3b shows the accumulated probability function, or the probability that the margin difference between mechanical and hand harvesting exceeds each of the X axis values. Each point on the curve indicates the probability that the difference between margins was lower than the corresponding value on the X axis. For example, the probability that the margin is 0.01 € kg^{-1} or less is practically zero in January and February but 0.10 € kg^{-1} in March. The probability that the margin is not higher than 0.02 € kg^{-1} is 3 % in January, 2 % in February and 0.10 % in March. Thus, for January and February it is possible to state at a 5% confidence that the margin of mechanical harvesting will exceed that of hand harvesting by 0.02 € kg^{-1}, but this cannot be said for March. Moreover, the probability that mechanical harvesting exceeds hand harvesting by 0.025 € kg^{-1} is 97%, 93%, and 96% in January, February, and March, respectively. So, in all cases there is less than a 10% probability that the mechanical margin will not exceed that of hand harvesting by more than 0.025 € kg^{-1}.

To complete the sensitivity analysis it has was considered appropriate to introduce the results obtained for $VaR_{5\%}$ and $VaR_{10\%}$ (Table 6) that represent the values exceeding 95% and 90% probability, respectively. $VaR_{5\%}$ indicates that in 95 % of the cases the mechanical harvesting margin exceeds that of manual harvesting in the indicated value. Thereby, for January and February it is possible to state that in 95 % of cases the mechanical margin is greater than the manual margin, but not for March harvesting (in this case it is only possible to state at 95% confidence that hand harvesting does not exceed mechanical harvesting by more than 0.004 € kg^{-1}). Conversely, $VaR_{10\%}$, indicates the minimum value at which the mechanical margin exceeds the manual one in 90% of cases. As it can be checked to 90% probability, it can be started that mechanical margin always exceeds the manual margin. Indeed, in January and February the mechanical margin exceeds the manual one by more than 0.014 € kg^{-1}, and in March by more than 0.002 € kg^{-1}.

Conclusions

Mechanical harvesting costs (80 %) plus hand harvesting costs (20 %) can be estimated at 0.028 € kg^{-1} and 0.046 € kg^{-1} for yields of 20,000 kg ha^{-1} and 60,000 kg ha^{-1}, respectively. Mechanically-harvested fruits need some complementary conditioning operations in the packing house such as the selection of damaged fruits and peduncle cutting; that can be estimated at 0.011 € kg^{-1} and 0.021 € kg^{-1} harvested, depending on the harvesting date. This variation is due to differences in the proportion of fruits detached with peduncles at each date. For all harvesting dates and for all yields, mechanical harvesting costs are lower (0.031-0.058 € kg^{-1}) than hand harvesting costs (0.065 € kg^{-1}). The economic margin of mechanical harvesting, which depends on tree yield, is greater than that generated by hand harvesting in January, February and March. Sensitivity analysis shows that the mechanical margin exceeds the hand margin by approximately 0.020 € kg^{-1}, with the dispersion being wider in March harvesting than in January and February, when in some cases, the hand margin may be higher than the mechanised one. This study shows that at 10 % there is not risk that the hand margin will exceed the mechanical one, this being minimal at 5 % probability and only for March harvesting. For these reasons, it can be stated that mechanical harvesting is a good economic alternative to hand harvesting, because it can increase farmer's incomes by 400 to 1200 € ha^{-1}.

Acknowledgement

This work was funded by Consejería de Agricultura y Agua de la Región de Murcia and by INIA and FEDER funds (Project RTA2014-00025-C05-02).

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Table 1 Operations involved in mechanical harvesting, showing the number of operators and the required time.

Operation	Operators (number)	Time (s)
1. Extend cushioned canvas under each side of the tree and shake it	4	40
2. Approach the tractor and hitch the shaker to the trunk	1	60
3. Shake	1	10
4. Remove the shaker and move the tractor to the line centre	1	30
5. Download the canvas in the line centre making a cordon of fruits	4	20
Total	**4**	**160**

Table 2 Harvesting cost per tree (€/tree)

	Hourly cost (€)	Number	Time (hours)	Total cost (€)
Additional hand labour	9	4	0.031	1.12
Tractor plus shaker*	60	1	0.031	1.87
Total				2.99

**Tractor cost includes shaker and driver.*

Table 3 Total harvest cost per kilogram, assuming that the machine shakes 80% of the production to the ground and the remainder is hand harvested.

Yield (kg/ha)	20,000	30,000	40,000	50,000	60,000
Total yield (kg/tree)	75	112	150	187	225
Production mechanically harvested (kg/tree)	60	90	120	150	180
Production hand harvested (kg/tree)	15	22	30	37	45
Mechanical harvesting cost (€/kg)	0.035	0.023	0.017	0.014	0.012
Hand harvesting cost (€/kg)	0.065	0.065	0.065	0.065	0.065
Total harvesting cost (€/kg)	**0.041**	**0.032**	**0.027**	**0.024**	**0.022**

Table 4 Percentage of fruit with calyx, peduncle and without calyx, and the cost per kg of classifying and cutting the peduncle according to the date of recollection (Torregrosa et al, 2010).

Date	Fruit without calyx (%)	Fruit with peduncle (%)	Fruit with calyx (%)	Conditioning costs, selection of damaged fruit and peduncle cutting (€/kg)
15th January	0	65	35	0.021
14th February	4	61	35	0.020
15th March	11	34	55	0.011

Table 5 Production value (€/ha) and total cost of mechanical harvesting (for the dates shown) and cost of hand harvesting according to production (kg/ha).

Yield (kg/ha)	**20,000**	**30,000**	**40,000**	**50,000**	**60,000**
Yield value (€/ha)					
15th January	5 450	8 175	10 900	13 625	16 350
14th February	5 217	7 825	10 433	13 042	15 650
15th March	5 509	8 264	11 019	13 774	16 528
Mechanised cost (€/kg)					
15th January	0.058	0.049	0.044	0.041	0.039
14th February	0.057	0.048	0.043	0.040	0.038
14th February	0.050	0.041	0.036	0.033	0.031
Hand Cost (€/kg)	0.065	0.065	0.065	0.065	0.065

Table 6 Value at Risk at 5 and 10% (VaR5% and VaR10%).

	15 Jan	15 Feb	15 Mar
$VaR_{5\%}$	0.012	0.013	-0.004
$VaR_{10\%}$	0.014	0.015	0.002

Figure 1 (a) Harvesting cost (€/kg) by production (kg/ha) for mechanical harvesting (black line), hand harvesting (red line) and weighted harvesting 80 % mechanical harvesting and 20 % hand harvesting (blue line). (b) Economic harvesting margin (€/kg) by production (kg/ha) for mechanical harvesting (black line), hand harvesting (red line) and weighted harvesting 80 % mechanical harvesting and 20 % hand harvesting (blue line).

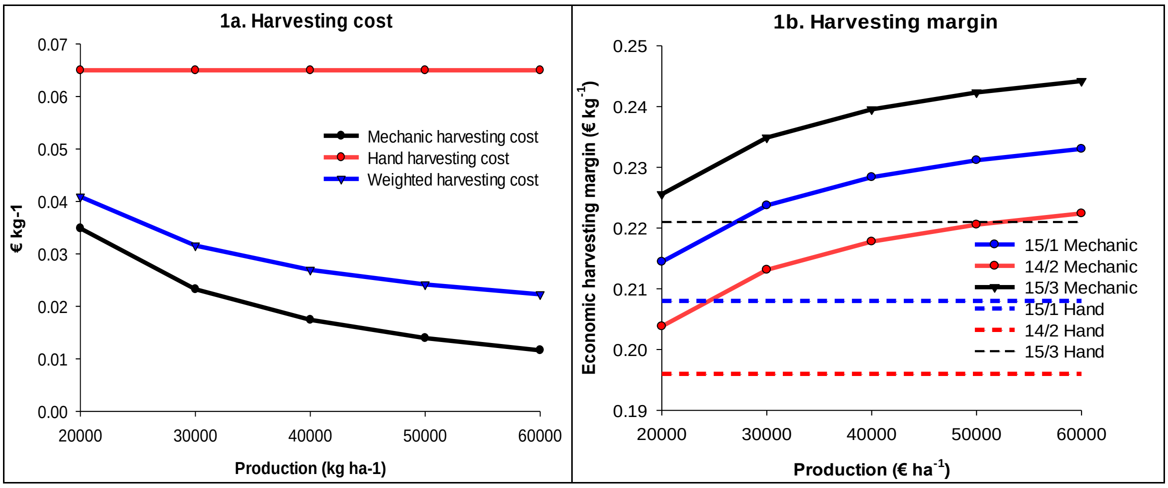

Figure 2 Weekly price of lemon in Spain from 2004 to 2015 (MAGRAMA, 2015)

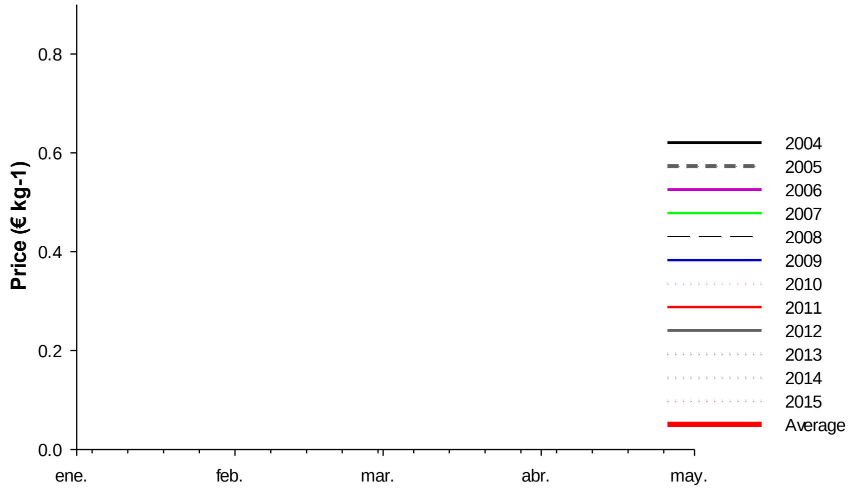

Figure 3 (a) Probability of the difference between the mechanical harvesting margin and the hand harvesting margin according to harvesting date, (b) Accumulated probability of the difference between the mechanical harvesting margin and the hand harvesting margin according to harvesting date.