Scientific quarterly journal ISNN 1429-7264

Agricultural Engineering

2014: 3(151):157-167

Homepage: http://ir.ptir.org

DOI: http://dx.medra.org/10.14654/ir.2014.151.068

PROBLEMS WITH DERIVING THE FRUIT TREE PRUNED BIOMASS FOR ENERGY USE

Leszek Romański[a*], Arkadiusz Dyjakon[a], Florian Adamczyk[b], Piotr Frąckowiak[b]

[a]Institute of Agricultural Engineering, Wrocław University of Environmental and Life Sciences
[b]Industrial Institute of Agricultural Engineering in Poznań
[*]*Contact details: ul Chełmońskiego 37/41, 51-630 Wrocław, e-mail: leszek.romanski@up.wroc.pl*

ARTICLE INFO

Article history:
Received: August 2014
Received in the revised form: August 2014
Accepted: September 2014

Keywords:
dendromass
pruning methods
collection of biomass

ABSTRACT

Biomass, wood in particular, is one of the main renewable energy sources. The authors' point of interest is the use of the orchard biomass, produced annually as a result of pruning the trees and shrubs, for the heating purposes, as such biomass is used for this purpose only to a little extent both in our country and in Europe. Such biomass, consisting mainly of branches and shoots, is usually shredded and left in the orchard interrows to serve as a natural fertilizer. This paper focuses on the reasons why it should be collected and removed from the orchard. It presents the technologies of pruning and collecting such biomass, and analyses the newest machine constructions that allow for fast collection and compaction of dendromass to the form which facilitates its storage and natural drying.

Introduction

As the civilization progresses, the world needs more and more energy. It is evident that the conventional energy sources are rapidly diminishing. Therefore, the use of the renewable sources is the necessity of our times. Nowadays, it is the biomass that is the main renewable energy source. It is the cheapest form of renewable energy and, importantly, it is easy to obtain (Romański, 2013). Forest dendromass constitutes the largest part of wood that is used for heating purposes in our country. The biomass derived from the municipal management sector, cultivation of trees growing on the roadside, parks, local green squares and short rotation plantations, is definitely used less frequently as a renewable energy source (Piszczalka et al., 2007). The orchard biomass, produced every year as a result of pruning of trees and shrubs, was used for heating purposes, both in our country and in Europe, only to a small extent.

According to the data of National Agricultural Census carried out in 2010, the orchard area in Poland amounted to 374,200 ha, and, compared to 2002, it was bigger by 103,200 ha, i.e. by 38.1% (GUS, 2013). On the other hand, the number of farms with orchards decreased by 10.2% (by 32,200 ha) compared to the previous census of 2002, and amounted to 284,600. The average area of orchards in agricultural farms was increased from 0.86 ha in 2002 to 1.31 ha in 2010, which reflects the fact that the orchards are localized in bigger

farms. Nowadays 60% of orchard farms in Poland grow their trees on the areas bigger than 5 ha. The largest parts of such areas are covered with apple orchards (fig. 1). We are the third largest producer and first largest exporter of apples in the world.

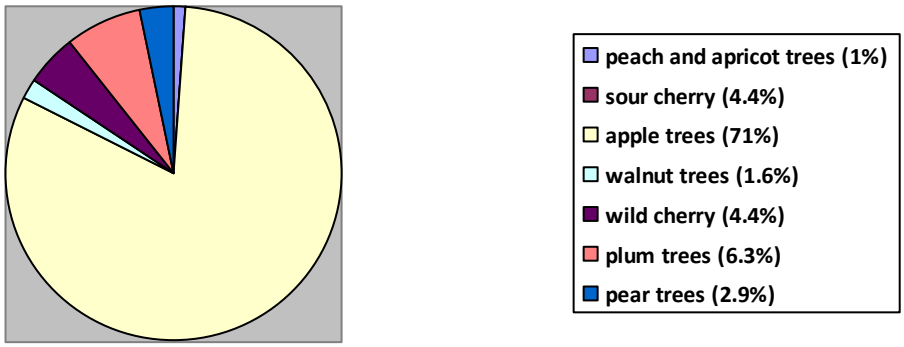

Figure 1. Pie chart illustrating the cultivation of fruit trees in Poland in 2012 (GUS, 2013)

A lot of biomass, mainly composed of branches and shoots, is obtained as a result of annual cultivation works carried out in high productivity farms. Pruning is the main and most important cultivation method. It is used to control the growth of trees and shrubs, as well as to improve the quality of fruit and the size of yield. It is difficult to determine the amount of dendromass produced in Poland as, up until now, the orchardists' interests and research focused mainly on the works aiming at the increase of amount and efficiency, as well as the deduction of costs of obtaining the fruit from a hectare.

There are major differences in the scarce specifications of the amount of biomass residue, depending whether it is the opinion of the practitioners or literature – both domestic and foreign. The substantial differences (100-300%) in the amount of pruned wood biomass most probably result from the method of calculating such amount. Table 1 presents the amount of wood that is possible to be derived from apple orchards (Maciak and Lipińska, 2006).

Assuming that the orchard is used for 25 years, the total of (40-70%) of wood pulp is derived from the yearly cultivation works (thinning) compared against the total biomass produced by the orchard during the time period of its use. The remaining amount (30-60%) includes the matter of trunks and branches recovered during the clearing of an orchard. As you can see, in the case of the total amount of the recovered wood, there will even be a two-time difference in the results.

The wood biomass, which is the fruit trees pruning residue, is rarely used in the energy sector. The cut-off branches and shoots are, in most cases, left by the trees. When the manual pruning is applied, the most popular method, both the branches and shoots are thrown onto the interrows. Thanks to that, they can be easily mechanically shredded and left as a natural fertilizer. Some of the orchardists remove the pruned biomass to the far end of the orchard and burn it, assuming that it is cheaper for them to manage the residue in such a way. The least popular method of handling such biomass involves collecting it and treating it as a heating fuel.

Table 1
Average amount of wood that is possible to be derived from apple orchards

Planting density ($pcs \cdot ha^{-1}$)	Amount of wood ($m^3 \cdot ha^{-1}$)		
	from trunks	from branches	from thinning
up to 1,200	12.75	13.04	0.83
1,200-2,400	11.98	6.84	1.71
above 2,400	2.90	2.18	–

Leaving the dendromass between the trees to serve as a natural fertilizer or burning it should be analysed, first of all, by taking into account the environmental protection. The LCA (Life Cycle Assessment) of the final product will enable the analysis of these two opposite technologies (fertilizing or combusting for heating purposes). The aim of the assessment is the comprehensive analysis of how the product affects the environment and natural resources.

The LCA analysis of the aforementioned two technologies used in apple orchards was carried out by Boschiero's team from the University in Bolano (Boschiero et al., 2013). The analysis proved that the technology in which the dendromass residue is collected and combusted for heating purposes is safer for the environment.

Furthermore, this technology leads to a decreased consumption of energy from conventional sources. The useful heat is the tangible and direct outcome of using this technology by an orchardist.

Orchard dendromass – pruning methods

The branches and shoots may be cut off manually or mechanically. The following tools are used for manual cutting, the method which is still used for most of the tree species: lever pruning shears, two-handed pruning shears, telescopic pruning shears, and all kinds of saws (Rabcewicz, 2007). Either the pneumatically (fig. 2) or electrically (fig. 3) driven tools may be used in order to facilitate the works carried out in the orchards with larger surface areas (especially apple and pear orchards), where winter pruning is commonly associated with aching muscles and sprained wrists.

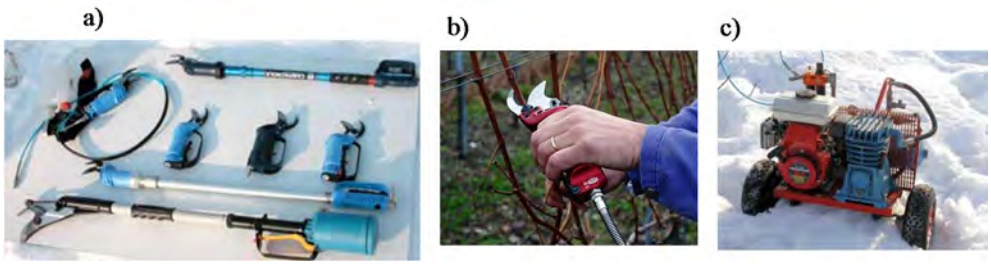

Figure 2. Set of pneumatically driven orchard tools: a), b) pruning shears, c) air compressor powered by a combustion engine

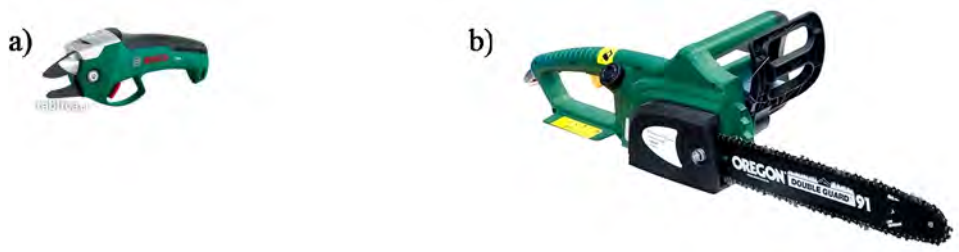

Figure 3. Set of electrically driven orchard tools: a) lever pruning shears with the battery under the housing, b) chain saw

The pneumatic pruning shears used in orchards are powered by 1-1.2 MPa compressed air generated in a portable compressor. Depending on the size of such compressor, it may supply power to 2 to 6 pruning shears at one time. If there are more than 3 pruning shears, the compressor unit is most commonly supplied with power from PTO (power take-off) of a tractor. The thickness of the cut amounts to approx. 30 mm. The use of the discussed pruning shears reduces the effort of the employees engaged for pruning work, and increases the work efficiency by 20-30% when compared to the use of manual pruning shears.

Electrical pruning shears allow for a greater freedom of movement and not being bound by the compressor unit.

Mechanical pruning in orchards is getting more and more popular in Western countries (Scholten, 2010). The main advantage of mechanical pruning of branches is the fact that the energy intensity of this activity is much lower. For example, the pruning time in an apple orchard is reduced from several dozen hours to approx. 3 $h \cdot ha^{-1}$ (Wilczyńska, 2013). The result of mechanical pruning is the so-called "fruit wall" in an orchard, i.e. a line which is not usually higher than 3.5 m and the crown thickness of which amounts to 0.6-0.8 m at the bottom and 0.4-0.6 at the top (fig. 4), depending on the species. The spacing between the rows should amount to 3-3.5 m so that the tractor with a cutting machine could move along. With this geometry of an apple orchard, it is possible to have 25 fruit from 1 m^2 of the wall, which means the crops in the amount of 70 $t \cdot ha^{-1}$.

The disadvantages of mechanical pruning include: 2-5-day delay in harvesting fruit compared to the manual pruning, risk of the tendency of producing fruit of small size and less intensive colours in the case of small variety of fruit.

The machines used for pruning the annual plant growth in orchards may be divided into blade and disc pruning machines (fig 5). The blade pruning machines are suitable for cutting off small branches, the diameter of which does not exceed 30 mm. Due to their simple structure, they are cheaper than disc pruning machines. The idea for the design was adopted from the cutter bar mowers used for cutting grass. Such machines are usually mounted at the front of the tractor and they are supplied with power from PTO. They consist of two operating sections: a vertical section – used for pruning the side of the line of trees, and a horizontal section, located above the vertical one – used for pruning the tops of the trees to a set height. The most popular machine on the European market is called Edward and it

is produced by a German company called Fruit Tec. Another popular machine, CMA 250 type, is produced by Italian company called FA MA.

Figure 4. Apple orchard after being pruned mechanically using the method: "fruit wall"

Figure 5. Pruning machine being operated in an apple orchard: a) blade pruning machine, b) disc pruning machine

The latter machine can cut the branches the diameter of which reaches up to 40mm. Moreover, one of the machine setups allows for cutting the branches between the trunks, making the so-called windows. This configuration is possible as the machine is equipped with two rows of cutting sections: the outer one which is used for shaping the tree crowns into the form of a wall, and the inner one, made of four blades, which cuts the shoots between the trunks (Czerwiński, 2013).

The disc machines for pruning trees in orchards (Wilczyńska, 2013) are characterized by their versatility, as they may be used for pruning the new plantings and for reconstruction cuts in old orchards. The 45 kW tractors should usually be sufficient to power such machine. Its main components include two operating bars: a horizontal and a vertical one, on which the cutting discs are installed – same as in the saws for cutting wood. The possi-

ble inclination of the vertical bar towards the cut line of trees is max. 30°. Depending on the type of machine and its producer, it is equipped with 6-9 cutting discs which may cut the 3.5-4 m long branches. The horizontal bar of the machine, equipped with 2-3 discs, is used for pruning the tops of the trees. Such bar is 0.6-1 m wide. Additionally, there is a disc installed at the bottom, which is used for cutting the branches that drop too low. The discs may be replaced with blades during summer pruning. The machine is operated from the tractor cabin, with the use of a joystick.

Regardless of the machine used for pruning braches, the principle of the technology of pruning the orchard into the so-called wall, is that the old orchards are converted in the wintertime. Following the wintertime conversion, the regrowth is pruned every ear at the turn of May and June, so 6-7 weeks after the blossoming of the trees. In the case of small-fruit apple trees (e.g. Golden Delicius, Szampion), they are pruned either when the buds are pink or directly after the harvesting of fruit.

Furthermore, the small-fruit trees should be pruned manually, as it allows for more precise cutting. Even in this case the difference in man-hours between the manual pruning and mechanical pruning with supplementary manual pruning will amount to approx. 50 $h \cdot ha^{-1}$.

Management of the pruned branches and shoots

The branches and shoots that have been pruned and left in the orchard interrows may be disposed of in two ways, i.e. by shredding or removing from the orchard. Hammer shredders (fig. 6) are used for shredding and leaving the dendromass in the interrows. They are also referred to as hammer mowers or mulchers. These machines are mounted on the back of the tractor on a three point linkage and they are supplied with power from PTO. The so-called oscillating hammer blades are mounted on the horizontal bar. Depending on the shape and thickness of such blades, the machine is suitable for cutting and shredding the grass, overgrowth or branches in orchards.

Figure 6. Hammer shredder being operated in an orchard

The removal of branches and shoots beyond the area of an orchard or plantation, despite being more costly, offers measureable benefits. First of all, the orchardist disposes of dendromass affected by diseases and pests, which positively affects the health of the trees, and second of all, the orchardist obtains the biofuel which may be used for heating purposes. The pruned dendromass may be collected in one or two-stage processes.

In the case of the common, yet more expensive, two-stage technology (Magagnotti et al. 2012), you need to first prepare the branches and shoots for removal by gathering them in the middle of the interrows. The machine called a sweeper (fig. 7), modelled on hay rakes and tedders, produced by the Polish company Agromod, may be used for this purpose. The presented machine simultaneously removes the branches from both sides of the interrows. It is possible thanks to the adjustable distance between the sweeping rotors, which are made of flexible, but highly resistant plastic bars. Adjustable distance allows the machine to be operated in orchards with the interrow spacing within the scope of 2.7-4.3 m. The rotational speed of rotors may be smoothly adjusted with the use of hydraulic drives, depending on the needs and conditions. The machine performance amounts to 1.5 $ha \cdot h^{-1}$ and when the shredder is mounted on it - to 1.5-1.7 m (at the back of the tractor the performance is a little lower and amounts to 1 $ha \cdot h^{-1}$).

Figure 7. Sweepers gathering the pruned pulp into the middle of the interrow: a) with raking out elements, b) with belts

In the second stage, the branches and shoots arranged in the middle of the interrows are collected and shredded by mowers (shredders) with collectors (fig. 8). The shredded wood biomass may then be used for the production of pellets or be combusted in a heater. The biofuels obtained in this manner may also be sold to the companies involved in energy generation. After both the shredder and the sweeper are mounted on the tractor, the collection of wood biomass may be carried out in one stage.

Besides the technology of collecting and shredding the dendromass, the dendromass baling technology is progressing as well. Nowadays, the balers (fig. 9) are mainly used at the grapevine plantations (Spineli and Pichci, 2010; Cavalagio and Contana, 2007; Contana

et al., 2009). They may also be used for pressing the pruned biomass in the orchards and berry plantations. The pruning residue is collected from the interrows with the use of a pickup. It is then fed into the machine where, in the bale chamber, the rubber belts, rolls, or a combination of rolls and chains, roll up the pruned residue into cylindrical-shaped bales.

Figure 8. Flail mower collectors of wood biomass

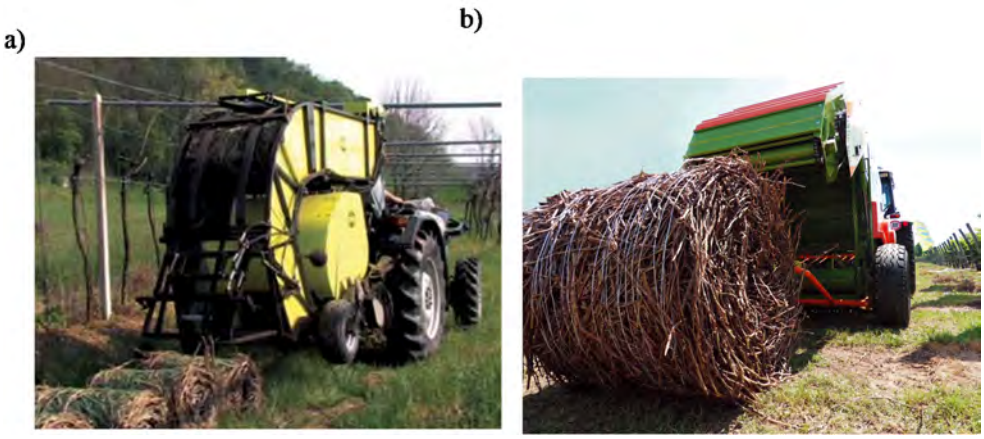

Figure 9. Baler: a) diameter of bales: 0.4-0.45 m, b) diameter of bales: 1.2 m

When the bale reaches the appropriate size and level of compaction, it is wrapped with a plastic net, rope or a thin wire. After securing such bale against unwinding, the rear wall of the baler is opened and the bale is released outside of the machine. The most common balers are the ones produced by the company CAEB International and Wolagri from Italy.

These are the machines that are mounted on the tractor and supplied with power from PTO. The main difference between these machines is their size, and so the mass of the rolled bales. The smaller machines (e.g. Quickpower series machines) for rolling single bales may be powered with 15 kW tractors. The diameter of the produced bales amounts to 0.4-0.45 m, and their length to 0.6 m. The weight of one bale does not usually exceed 35 kg, after it is dried: 10-15 kg. The machines may be optionally equipped with a "bales storeroom" for storing 8 bales (fig. 9a). Storing the bales facilitates and shortens the time for transporting them beyond the area of an orchard.

The company Wolagri manufactures much bigger and efficient machines (fig. 9b). These machines operate in a similar way to the ones discussed above. The diameter of the bales rolled by these machines reaches 1.2 m, with the length of approx. 1 m. Additionally, there are vertical cylindrical pick-up reels installed before the inlet to the bale chamber which facilitate the intake of the biomass. In order to supply the power to the baler, the tractor's power needs to be over 30 kW (Wolagri, 2013). On the one hand, large-sized bales shorten the time of collecting the pruned dendormass, but on the other hand, they might be difficult to use as they often do not fit into the boiler and furnace throats, or into the stationary shredders. Simultaneous shredding of several bales in the feed mixing wagon, used for the preparation of roughage for cattle, is an interesting solution (Cavalagio and Contana, 2007).

Except for the round balers, it is also possible to use rectangular balers that press the bales to the cuboid form (fig. 10). Such balers are not very popular in Europe.

Figure 10. Rectangular baler for compacting the dendromass.

The humidity of the collected pruned material often exceeds 40% and makes it unsuitable for burning. Therefore, such material should be dried first. The bales should be arranged in stockpiles in order to dry as quickly as possible. The drying is easier if the bales are not densely compacted (400-550 $kg \cdot m^{-3}$). As a result, the material is ready to be combusted in the form the entire bales or chips (after being shredded), already after several months. Such drying method guarantees the elimination of fermentation and mould growth risk.

Conclusion

The branches and shoots pruned in Polish orchards as a result of the cultivation and sanitary purposes are either shredded and left in the interrows, or removed from the orchard area and incinerated. In the first case, the dendromass is treated as a natural fertilizer. In the second one, besides the removal of branches from the orchard, we also eliminate the potential sources of infection for the healthy trees. Therefore, this method could be recommended if the economic balance was not taken into account. Each kilogram of wood pulp that is burned is the unused heating source (2-4 $kWh \cdot kg^{-1}$). The international research team has been established within the project called Europruning in order to prevent these unbeneficial tendencies. The objective of this team, the members of which also include the authors of this paper, is to comprehensively solve the problem of the dendromass produced every year in orchards. The aim of the Polish part of the team is to specify the amount of the dendromass in Polish orchards and its energy potential, as well as to design, execute and test the prototypes of machines used for collecting and compacting the biomass residue in orchards. This paper, presenting the review of the applied technologies and machines used for pruning and management of orchard dendromass, is one of the many works implemented by the persons engaged in the execution of the project, as a result of which the problem of obtaining and preparing the dendromass for the energy purposes will be resolved comprehensively.

Acknowledgements

This scientific paper is co-financed by the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 312078, and by funds on science in the years 2013-2016 granted by the Polish Minister of Science and Higher Education (Grant Agreement No. 2896/7.PR/2013/2 from 18.11.2013) on the realisation of the international project EuroPruning: "Development and implementation of a new and non-existent logistics chain for biomass from pruning".

References

Bisaglia, C. (2010). *Collecting and baling prunings to produce energy*. Pozyskano z: http://www.caebinternational.it/w/lang1/biomasses.html.

Boschiero, M.; Neri, P.; Zerze, S. (2013). Apple orchard pruning residues as a potential bioenergy source in South Tyrol: a LCA case study. *Bioresources Technology, 128*, 697-703.

Cavalagio, G.; Contana, S. (2007). *Recovery of vineyards pruning residues in an agro-energetic chain*. 15th European Biomass Conference & Exibition. Florence.

Contana, F.; Cavalagio, G.; Rinaldi, S. (2009*). Energy and environmental performance of a polygeneration plant from vineyard pruning residues*. 17th European Biomass Conference & Exhibition . Amburgo. Pozyskano z: http://www.crbnet.it.

Czerwiński, H. (2013). Cięcie mechaniczne w praktyce. *Owoce warzywa kwiaty, 1*, 52-55.

GUS. (2013). *Produkcja ogrodnicza. Badanie sadów.* Wyd. GUS Warszawa, ISNN 1898-4347.

Maciak, A.; Lipińska, G. (2006). Możliwości i koszty pozyskiwania drewna z sadów. *Nowy sad,* 3, 59-61.

Magagnotti, N.; Pari, L.; Pichci, G.; Spinelli, R. (2012). Technology alternatives for tapping the pruning residue resource. *Bioresour Techol., 128*, 697-702.

Piszczalka, J.; Kaernko, M.; Rutkowski, K. (2007). Ocena energetyko-ekonomiczna ogrzewania dendromasom. *Inżynieria Rolnicza, 6*(94), 189-196.
Rabcewicz, J. (2007). Maszyny i narzędzia do cięcia krzewów jagodowych. *Hasło ogrodnicze, 1*, 12-16.
Romański, L. (2013). Energia odnawialna. *Ekonatura, 11*,14-19.
Spineli, R.; Pichci, G. (2010). Industrial harvesting of olive tree pruning residua for energy biomass. *Bioresource Technology, Vol.101*, Issue 2 ,730-735.
Scholten, H. (2010) .Szpaler koroną przyszłości?. *Sad Nowoczesn*, *4*, 12-14.
Silvestri, S.; Cristoforetti, A.; Mescalchin, E. (2011). *Recovery of pruning waste for energy use: agronomic, economic and ecological aspets*. Central European Biomass Conference. Graz. Austria.
Wilczyńska, A. (2013). Mechaniczne cięcie jabłoni. *MPS Sad, 2*, 12-13.
Wolagri. (2013). *Katalig-Columbia R98 Energy*. Pozyskano z: http://www.wolagri.com.

PROBLEMY POZYSKIWANIA BIOMASY Z PRZYCINKI DRZEW OWOCOWYCH DLA CELÓW ENERGETYCZNYCH

Streszczenie. Jednym z głównych źródeł energii odnawialnej jest biomasa, a szczególnie drewno. W obszarze zainteresowania Autorów jest masa drzewna z upraw sadowniczych, corocznie powstająca w wyniku przycinania drzew i krzewów dla celów grzewczych, gdyż w naszym kraju, ale także w Europie, jest ona wykorzystywana w małym stopniu. Masa ta, głównie w formie gałęzi i pędów jest najczęściej rozdrabniana i pozostawiana w sadach w międzyrzędziach drzew jako naturalny nawóz. W pracy zwrócono uwagę na powody, dla których powinna ona być zbierana i wywożona z sadu. Przedstawiono technologie wycinania i zbioru tej masy oraz omówiono najnowsze konstrukcje maszyn umożliwiające szybki zbiór i zagęszczenie dendromasy do postaci, w której ułatwione będzie jej przechowywanie i naturalne podsuszanie.

Słowa kluczowe: dendromasa, metody wycinki, zbiór masy drzewnej