Selection of Materials for the Protection of the Hoe Blades of the Inter-Row Cultivator

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Selection of Materials for the Protection of the Hoe Blades of the Inter-Row Cultivator

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Abstract: The paper presents the results of comparative wearing of cultivator hoes protected with two different materials with regard to the lifespan of the blades. During the operation of the hoes outside the track of the tractor wheels with protected blades of materials M1 and M2, equal wear of mass and surface was recorded. The hoes lost an average of 0,563 g/ha cultivated area or an average of 119,46 g with a standard deviation of 2,876 when working with both blades in compacted soil (in the tracks of tractor wheels) protected by M1 material. For hoes protected by M2 material, the average loss was 0,566 g/ha of cultivated area or an average of 120,10 g for the research period with a standard deviation of 4,609. Both materials in the most difficult working conditions showed equal resistance to wear and retention of the initial shape of the hoe.

Keywords: cultivator; hard materials; hoe blades; wear protection

1 INTRODUCTION

Increasing and maintaining the trend of growth field production is possible only by consistent application of efficient existing technology or gradually introducting new ones. Continuous technological development requires the use of modern materials in agricultural engineering. It can almost certainly be argued that in the past few years there have been no significant changes in the technique and procedures of performing inter-row soil tillage. Inter-row cultivation with simultaneous fertilization of crops is very important, especially if it is done in a timely and quality manner. The quality of work is influenced by many factors, and one of the most important is the maintenance of the geometry of the blade and the shape of the hoe during the operation of interrow cultivation. During the exploitation of agricultural machinery, the working parts of soil tillage machines and tools are exposed to different types of wear depending on their geometry, tillage conditions and physico-chemical condition of the soil. The actual forms of wear, which occur under operating conditions, consist of two or more basic wear mechanisms, and they act simultaneously or in chronological order, depending on the type of tribosystem, relative movement and operating conditions [1]. The most dominant wear mechanism is abrasion, which occurs due to direct contact of the working surface of the hoe with soil particles due to sliding, impact and pressure of soil particles [2]. Authors [3] state that the abrasive in the process of wear is a group of soil particles, composed of substances of different properties. The main abrasion element in the soil is quartz, but there may be other modifications of silicon dioxide. Other abrasive elements are various metal oxides that are an integral part of the soil (oxides of calcium, iron, aluminum, etc.). Abrasive wear is one of the dominant and common processes of tribological wear. As for agricultural machinery, it is the direct cause of 75-80 % of their failure, says the Author [4], resulting in increased production costs, say Authors [5]. Many types of wear have been identified such as abrasive, erosive, adhesive, corrosive, oxidative and surface wear, etc. It is estimated that a total wear of 80-90 % of elements can be identified as abrasion and 8 % as fatigue wear material. Contribution of other types of wear is small according to Author [6]. The size and nature of impact on the working elements primarily depends on the properties of the materials from which the working elements are produced, the physicochemical properties of the soil and the technical characteristics of the construction of agricultural machinery. It was demonstrated that [7] among other factors, wear intensity geometry changes of the working elements depend on the moisture content in soil, [8] the granulometric composition of soil [9] or the soil tillage speed [10]. During the operation of agricultural aggregates, their working elements are unevenly worn off. The most dominant wear is recorded in the soil zone in the area of the tractor tire passage. It is in this part of the soil that the working elements are exposed to the highest loads, which corresponds to the highest wear [11-13]. The results of total wear and the results of wear intensity of the length, thickness and width of the hoe placed on the first beam of the cultivator indicate that they work in the most difficult conditions (due to compaction and impact of intact soil structure). In contrast, the intensity of wear of the hoe placed on the third and fourth beams is the lowest, which indicates the lowest load of these elements during operation. The topicality of problems related to wear and working durability in the soil are determined by the high variability of working conditions, with little and rare tendency to introduce new material and improved construction solutions, as well as incomplete knowledge of interactions between working elements and abrasive soils. The consequences of wear and tear can cause pollution of the production space (soil), and significantly reduce the economy of agricultural production and create organizational problems [14]. In addition to abrasion, adhesion, surface fatigue and tribocorrosion can occur in the wear process. Due to the importance of this problem, it should be emphasized that increasing the longevity of hoes for cultivation is one of the current problems of their further development. As a result of wear of hoes, i.e. reduction of construction width [7] discontinuity of tillage occurs by reducing the width of the cultivated strip and disappearance (elimination) of the overlapping area of hoes during cultivation in front and rear hoe sections of cultivators. As the edges of the blades wear out, so does their thickness, which reduces the ability to cut and maintain the uniformity of the working depth as well as increase the tensile strength, especially in compacted surfaces. This is especially important in the current conditions of production when a large number of small producers and suppliers of hoes appear on the market. A large number of hoe manufacturers almost do not shape the blade to reduce the cost of production, and very rarely are hoes with a shaped blade and the possibility of direct installation on the inter-row cultivator without prior preparation. The failure of the cutting elements of agricultural machinery occurs due to the blunting of the blades (increasing their radius) to the limit values. The most effective method for increasing the wear resistance of agricultural machinery is to achieve the effect of self-sharpening of cutting elements [14]. The mechanical composition of the soil affects the stability of agricultural machinery and directly affects fuel consumption. Increasing the blade thickness from 0.2 mm to 0.3 mm or from 0.8 to 1.2 mm increases the tensile strength of the cultivator from 7 to 14%. While increasing the blade thickness to 2 mm increases the tensile strength of the cultivator by 34% [15, 16]. Research on this topic [7] has mainly focused on some selected aspects of the phenomenon that occurs in the system "working element - soil". For example, many research studies have considered the influence of soil conditions and tillage parameters on the wear of soil-working elements [10, 17-19]. To combat the wear problem [20, 21], authors state that surfacing is the most versatile process among many alternatives to improve the life of worn components and reduce replacement costs. Induction cladding procedures [22] and various thermal spraying procedures [23] are also used as procedures for protection of parts of agricultural machinery from wear. Improving the blade reduces downtime because parts last longer and reduces the downtime required to replace them. Field tests are necessary to determine wear in the agricultural sector due to difficulties in laboratory simulation of load changes that occur during soil work. Authors [24], states that hard coating is one of the most useful and economical ways to improve the performance of components exposed to severe wear conditions. Furthermore, the same author states that the welding process using the electrodes DIN 8555 E-10-UM-60R and DIN 8555 E6-UM-60 significantly increased the wear resistance. Authors [25] state and confirm with their research that significantly less wear of samples is subjected to hardening and boronization compared to steel in the normalized state, which proves the justification of these treatments as protection against wear of parts of agricultural machinery. The obtained research results are confirmed by [26] with the hypothesis of a positive effect of strengthening (pointed) cultivator hoes with wear-resistant coating. In the process of work, the protected blades of hoes "in segments" get an oblong shape, and the wear of their blade wings is reduced by 32%, and the front part by 70%. In this procedure, the author states that a reduction in material weight consumption by 23% was found. The durability of the cultivator blade can be increased by adding alloying components to the chemical composition of the reinforcement material to form structures that reduce wear processes [27, 28]. Authors [29] also state that the welding process prolongs the life of hoes compared to unwelded hoes. They also state that in their examination, the T-590 electrode was used, which achieved three times less mass wear of the hoe blade. The wear rate also changed accordingly from 0.51 g/ha for hoes welded with T-590 compared to 2.24 g/ha for standard unwelded hoes of the control group. Authors [30] found that the rate of wear in the laboratory and in field trials differed statistically significantly. When the cost is taken into account, it has been claimed in their research that the EH-600 and EH-350 are acceptable for the protection of hoe blades. The task is to determine the intensity of material wear and preservation of the geometric shape of the hoe blade during the operation of the inter-row cultivator, with regard to the cost of production and the achieved effect.

The aim of the study is to gain knowledge about the justification of the use of different materials and processes for the protection of the inter-row cultivators hoes.

2 MATERIALS AND METHODS

The wear testing of material of new cultivator hoes made of sheet steel, shown in Fig. 1, was carried out according to the methodology developed in the Department of Agricultural Engineering and Renewable Energy Sources at the Faculty of Agrobiotechnical Sciences Osijek.

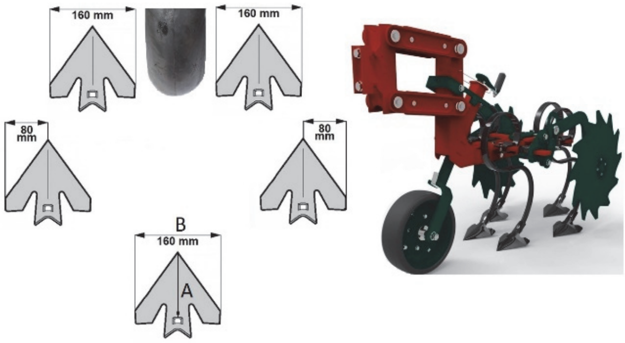

Figure 1 Cultivator hoes and the theoretical side of wear in the cultivator section

The chemical composition and mechanical properties of materials used to make cultivator hoes are shown in Tab. 1.

Table 1 Chemical composition and mechanical properties of materials used to make hoes [14, 31]

Sample mark	Basic material (BM)	Material M1 used for metallization	Material M2 used for TIG process
Qualitative chemical composition / %			
C	0,45	3,30	< 5,00
Si	0,40	1,49	< 2,00
Mn	1,50	0,43	0,50-2,00
P	0,04	-	< 0,03
S	0,04	-	< 0,003
Cr	–	24,32	20,00-25,00
Co	–	3,20	–
Tensile strength σ_M / N/mm^2	1200 – 1400	1710	
Yield strength $\sigma_{0,2}$ / N/mm^2	1050	1400	
Powder melting point / ºC	–	900-1050	-
Elongation / %	7	6	
Sample hardness	230 / HB	62 / HRC	60-68 / HRC

The basic material for making cultivator hoes is steel sheet with a thickness of δ = 4 mm, which is formed in the pressing tools for pressing (shaping) with pre-heating. Thereby, efforts were made to maintain the previous hardness and wear resistance. According to [4], with this process the material hardens and becomes highly resistant to wear and corrosion. A slot 10 mm wide and 1.5 mm deep is milled on the upper surface of each hoe. In the milled slots wear-resistant hard layers are applied by processes of induction cladding (M1) and TIG (Tungsten Inert Gas) welding (M2). With such processes < 2 mm thick layer was achieved. Induction-cladded (M1) hoes are marked with numbers 1 to 11, and TIG-welded hoes (M2) with numbers 12 to 21, and they are arranged according to Fig. 2.

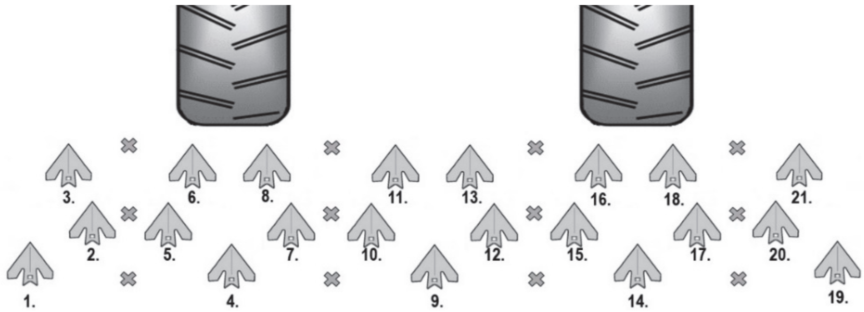

Figure 2 Marking and position of the tested hoes on the Rau cultivator in regards to the tractor wheels

The hoes are mounted on a standard S-tine bracket 25 mm wide and height to frame 300 mm. The vibrating action of S-tines create soil disturbance that mixes the top layer well, making it a great tool for eliminating weeds and incorporating soil amendments. The coiled spring alleviates shock when encountering obstacles and helps to extend the life of the hoe coulters. During the research the following indicators were measured:

- mass of the hoe before field work,
- mass of the hoe after field work,
- linear dimensions of the hoe before starting work in the field (distance from the sock to the mounting hole A and width of the hoe B),
- linear dimensions of the hoe after completion of field work (distance from the sock to the mounting hole A and width of the hoe B).

Cultivator hoes are set to handle a row spacing of 60 cm. As the inter-row cultivator has protective plates, it is able to leave a protective belt of 5 cm to the corn plant on both sides. From Fig. 1 it can be seen that the complete cultivator section works with a total blade length of 108 cm. The central rear hoe cultivates a strip width of 12 cm (75 %) to overlap with the hoes in the first row, i.e. it uses (both sides) a total of 24 cm blade length.

2.1 Soil Moisture

Average moisture values and some physical soil properties were determined in the Central Laboratory for Agroecology and Environmental Protection, Faculty of Agrobiotechnical Sciences, Osijek and are listed in Tab. 2.

With the standard technology of sowing corn (row spacing 0,70 m) with a four-row seeder, we trampled with a tractor tire 71 interspaces or 35,50 % of the ha-1 area or 3550 m^2. The same area is trampled in the case of inter-row cultivation with a four-row cultivator, and 14 inter-spaces or 700 m^2 (7% of the area ha) when spraying corn with a sprayer of 15 m in one treatment. Measure of resistance to soil penetration was determined by soil penetrometer Manufacturer Eijkelkamp Soil & Water (Force resolution 1 N) with cone type 2,0 cm^2. Penetration speed was 2 cm/s. Measurements were performed throughout the test on the working surfaces of the inter-row cultivator. The obtained maximum and minimum values measured outside the tractor wheel track and on the tractor wheel track are shown in Fig. 3. From Fig. 3 it can be seen that significantly higher soil compactions were observed behind the tractor wheels compared to the row spacing outside the tractor wheel track.

Table 2 Average moisture values (%, three terms of measuring, mean of 30 samples in each term) in the cultivate layer during the investigation and some physical soil properties*

Elements	Average soil moisture values / %	Content of water in the soil under, vol %		
	soil depth / cm	FWC	LCW	WP
	0-10	0,033 MPa	0,625 MPa	1,520 MPa
The lowest	20,4	36,72	17,94	15,42
The highest	24,5	39,42	19,25	17,26
Average	22,6	38,85	18,35	16,50

Some physical soil properties

	Soil texture (%)			Bulk Density / g/cm^3	Total Porosity Volume / %	Specific Gravity / g/cm^3
Soil Depth / cm	Sand 2-0,05 / mm	Silt 0.05-0,002 / mm	Clay < 0,002 / mm			
0-10	7	61	32	1,50	48	2,78

*FWC= field water capacity, WP = wilting point, LCW = lentocapilar water content

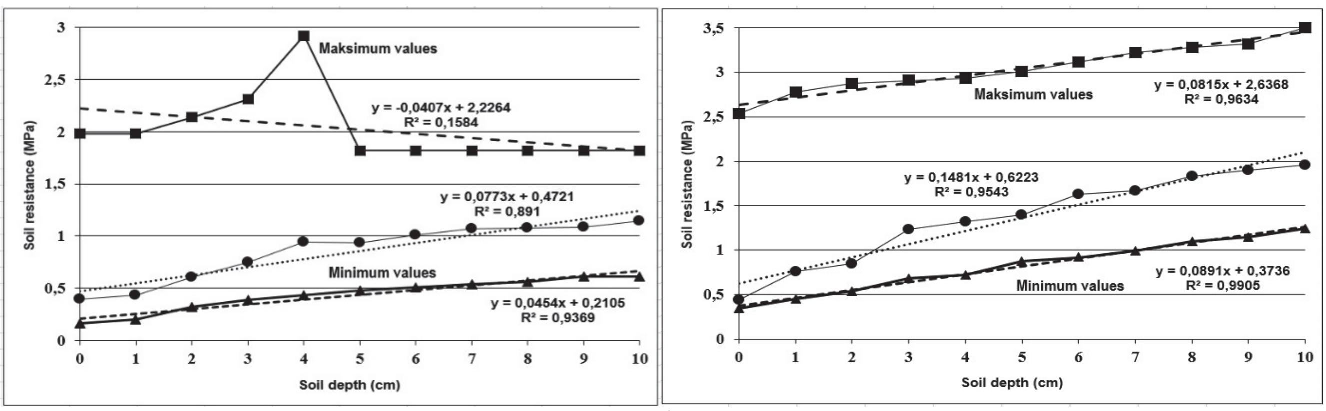

Figure 3 Maximum and minimum values of soil compaction at the investigation time

3 RESULTS AND DISCUSSION

Results of measuring the depth and speed of work and the effect of the tested interrow cultivator are shown in Tab. 3. During the test, the minimum operating speed v_{min} of 2,0 km/h and the maximum v_{max} of 6,30 km/h was recorded. The average v_x of 4,40 km/h for the entire research period was recorded with a CV of 28,95 %. The depth of work was within the allowed limits, with the lowest of a_{min} = 2,20 cm and maximum a_{max} = 5,30 cm.

The average working depth for the test period was a_x = 4,10 cm with a CV of 24,15 %. In the research period from 23rd May to 20th June 2021, the tested four-row cultivator cultivated a total corn area of 212 ha, whereby (35,5 passes of 100 m per ha) crossed a road length of 752,6 km. The total effect per cultivator section was 53 ha.

Table 3 The parameters of wear of cultivator hoes

Protected material - M1					Protected material - M2				
Mark	Hoe weight / g			Loss / %	Mark	Hoe weight / g			Loss / %
	Before the test	After the test	Loss / g			Before the test	After the test	Loss / g	
Central hoes - worked with both blades off the track of the tractor wheels									
Nr. 1.	342,89	260,26	82,63	24,098	Nr. 13.	349,23	262,89	86,34	24,723
Nr. 3.	346,78	251,57	95,21	27,455	Nr. 19.	351,48	252,84	98,64	28,064
Nr. 9.	348,56	265,44	83,12	23,846	Nr. 21.	350,46	261,01	89,45	25,523
Nr. 11.	347,97	259,52	88,45	25,418	-	-	-	-	-
Central hoes - worked with both blades in the track of the tractor wheels									
Nr. 4.	345,24	228,53	116,71	33,805	Nr. 14.	349,86	230,1	119,76	34,230
Nr. 6.	348,29	225,84	122,45	35,157	Nr. 16.	352,56	236,89	115,67	32,808
Nr. 8.	347,29	228,05	119,24	34,334	Nr. 18.	351,45	226,58	124,87	35,529
Hoes - worked with the left side of the blade out of the wheel track									
Nr. 10.	348,89	296,32	52,57	15,067	Nr. 20.	352,34	297,36	54,98	15,604
Hoes - worked with the left side of the blade in the wheel track									
Nr. 5.	349,79	281,97	67,82	19,388	Nr. 15.	352,91	279,38	73,53	20,835
Hoes - worked with the right side of the blade outside the wheel track									
Nr. 2.	348,38	296,74	51,64	14,822	Nr. 12.	349,67	293,18	56,49	16,155
Hoes - worked with the right side of the blade in the wheel track									
Nr. 7.	348,11	271,45	76,66	22,021	Nr. 17.	353,29	271,96	81,33	23,020

It can be seen from Tab. 3 that on hoes Nr. 1., 3., 9. and 11., protected with material M1, when working outside the tractor wheel track, the average mass loss of 87,35 g with a standard deviation σ = 5,864 and CV of 6,71 % was recorded. On hoes Nr. 4., 6. and 8. protected by the same material, when working in the track of the wheels, an average loss of 119,46 g was obtained with σ = 2,876 and a CV of 2,40 %. Similar results were obtained during the operation of hoes Nr. 13., 19. and 21. protected with material M2 when working outside the wheel track, i.e. the mean recorded weight loss was 91,47 g with σ = 6,395 and a CV of 6,99 %. On hoes Nr. 14., 16. and 18. protected with material M2, when working in the track of wheels, an average loss of 120,10 g with σ = 4,609 and a CV of 3,83 % was recorded. Hoes protected with material M1, when working off the wheel track, had an average mass loss of 0,412 g/ha of treated area, while an average mass loss was 0,563 g/ha when working behind the tractor wheels. In the case of hoes protected by material M2, when working outside the wheel track, a mass loss of 0,431 g/ha was recorded, and when working in the wheel track the mass loss was 0,566 g/ha of the treated area.

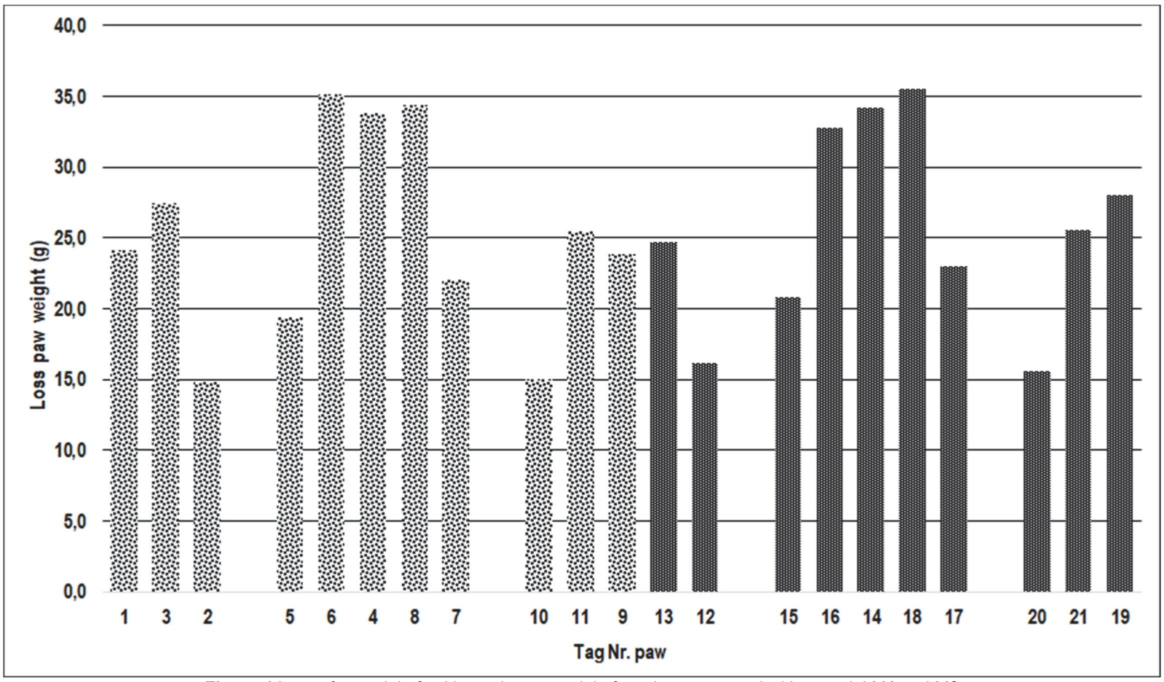

Figure 4 Loss of material of cultivator hoe material of sections protected with material M1 and M2

Table 4 Research results linear characteristics of lancet hoes

Hoecipher	Group	Size dimension "A" / mm					Size dimension "B" / mm				
		Before the test	After the test	Wear / mm	Average wear / mm	σ	Before the test	After the test	Wear / mm	Average wear / mm	σ
Central hoes - worked with both blades off the track of the tractor wheels											
Nr. 1.	Protected material - M1	117,10	88,90	28,19	27,05	1,977	160,23	127,67	32,56	31,45	2,608
Nr. 3.		115,47	91,06	25,16			159,89	125,33	34,56		
Nr. 9.		116,34	87,08	29,25			161,90	132,01	29,89		
Nr.11.		116,32	90,68	25,63			160,45	131,66	28,79		
Nr.13.	Protected material - M2	116,32	88,81	27,50	26,12	2,361	160,43	127,31	33,12	30,90	1,945
Nr.19.		116,23	88,74	27,48			161,11	131,00	30,11		
Nr.21.		117,56	94,15	23,40			160,12	130,64	29,48		
Central hoes - worked with both blades in the track of the tractor wheels											
Nr. 4.	Protected material - M1	115,86	83,11	32,74	35,93	3,14	159,88	120,63	39,25	39,72	2,434
Nr. 6.		117,10	78,06	39,03			160,12	117,76	42,36		
Nr. 8.		116,20	80,17	36,02			158,88	121,32	37,56		
Nr.14.	Protected material - M2	115,70	82,38	33,31	34,88	4,163	159,89	120,95	38,94	37,85	2,491
Nr.16.		116,10	84,38	31,73			160,11	120,50	39,61		
Nr.18.		116,22	76,47	39,60			160,09	125,09	35,00		

From Tab. 4 it is possible to analyse the length and width of the double-sided hoe before and after work as an indicator of surface reduction. The average reduction in length "A" for hoes No. 1, 3, 9 and 11, protected with material M1, when working outside the tractor wheel track was 27,05 mm with σ = 1,977, the average reduction in width "B" was 31,45 mm with σ = 2,608. In the case of hoes marked Nos. 4, 6 and 8 protected by the same material when working in the wheel track, there was an increase in the average decrease in length "A" of 35,93 mm with σ = 3,13 and average width of 39,72 mm with σ = 2,434. Slightly less average decrease in length was recorded for hoes marked 13, 19. and 21. protected with material M2 and when working outside the wheel track of 26,12 mm with σ = 2,361, and an average width of 30,90 mm with σ = 1,945. However, in the case of hoes, marks no. 14, 16. and 18. when working in the track of wheels with protection with material M2, an average loss of length of 34,88 mm was recorded with σ = 4,163, and width of 37,85 with σ = 2,491.

Based on the obtained results (shown in Tab. 4), linear regression models with relatively high coefficients of determination (R^2) were developed, shown in Figs. 5 and 6.

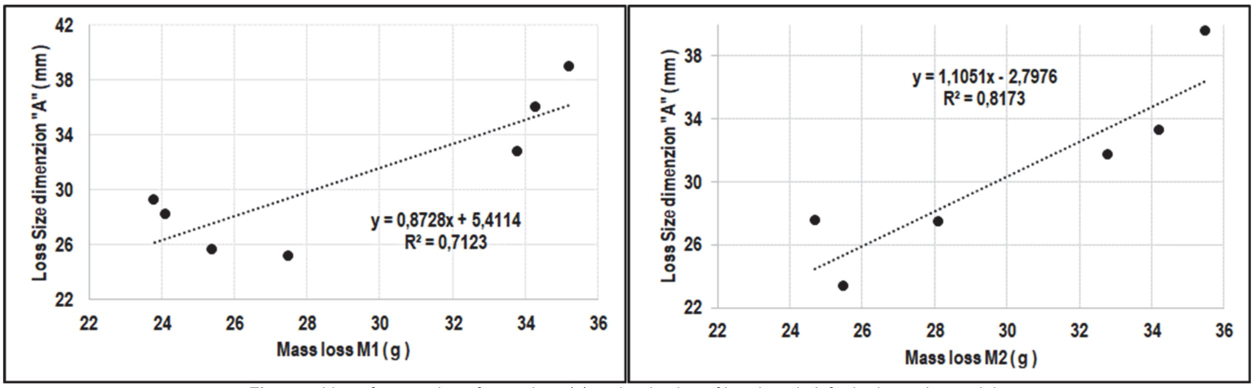

Figure 5 Line of regression of mass loss (g) and reduction of hoe length A for both used materials

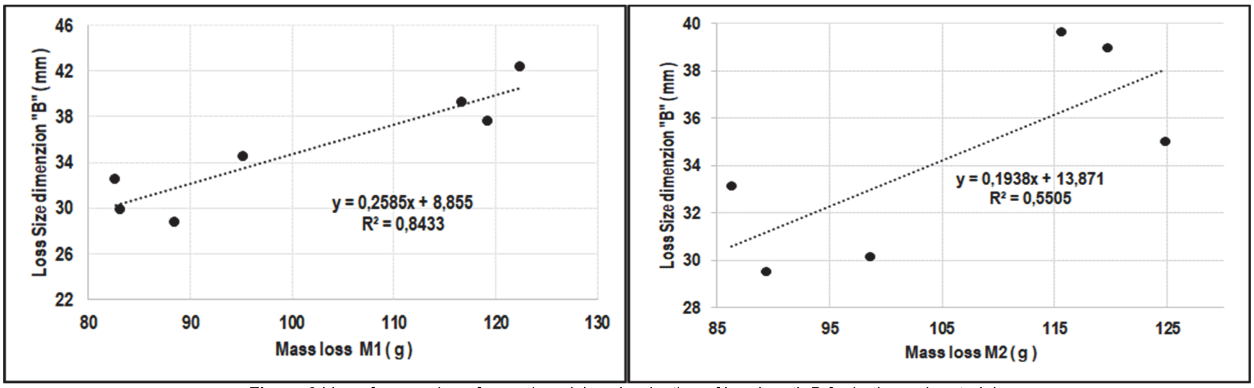

Figure 6 Line of regression of mass loss (g) and reduction of hoe length B for both used materials

4 CONCLUSION

The wear testing of cultivator hoes protected with hard materials M1 and M2 was performed during 29 working days in May and June 2021. The test was performed on soils of average compaction with an average moisture content of 22,6 % and at an average speed of the unit (tractor + cultivator) for the entire research period of 4.40

km/h with a CV of 28,95 %. The average working depth was within the allowed limits and was recorded for the test period of a_x = 4,10 cm with a CV of 24,15 %. Equal wear was recorded when working the hoe off the track of the tractor wheels with protected blades material M1 and M2. When protecting with material M1, an average mass loss of 87,35 g with a standard deviation of 5,864 and when using material M2 an average mass loss of 91,47 g with a standard deviation of 6,395 were recorded. Hoes protected with material M1, when working with both blades in compacted soil (following the tractor wheels), had average mass loss of 119,46 g with a standard deviation of 2,876 and a CV of 2,40 %, and for hoes protected with material M2 the average mass loss was 120,10 g with a standard deviation of 4,609 and a CV of 3,83 %. If the mass loss is observed with regard to the total performance of the cultivator, it can be concluded that the hoes protected by material M1 had an average mass loss of 0,412 g/ha of treated area when working off the wheel track, while the average loss of mass when working behind the tractor wheels was 0,563 g/ha of treated areas. In the case of hoes protected with material M2, the average recorded mass loss was 0,431 g/ha and in the wheel track 0,566 g/ha of treated area. Analysis of the hoes dimensions after work shows that hoes with both protecting materials, when working in the compacted part of the plot decreased the average length and width. For the hoes with material M1 this average reduction of length A was 35,93 mm and reduction of width B 39,72 mm. For the hoes with material M2 reduction of length A was 34,88 mm and reduction of width B was 37,85 mm. As can be seen from the presented results, the hoes protected with both materials (M1 and M2) had a greater loss of mass in the area behind the tractor wheels, which is a consequence of greater soil compaction and thus greater friction between the hoes and the soil. Based on the obtained results, it was concluded that both materials showed equal wear resistance in the most difficult working conditions, but it is recommended the use of material M2 to protect the hoe blades of the inter-row cultivator due to its slightly lower purchase price.

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