Contemporary Engineering Sciences, Vol. 9, 2016, no. 27, 1315 - 1337
HIKARI Ltd, www.m-hikari.com
http://dx.doi.org/10.12988/ces.2016.68133

Comparisons between Battery Chainsaws and Internal Combustion Engine Chainsaws: Performance and Safety

A. Colantoni, F. Mazzocchi, F. Cossio, M. Cecchini, R. Bedini and D. Monarca

Tuscia University, Department of Agricultural and Forestry Sciences (DAFNE)
Viterbo, Italy

Abstract

The thesis compares the features and performance of three of battery chainsaw models of two Manufacturers against two equipped with internal combustion engine and all designed for use in pruning. The cutting times for five woody species with different hardness of the wood have been examined; assessed the safety in use of the individual machines and a rough evaluation for the energy consumption. The purpose is to understand the potential of these battery chainsaws, currently used for pruning, for possible use in forest exploitation.

Keywords: battery chainsaw, forest exploitation, safety and health

1 Introduction

Currently there is a great development of machines for the management of portable battery-green, in a "green" development, to protect the environment and the operator.

Currently there is a great development of portable battery machines for urban green management, to protect the environment and the operator's health. as we shall see, the battery chain saws are able to decrease number of specific risks, which makes them ideal for use in arboriculture (and other sectors such as agriculture,

food industries, etc.) where occupational hazards are high and it is important to minimize (Mazzocchi et al. 2015, Cecchini et al. 2010 b, Marucci et al. 2012, Marucci et al 2013, Di Giacinto et. al. 2012). Electric instruments technology has been developed deeply, but is newly introduced in the urban green areas management, because of the need to have a relatively high power but away from the public network (Blanco et al. 2013, Blanco et al. 2014), and for all the duration of the working day. Latterly development of batteries, has led to a sufficiently high level of power and durability, suitable for this purpose, with considerably reduced weights compared to older types of battery. Moreover, Lithium-ion batteries could now be recycled with an efficiency of 97% w/w of the valuable battery active materials (Hanisch C.et al 2015, Boubaker et al. 2014). In this study were taken into the cordless chainsaws exam, in two different types: with built-in battery and separate battery to take backpack.

2 Materials and methods

For comparisons, in this work, have been used different machines, which represent the most advanced technology available for operators, provided from the market.
Small chainsaws were selected, since light compact equipment, are necessary for pruning with very short bars, because of the diameter of the branches cut that rarely exceeds 10-15 cm. At the same time a discrete power is necessary, to cut easily hard or dry wood.
They were taken into consideration:

- Pellenc Selion C15- top handle backpack battery chainsaw;
- Pellenc Selion C20- top handle backpack battery chainsaw;
- Stihl MSA160C-BQ- battery forestry-shaped chainsaw;
- Stihl MS192T- 2-stroke pruning chainsaw;
- Stihl MS200T- 2-stroke pruning chainsaw;

Used battery are the following:

- Pellenc Poly 5- ULiB Battery, with charger;
- Stihl AP 160- Lithium ion battery, with fast charger AL 300.

2.1 Data acquisition mode.
The key parameter to judge the performance of a chainsaw is the cutting speed. A valid machine must have a low cutting time, in relation to the diameter and to the test species. Two operators are needed to detect this gave, the first dealt with the cutting with the machine in question, the second fitted with chronometric table, taking

the cutting time and reported on a special grid where also write the diameter of the branch. The cutting times are obtained with a chronometric table, equipped with four analog chronometers, of which one is used for the relief of the total times, the three other alternately actuated by a lever may be used for the relief of partial rates. On the chronometric table sheets can be fixed to write rapidly the measured times. The detection accuracy is the hundredth of a minute.
Since those chain saws intended mainly for use in pruning, it is chosen to detect the timing of diameters from 30 to 100 mm, given that beyond this cutting diameter is provoke major wounds to the plants and below, to obtain a good cutting, the hacksaw or tin snips are required.
To detect the size of the branch subjected to cutting, the tree calliper, for larger diameters (in excess of 60mm) was used, while for smaller diameters (from 30 to 60mm) the caliber was used.
A small part of the test however was extended to larger diameters, in which the Stihl MS 200 T was used, whose scope also extends to fell small trees. The material for the tests has been found on different work sites, where the required size logs were identified, and taken to a square where once placed on an easel, it started cutting and detect time. They were only used branches and green trunks.
Both operators were provided with the appropriate personal protective equipment: chainsaw protection trousers class 1, chainsaw protection boots class 1 cut-resistant, protective glasses and earplugs and the operator which was cutting wore also safety helmet.

2.2 Features of the used machines (declared by the manufacturer).

Pellenc Selion C15-C20

The Selion C15 is the first electronic chainsaw introduced by the French company in 2008, which was joined by the model Selion C20 with more power (in 2010). Both of reduced dimensions but with a 30cm long bar, brushless electric motor, able to develop 1500W to 2000W for the C15 and C20, very light because the battery is not incorporated but is brought to backpack. The engine is connected directly to the pinion that moves the chain and therefore the friction and the speed reducer are absent. The chain brake has an electronic clutch, controlled by a sensor which reacts to the machine falling or bouncing, and is also equipped with fixed grip front protection.
The chain tension adjustment is automatic, just engage the guide on the tool head that tends properly via a spring mechanism, while removing the chain cover is facilitated by an integrated removable key. The oil flow is electronically controlled,

depending on the absorption of the motor, to avoid waste, and the start of the engine is controlled by the double pulse trigger can only be activated if you press the handle positioned security simultaneously. The energy delivery depends on the absorption of torque, required at the time of the cut, thus optimizing fuel consumption.

Table 1. Technical data: Pellenc Selion C15 e C20

Features	U.M.	Pellenc Selion C15	Pellenc Selion C20
Weight*	kg	2	2
Power	kW	1,5 at 5400 rpm	2 at 6200 rpm
Chain speed	m/s	10,3	14,4
Guide bar	cm	30	30
Saw chain		Oregon ¼ Micro Chisel 25AP	Oregon ¼ Micro Chisel 25AP
Measured power sound level	dB(A)	84	84
Guaranteed sound power level	dB(A)	96	96
Vibration level (left)	m/s^2	4,2	2,8
Oil tank capacity	l	0,25	0,25

* without guide bar, saw chain and oil

Stihl MSA 160C-BQ

The Stihl MSA C-BQ cordless chainsaw is the first of the German House, and keeps the traditional design with rear handle for the right hand and tophandle for the left hand. Also here there is an electronically controlled brushless motor. The battery is inserted in the machine, vertically, right behind the front handle, which is protected by hand guards that acts as a switch for the chain block in case of impact or kickback. The chain tension is adjusted by the rotation of a wheel located over the drive sprocket, which also owns an integrated lever to loosen and tighten the chain cover.

This model has supplied the chain brake Quick Stop Super, which locks the chain not only in case of activation of the front hand guard, but also in the case of the throttle trigger release. To work more comfortable, a belt where to place the battery is

available. Operator can connect it to the chain saw by a cable, reducing the overall weight of 1.7 kg in order of work.

Table 2. Technical data: Stihl MSA 160 C-BQ

Features	**U. M.**	**Stihl MSA 160 C-BQ**
Wheight whitout battery	kg	3,2
Wheight with battery	kg	4,9
Guide bar	cm	30
Saw chain	"	¼ PM3
Power sound level	dB(A)	98
Sound power level	dB(A)	88
Vibration level (left/right)	m/s^2	2,0/2,0

Stihl MS 192 T

It is the lightest of the Stihl chainsaw for the maintenance of the trees at the time of testing. It is equipped with the ignition microprocessor to minimize the bounces startup. The handle is mounted on anti-vibration dampers to reduce the perception of vibrations by the operator. It is equipped with a low bounce chains and you can mount the carving bar to work with greater precision. Mounts a 30 cm long guidebar and with its 2-stroke engine, it develops 1.3kW. The side chain tensioning is operated from the supplied wrench to unscrew the plug. It owns the manual fuel pump to facilitate the start-up after a period of inactivity. The closures of the tanks can be opened without tools, but ensure a perfect fluid seal. The safety devices are the classic: accelerator with security, front hand guard button that actuates the chain brake in the event of a collision, chain catcher mounted beneath the pinion to decrease the speed of impact of the chain in case of breakage.

Table 3. Technical data: Stihl MS192T

Features	**U. M.**	**Stihl MS192T**
Displacement	cm^3	30,1
Weight*	kg	3,1
Power	kW	1,2
Guide bar	cm	30

Saw chain pitch	"	3/8 P
Sound pressure level	dB(A)	109
Sound power level	dB(A)	97
Vibration level left/right	m/s2	2,9/3,1

* without guide bar, saw chain and oil

Stihl MS 200 T

A lightweight and powerful precision chainsaw, designed to work specifically for arborists. It has good handling thanks to the top handle and good balance. Fitted with 35 cm long guide bar and low bounce chain for higher safety in use. It mounts an oil pump with adjustable flow, a compensator that maintains the fuel-air mixture even when increased air filter dirt. It is equipped with a damping element integrated in the tear-starting system that absorbs peak of force generated during start-up, making them uniform and facilitating the setting in motion (Stihl ElastoStart). The oil pump is supplied with adjustable flow, for precision dosing of the required amount of oil depending on the type of wood and the cutting length. The chain lock mechanism kicks in with "bump" on the traditional protection of the left hand. The chain tensioner is lateral and operated from the supplied wrench to unscrew the plug. The right handle locates the throttle control with an attached security on top, and the ignition command, shutdown and cold ignition.

Table 4. Technical data: Stihl MS200T

Features	**U. M.**	**Stihl MS200 T**
Displacement	cm^3	35,2
Weight *	kg	3,6
Power	kW	1,7
Guide bar	cm	35
Saw chain pitch	"	3/8 P
Sound pressure level	dB(A)	109
Sound power level	dB(A)	98
Vibration level left/right	m/s^2	3,4/3,8
Chain speed	m/s	26

* without guide bar, saw chain and oil

2.3Used batteries

Pellenc Poly 5

The ULiB Poly 5 battery is designed specifically to deliver high power as that required by chainsaws C15 and C20 and for use in pruning climbing. The whole is structured to be carried on the shoulders like a backpack. The lithium-polymer components are less heated of other elements, and it allows to have a greater power at the moment of cutting, while maintaining the reduced weight, as well as the dimensions: thickness of only 45mm. The ergonomic vest allows the operator to move freely while climbing. The display autonomy expressed in percentage (1-99%) and the sockets for charging and the cable coupling of the instrument are present.

Table 5. Technical data: Pellenc ultra lithium battery poly 5

Features	**U. M.**	**Pellenc Ultra Lithium Battery Poly 5**
Total weight	kg	3,6
Voltage	V	50,2
Amperage	Ah	10,6
Stored energy	Wh	500
Life cycle	cicli	1200
Kind		Lithium-polymer

Stihl AP 160

This is a very powerful battery with lithium ions, which must be inserted inside the chain saw, hangs pushing it to the bottom and can be removed by pressing two buttons on the machine head. In the upper part of the battery there is the indicator displays the state of charge formed by 4 LED representing 1/4, 2/4, 3/4, 4/4 autonomy.

Table 6. Technical data: Stihl AP160

Features	**U. M.**	**Stihl AP 160**
Total weight	kg	1,7
Voltage	V	36
Amperage	Ah	4,5
Stored energy	Wh	160
Kind		Lithium-polymer

2.4 Vibration and weight

In addition to cutting performance, it is important to also consider other features to understand the quality of these instruments and disadvantages if any. The data are declared by the manufacturer.

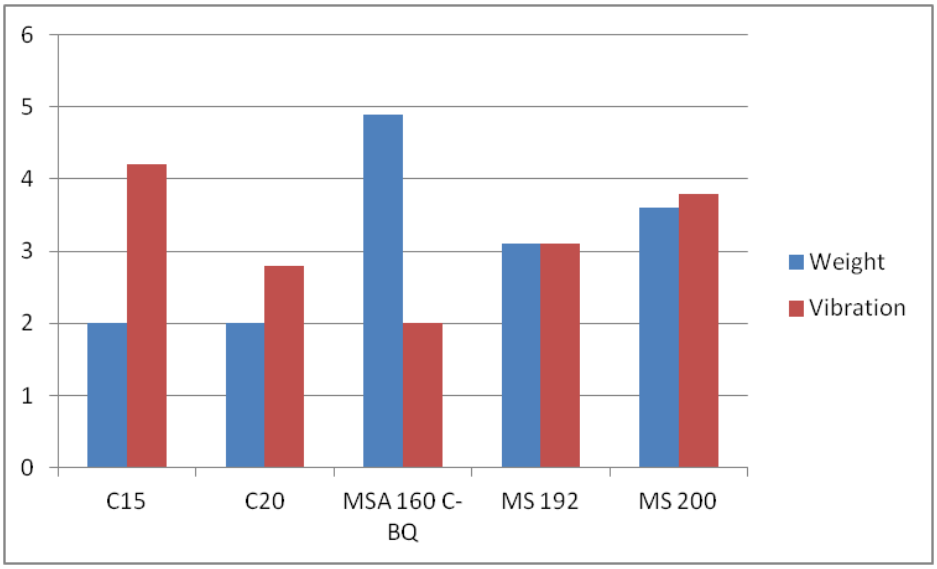
Vibrations are generally low frequency wave phenomena, transmitted through a solid medium. They become a source of noise when their frequency is within the range of human audibility (from 20 to 20,000 Hz). The vibration measurement unit is the frequency, expressed in number of cycles per second (Herz), but to describe the physical characteristics the reference parameter is the acceleration generated (m/s^2). The chainsaw produces vibrations due to piston movements and the impact of the chain with the wood that is being cut. These can cause damage to the hand-arm system at osteoarticular level; at the level of the central nervous system and vascular (Rottensteiner, C. 2013, Deboli et al. 2014, Proto et al. 2010, Proto et al 2015). The perception of vibration, and the effect it can cause, it is worse by cold, by an intense contraction of the muscles of the hands and fingers, the pressure of the tool on the limb. These last two items depends largely on the weight of the tool, so if that is high not only increases the muscular work for an operator to perform, but also increases the risk of occurrence of diseases due to vibration.

According to the Legislative Decree no. 81/2008 Title VIII Chapter III, an operator should not be exposed beyond a daily value limit of vibration (as far as $5m/s^2$ hand-arm), while the value daily exposure is set at 2.5 m/s^2, remaining allowable exposure for short periods up to 20 m/s^2. Beyond these values the operator is considered at risk and must be subjected to surveillance by a competent physician.

Table 7. Levels of vibrations and weight of models tested

Model	**Vibration L/R (m/s^2)**	**Weight (kg)**
Pellenc Selion C15	4,2/4,2	2
Pellenc Selion C20	2,8/2,8	2
Stihl MSA 160C-BQ	2,0/2,0	4,9
Stihl MS 192T	2,9/3,1	3,1
Stihl MS 200T	3,4/3,8	3,6

Chart. n° 1 Average value of the vibration level and weight, for all chainsaw tested



Electric chainsaws C20 and MS160C-BQ value less than 3 m/s^2, with the absolute minimum of MS160C-BQ that generates only 2m/s^2. To counter this last model turns out to be the heaviest (almost 5kg) even more of chainsaws equipped with endothermic motor under test. The model Pellenc Selion C20 combines a low level to a low weight vibration to sustain in hand, since the batteries for a backpack on the operator's back with a special harness, avoiding to highlight the harmful effects of vibration due to the tension muscle that must be applied with higher weights.

From the graph it can be seen that the motor machines endothermic develop more vibration, up to 3.8m / s2. The C15 electric model is not generating little vibration as other electric models. Probably the C15 being an older model and advanced than the C20 is built with less advanced techniques.

2.5 The noise

Noise is an acoustic phenomenon arising from vibration frequencies of between 20 and 20,000 Hz, which is unpleasant, or even may cause damage to health. The hearing damage may occur remaining exposed to noise levels between 90 and 130 dB (A), or at lower levels but with prolonged exposure. Hearing loss due to noise exposure in the workplace is a significant health problem with economic consequences (Lie A. et al. 2016). In addition to hearing loss phenomena it can undergo numerous collateral damage, such as stress, increased heart rate, blood pressure, respiratory rate, vascular tone, gastric secretion, sweating, muscle tone, pupil size. It is very important to wear ear protectors (headphones or inserts) when working with machines that generate noise during use, but it is also very important

that these machines are made to minimize this type of disorder (Cecchini et al. 2010 a; Riccioni et al. 2015).

Table 8. Test models' sound pressure level

Model	Sound pressure level dB(A)	Sound power level dB(A)
Pellenc Selion C15	84	96
Pellenc Selion C20	84	96
Stihl MSA 160C-BQ	99	88
Stihl MS 192T	109	97
Stihl MS 200T	109	98

We can note that models equipped with endothermic motor, generating high acoustic pressures, 109 dB (A), making it essential to use by the operator of PHPE for not incurring the problems mentioned above. The Stihl MSA160C-BQ develops a lower noise, 99 dB (A), which is already appreciate the benefits of the electric motor, decreasing considerably.

Electric models Pellenc C15 and C20 generate an even lower sound pressure level 84 dB (A), and the M12 model generates 89 dB (A), all lower than the endothermic motor models. In any case it is compulsory to work with the auditory protection to ensure a better working comfort and the maintenance of the hearing ability of the operator.

2.6 Safety

Many studies shows the dangers of chainsaw. Even workers experts are involved in serious injury and death (Cividino S.R.S. et al. 2013; Proto and Zimbalatti 2010; Proto and Zimbalatti 2015). Pruning chain saws are designed to be used both on land and climbing inside the tree canopy, where it has less room to maneuver, so they are compact machines with the right grip positioned over. This gives greater maneuverability, but makes the machine less controllable in the event of inadvertent collision of the tip of the guide bar during cutting. To avoid this kind of inconvenience Stihl mounts specially designed chains to limit the rebound and bounce (Picco Micro Mini Comfort 3 for MS192T, Picco Micro Comfort 3 for MS200T and Picco Micro 3 for MSA160C-BQ) but ensure high cutting capacity, especially for the PMMC3 model in which the cutting edge of the tooth thickness is less. MS 200T, MS192T and MSA160C-BQ come standard with a safety trigger to avoid unintentional acceleration, and the chain brake which comes into operation only if the operator drive. The models C15, C20 and M12 are equipped with Pruning chains Oregon Micro Chisel specifications and low bounce. These models have supplied the electronic brake of the chain, which enters into action instantaneously, automatically (so 10 times more sensitive than

a traditional chain brake) whenever the sensor senses an abnormal movement of the machine that can be originated from a phenomenon of kickback or tool failure. Such electronic system is more performing than manual, as seen with other electronic systems (Cividino et al. 2015, Pascuzzi 2015, 2013; Proto and Zimbalatti 2016). This improvement of the reaction of the chain brake is very important because of the great number of injuries which happens every year (Dąbrowski, A. et al. 2015) and which could be avoided. Arnold (2015) has also seen that gasoline-powered saw showed the same propensity to kickback as those with the battery-powered saw; however, the rotational velocities during a kickback were greater, approximately double (1,000°/s for gasoline chainsaw against 600 °/s for battery chainsaw). Moreover, the instrument has a self-diagnosis function that allows the ignition only in the case in which this sensor is functioning, otherwise it is not allowed. Additional security comes from the ignition trigger double pulse: it is necessary to double click to start the engine.

3. Results and discussion

3.1 Castanea sativa Mill.

The chestnut wood has a density variable fresh from 700 to 1180kg / m^3 and is moderately hard: 18N / mm^2 Brinell hardness. In this test, there have been available models: Stihl MSA160C-BQ, Pellenc Selion C15 and C20, and Stihl MS192T MS200T.

The available material has been primarily used to test the performance of the electric chain saws, and the chain saw is equipped with a combustion engine specific for pruning (MS192T) to have a valid term of comparison. The MS200T has had so less material to work on to which the curve that represents the cutting time was generated by the software using a trend line on the basis of a smaller number of observations. The working times were measured on diameters from 30 to 100mm, and at least 60 tests for each diameter, and then averaged. The times shown in red in the table are processed on the basis of the trend line generated with the available data, that gives the lowest value of R^2.

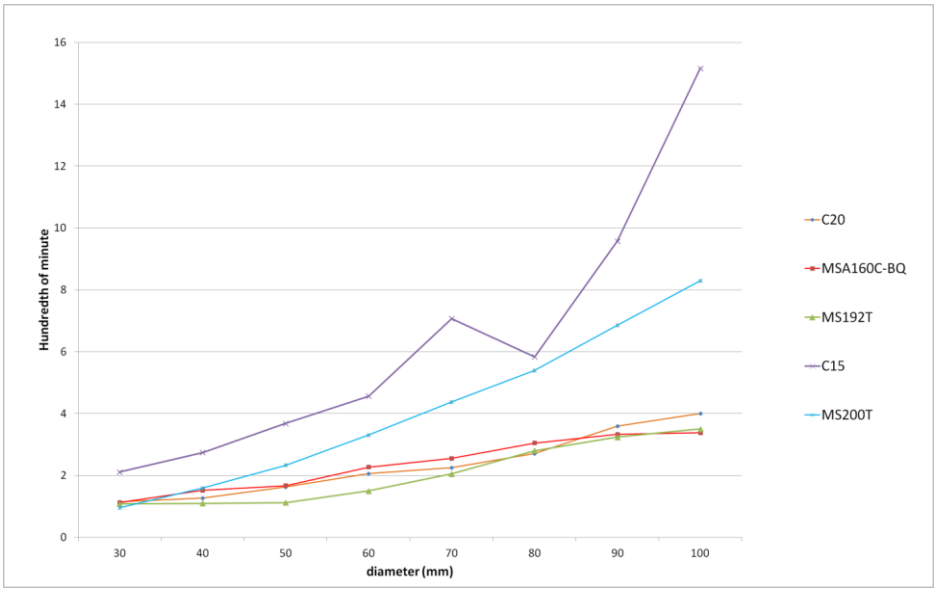
For the detected times of the C15 it is used an exponential curve with an R^2 of 0.8977, while for the MS200T a power curve, having an R^2 of 0.9984. R^2 values next to 1 have a high correlation coefficient between the actual data and the trend line.

Table 8. Average cutting times obtained in tests with five different chainsaws on chestnut wood

	C20	**MSA160C-BQ**	**MS192T**	**C15**	**MS200T**
Diameter (mm)	Average time (hundredth of a minute)	Average time (hundredth of a minute)	Average time (hundredth of a minute)	Average time (hundredth of a minute)	Average time (hundredth of a minute)
30	1,15	1,12	1,08	2,11	0,95
40	1,27	1,52	1,1	2,74	1,60
50	1,63	1,67	1,12	3,68	2,33
60	2,06	2,27	1,5	4,56	3,31
70	2,25	2,55	2,05	7,07	4,38
80	2,71	3,05	2,8	5,84	5,39
90	3,6	3,33	3,24	9,57	6,86
100	4	3,38	3,5	15,16	8,30

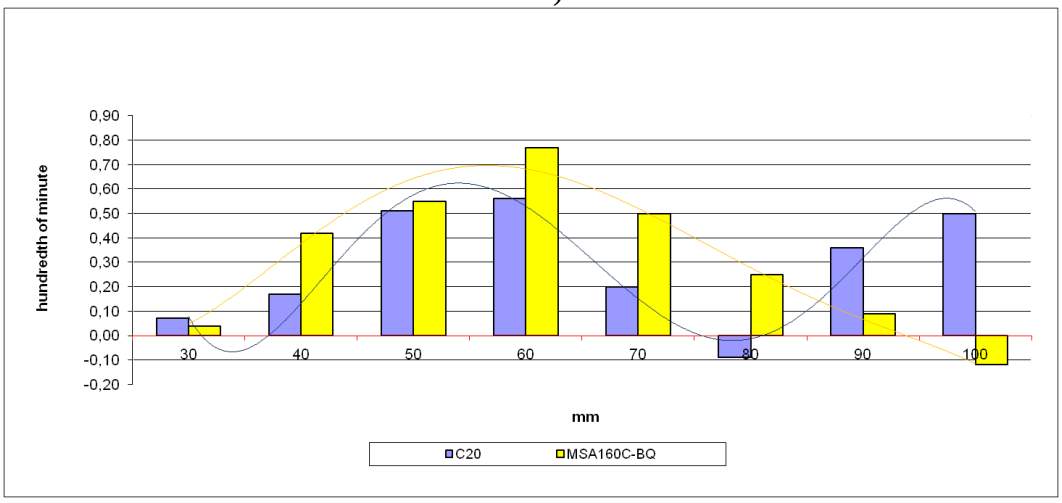
From the data and from the chart n°2 we can note that the cutting times of Pellenc Selion C15 are higher than the others, this is clearly due to the lack of available power (1.5kW) and the low speed of the chain (10,3m/s). The cutting times of the other two battery chainsaws C20 and MSA160C-BQ are very close to each other and also to MS192T which is one of the best models on the market for pruning.

Chart. n° 2. Cutting times on chestnut wood with five chainsaws



With the values obtained was processed a second chart (chart n°3), the line of the x-axis has been set to act as a benchmark and represents the cutting time of the saw which obtained the best performance in this test cutting: Stihl MS192. Assuming this, the positive values indicate a lower performance, while negative values represent a superior performance compared to the benchmark machine. The differences of the measured average times were made for each diameter. The trend lines that best express the trend of gap, are 5th order polynomial lines, with R^2 value for C20, respectively, 0.956 and 0.967 of MSA160C-BQ.
By the MSA160C-BQ trend line you notice that the gap positively increases up to 60mm in diameter, and then down and become negative over the 90mm diameters and achieve better performance than the MS192T. The C20 trend is less linear, tends to increase up to 60mm, to go down until it becomes negative at the 80mm, then becomes positive.

Chart. n° 3. Difference in cutting times compared with MS192T (Castanea sativa Mill.).



The greatest torque generated by the electric motors helps chainsaws to maintain a constant engine speed as the cutting diameter, contributing to the improvement in the detected timing.
As for the consumption, the three models mentioned above were used for 480 cuts each, for which the C20 has consumed 28% of the battery, the MSA160C-BQ has consumed over 80% of its accumulator (a flashing diode on the display), the MS192T has consumed less than a full tank of mixture.

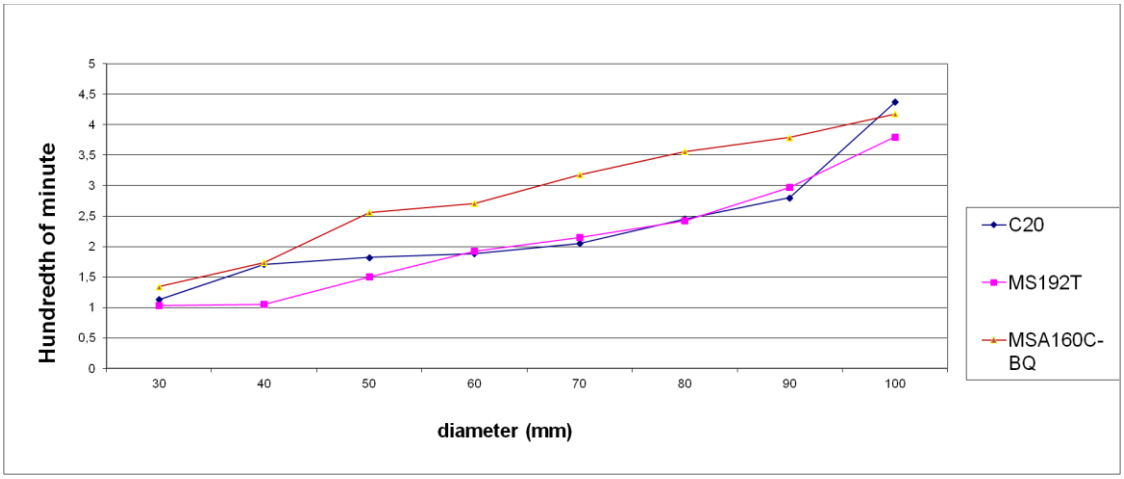
3.2 Picea abies Dietr.
The spruce has a light wood (fresh mass density of 860 kg / m^3) and tender (11N / mm^2 Brinell hardness).

In this site we used the models Stihl MSA160C-BQ, Pellenc Selion C20 and Stihl MS192T.

Table 9. Average cutting times obtained in tests with three different chainsaws on spruce wood

	C20	**MS192T**	**MSA160C-BQ**
Diameter (mm)	Average time (hundredth of a minute)	Average time (hundredth of a minute)	Average time (hundredth of a minute)
30	1,13	1,03	1,34
40	1,71	1,05	1,74
50	1,82	1,5	2,56
60	1,88	1,92	2,71
70	2,05	2,15	3,18
80	2,45	2,42	3,56
90	2,8	2,97	3,79
100	4,37	3,8	4,18

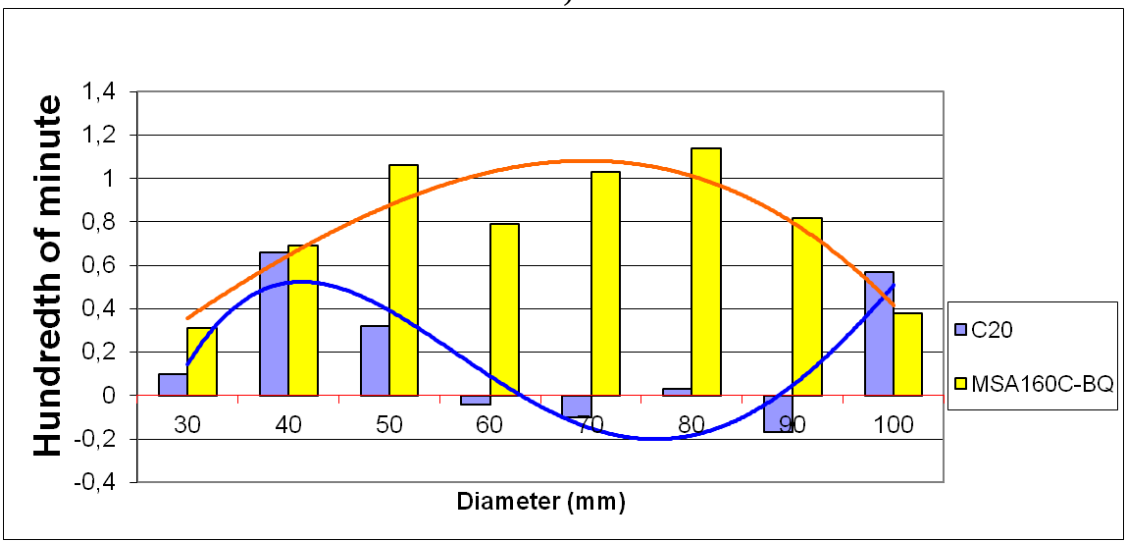
Chart. n° 4. Cutting times for the three chainsaws tested on Picea abies Dietr., in function on diameter



From the obtained data it is noted that also in the case of spruce, cutting times of the three machines are very close to each other. In an absolute sense are very short times, which highlight the high performances of the three models. The best results are registered with the MS192T and C20 with slightly better values. MS192T gets better times with a diameter of up to 60 mm, while C20 gets better times, even if

only slightly, from 60 to 90 mm. In this test the MSA160C-BQ pointed Rates of the highest compared to the other two machines, up to more than 1 hundredth of a minute.
Also in this case the line of the x-axis has been set to act as a benchmark and represents the cutting time of the saw which obtained the best performance in this test cutting: Stihl MS192.
In the graph, the positive times show a worse performance than the comparison machine, while negative values indicate a better performance and hence better productivity defined as the ability to cut a given diameter in less time.

Chart. n° 5. Difference in cutting times compared with MS192T (Picea abies Dietr.)



The trend lines express the trend of deviations from the benchmark time, are 4th order polynomial lines, with R^2 value respectively 0.7894 for C20, and 0.8243 forMSA160C-BQ.
From the graph you can see that the scraps of cutting times of MSA160C-BQ than the comparison chainsaw tend to increase up to 80mm in diameter and then decreased but always remaining above the reference time. The trend of the C20 line instead has positive values up to 50mm in diameter, while does record negative deviations and thus superior performance to the reference machine; from 60 to 90mm in diameter. Besides this diameter the times and the scraps return again to increase.
As for the consumption, the three models mentioned above were used for 480 cuts each, for which the C20 has consumed 21% of the battery, the MSA160C-BQ has consumed over 80% of its accumulator (a flashing diode on the display), the MS192T has consumed less than a full tank of mixture.

3.3 Fagus sylvatica L.

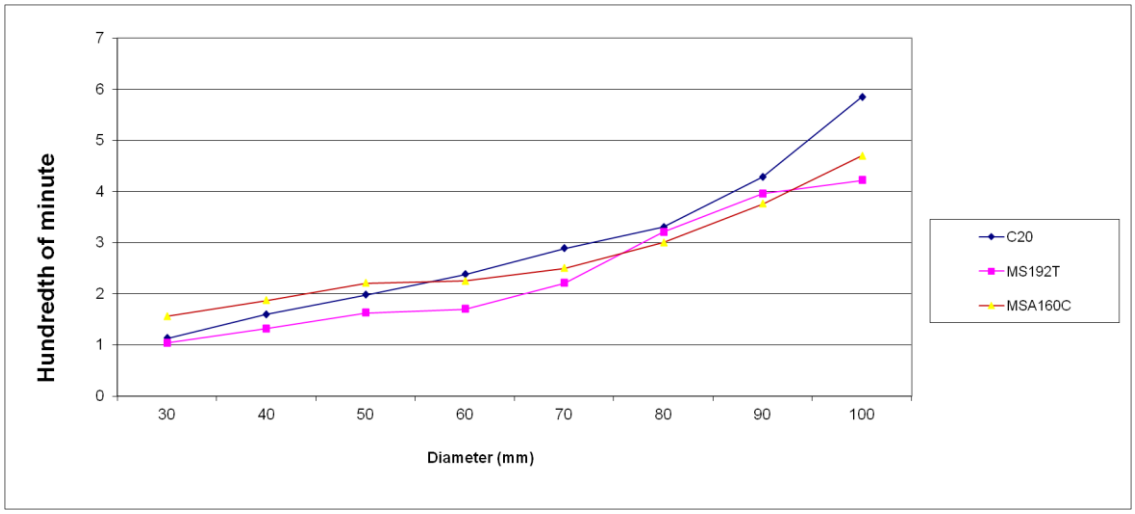
The beech is a heavy wood (fresh mass density of 1050 kg / m^3) and quite hard (34N / mm^2 Brinell hardness).

The machines used were the three previously used: Stihl MSA160C-BQ, Pellenc Selion C20 and Stihl MS192T.

Table 10. Average cutting times obtained in tests with three different chainsaws on beech wood

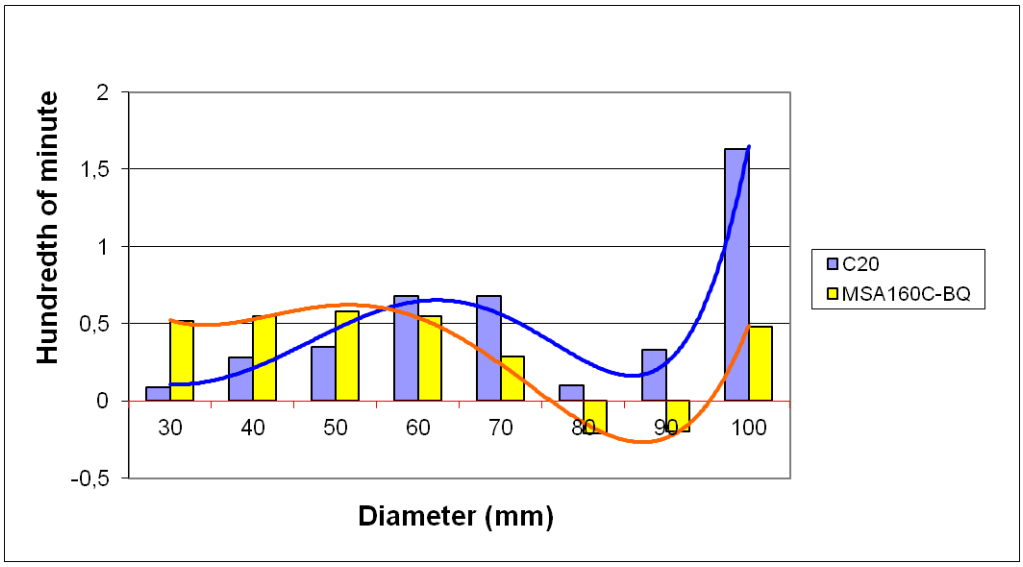
	C20	**MS192T**	**MSA160C-BQ**
Diameter (mm)	Average time (hundredth of a minute)	Average time (hundredth of a minute)	Average time (hundredth of a minute)
30	1,13	1,04	1,56
40	1,6	1,32	1,87
50	1,98	1,63	2,21
60	2,38	1,7	2,25
70	2,89	2,21	2,5
80	3,31	3,21	3
90	4,29	3,96	3,76
100	5,85	4,22	4,7

Chart. n° 6. Difference in cutting times compared with MS192T (Fagus sylvatica L.).



The graph shows the similarity in performance between the three chainsaws without the predominance of one over the other. In particular it is noted that the performance of the C20 are in no case the best MS192T, while for diameters from 80 to 90 mm of the Stihl cordless model manages to be more powerful than that provided with endothermic engine.

Chart. n° 6. Difference in cutting times compared with MS192T (Fagus sylvatica L.)



The chart took, like its predecessors, the MS192T as a comparison. It has been calculated that the difference between the cutting times obtained with the other two chainsaws. To chart the trend lines have been added that best express the trend of deviations from the benchmark time. They are 5th order polynomial lines, with R^2 value for C20 respectively 0.9616 and 0.9854 MSA160C-BQ. In the cutting test on beech, the MSA 160 C-BQ continues to show an improvement of cutting times more than the diameter of 60mm, compared to the 2-stroke model. The C20 obtains performance close to those of comparison, only between 80 and 90mm but never best. As for the consumption, the three models mentioned above were used for 480 cuts each, for which the C20 has consumed 26% of the battery, the MSA160C-BQ has downloaded more than 80% of its accumulator (a flashing diode on the display), the MS192T has consumed less than a full tank of mixture.

3.4 Quercus pubescens Willd.

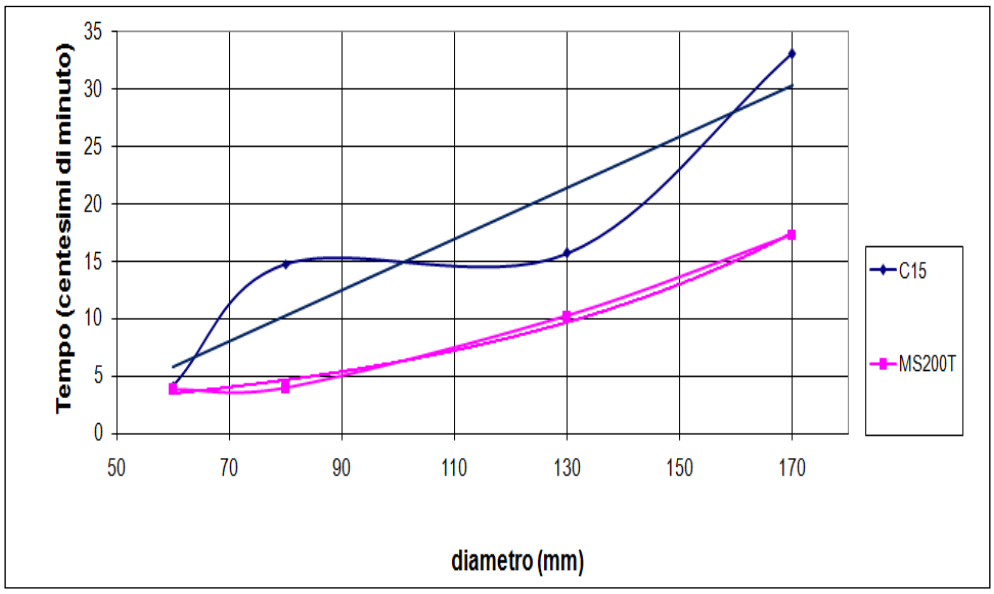
The oak wood is heavy and hard (fresh density 1080 kg / m^3, Brinell hardness of 34 N / mm^2). For this test we were used C15 and MS200T models, the first great

for a work of pruning, the other for the sawing and small felling work. The cuts were made on the available diameters, trying to increase the maximum diameter also to better highlight the features of MS200T.

Table 11. Average cutting times obtained in tests with three different chainsaws on oak wood

	C15	**MS200T**
Diameter (mm)	Average time (hundredth of a minute)	Average time (hundredth of a minute)
60	4,05	3,79
80	14,76	3,94
130	15,67	10,25
170	33,04	17,30

Chart. n° 7. Graphical representation of a function cutting times of diameters on the two chainsaws tested on Quercus pubescens Willd



Obviously the results are quite different from each other. The cutting times are similar only for the minimum measured diameter (60 mm), while the diameter increases the performance difference tends to increase. This is due not only to the increased power of MS200T (1,7kW) but above all to the high chain speed: 27 m/s against the C15 10,3 m/s).

3.5 Pinus pinea L.

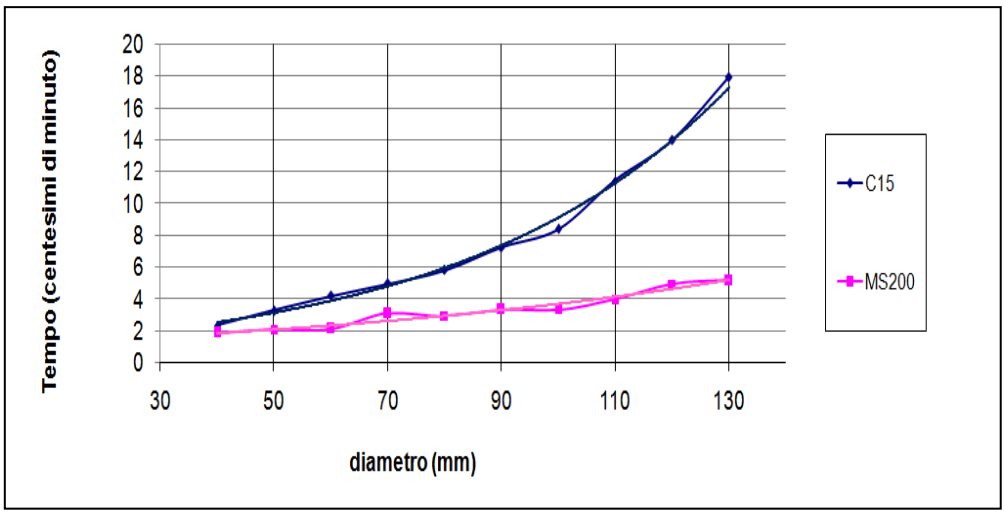
Il legno di pino domestico è un legno pesante (massa volumica fresca 900kg/m^3). Anche in questa prova sono stati utilizzati i modelli C15 e MS200T.

Table 12. Average cutting times obtained in tests with three different chainsaws on pine wood

	C15	**MS200T**
Diameter (mm)	Average time (hundredth of a minute)	Average time (hundredth of a minute)
40	2,36	1,89
50	3,29	2,11
60	4,23	2,14
70	5,00	3,12
80	5,83	2,96
90	7,27	3,35
100	8,43	3,35
110	11,47	4,00
120	13,97	4,96
130	17,97	5,18

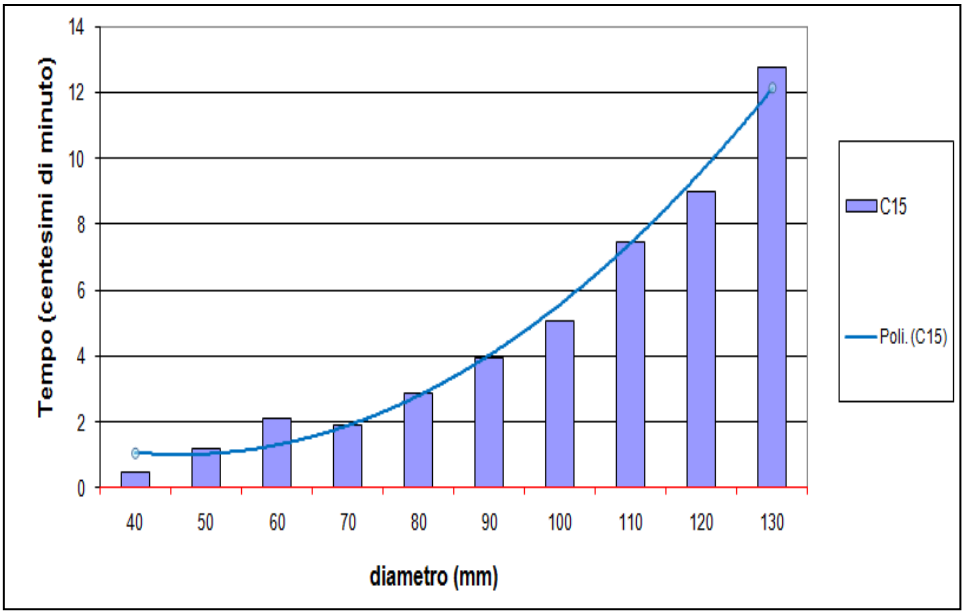
The values in the table highlighted in red, are values generated by the equation of the exponential curve that best approximates the trend of the values of the MS200T cutting times. This was necessary because the available material was not enough to test all diameters.

Chart. n° 8. Graphical representation of a function cutting times of diameters on the two chainsaws tested on Pinus pinea L.



As in the case of tests with oak, even for this species there are differences in cutting times ranging increasing proportionally to the diameter, highlighting the vocation of MS200T more for cutting large branches and trunks of true and proper pruning, where it is more appropriate to use the saw.
In the graph constructed based on the difference between the times of the MS200 taken as a reference, placed on the horizontal axis, and the C15, we see that the trend line has a fairly linear up to 60mm, and then have an exponential trend. This means that despite the performance of the C15 are lower than those of the MS200T, they are in a contained manner for the case of smaller diameters, while, conversely, become increasingly large with the increase of the cutting dimensions. This difference in results confirms the different areas of use for which the two machines are designed.
The trend line used is a 2nd order polynomial with R^2 of 0.9853.

Chart. n° 9. Difference in the cutting times for model C15 greater than those associated with MS200T



4 Conclusions

Battery chainsaws have achieved good results in the absolute sense, and in some cases have been able to achieve higher cutting performance than the reference model with internal combustion engine. The first case is the test with the chestnut wood (Pellenc C20 and MSA160CBQ Vs MS 192T) to the diameter 80 mm for Pellenc and 100 for Stihl.

The second case is the test with the spruce wood (Pellenc C20 to the diameter 60-70-80-90 mm.
The third case is the test with the beech wood (Stihl MSA160CBQ) to the diameter 80-90 mm.
In the fourth and fifth case (with oak and pine) the cordless chainsaws did not get superior performance to homologous with combustion engine. Thanks to the high power of the electric motors in relation to its own weight, it is conceivable to obtain a battery chain saw for forest use, increasing the performance and the length of the bar. The only current limitation is the battery, which for models that included lead in the body to find the right balance with the weight, it has a very limited life span, while for models that lead separate, a backpack, forcing to have a connecting cable to the machine that makes it less maneuverable than its competitors.
Further developments in this technology would lead to having chainsaws cleaner, eliminating the carcinogenic risk of forest workers (Kawachi I. 1989) after removing the combustion of the mixture. Furthermore, the electric motors, do not develop inside them alternating motions, thanks to the rotation of the rotor, the vibrations are substantially reduced, as well as noise, much lower than the endothermic engines.

References

[1] D. Arnold, J. P. Parmigiani, A Study of Chainsaw Kickback, *Forest Products Journal*, **65** (2015), no. 5-6, 232-238. http://dx.doi.org/10.13073/fpj-d-14-00096

[2] K. Boubaker, A. Colantoni, E. Allegrini, L. Longo, S. Di Giacinto, D. Monarca, M. Cecchini, A model for musculoskeletal disorder-related fatigue in upper limb manipulation during industrial vegetables sorting, *International Journal of Industrial Ergonomics*, **44** (2014), 601-605. http://dx.doi.org/10.1016/j.ergon.2014.03.005

[3] M. Cecchini, A. Colantoni, R. Massantini, D. Monarca, Estimation of the risks of thermal stress due to the microclimate for manual fruit and vegetable harvesters in central Italy, *Journal of Agricultural Safety and Health*, **16** (2010), no. 3, 141-159. http://dx.doi.org/10.13031/2013.32040

[4] M. Cecchini, A. Colantoni, R. Massantini, D. Monarca, The risk of musculoskeletal disorders for workers due to repetitive movements during tomato harvesting, *Journal of Agricultural Safety and Health*, **16** (2010), no. 2, 87-98. http://dx.doi.org/10.13031/2013.29593

[5] S.R.S. Cividino, F. Blanchini, R. Lombardo, D. Dell'Antonia, T.D. Vujinovic, O. Malev, R. Gubiani, An improved safety device for electric chainsaws, *Contemporary Engineering Sciences*, **8** (2015), no. 27, 1229-1244. http://dx.doi.org/10.12988/ces.2015.56180

[6] S. Di Giacinto, A. Colantoni, M. Cecchini, D. Monarca, R. Moscetti, R. Massantini, Produzione casearia in ambienti termici vincolati e sicurezza degli addetti alla produzione, *Industrie Alimentari*, (2012), no. 530, 5-12.

[7] A. Marucci, B. Pagniello, D. Monarca, A. Colantoni, P. Biondi, Heat stress suffered by workers employed in vegetable grafting in greenhouses, *Journal of Food, Agriculture & Environment*, **10** (2012), 1117-1121.

[8] A. Marucci, D. Monarca, M. Cecchini, A. Colantoni, A. Cappuccini, The heat stress for workers employed in laying hens houses, *Journal of Food, Agriculture & Environment*, **11** (2013), 20-24.

[9] C. Hanisch, T. Loellhoeffel, J. Diekmann, K.J. Markley, W. Haselrieder, A. Kwade, Recycling of lithium-ion batteries: a novel method to separate coating and foil of electrodes, *Journal of Cleaner Production*, **108** (2015), 301-311. http://dx.doi.org/10.1016/j.jclepro.2015.08.026

[10] I. Kawachi, N. Pearce, J. Fraser, A New Zealand cancer registry-based study of cancer in wood workers, *Cancer*, **64** (1989), no. 12, 2609-2613. http://dx.doi.org/10.1002/1097-0142(19891215)64:12<2609::aid-cncr2820641234>3.0.co;2-e

[11] A. Lie, M. Skogstad, H.A. Johannessen, T. Tynes, I.S. Mehlum, K.-C. Nordby, B. Engdahl, K. Tambs, Occupational noise exposure and hearing: a systematic review, *International Archives of Occupational and Environmental Health*, **89** (2016), no. 3, 351-372. http://dx.doi.org/10.1007/s00420-015-1083-5

[12] F. Mazzocchi, M. Cecchini, D. Monarca, A. Colantoni, L. Caruso, F. Colopardi, G. Cipollari, R. Rapiti, An Improved Safety Device for Electric Chainsaws, *Contemporary Engineering Sciences*, **8** (2015), no. 25, 1171-1177. http://dx.doi.org/10.12988/ces.2015.56175

[13] S. Riccioni, M. Cecchini, D. Monarca, A. Colantoni, , Longo, L., Cavalletti, P., Bedini, R. Overview of the noise measurements process in recent years, *Contemporary Engineering Sciences*, **8** (2015), no. 26, 1179-1191. http://dx.doi.org/10.12988/ces.2015.56176

[14] C. Rottensteiner, K. Stampfer, Evaluation of operator vibration exposure to chainsaws equipped with a Kesper safety bar, *Scandinavian Journal of Forest Research*, **28** (2013), no. 2, 193-200.

http://dx.doi.org/10.1080/02827581.2012.706636

[15] I. Blanco, S. Pascuzzi, A. S. Anifantis, G. Scarascia Mugnozza, Study of a pilot photovoltaic-electrolyzer-fuel cell power system for a geothermal heat pump heated greenhouse and evaluation of the electrolyzer efficiency and operational mode, *Journal of Agricultural Engineering*, **45** (2014), 111-118. http://dx.doi.org/10.4081/jae.2014.238

[16] I. Blanco, A. S. Anifantis, S. Pascuzzi, G. Scarascia Mugnozza, Hydrogen and renewable energy sources integrated system for greenhouse heating, *Journal of Agricultural Engineering*, **44** (2013), no. s2, 226-230.

[17] R. Deboli, A. Calvo, F. Gambella, C. Preti, R. Dau and E.C. Casu, Hand arm vibration generated by a rotary pick-up for table olives harvesting, *Agricultural Engineering International: CIGR Journal*, **16** (2014), no. 1, 228-235.

[18] S. Pascuzzi, The effects of the forward speed and air volume of an air-assisted sprayer on spray deposition in "tendone" trained vineyards, *Journal of Ag. Eng.*, **44** (2013), no. 3, 125-132. http://dx.doi.org/10.4081/jae.2013.189

[19] S. Pascuzzi, A multibody approach applied to the study of driver injures due to a narrow-track wheeled tractor rollover, *J. Agric. Eng*., **46** (2015), 105-114. http://dx.doi.org/10.4081/jae.2015.466

[20] A.R. Proto & G. Zimbalatti, Risk assessment of repetitive movements in the citrus fruit industry, *Journal of Agricultural Safety and Health- Ed. American Society of Agricultural and Biological Engineers (ASABE)*, **16** (2010), no. 4, 219-228. http://dx.doi.org/10.13031/2013.34834

[21] A.R. Proto, & G. Zimbalatti, Risk assessment of repetitive movements in olive growing: analysis of annual exposure level assessment models with the OCRA checklist, *Journal of Agricultural Safety and Health - Ed. American Society of Agricultural and Biological Engineers (ASABE)*, **21** (2015), no. 4, 241-253. http://dx.doi.org/10.13031/jash.21.10884

Received: August 1, 2016; Published: October 3, 2016