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IMPACT OF DIFFERENT PARAMETERS ON THE PRODUCTIVITY OF CHIPPING WOOD FROM THINNINGS

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Abstract

In this article a study is described for determining the impact of the chipper power and the size of materials on the productivity of different chippers. Machines with various engine powers have been used in the range of 21 to 70 kW, being equipped with disc or drum chipping mechanism propelled by either self-engine or PTO. The experiments have been carried out with fresh, scots pine small-size wood, grouped into nine groups of materials. The results indicate that the greatest impact on the productivity of the chipping machines has their power, then is the diameter of the materials and least is the influence is the length of the materials.

Key words: chippers, chipper power, scots pine wood, small sized wood.

Introduction

Over the last few years there has been a growing interest in wood biomass (Georgiev 2013, Marinov et al. 2013, Stoilov et al. 2008). From thinnings in young stands large quantity of primarily small-size wood is obtained, which can be used as a biofuel for heat production. As technological chips this wood is used in electrical power stations and cogeneration plants, in biogas stations, for producing densified biofuels such as pellets and briquettes (Alakangas 2005, Abdallah et al. 2011).

Logging technologies used for thinnings envisage harvesting of round materials. They include many operations like removing of branches and cross cutting the stems into small sections. The costs are very high, making the final product too expensive. It is known that no valuable materials are obtained from thinnings because the harvested wood is mainly for firewood, for pulp and plate production. This once again confirms that the currently applied technologies for thinnings are not efficient enough (Jylhä 2011, Georgiev 2013, Peev 2017).

In many countries, including in Bulgaria this wood has to be chipped into technological chips, which can be done in the forest, on the roadside or on the place where it would be processed. For this purpose, different chippers are used – mainly mobile, disc or drum driven by a tractor or by self-engine. In case when the raw material is near the processing site, stationary chipping machines with electric drive are also used.

The variety of machines that are used concerning their type, their construction and operating parameters is great, which affects their productivity and the quality of the chips.

Studies have shown that chipping machines with too great power for this kind of wood – very often over 80 kW (Spinelli et al. 2005) have high prices which means high chipping costs.

The size of the materials affects the productivity of the chipping machines and its increasing leads to growth of productivity. Increasing the length of the chips also increases the productivity of the chippers due to the reduction of the number of cuts, respectively reducing the cutting work of wood materials into longer chips (Georgiev 1986, Spinelli and Magagnotti 2012, Di Fulvio 2015).

The number of rotations of the cutting mechanism, the number of knives, the cutting angle etc. also impact the productivity of the chippers (Valshchikov 1970, Fetyaev 2016). According to Kováč et al. (2011), the greatest impact on energy consumption have the size of the materials, the wood species and the sharpening angle of the knives.

According to other authors (Nati and Spinelli 2010, Glushkov et al. 2015) increasing of knife's wear significantly increases fuel consumption.

In conclusion, it can be said that the comminution of wood has been subject of many studies in different countries. The experiments have been carried out at different time under different conditions and with different wood materials – coniferous and deciduous small-sized materials (Brik and Vasilyev 1975, Hellström 2010, Abdallah et al. 2011, Spinelli and Magagnotti 2012, Di Fulvio et al. 2015) and logging waste (Nati and Spinelli 2010, Yoshida et al. 2016), which does not allow good analysis and comparability of the results.

The purpose of this study is to determine the impact of the dimensions of materials and the power of the cutting machine on the productivity during the chipping of wood from thinnings. At the same time, the particle size of the chips obtained by means of different chipping machines is determined, and according to the requirements of the standards their application has been determined.

Due to the limit of volume this article presents the results from investigations only on the chipping productivity of wood from thinnings by chippers with different power. The goal is ultimately to optimize the chipping process and to determine the most suitable chipping machine according to the size of the chipped materials. The optimization of the chipping process is an object of another study, the results of which will be published later.

Material and Methods

The research that is the aim of this study has been carried out with mobile chippers Schliesing 200 MX, Vermeer BC 1000 XL, Heizohack HM 6-300 EM, Bruks 850 M и Wallenstein BX 62 R.

The object of the study can be represented schematically with the 'black box' model (Fig. 1).

According to the diagram, the values Y_P (i = 1, 2...p) represent the baseline of

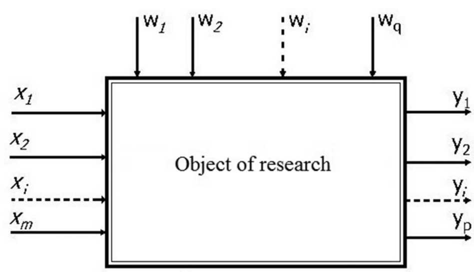

Fig. 1. Cybernetic model of the researched object.

the study. The necessary condition for realizing of an active experiment is to have a real opportunity to impact the technological process and to maintain the level of factors. All possible ways of action are called input factors and are marked with X_i (i = 1, 2...m). The dimensions W_i (i = 1, 2, ..., q) are disturbing factors that are unmanageable during the process.

The mobile chippers are adjusted to produce 0.02 m long chips. There are possibilities to control the factors by the dimensions of the chipped materials and the power of the chippers. The following manageable factors are selected for the study:

X_1 – diameter of materials, cm;
X_2 – length of materials, m;
X_3 – power of chipper, kW.

Other controllable factors influencing the process are:

X_4 – length of the chips, m;
X_5 – moisture content, %.

To reduce the number of attempts, the factors X_4 and X_5 are maintained at a single level. The moisture content of wood X_5 is maintained at about 50–55 %. The length of the chips X_4 as mentioned above is maintained at 0.02 m. Wood materials from scots pine are used, because it has the largest participation among coniferous species in our country.

A multifactor experiment of type 3^m is carried out, where m is the number of factors that are maintained at three levels as follows: X_1 – 6, 10, 14 cm; X_2 – 1, 3, 5 m; X_3 – 21, 45.5, 70 kW.

The target function is in accordance with the subject of the study and is presented with the main indicators of the research process: Y – productivity, m^3/h.

To determine the productivity, the cutting time of the different groups of materials is determined. The time is measured with a stopwatch accurate to 0.1 s. The productivity of chippers is determined by the following formula (1):

$$P_h = 3600\frac{V_c}{t_c}\ \text{m}^3/\text{h}, \quad (1)$$

where: P_h is the productivity in m^3/h; V_c – the volume of the chipped group of materials, m^3; t_c – time for chipping of the materials, s.

The volume of chipped groups of materials is determined by the Smalian formula (2):

$$V_c = \left(\frac{G_1 + G_2}{2}\right) l\ \text{m}^3, \quad (2)$$

where: V_c is the volume of chipped materials in m^3; G_1 – the circular area of the thick end of the materials, m^2; G_2 – the circular area of the thin end of the materials, m^2; l – the length of the chipped materials, m.

The circular area of the thick or thin end of the materials is determined by the formula (3):

$$G_i = \frac{\pi d^2}{4}\ \text{m}^2, \quad (3)$$

where d is the diameter of the thick or thin end of the materials, m.

Formula (2) is used to determine the volume of round wood materials up to 5 m in length.

Achieving the set goal is realized through a planned multifactor experiment.

The complete square equation for determine the influence of the three factors X_1, X_2 and X_3 on the productivity is as follows (formula 4):

$$Y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + \\ + b_{13}x_1x_3 + b_{23}x_2x_3 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2 \quad (4)$$

The stepwise regression analysis is used to find out which model is the most suitable one.

Based on the advanced matrix of the

model, different models in CranR and STATISTICA programs and the most suitable is defined. This is based on the Akaike's Information Criterion (AIC), according to which the smaller AIC criterion is more appropriate and simplified in terms of stepwise regression analysis (Crawley 2007).

Results and Discussion

According to methodology of the study in Table 1 are shown the levels and the intervals of variation of the studied factors.

Table 1. Basic level and factor variation intervals for determining the productivity of the chipping machine.

Indicator	*D*, cm	*L*, m	*N*, kW
Coded factor	X_1	X_2	X_3
Basic level (X_i = 0)	10	3	45,5
Interval of variation	4	2	24,5
Top level (X_i = 1)	14	5	70
Bottom level (X_i = -1)	6	1	21

Due to the difficulty to find and test a chipping machine with a power equal to the mid-range (45.5 kW), a machine with a near power (55 kW) are used and that has been taken into account in the coding of factor values.

To describe the target function or the function of the productivity response, a stepwise regression analysis is performed using a second degree polynomial of type (4). Experimental data are processed with STATISTICA program. The results obtained for the estimation of regression coefficients in the model are shown in Table 2.

The results show that the coefficient of determination R^2 = 0.766 which indicate that 77 % of the change of *Y* is described by the second degree model. The Fisher's criterion F_T (9, 80) = 29.161 and the corresponding probability p < 2.2e-16 < 0.05 show that the equation is adequate. At level of significance α = 0.05 the coefficients b_{23} = -0.011 and b_{22} = -0.707 are non-significant and should be excluded.

Table 2. Results of regression analysis to determine the productivity of the chipping machine.

N = 90	b_i	Std. Err. of b_i	*t*(80)	*p*-level
Intercept	5.99472	0.568035	10.55342	0.000000
X_1	2.15038	0.280409	7.66873	0.000000
X_2	-0.74410	0.280409	-2.65364	0.009602
X_3	3.21944	0.341235	9.43467	0.000000
X_{12}	-0.89500	0.323724	-2.76470	0.007070
X_{13}	2.34169	0.400070	5.85320	0.000000
X_{23}	-0.01095	0.400070	-0.02737	0.978231
X_{11}	-1.23167	0.457815	-2.69031	0.008687
X_{12}	-0.70667	0.457815	-1.54356	0.126641
X_{13}	3.10028	0.542748	5.71220	0.000000

Note: R = 0.87543613; R^2 = 0.76638842; Adjusted R^2 = 0.74010712; F_T (9.80) = 29.161; p < 2.2e-16; Std. Error of estimate: 2.0474.

The full regression model that describes the best target function and has the best predictive values is the following (formula 5):

$$Y = 5.99 + 2.15x_1 - 0.74x_2 + \\ +3.22x_3 - 0.90x_1x_2 + 2.34x_1x_3 - \\ -0.01x_2x_3 - 1.23x_1^2 - 0.71x_2^2 + 3.10x_3^2 \quad (5)$$

According to the CranR program, the model that is most suitable excludes only the coefficient b_{23}. This is based on the Akaike's Information Criterion (AIC), according to which the model with the lower AIC criterion is more suitable and sufficiently simplified in terms of stepwise regression analysis.

The equal after the stepwise regression analysis is as follow (formula 6):

$$Y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + \\ +b_{13}x_1x_3 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2 \quad (6)$$

The results from stepwise regression analysis are shown in Table 3.

Table 3. Results of regression analysis for determine the productivity after exclusion of factor X_2X_3.

***N* = 90**	***b*$_i$**	**Std. Err. of *b*$_i$**	***t*(80)**	***p*-level**
Intercept	5.99472	0.564521	10.61912	0.000000
X_1	2.15038	0.278674	7.71648	0.000000
X_2	-0.74667	0.262684	-2.84245	0.005663
X_3	3.21944	0.339124	9.49341	0.000000
X_{12}	-0.89500	0.321721	-2.78191	0.006721
X_{13}	2.34169	0.397594	5.88965	0.000000
X_{11}	-1.23167	0.454983	-2.70706	0.008277
X_{12}	-0.70667	0.454983	-1.55317	0.124281
X_{13}	3.10028	0.539389	5.74777	0.000000

Note: R = 0.87543488; R^2 = 0.76638623; Adjusted R^2 = 0.74331327; F_T (8.81) = 33.216; p < 2.2e-16; Std. Error of estimate: 2.0347.

After removing of non-essential factor and substitution with the regression coefficients, the equation is as follow (formula 7):

$$Y = 5.99 + 2.15x_1 - 0.75x_2 + \\ +3.22x_3 - 0.90x_1x_2 + 2.34x_1x_3 - \\ -1.23x_1^2 - 0.71x_2^2 + 3.10x_3^2 \quad (7)$$

The coefficient of determination R^2 = 0.766, the Fisher's criterion F_T (8, 81) = 33.216 and the corresponding probability p < 2.2e-16 show that the equation is adequate.

The results from the regression analysis indicate that the biggest impact on the productivity during the chipping of small sized wood affect the power of the chipping machine, then the diameter of the materials and at the end – the length of materials. A basis for this conclusion gives the comparison between the values of regression coefficient. The coefficient before the factor power of the chipper has the biggest absolute value.

In figures 2, 3 and 4 the surface of equal response of the target function is shown, respectively for $Y = f(x_1x_2)$, $Y = f(x_1x_3)$, and $Y = f(x_2x_3)$. In figures 5, 6 and 7 are represented the lines of equal response respectively for $f(x_1x_2) = Y =$ const, $f(x_1x_3) = Y =$ const, and $f(x_2x_3) = Y =$ const, according to the sizes of materials and the power of chipping machine.

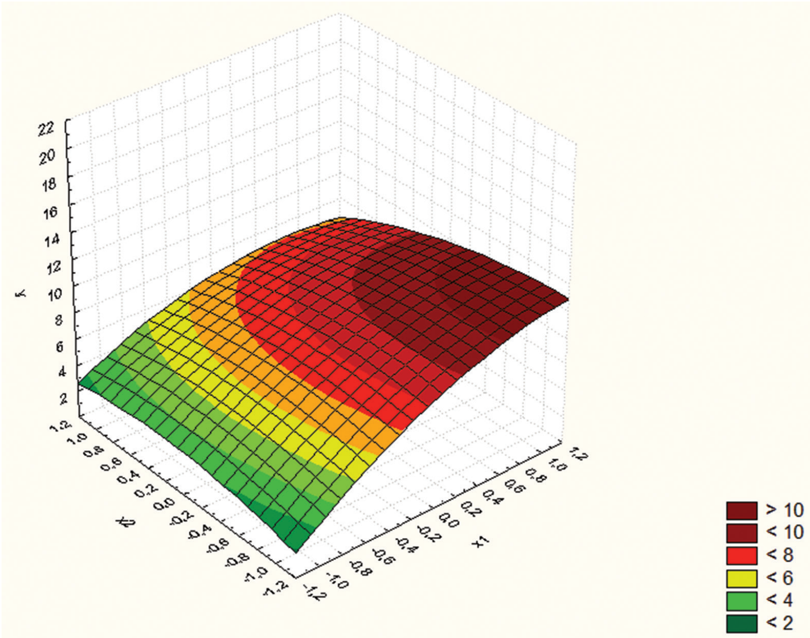

Fig. 2. Surface of response $Y = f(x_1x_2)$ for the productivity of chipping machine according to the diameter of materials (x_1) and their length (x_2).

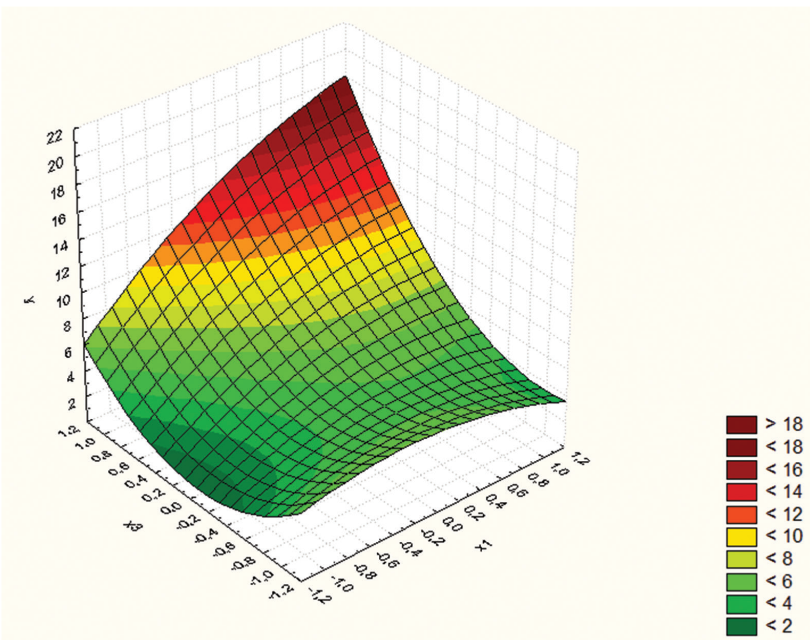

Fig. 3. Surface of response $Y = f(x_1x_3)$ for the productivity of chipping machine according to the diameter of materials (x_1) and the power (x_3).

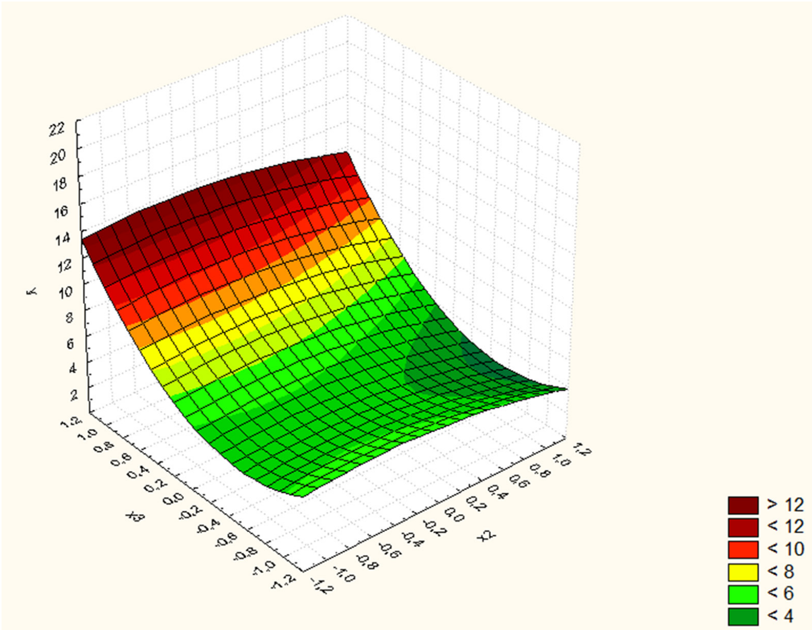

Fig. 4. Surface of response $Y = f(x_2x_3)$ for the productivity of chipping machine according to the length of materials (x_2) and the power (x_3).

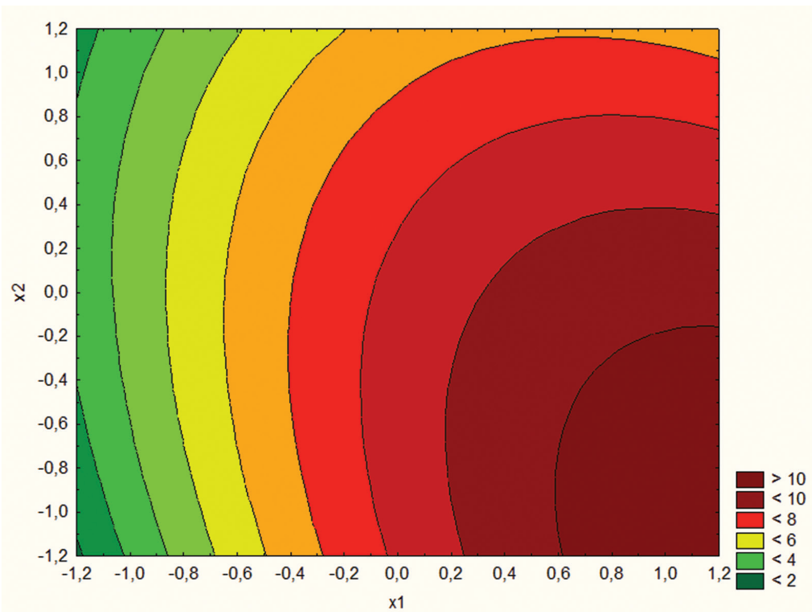

Fig. 5. Lines of equal response $f(x_1x_2) = Y = const$ for the productivity of chipping machines according to the diameter (x_1) and the length (x_2).

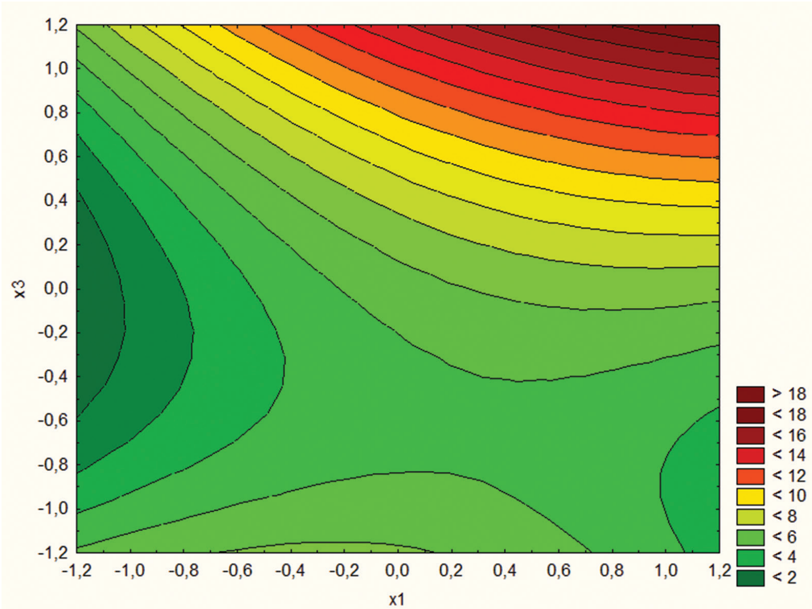

Fig. 6. Lines of equal response *f* (x_1x_3) = *Y* = *const* for the productivity of chipping machines according to the diameter of the materials (x_1) and the power (x_3).

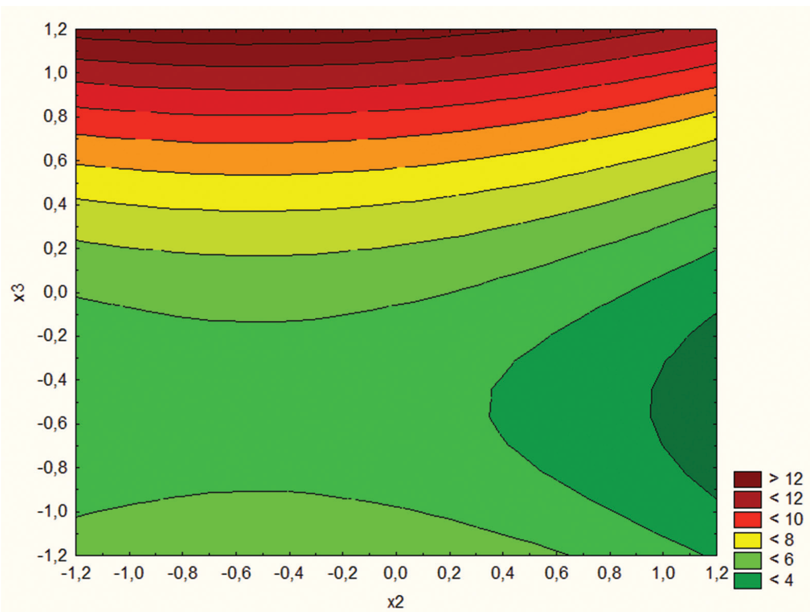

Fig. 7. Lines of equal response *f* (x_2x_3) = *Y* = *const* for the productivity of chipping machines according to the length of the materials (x_2) and the power (x_3).

In figures 2 and 5 it can be seen that surface of response and the lines of equal response have maximum when the diameter of materials is 12–14 cm (x_1 from 0.6 to 1.0) and the length is from 1 m to 2.8 m (x_2 from -1 to -0.1). For the chippers with power around 50 kW the productivity is 10–11 m^3/h when the materials that are chipped have diameter 13 cm and length 3 m. If the length of the materials is more than 3 m, the productivity starts to go down.

Figures 3 and 6 show that when the length of materials is 3 m, the surface of response and the lines of equal response for the productivity, have maximum when the diameter is between 12 and 14 cm (x_1 from 0.5 to 1.0) and the power of the machine is 70 kW (x_3 = 1.0). The biggest productivity at these parameters is 16–17 m^3/h.

The analysis of the data referring to the impact of the length of materials and the power of chipping machine (figures 4 and 7) indicates that the surface of response has a maximum at power 70 kW and 3 m length. In Figure 4 it can also be seen, that if the length of chipped materials is more than 3 m the productivity is lower.

It's interesting to see the influence of the length of materials when the power of the chipping machine is lowest – 21 kW. In Figure 7 it becomes clear that at diameter 10 cm diameter (the middle if the interval), the productivity is the highest at the length around 2 m, after that because of the overloading of the engine it goes down.

As a whole the impact of the length when 1 m long materials are chipped is weaker. This is due that the small in diameter and length materials have been fed in the chipping machine almost without any pauses.

In figures 8, 9 and 10 the impact of the

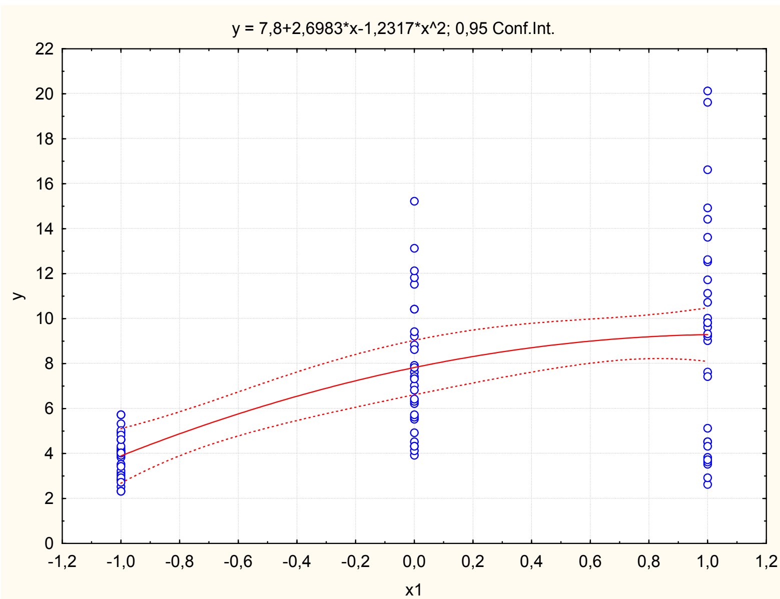

Fig. 8. Productivity of chipping machine according to the diameter of materials (x_2=0; x_3=0).

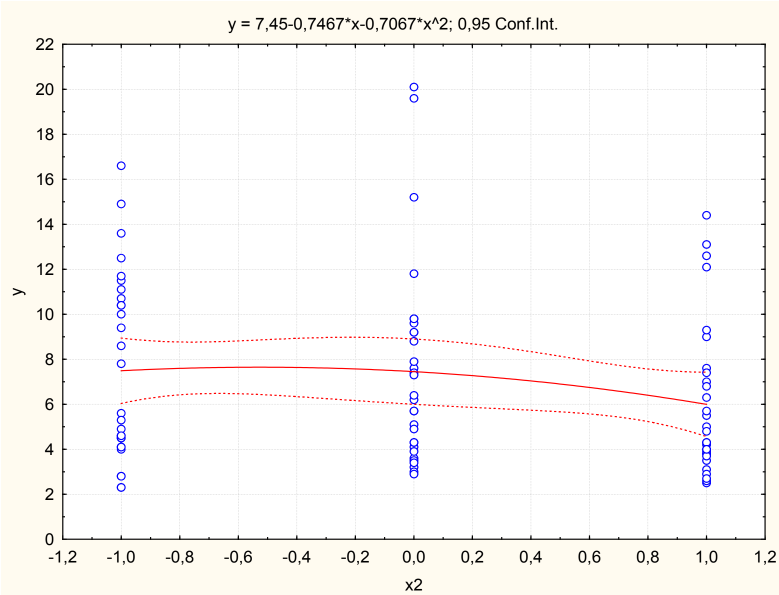

Fig. 9. Productivity of chipping machine according to the length of materials (x_1=0; x_3=0).

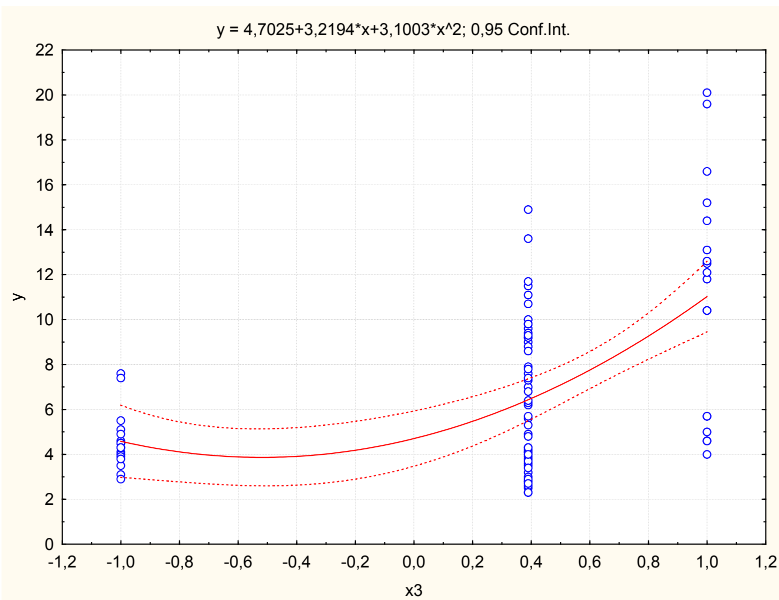

Fig. 10. Dependence between the productivity of chipping machine and its power (x_1=0; x_2=0).

separate factors on the productivity of the chipping machine is shown, confirming the conclusions made above.

In Figure 8 it can be seen that the degree of growth of the productivity is different. When the diameter grows from 6 cm to 10 cm (x_1 from -1.0 to 0.0) the productivity increases almost double – with 95 %. When the diameter of materials grows from 10 cm to 14 cm (x_1 from 0.0 to 1.0) the degree of increase is smaller – 18 %, because the loading of the engine grows. These results correspond to a power of the chipper in the middle of the interval – 45.5 kW. In the same figure it can be seen that for higher or lower machine power the level of curve line is higher or lower than the main curve, but the tendency is the same.

Conclusions

An investigation has carried out to establish how the diameter and the length of materials and the power of the chipper itself influence on the productivity during the chipping.

A multiple mathematical model has been created the influence of diameter and the length of wood materials and the power of the chipping machine on its productivity has been determined. The scots pine materials from thinning have been chipped. The impact of the power of the chipper on the productivity is most considerable, next is the impact of the diameter of the materials and lowest is the impact of length.

The maximum productivity has been achieved when the power of the chipping machine is highest and the diameter of the materials is largest at the length 3 m, which could be expected.

The impact of the length of wood materials on the output of chipper is quite interesting, because it is stronger when chipping is done by machines with lower power.

For instance when the power of the chipper is 21 kW, the best productivity during chipping of materials with diameter of 10 cm is achieved at the length 2 m. Over that length the productivity gets lower.

The result of the investigation shows, that the impact of the length of materials on the output of chipping machine, at power 50–70 kW, is better visible when the length is more than 3 m, because then it starts to go down. It is due to overloading of the engine.

It should be taken into consideration, that more power of the chippers means higher machine's price and high chipping costs. The result of this investigation put the question is it suitable to use chippers with high power engines for chipping of small sized wood from thinnings. The obvious answer is that the parameters of chipping machines and most of all their power, must correspond to the type and dimensions of chipped materials.

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References

Abdallah R., Auchet S., Méausoone P. 2011. Experimental study about the effects of disc chipper settings on the distribution of wood chip size. Biomass and bioenergy 35: 843–852.

Alakangas E. 2005. Properties of wood fuels used in Finland. Technical Research Centre of Finland. VTT Processes, Project report PRO2/P2030/05 (Project C5SU00800), Jyväskylä 2005. 104 p.

Brik M.I., Vasilyev B.A. 1975. Technological chips. Ed. Forest industry, Moscow. 207 p. (in Russian).

Crawley M. 2007. The R Book. Imperial College London at Silwood Park. UK. 942 p.

Di Fulvio F., Eriksson G., Bergström D. 2015. Effects of wood properties and chipping length on the operational efficiency of a 30 kW electric disc chipper. Croatian journal of forest engineering 36(1): 85–100.

Fetyaev A.N. 2016. Justification of the parameters and modes of operation of the feed device of chipping machine. PhD thesis. Saratov State Agrarian University, N.I. Vavilov, Saratov. 188 p. (in Russian).

Georgiev D. 1986. Possibilities for application of low-waste and waste-free technologies for thinnings in scots pine cultures. PhD thesis, Universuty of Forestry, Sofia. 175 p. (in Bulgarian).

Georgiev D. 2013. Small-sized wood of thinnings. Published house at University of Forestry, Sofia. 18 p. (in Bulgarian).

Glushkov S., Spinelli R., Markov I., Magagnotti N., Stoianov St., Chakarov V., Madjov Sv. 2015. Study of the process of industrial extraction of energy chips with a BIBER-70 cutting machine. Forest Science [Nauka za gorata] 2: 107–125 (in Bulgarian).

Hellström L. 2010. On the wood chipping process – A study on basic mechanisms in order to optimize chip properties for pulping. PhD thesis. Department of Natural Sciences, Engineering and Mathematics. Mid Sweden University, Sundsvall, Sweden. 36 p.

Jylhä P. 2011. Harvesting undelimbed Scots pine (*Pinus sylvestris* L.) from first thinnings for integrated production of kraft pulp and energy. PhD thesis, University of Helsinki. 73 p.

Kováč J., Krilek J., Mikleš M. 2011. Energy consumption of a chipper coupled to a universal wheel skidder in the process of chipping wood. Journal of Forest Science 57(1): 34–40.

Marinov K., Gochev Zh., Stoilov S. 2013. Technological opportunities survey of forest short rotation plantations in Bulgaria for energy biomass production. Part 1: Analysis of the production of energy from biomass in Bulgaria and perspectives for creating energy plantations from short rotation wood crops. Innovation in Woodworking Industry and Engineering Design 2(1): 148–160.

Nati C., Spinelli R. 2010. How blade wear of chippers can affect fuel consumption and wood chip size distribution. Forest Engineering: Meeting the Needs of the Society and the Environment. Padova, Italy: 1–7.

Peev D. 2017. Thinnings – problem and opportunities. Management and Sustainable Development 6(67): 68–78 (in Bulgarian).

Spinelli R., Magagnotti N., Hartsought R.B. 2005. Testing Mobile Chippers for Chip Size Distribution. International Jurnal of Forest Engineering 16(2): 29–35.

Spinelli R., Magagnotti N. 2012. The effect of raw material, cut length, and chip discharge on the performance of an industrial chipper. Forest Products Journal 62(7/8): 584–589.

Stoilov S., Marinov K., Gochev Zh. 2008. Biomass potential of Bulgarian forest-based sector for energy production. In: Proceedings of the 6th International Science Conference ‘Chip and chipless woodworking processes’, September 11–13, Štúrovo, Slovakia: 381–386.

Valshchikov N.M. 1970. Chipping machines. Machinebuilding, Leningrad. 328 p. (in Russian).

Yoshida M., Berg S., Sakurai R., Sakai H. 2016. Evaluation of chipping productivity with five different mobile chippers at different forest sites by a stochastic model. Croatian Journal of Forest Engineering 37(2): 309–318.