Agronomy Research **14**(5), 1519–1529, 2016

Developing a new design of wood chopper for grape vine and fruit tree pruning and the results of field testing

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Abstract. The problem of collecting and utilising the pruned canes of grape vines and branches and twigs from fruit trees that are left in vineyards and orchards all year round after the scheduled pruning of plantations in early spring is the topic of the day, and it is one that requires an effective solution. One of the ways in which the problem might be solved is the utilisation of pruning material as an organic fertiliser after it has been gathered, so that it is chopped, evenly spread in the inter-row spaces in the plantation, and ploughed into the soil, so that it decomposes there, and is digested. Meanwhile, the degree of pruned material disintegration and the level of quality shown in the work of spreading it across the area both have to ensure the complete decomposition of any such ploughed-under wood waste within one calendar year. The aim of this research project was to increase efficiency levels in chopping and spreading grape vine and fruit tree pruning material on the basis of the development of a new design of wood chopper and the results obtained in field testing this piece of equipment. The research uses engineering and design methods which are based on the theory of collecting from ground level and further transporting wood and plant materials, the theory behind cutting, crushing, and spreading, and also the methods used in experimental research, field testing, and the statistical analysis of test results. We have developed a new design arrangement for a wood chopper for grape vines and fruit trees, one which combines the mechanism for collecting slender, flexible waste wood pieces that are of a considerable length from the ground with a system that involves the transportation, chopping, shredding, and spreading over the soil surface of such materials. The prototype wood chopper design which was subsequently produced has been tested for several years in the laboratory and in field conditions and has delivered positive results. From the results of the field tests it has been found that, when using the aforementioned work process, a considerable reduction is achieved in terms of energy consumption and labour input in comparison with similar indicators for wood choppers that have been produced by recognised manufacturers. For example, the power demand for one metre of the machine's working width is just 15 kW, which is virtually two times less than the respective figure for a similar, recognised machine. The degree at which pruning material is collected from the ground is 95.4%, while the degree at which they disintegrate lengthwise is within a measurement of 10 cm, while the weight of the chopper is 1.5 times smaller than that of the similar machine used in the comparison studies. The use of these wood choppers provides an opportunity to implement widely across the horticultural industry those innovative technologies that not only aim at reducing energy and labour consumption, but which also help substantially to cut down the demand for the input of mineral fertilisers, which improves the overall ecological characteristics of the natural environment.

Key words: vineyard, fruit tree, chopper, product design and development.

INTRODUCTION

Currently, in Ukraine, Moldova, Russia, Armenia, and other countries prunings from vines, as well as branches and twigs that have been pruned from fruit trees, are in the overwhelming majority of cases collected from the plantation's inter-row spaces, following which they are transported outside the planted area and are simply burned. This is especially customary in the case of pruning materials from vines, because the length of pruned canes can be either large or small (Ntalos & Grigoriou, 2002), while their diameter is always small and therefore it is not practical to use them further for any purpose other than burning. At the same time, this method of collection, transportation, and utilisation of pruned material not only consumes considerable amounts of energy and labour, but also results in additional levels of environmental pollution.

According to the results of our calculations, only in Crimea does the annual volume of unproductive incineration amount to about 180,000 tons of grape vine and fruit tree waste wood produced during the scheduled pruning of branches and canes in early spring. Undoubtedly, this causes significant damage to the environment (Calatrava & Franco, 2011; Gonçalves et al., 2011; Spinelli et al., 2014). Meanwhile, the calculations also show that the calorific capacity of waste wood in the form of pruned grape vine canes and fruit tree branches is close to 15.3 10^3 MJ t^{-1}, which at the aforementioned volume is equivalent to burning down 112,500 tons of coal. At the same time, between 10 to 14 kg of nitrogen, between 6 to 8 kg of phosphorus, and between 12 to 15 kg of potassium are taken away from each hectare of grape vine and fruit tree plantation together with pruned canes and branches. In this manner, the accumulated chemical and energy potential of the annual gain in biomass effectively is lost.

The technology that enables pruned vine canes and fruit tree branches to be reduced into segments of a length of under 10 cm and then ploughed into the soil in plantation inter-row spaces (which is a task that is already carried out each year) – ie. the utilisation of pruning material that is chopped up and is later digested as a valid organic fertiliser – is capable of preventing the aforementioned losses and can also protect the environment. The pruned canes which were reduced to the indicated degree (ie. to sizes with a length of under 10 cm) will be fully digested into the soil and turned into an organic fertiliser within one calendar year.

The indispensable need to replenish the soil's resources in grape vine plantations with fertilisers is due to the fact that the grape vine as a monoculture is cultivated in the same place for thirty years or more. At the same time, those soil types which are appropriate for grape cultivation are generally rather lean when it comes to their nutrient content. They can easily be dry, stony soils with a humus content of only 1–2%. Therefore, the chopped mass of grape vine pruning material which is retained in the field and is ploughed into the soil will, after it has been digested and turned into a fertiliser, contribute to the natural improvement of the soil's fertility and decrease the overall demand for the application of mineral fertilisers.

However, the possibility of using the chopped up and collected mass of grape vine pruning material for some other purpose is not excluded from consideration (Ntalos & Grigoriou, 2002; Benito et al., 2006; Youkhana & Idol, 2009; Calatrava & Franco, 2011; Rosua & Pasadas, 2012; Gomes-Munoz et al., 2016; Corona & Nicoletti, 2010). For example, such material can be used for the production of fuel bricks, which can be as important in energy crisis periods. That said, if we estimate the level of costs associated with this specific type of utilisation, then it becomes evident that the use of chopped up grape vine canes as an effective organic fertiliser is of a higher priority than the second method of utilisation for such material.

Currently, research into the rational use of grape vine pruning material is in progress, both within our country and abroad. Several production prototypes of machines have already been developed for collecting and chopping up pruned grape vine canes (Recchia et al., 2009; Spinelli & Picchi, 2010; Spinelli et al., 2010; Acampora et al., 2013; Managnotti et al., 2013) and then spreading them over the soil's surface. In this process, there is a pronounced trend towards developing dedicated pick-up wood choppers for grape vine and fruit tree pruning material. And for these machines, towed, semi-mounted, and fully mounted versions of the design layout are developed. When analysing the process and design features of agricultural implements of this type where they already exist in the world, it can be seen that pick-up wood choppers, as a rule, collect pruned grape vine canes or fruit tree branches and twigs from the ground with the use of a separate pick-up attachment, and then transfer the material to the machine's adjacently-located wood chopping equipment. There are two types of pick-up attachments: passive, meaning the involvement of rake type equipment, and active, meaning rotor type equipment, in the form of drums with fingers (rods) or belts with fingers. The latter are designed as belt conveyors, which feature fingers for collecting and lifting pruned waste wood, attached to the belt with the use of strips.

The chopping tools can be divided into the following main types according to the method used in disintegrating wood and plant material: cutting, chopping, sawing, and crushing. When it comes to their design, almost all wood choppers are made in the form of fast-rotating drums to which are attached some form of cutting or crushing implement (in the form of knives or hammers or similar). Depending on the form of implement being used, the wood chopper drums are accordingly equipped with shear bars, decks, or concaves. By far the majority of grape vine wood chopper designs have been developed in France, but their embodiments are rather complex and energy-intensive machines, which are very highly-priced and involve considerable cost in terms of their operation (Spinelli et al., 2014).

The detailed analysis of the existing designs of wood chopper for grape vine and fruit tree pruning material has shown that, in general, these machines feature the following essential drawbacks: high energy intensity involved in the process, the non-uniformity of segment sizing in the final product with a high content of segments that have been chopped up insufficiently, low reliability levels, and a complexity of operation. Due to the diverse composition of the raw material that is being collected from the ground (apart from wood and plant pruning material) – specifically: stones, metal, or concrete chips from the posts – intensive wear and tear occurs and frequent breakdowns are recorded for collection tools and, especially, chopping tools.

The aim of the research was improving the efficiency of chopping and spreading grape vine and fruit tree pruning material on the basis of the development of a new design of wood chopper and the results of its field testing.

MATERIALS AND METHODS

Used within the research are those methods of engineering and design that have been based on theories which are related to collecting wood and plant material from the soil's surface and further transporting such material, plus theories which are related to the cutting, crushing, and spreading of such material, and also the methods being used in experimental research, field testing, and the statistical analysis of test results.

RESULTS AND DISCUSSIONS

On the basis of the exploratory theoretical and experimental studies that have been carried out, including associated engineering and design work, a breadboard model of the new grape vine and fruit tree pruning wood chopper has been developed. As part of the development process, substantial modifications were made to the wood chopper design, and these were applied with regard to ensuring efficient operation in conventional orchards, trellis system orchards, and various types of vineyard.

The industrially-produced wood chopper prototypes have undergone laboratory and field tests. The preliminary results of the tests provide evidence of achieving the following points:

– increased quality in terms of pruned wood chopping and spreading over the field;
– improvements in the ecological state of the natural environment;
– a reduced demand for fertilisation;
– significant lowering of energy consumption levels in comparison with similar machines that are made by foreign manufacturers.

Moreover, the chopper falls into the category of innovative products (Pahl et al., 2007), with these being in line with the priority trends in the mechanisation of labour and energy intensive processes in horticulture and viticulture in many countries around the world.

Over the next few paragraphs, we are going to examine in detail the design and performance characteristics of the grape vine and fruit tree waste wood chopping machine that we have developed.

The grape vine and fruit tree waste wood chopper is intended primarily for collecting, chopping, and spreading vine canes in vineyard plantation inter-row spaces and wood that is pruned from fruit trees at an inter-row spacing of at least 2.5 m. The application of this wood chopper with other inter-row spacing values is possible, but in such cases the achievement of high operation and performance figures is not guaranteed.

The wood chopper allows for the collection and chopping of pruned grape vine canes of any length with a diameter of up to 35 mm (this dimension will also be applied in cases in which the wood chopper is being used for pruned branches and twigs from fruit trees), with the output being reduced to small segments with a length of under 10 cm, while the machine itself can operate on level plots in orchards and vineyards, and also on slopes with a gradient of up to five degrees, and on all types of soil, including stony ground (ie. soils which contain stones that have a diameter of up to 80 mm). The design of the pick-up system precludes the entrainment of stones and other non-vegetable material from the soil's surface which has a dimension that is greater than that already mentioned. The pruning material wood chopper is aggregated with a wheeled tractor.

The design and process setup for the new grape vine and fruit tree waste wood chopper is presented in Fig. 1. Fig. 2 shows the chopping unit (top view).

The major elements of the new pick-up wood chopper design are: frame (1), with a front section onto which the pruned wood collection unit (2) is mounted; plus tool drive components including: a hydraulic motor (7) which drives the collection unit (2), drive gear (4) (driven by the power take-off shaft of the aggregating tractor), which is installed on the central part of the frame (1), intermediate gear (5) and belt transmission (6), the chopping unit with blades (3) and a specially designed upper casing, free-wheel clutch (8), and supporting gauge wheels (9) (Fig. 1).

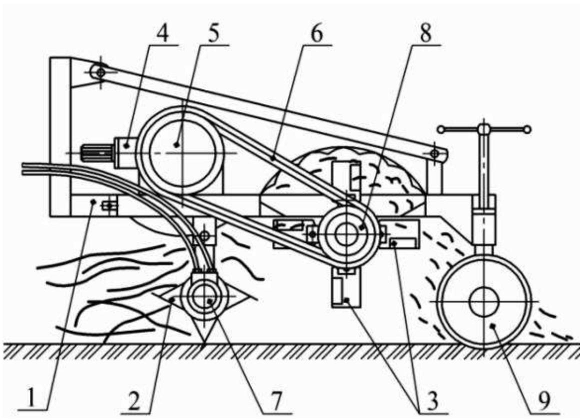

Figure 1. The design and process setup of the grape vine and fruit tree waste wood chopper (sectional side view): 1 – frame; 2 – pruned wood pick-up unit; 3 – chopping unit blades; 4 – drive gear; 5 – intermediate gear; 6 – belt transmission; 7 – pick-up unit drive hydraulic motor; 8 – free-wheel clutch for chopping unit drive; 9 – gauge wheel with height adjustment mechanism.

The frame (1) on the chopper is a welded assembly that is fabricated from rectangular tubes and channel beams. The front of the frame features a rigidly-fixed standard three-point linkage for hinging to the aggregating tractor.

The collecting unit (2) consists of a tubular shaft with welded rods which are installed on the lower part of the frame (1) with the use of telescopic struts, which allow adjustments to be made in the vertical position of the collecting unit (2) in steps to a total of 200 mm by repositioning the locking pins.

The chopper drum with chopping blades (3) consists of a tubular shaft, to which clevis lugs made from angled sections are welded. In the clevis lugs, two types of chopping blade are installed so that they pivot: straight blades and L-shaped blades. The chopper drum shaft rotates on two bearing supports which are attached to the frame with the use of stud bolts and collar clamps (Fig. 2).

The actuation of the chopper drum is provided by the aggregating tractor's PTO shaft (at 540 rpm) which drives the step-up gear (4), and then the intermediate gear (5), the belt transmission (6), and the free-wheel clutch (8). The last item is mounted directly onto the shank of the chopper drum. At the top, the chopper drum is covered with a special casing.

The described chopper design utilises a single-stage step-up bevel gear (with four positions) that increases the speed of rotation at a gear ratio of 2.4.

The intermediate gear (5) consists of the shaft (which connects the central part of the frame (1) with its side end), which is installed on two bearing supports and is connected to the gear unit (4) by the use of a bush roller coupling. The other end of the shaft of the intermediate gear (5) features the attached greater pulley for the V-belt transmission (6). The intermediate gear (5) and belt transmission (6) are covered with protection casings.

The gear unit (4) and intermediate gear (5) are mounted onto the frame (1) by the use of a special plate to which they are bolted. The plate is also fastened to the frame (1) using bolts that pass through elongated holes, which allow the plate to be shifted on the frame (1) in order to adjust the tension in the belts at the belt transmission (6). In order to be able to carry out this adjustment, the two tension bolts connecting the front part of the frame (1) and the aforementioned special plate are used.

The pick-up unit (2) is driven by the hydraulic motor (7) which is mounted onto the collecting unit's support bracket and is connected by pipelines to the aggregating tractor's hydraulic system. Two supporting gauge wheels (9) provide for the adjustment of the positioning of the frame (1) in relation to the soil's surface, depending on the height of the windrow of pruned grape vine canes or fruit tree branches and twigs.

Fig. 3 shows the general view of the new grape vine and fruit tree pruning material wood chopper, which was manufactured and tested first in a laboratory, and then also in field conditions (rear view).

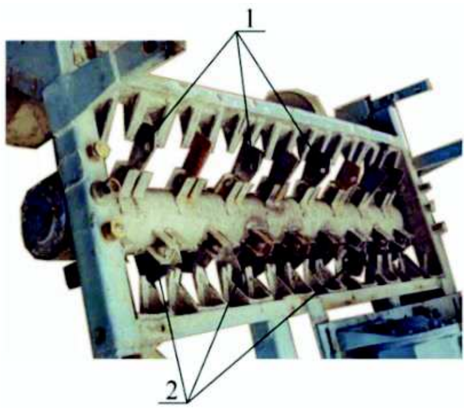

Figure 2. Chopping unit: 1 – straight blades; 2 – L-shaped blades.

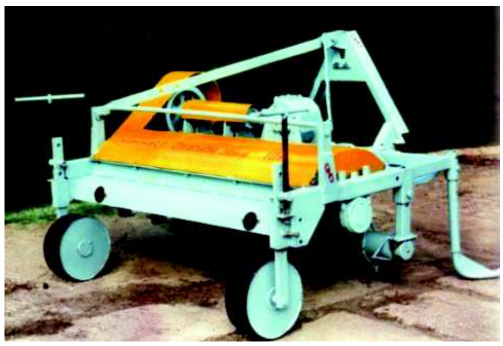

Figure 3. Experimental model of the wood chopper.

The work process that can be managed by the collecting unit of the new design is now described further. The aggregating wheeled tractor moves progressively through the inter-row spaces in the grape vine or fruit tree plantation at a pre-set travel speed. The wood chopper, mounted on the aggregating tractor's rear hitch, picks up pruned wood that lies on the soil's surface in the inter-row spaces, using the collecting unit (2) to achieve this and then transferring the material into the wood chopper's upper section, into the operating zone of the chopper drum. The chopper drum entrains the pruning material with its blades (3) and draws it through the casing that covers the drum from above. The chopper drum's upper casing has a design which ensures that the recesses which is arranged on its inner surface plays the role of shearing blades. As a result of such an arrangement, the straight blades (3) at once efficiently cuts up pruned material into smaller segments. Furthermore, the L-shaped blades (3) also entrain the waste wood and crushes it to the required degree (to a length of under 10 cm). In this process, the ratio between the wood chopper's drum revolution rate and the wood chopper collecting travel rate is selected so that it ensures an adequate chopping quality and high levels of productivity.

During the machine's progress forwards along its path, the rear wheels of the aggregating tractor and the gauge wheels (9) of the wood chopper ensures that soil surface irregularities in the inter-row spaces grape vine and fruit tree plantation do not result in any irregularities in terms of collecting up material. The wood chopper is placed in the horizontal position at the required height by using the mechanism in the gauge wheels (9). At the same time, the shaft of the waste wood collecting unit (2) has been designed so that its rods can enter the top soil easily, almost entirely without entraining and lifting up soil particles. Also, the design allows the elevation of the collecting unit (2) to be adjusted with the use of the telescopic struts and lock pins. After chopping up pruned grape vine canes or fruit tree waste wood, the blades (3) in the chopper drum spread the resultant material evenly over the soil's surface.

In the period between 2011 and 2015, annual field tests of the new wood chopper design were carried out in three vineyards in the Crimea, each being located in a different area – on a plain, in the foothills, and in the mountains. During these tests, the existing standard test procedures were used, measurements were recorded and processed, and the wood chopper in our design was compared to the TRP-175 grape vine cane shredder (KUHN).

After a statistical analysis had been carried out on the results of the five-year field testing process, the designers were able to arrive at finalised results for the principal processes, performance, and operational indicators which are characteristic of the operation of the compared models. The data obtained in these long-term tests are presented in Table 1.

Table 1. The comparative characteristics of process, performance, and operational features of the new design of wood chopper and a similar machine

Pos. no	Technical and economic index (description and measurement unit)	TRP-175 Shredder (KUHN)	Experimental model of chopper
1	Production rate per hour of productive time (ha h^{-1})	1.43	1.43
2	Operational travel speed (m s^{-1})	1.24	1.24
3	Effective width (mm)	1,750	1,500
4	Width of processed inter-row spaces, at least (m)		2.5
5	Overall dimensions (mm):		
	length	1,750	1,500
	width	2,160	1,860
	height	1,210	1,010
6	Weight (kg)	950	650
7	Diameter of collecting drum at rod ends (mm)	350	355
8	Drive and revolution rate of collecting drum (rpm)	belt transmission 350	hydraulic motor 350÷450
9	Type of wood chopper drum	hammers	blades
10	Diameter of wood chopper drum (mm)	465	485
11	Revolution rate of wood chopper drum (rpm)	1,960	2,150
12	Number of blades/hammers (pcs)	28	34
13	Power consumption (kW hp^{-1})	49/67	22.5/30.6
14	Pick-up ratio (%)	89	95.4
15	Average length of segments after disintegration (cm)	1.4	4.8

It can be seen from the data shown in the table that the weight of the experimental model of wood chopper is one and-a-half times less, and is equal to 650 kg versus the 950 kg of the TRP-175 shredder, while its power consumption per metre of working width is a mere 15 kW versus the 29 kW of the model being used as a comparison. The experimental wood chopper model shows a higher level of accuracy when it comes to collecting pruned materials from the soil's surface, ie. 95.4% versus the 89% of the TRP-175 shredder.

The degree to which collected grape vine pruning material is chopped up by the experimental chopper meets the agricultural requirements for the respective work process. The volume of chopped segments that have a length of 10 cm does not exceed 5% of the total mass of the chopped vine. Meanwhile, the average length of segments being outputted by the experimental chopper is 4.8 cm, which is greater than in the case of the compared TRP-175 shredder (1.4 cm). However, such minimal dimensions are not required for the chopped mass of waste wood, since agrochemical studies that have already been conducted have shown that chopped segments with a length of up to 5 cm, if ploughed under the soil, can be digested within one calendar year just as effectively as any smaller segments. At the same time, the high degree of grape vine shredding in the French shredder is achieved by positively pressing the chopped mass through the deck (screen) with a mesh size of no more than 2.5 cm^2. But it is just this type of shredding process that results in a two-fold increase in the power consumed by the drive of the chopping/shredding drum.

Fig. 4 shows an area in the inter-row space in a vineyard plantation after the spring pruning of the grape vines. In Fig. 5, the same area is shown after a run-through by our new design of wood chopper.

Figure 4. A section of the inter-row space in a grape vine plantation after spring pruning for vines, with the grape vine pruning material piled in the middle.

Figure 5. The same section of inter-row space in a grape vine plantation after the pruning material has been chopped up.

The results that we obtained from the completed field tests for the experimental model of wood chopper and the data from literature about similar results of tests with wood choppers/shredders that have been produced by other foreign manufacturers show that our design of experimental wood chopper model consumes between 1.5 to 2.0 times less metal per metre of working width, while providing a rather high level of chopping quality. According to our calculations, the annual economic benefit from the implementation of the described experimental chopper in 2015 in Ukraine had amounted to more than 2,500 dollars. At the same time, the implementation of the mechanised technology for collecting, chopping, and spreading the chopped mass over the soil's surface reduces the demand for fertilisation by 25%.

Following the completion of calculations, we have found that the annual demand for such pruning material wood choppers in Ukraine is at least 400 units, while in Russia about 600 units would be required, and in Armenia (for chopping fruit tree pruning material) at least 150 units would be required at an annual workload of 270 ha per chopper. In the case of the mass use of such wood choppers in the horticultural industry, the indicated figures should be multiplied by a factor of ten. Therefore, annual production of the new machines has to be around 1,000 units with a service life of at least six years. According to the preliminary calculations, the cost of one chopper at 2013's rates was 5,000 dollars.

CONCLUSIONS

1. A new wood chopper has been developed for grape vine and fruit tree pruning material . The machine has a simple and robust design, which allows the work process to be carried out when it comes to mechanised collection, transportation, and chopping up pruning material and spreading the chopped mass over the soil's surface at a high level of quality and with improved efficiency.
2. The industrially-produced prototype of the new wood chopper has, for several years, passed laboratory and field tests and has delivered exceptional results with respect to the quality and efficiency of its operation.
3. The results of the field tests show that a considerable reduction in energy and labour consumption is achieved in the described waste wood disintegration work process when compared to similar indicators for wood choppers that have been produced by recognised manufacturers. The power consumption rates for the proposed wood chopper is 15 kW per single metre of working width, which is virtually two times less than in the case of the other, similar machine. The level of completeness in terms of collecting pruning material from the soil's surface exceeds 95%, while the degree of disintegration lengthwise remains within 10 cm and is 4.8 cm on average. The weight of the improved wood chopper is 1.5 times less than the weight of a similar machine with which it was compared.
4. The use of the new wood chopper will facilitate the implementation of innovative technologies in horticulture and viticulture, aiming not only at a reduction in energy and labour consumption, but also at the substantial lowering of the demand for mineral fertilisers, which will significantly improve the ecological indices of the natural environment.

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