agricultural engineering.eu 81(3), 2026, 205–219
DOI:10.15150/ae.2026.3367

agricultural engineering.eu

Factors influencing the wear of standard cultivator shares under practical operating conditions

Moritz Gombert, Susanne Demba, Kai Potthoff, Wilko Flügge, Sandra Rose

Abrasive wear is the main process involved in the wear of agricultural tillage tools. The aim of the study was to determine whether thermal coating increases wear resistance. In preliminary tests, different coatings were tested by an ASTM G65 constant load abrasion test. The shares were thermally coated using Iron based arc spraying. The elements were mounted on the cultivator and analyzed in field tests against uncoated elements. Mass loss in g/ha and length change in mm/ha were used to determine abrasive wear. No significant influence of different coatings on wear could be found. The wear of uncoated shares was the same as the thermally coated shares. In some cases, the thermally coated shares were even more worn. This may indicate an early failure of the coating. One possible cause could be poor adhesion between the alloy and the tool material. Therefore, a correct coating of tillage tools is important to improve their wear resistance.

Keywords
abrasive wear, thermally sprayed, coatings, arc spraying, wear resistance

Mechanical soil cultivation in agriculture involves very high energy consumption and a high use of resources (Denisenko et al. 2025). In this context, tool life is considered one of the most important criteria in terms of material quality and cost-effectiveness (Listauskas et al. 2024). High wear rates lead to material losses, recurring labor costs, increased fuel consumption, downtime, energy losses, and replacement costs for worn parts (Malvajerdi 2023). Essentially, the costs incurred by the farmer depend on the tool life of the cultivator shares and the price of the share tips. For example, carbide or plasma-powder-coated shares, which are more expensive than standard shares, must offer a tool life that is 2.5 to 4.9 times longer for the price to be economically viable for the farmer (Handler et al. 2015). In addition to the tool life of the shares, however, the installation time required to replace worn shares should not be overlooked. Replacing a complete set of shares can take up 1.5 hours of labor (Renfert-Deitermann 2018). Furthermore, studies show that shares with a shorter tool life require more frequent replacement, thereby significantly increasing costs. The Natural Research Council of Canada reports total annual costs of $940 million caused by wear and tear alone (Jacob et al. 2017). Farmers in Australia spend more than $40 million annually on replacing duckfoot sweeps (Jacob et al. 2017, Malvajerdi 2023). Furthermore, working depth and quality changes as wear increases over time. For example, worn share tips increase the required draft force and thus also fuel consumption (Tulaganova et al. 2022). Therefore, it is very important to explore various wear protection mechanisms that can extend the tool life of materials and thereby reduce costs. Various manufacturing techniques have been developed to improve the wear resistance of tools. For example, heat treat-

received 6 March 2026 | accepted 25 August 2026 | published 23 September 2026

ment techniques, build-up welding, peening techniques, hard coating and thermal coating techniques (Aramide et al. 2021, Homberg and Rostek 2014, Lemecha et al. 2024, Malvajerdi 2023, Saygili et al. 2025). In principle, these techniques have great potential to increase the tool life of materials. However, the studies also reveal contradictory results. On the one hand, positive effects were achieved between untreated steel and treated steel (Singh et al. 2020). On the other hand, only minor progress was achieved (Nalbant and Palali 2011). To date, there is no clear evidence in the literature as to which treatment method in combination with which alloy achieves reliable results. Furthermore, it is unclear which combination also achieves economically viable results. The recording and quantification of all physical wear parameters that occur during tool-soil interactions represent a major challenge for the agricultural practice.

During soil cultivation, the tools of agricultural tillage equipment are exposed to high dynamic loads as they come into contact with the mineral substances in the soil (Homberg and Rostek 2014). The wear process is controlled by various environmental influences, such as the material composition of the steel, the mechanical and chemical composition of the soil, soil compaction, distance travelled, tool position, working depth and working speed (Owsiak 1997). One of the most common challenges is material wear of the tools. This process is described in the literature as abrasive wear. There are several types of abrasive wear. The process that applies to soil cultivation is referred to as low-stress abrasion. This is a dry, unlubricated contact between the soil and the tillage tools (Yu and Bhole 1990). Hard soil particles impact the softer surface of the material along the direction of movement. This vertical contact movement causes small scale furrows, smaller scale cutting or cracks to scale in the material. This leads to the material fracturing and being worn away (Aramide et al. 2021). Researchers report that conventional materials are mostly made of simple low alloy steels or mild steel and therefore have low wear resistance (Aramide et al. 2021, Homberg and Rostek 2014, Sidorov et al. 2021, Yu and Bhole 1990).

Various wear protection systems have become established in agricultural soil cultivation, which are essentially based on a combination of suitable material selection, heat treatment, structural design and additional surface protection layers (Wang et al. 2023). The aim is to increase the service life of the tools under abrasive soil conditions without unduly impairing the breaking or bending strength of the base body. The basis of many tool systems is the use of highly wear-resistant steels, in particular boron-alloyed and tempered steels. These materials are designed to combine high abrasive wear resistance with sufficient toughness. The hardness is often adjusted by means of suitable heat treatment so that the base body ensures the necessary load-bearing behavior, while the edge areas are protected against abrasion from soil particles, for example by induction or flame hardening on cutting edges (Yazici 2021).

Another established principle is constructive wear protection. Here, wear is concentrated on specific components that can be replaced easily and cost-effectively, e.g. using quick-change mechanisms. Typical examples are replaceable or reversible shares and tips. Reversible designs also allow the same component to be used multiple times before replacement is necessary. The base body of the tool (e.g. tine carrier, share holder) is thus decoupled from areas of direct wear and protected in the long term (Yazici 2021).

Hard surfacing is often used to further increase service life. This involves applying hard-faced weld layers (e.g. chrome or carbide-containing systems) to areas subject to particular stress, such as front edges, undersides or the noses of chisels and shares. These layers are significantly harder than the base material and delay material wear. The design of the weld overlay (number of layers, geometry, alloy) is tailored to the specific soil conditions, such as sand content or stone content (Malvajerdi 2023).

An alternative to this is thermal spraying, in which powder or wire-shaped filler materials are applied to the tool surface using a plasma jet or electric arc in order to increase resistance to erosion, cavitation and corrosion. This application will be the focus of the following considerations (Möhrke et al. 2024).

For highly demanding and intensive applications, the use of hard metals, typically tungsten carbide, has also become established. These are soldered or welded on in the form of plates. This type of coating enables very long service life under extremely abrasive conditions, but is more cost-intensive and requires a suitable design of the joint zone to avoid brittle fractures (Malvajerdi 2023).

The selection of these systems for practical use is generally based on the type of equipment, the intensity of use and the type of soil. In order to achieve an optimized balance between service life, costs and operational safety, different combinations are often used.

Natural soil systems are complex systems as they are typically highly heterogeneous and variable over time (Wanzek et al. 2018). Therefore, the wear mechanisms at work within them are subject to pronounced fluctuations in terms of moisture content, porosity, particle size distribution, grain shape, organic content, mineralogy, and the density and distribution of larger solids (e.g. stones or gravel). In addition, combined forms of stress often occur in real-world applications, such as the superimposition of sliding, rolling and impact stresses under changing mechanical and hydraulic boundary conditions. In particular, shock and impact stresses caused by larger particles can only be approximated in standardized test procedures.

Laboratory tests are the central methodological starting point for the quantitative evaluation of wear processes. They enable the targeted generation of tribological stresses under strictly controlled and reproducible boundary conditions and thus form the basis for systematic material and process characterization. Standardized or partially standardized test benches are generally used for this purpose, which allow for defined variation of key influencing factors such as normal force, sliding or rolling distance, relative speed, grain size distribution, and type and feed rate of the abrasive. This experimental control allows wear phenomena to be considered in isolation and complex chains of influence to be broken down step by step (Bührke et al. 2018).

The resulting key scientific challenge is to combine the high precision and comparability of standardized laboratory tests with sufficient realism. While laboratory tests generate highly reproducible parameters, their significance for specific operational applications is only directly transferable to a limited extent. Field measurement trips, on the other hand, have the advantage that the actual operating conditions are recorded directly. Energy requirements, process forces and the formation of characteristic wear patterns can be recorded under realistic conditions using measurement technology. The data generated in this way is highly relevant in practice, as it reflects the actual stress on the tools and the superimposition of various wear mechanisms in real-world use. These include the combined effect of abrasive and adhesive wear mechanisms, the interactions between soil moisture and tool material, and the dynamically varying loads resulting from different working depths and driving speeds (Bührke et al. 2018). However, these strengths are associated with considerable methodological limitations. Field trials are usually costly, time-consuming and only reproducible to a limited extent (Swanson et al. 1993). Even slight variations in soil conditions, climatic influences or different farming practices can significantly alter the measurement results and limit their comparability. In addition, conducting extensive test series under practical conditions is organizationally demanding, so that only a limited number of application scenarios can be systematically recorded (Mamkagh 2019).

Therefore, a targeted combination of laboratory and field tests should enable practical wear testing under realistic conditions. Since there are no known reliable, direct correlations between the two approaches, a combination of both methods is required. For example, a laboratory test can be used to preselect potentially suitable coating systems, while the actual validation takes place in the field (Wang et al. 2023).

The aim of the study is to investigate whether and which thermal coating can reduce wear on soil cultivation tools. Thereby, it is hypothesized that thermal coating generally reduces the wear on soil cultivation tools.

Material and methods

Laboratory tests

A widely used reference method for characterizing dry abrasive wear is the 'dry sand/rubber wheel' method described in ASTM G65 (ASTM International 2021). In this method, a flat sample surface is pressed against a rotating rubber wheel with a defined normal force. The load intensity can be adapted to various applications, for example to simulate abrasion loads ranging from low to high intensity. The purpose of the preliminary test was to investigate the most wear resistant combination of cultivator share, coating technique and chemical composition of the alloy. Two different coating techniques were tested and then compared with each other. One was atmospheric plasma spraying (APS), consisting of an APS coating based on iron molybdenum and aluminum (FeMoAl). The other was arc spraying (LBS), consisting of an LBS coating based on iron (Fe).

First, the surfaces of some sample pieces were blasted with a corundum blasting agent (F24). These were then thermally coated. Tests based on the ASTM G65 standard have shown that the LBS layer has the highest wear resistance compared to the APS layer. Compared to the average mass loss on an uncoated test piece, the mass loss on an APS sample was approximately 30% lower. Using LBS, the mass loss was even reduced by 60% (Table A1 in the Appendix). For this reason, the individual share tips for the following field tests were thermally sprayed with the Fe-based LBS coating. The coating height on the share tips was around 12.5 centimeters. Arc spraying was carried out in accordance with DIN EN ISO 12670.

Due to the clearly defined test parameters, the method offers a high degree of reproducibility and is widely used internationally, making material properties from different studies comparable. At the same time, it should be noted that ASTM G65 ideally represents dry three-body abrasion under defined contact geometry. Complex real-world stresses, in particular changing moisture contents, combined impact, sliding and rolling loads, and heterogeneous soil mixtures, are therefore only partially covered. However, in combination with other application-specific test methods, ASTM G65 can serve as a standardized reference for classifying the abrasion resistance of materials and quantifying relative performance differences under well-defined conditions.

Field experiments

The cultivator used in the field experiments is a widely applied implement in agricultural practice for efficient and high-capacity soil tillage in arable farming. The machine has a working width of 4 m and is designed as a four-bar frame construction, which ensures good soil flow through the structure and a reduced tendency to clogging. In total, 15 tines are mounted, resulting in an average tine spacing of approximately 270 mm (Figure 1). The tines are mounted in a straight configuration on the frame, while their lower section is bent. This geometry results in an inclination angle of about 55° relative to the soil surface, which significantly influences soil penetration and loosening performance. Each tine is equipped with a so-called Topmix share including a deflector plate. This 80 mm wide share is designed as a universally applicable standard tool, allowing flexible use across different tillage systems. In the present experimental setup, the share was additionally combined with a winged share in order to achieve an enhanced lateral soil movement. The share geometry follows a three-stage functional principle consisting of a shallow entry zone at the front, a progressive curvature for controlled soil lifting, and a subsequent transition into a mixing or homogenisation zone. This design combines reduced draft requirements during soil entry with intensive horizontal soil displacement in the central working section and a controlled rearward soil flow in the trailing area. The comparatively large curvature radius in the front section of the share results in a soil entry angle of approximately 30°, thereby enabling a smooth force transfer into the soil and a stable material flow along the share geometry.

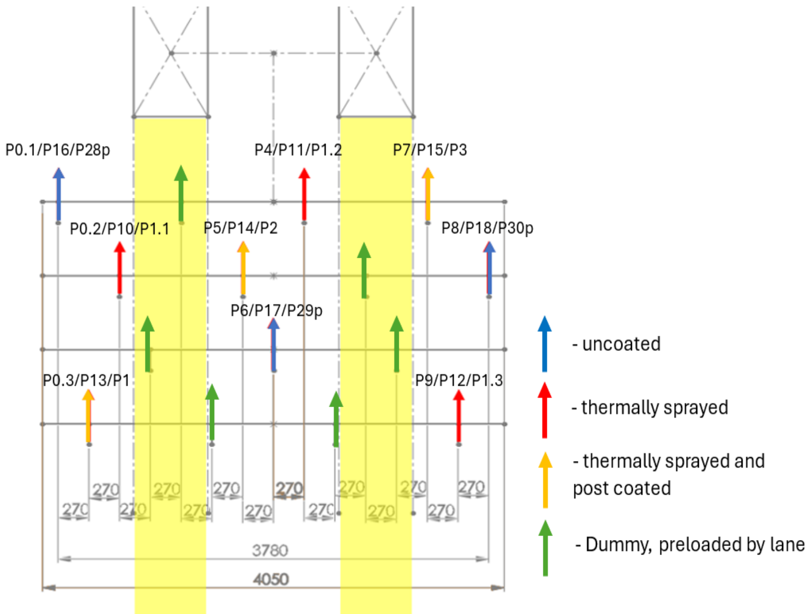

Figure 1: Arrangement of the cultivator shares – the shares were arranged so that each row of shares contained one uncoated share (blue), one thermally sprayed share (red) and one thermally coated and post coated share (yellow); the yellow boxes represent the track in which the dummys ran (green)

For the field tests described here, a standard scenario was chosen in which all influencing factors were as similar as possible. This ensured that the cultivator shares with their different coating variants could be compared. The thermally sprayed shares were mounted on the towed 4-bar cultivator

'Köckerling Quadro 400'. Three different locations were then cultivated on with three different assemblies (Table 1).

Table 1: All coatings for all individual shares (P) sorted by assemblies used in this investigation with OEM = Original Equipment Manufacturer and IAM = Independent Aftermarket

	Assemblies		
	1. Assembly OEM parts	**2. Assembly OEM parts**	**3. Assembly OEM and IAM parts**
Assemblies on 'Köckerling Quadro 400'	OEM pats uncoated **P0.1/P0.2/P0.3**	IAM parts uncoated **P16/P17/P18**	IAM parts uncoated **P28p/P29p/P30p**
	OEM parts thermally sprayed **P4/P5/P6**	IAM parts thermally sprayed **P10/P11/P12**	OEM parts one side coated **P1/P2/P3**
	OEM parts thermally sprayed + post coated **P7/P8/P9**	IAM parts thermally sprayed + post coated **P13/P14/P15**	OEM parts one side coated + copper band coat **P1.1/P1.2/P1.3**

The shares were arranged in each assembly so that three different manufacturing techniques run side by side in each row (Figure 1).

All locations were cultivated at a working speed of 10 km/h and a working depth of 15 cm. The working depth was set on the cultivator beforehand and then checked using a folding rule. The field trial was carried out using a John Deere 7230R with 650 mm wide tires (Figure 1). This is equipped with a John Deere DGPS system. The DGPS ensured that track overlaps were limited to just a few centimeters. The tractor drove in a straight lane, track by track. Thef working speed was set via the drive lever. This enabled the tractor to maintain a constant speed. The average speed values were displayed on the tractor terminal.

According to the farmers determination, the soil type for the first and second assemblies was sandy clay loam (sL). The soil type for the third assembly was a mixture of sandy clay loam and clay loam sand (sL and Ls) (Sponagel 2005). The field trials were conducted on July 20, 2023, and the following days. The previous crop was barley, which had been harvested about a week earlier. This was followed by the first stubble cultivation using a Köckerling Quadro 400 cultivator at a working depth of approximately 20 cm on the harvested field. Conditions were very dry during the trials. However, the moisture content was not measured. The straw was baled and removed. It was worked in A-B lines. The headland was omitted.

The first assembly cultivated a total area of 55 hectares. The manufacturing techniques were untreated (UT), thermally sprayed (TS) and thermally sprayed and post treated (TS and PT). This assembly used OEM (Original Equipment Manufacturer) parts of cultivator shares. The second configuration cultivated a total area of 48 hectares. The manufacturing techniques were the same as with the first assembly. These were IAM (Independent Aftermarket) parts of cultivator shares. The third assembly cultivated a total area of 26.5 hectares. The manufacturing techniques were untreated (UT), coated on one side (COS), and coated on one side with copper bond coat (COS and CB). The copper bond coat is used as a wear indicator and should improve coating adhesion. OEM and IAM parts of shares were used for this purpose. Dummies ran in the lanes of the three assemblies. However, these were not considered in the evaluation.

Mass loss in g/ha (ML) and length change in mm/ha (LC) were defined as criteria for wear resistance in this study. The ML was determined by weighing the shares before they were mounted on the cultivator. The shares were then weighed again after the field trial had been completed. The difference between the two weighings gave the ML. The LC was calculated from the difference between unused shares before the field trial and the worn shares after the trial had been completed. The LC was measured using a folding rule.

Statistical analyses

Data were analyzed using the R 4.5.1 software package (The R Foundation for Statistical Computing, Vienna, Austria). The describedBy-function of the "psych" package version 2.6.3 (Revelle 2026) was used to calculate the descriptive statistics for ML and LC. As the tools should shorten in a similar ratio to the mass loss, Pearson's correlation coefficient (r) was additionally used to estimate the correlation between ML and LC. The data were tested for normal distribution using the Shapiro-Wilk test.

Generalized linear models (GLM) were used to estimate the influence of treatment and assemblies on both measured traits. Given that the data were normally distributed for ML, GLM was performed with 'identity' link function. For LC, GLM was performed with the Poisson distribution and the 'log' link function. The null hypotheses for both response variables were that there were no influences of the tested factors. The following model was used to calculate the influence of the treatment and the assemblies on both ML and LC:

$$\gamma_{ij} = \mu + \beta_1 T_i + \beta_2 A_j + \varepsilon_{ij} \quad \text{(Eq. 1)}$$

where y_{ij} is the observed values of the i-th treatment (i = untreated, thermally sprayed, thermally sprayed and post treated, one side coated, one side coated and copper bond coat) and the j-th assembly (j = A, B, C) for ML and LC; µ is the overall mean; β_1 is the fixed effect of treatment T_i (i = untreated, thermally sprayed, thermally sprayed and post treated, one side coated, one side coated and copper bond coat); β_2 is the fixed effect of the assembly A_j (J = A, B, C); ε_{ij} is the residual. All tests were performed at a significance level of 0.05 and all estimated values are given with the standard error of the mean.

Results

Correlation between mass loss and length change

The values of ML decreased monotonically with decreasing LC. The Pearson correlation coefficient between the two traits was $r = 0.89$ ($p < 0.001$). The relationship between ML and LC is presented as a counter check in Figure 2.

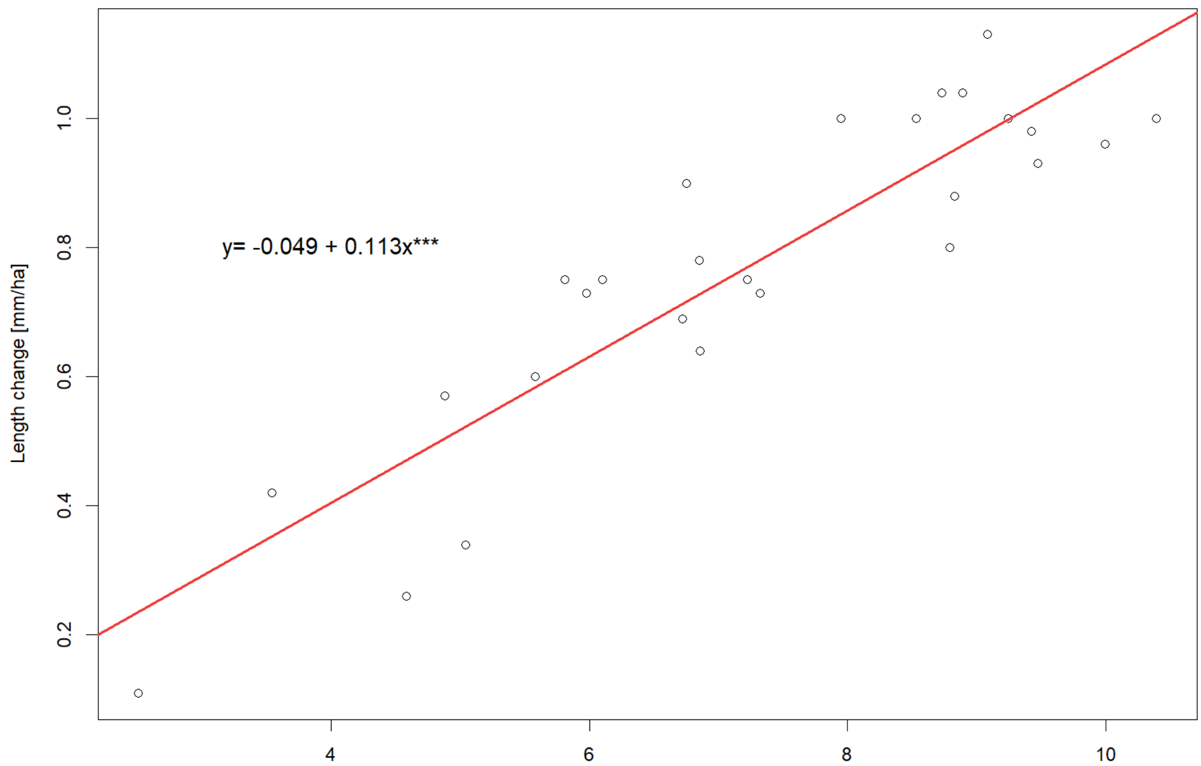

Figure 2: Correlation between tine/share mass loss and length change. Significance levels: *** p < 0.001; ** p < 0.01; * p < 0.05; results with p < 0.05 were considered statistically significant, field experiment 2023

The regression of the graph is linear with a positive slope ($m = 0.113$). Subsequently, the correlation between mass loss and length change in the manufacturing techniques of all assemblies was presented in Figure 3. It can be seen here that the regression slope in the coated shares tend to be flatter than those of the untreated tools. This suggests a stronger correlation between mass loss and length change. Statistical tests showed that the regression slopes between the treatment groups do not differ significantly ($p = 0.055$).

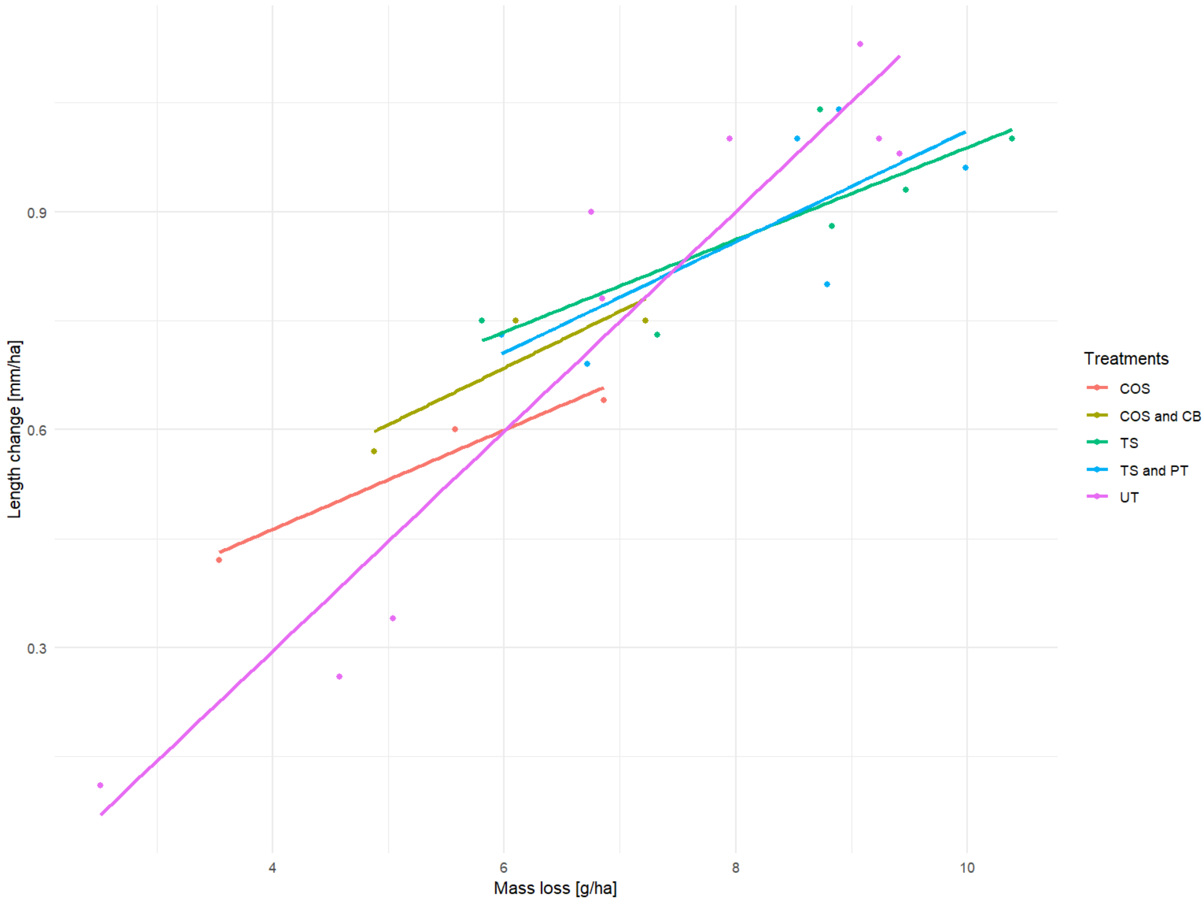

Figure 3: Correlation between tine/share mass loss and length change sorted by treatments, UT = untreated, TS = thermally sprayed, TS and PT = thermally sprayed and post treated, COS = coated on one side, COS and CB = coated on one side and copper bond coat; in field test on site A,B,C in 2023

Mass loss and length change

On average, ML was 6.82 ± 0.80 g/ha, 8.43 ± 0.67 g/ha, 8.15 ± 0.61 g/ha, and 5.33 ± 0.97 g/ha for untreated, thermally sprayed, thermally sprayed and post treated and one side coated tools, respectively (Table A2 in the Appendix). Thereby, ML ranged from 2.51 g/ha to 9.42 g/ha in untreated tools, from 5.81 g/ha to 10.39 g/ha in thermally sprayed tools, from 5.98 g/ha to 9.99 g/ha in thermally sprayed and post coated tools, and from 3.54 g/ha to 6.86 g/ha in one side coated tools (Figure 4).

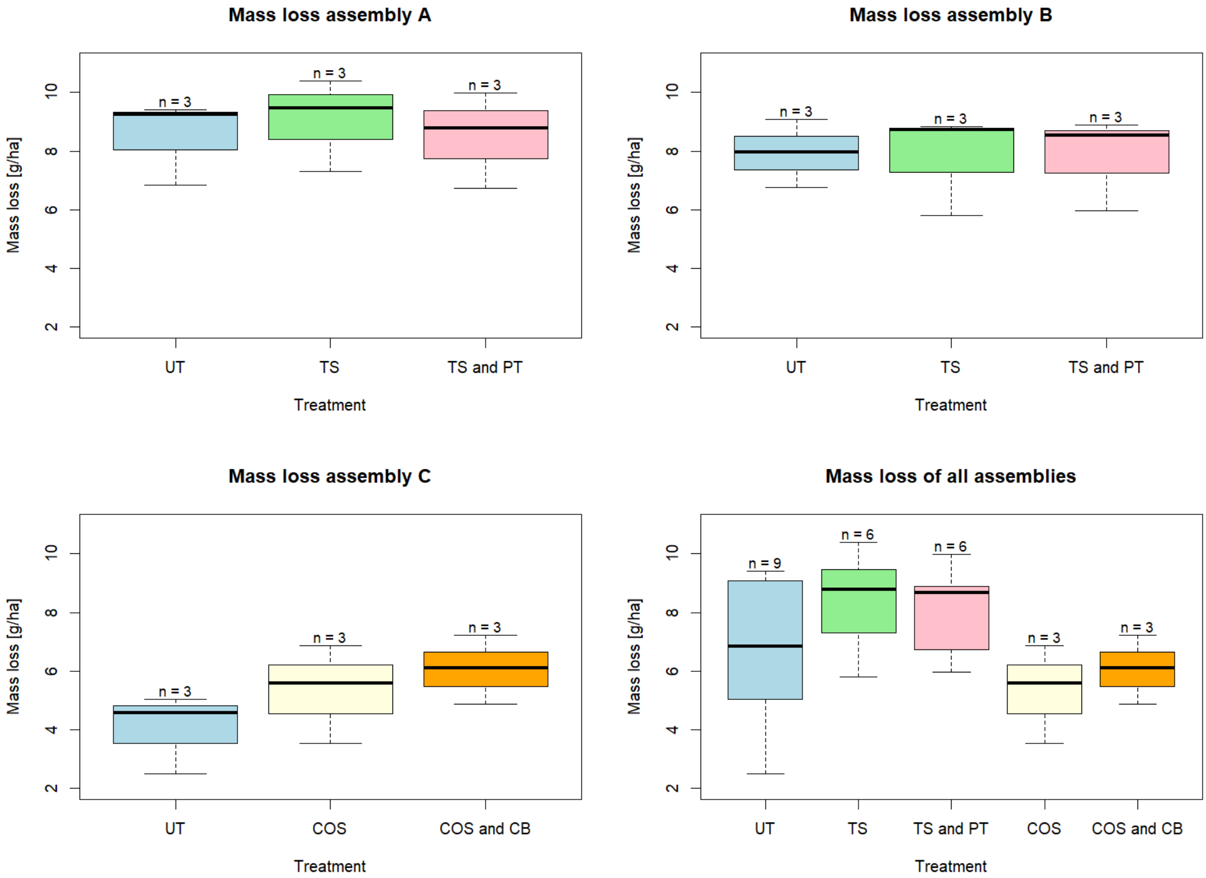

Figure 4: Boxplots showing the minimum and maximum (whiskers), median (line in the box), interquartile range (length of the boxes) of the mass loss of the tested tillage tools per assembly with UT = untreated, TS = thermally sprayed, TS and PT = thermally sprayed and post treated, COS = one side coated, COS and CB =one side coated and copper bond coat

The results of the GLM show a significant influence of assembly on ML (p = 0.0003). Thereby, assembly C significantly differs from both assembly A (p = 0.0009) and assembly B (p = 0.0057) with lower ML values for assembly C, respectively. No significant influence of the treatment on ML could be found.

The average values of LC were 0.72 ± 0.13 mm/ha, 0.83 ± 0.05 mm/ha, 0.87 ± 0.06 mm/ha, 0.55 ± 0.07 mm/ha, and 0.69 ± 0.06 mm/ha for untreated, thermally sprayed, thermally sprayed and post treated, one side coated, and one side coated and copper bond coat tillage tools, respectively (Figure 5). Depending on the treatment, LC ranged from 0.11 mm/ha (untreated), 0.73 mm/ha (thermally sprayed), 0.69 mm/ha (thermally sprayed and post treated), 0.42 mm/ha (one side coated), and 0.57 mm/ha (one side coated and copper bond coat) to 0.1.13 mm/ha (untreated), 1.04 mm/ha (thermally sprayed), 1.04 mm/ha (thermally sprayed and post treated), 0.64 mm/ha (one side coated), and 0.75 mm/ha (one side coated and copper bond coat). According to the GLM, neither the treatment nor the assembly significantly influenced LC.

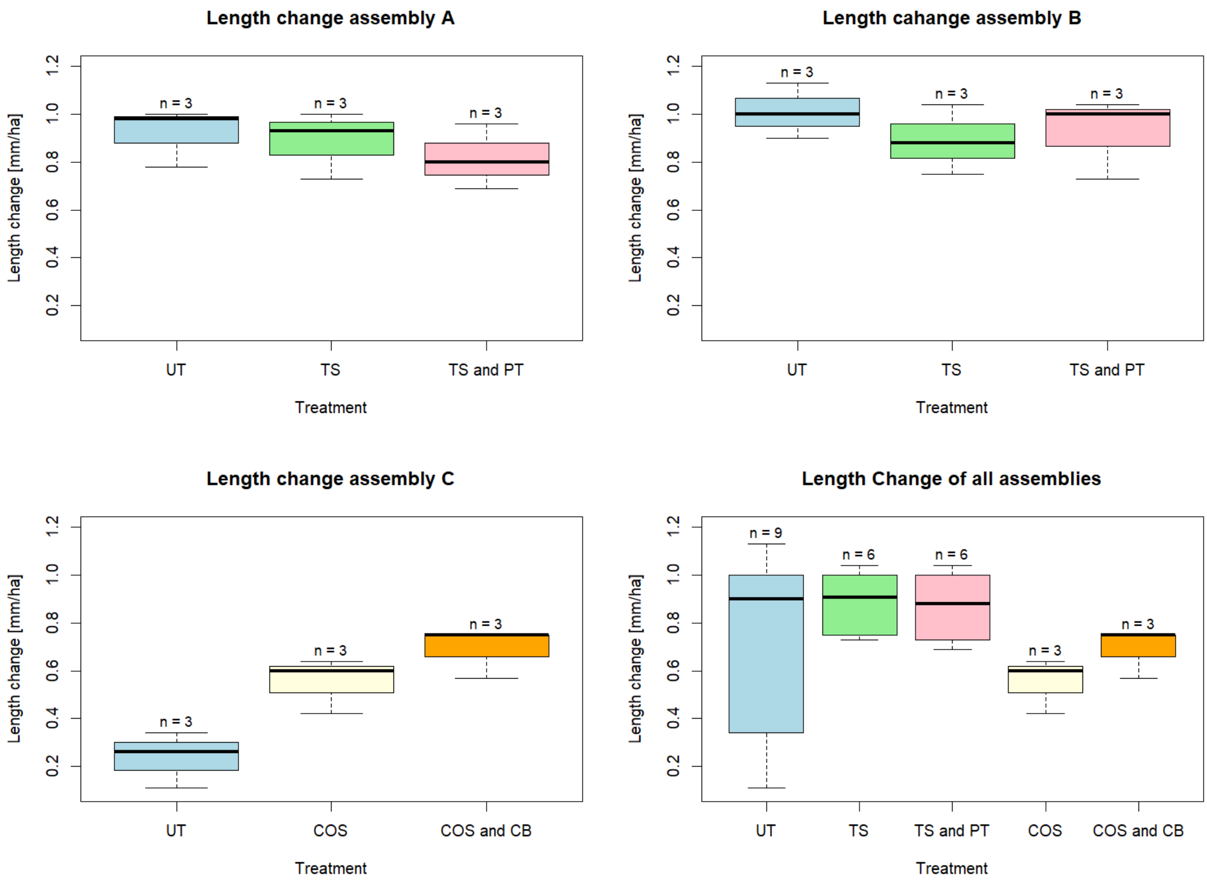

Figure 5: Boxplots showing the minimum and maximum (whiskers), median (line in the box), interquartile range (length of the boxes) of the length change of the tested tillage tools per assembly with UT = untreated, TS = thermally sprayed, TS and PT = thermally sprayed and post treated, COS = one side coated, COS and CB = one side coated and copper bond coat

Discussion

The wear and tear of tillage tool were investigated in both laboratory and farm tests using ML and LC as criteria for wear resistance. Thereby, a positive correlation between these criteria could be found. This close correlation shows that the two traits can generally accurately represent wear resistance. The correlation between ML and LC tended to be stronger in coated compared with untreated tools. This could indicate a positive effect on wear resistance of the thermally sprayed tools. In comparison to these assumptions, it was shown that the wear resistance can generally be increased by various coating techniques (Aramide et al. 2021, Lemecha et al. 2024, Listauskas et al. 2024).

Mass loss and length change are good indicators for wear investigations because they represent direct, measurable effects of material degradation. Mass loss reflects the actual amount of material removed through abrasion, erosion, or corrosion, making it a clear measure of substance loss. Length change indicates wear or deformation, for example due to surface abrasion or permanent plastic deformation under load. Both parameters are objective, easy to measure, and allow reliable comparison between different materials and operating conditions, which makes them well suited for quantitative wear analysis.

In coated tools, the correlation between mass loss and length change is generally stronger because wear occurs in a more uniform and surface-controlled manner. The coating acts as a homogeneous protective layer, so its gradual removal leads to a more direct and proportional relationship between material loss and geometric change. In uncoated tools, wear is typically more heterogeneous, involving localized abrasion, micro-chipping, plastic deformation, and adhesive effects. As a result, mass loss and length change do not always evolve proportionally, which weakens their correlation.

Neither ML nor LC were affected by thermal coating during the present investigation. The soils in the field trials were highly heterogeneous and contained both large and small stones. The smaller particles were associated with the sandy soil fractions. No spalling caused by impact loads was observed during the field tests. Similar findings were reported by Nalbant and Palali (2011), who showed that under certain operating conditions coated tools exhibited wear rates comparable to those of uncoated tools. This suggests that the thermal coating was unable to provide a significant stabilizing effect under the prevailing field conditions. One possible explanation is premature failure of the coating layer caused by insufficient adhesion between the coating and the substrate. Another explanation may be that the coating system is less suitable for curved share surfaces, whereas improved adhesion could potentially be achieved on flatter surfaces (Kushwaha et al. 1990). Karoonboonyanan et al. (2007) reported minor chipping on tool surfaces caused by interactions between soil particles and the tool material. Repeated impacts of small stones may contribute to local damage, especially in soils with a higher proportion of coarse abrasive particles. Although no chipping or spalling was observed in the present study, such mechanisms may still have contributed to coating degradation at a microscopic scale.

In addition, soil texture plays an important role in abrasive wear. According to Malvajerdi (2023), abrasive wear increases with increasing sand particle size. Furthermore, Listauskas et al. (2024) reported that wear rates are primarily governed by abrasive soil constituents such as silicon and aluminium oxides, whose hardness exceeds that of the tool material. However, despite the comparatively sandy soil conditions (sL, Ls), assembly C exhibited a lower mass loss than assemblies A and B. This indicates that sand content alone cannot explain the observed wear behavior.

The literature describes various relationships between soil moisture and the wear of soil cultivation tools. On more sandy soils, the wear resistance of shares often decreases as soil moisture increases. This is primarily attributed to the effect of dissolved salts, which increase the activity of the absorption medium and thereby promote the dispersion of the share material (Fouda and El-Tarhuny 2010). Furthermore, it is reported that increasing soil moisture reduces soil hardness. The lower soil hardness leads to a reduction in soil pressure on the share and thus to a lower wear rate (Natsis et al. 2008). However, the interaction between soil type and water content is decisive for the actual wear rate. On sandy soils, the wear rate often increases with rising soil moisture. On loamy soils, however, a different behavior is observed. There, the wear rate initially increases with rising soil moisture up to a certain optimum. If this moisture level is exceeded, a further increase in water content leads to a reduction in the wear rate of tillage tools (Singh et al. 2017). These findings show that the interactions between soil type, soil moisture and the material properties of the tool can be highly complex. Wear behavior cannot therefore be explained solely by soil type or grain size distribution. In this context, soil moisture could provide a possible explanation for the lower wear rate of assembly C compared to assemblies A and B, even though the soil conditions there were comparatively sandier. In addition, the heterogeneous soil conditions suggest that additional factors, such as particle size distribution, stone content, local loading conditions, or differences in impact stresses, may have influenced the wear mechanisms and partially outweighed the expected effect of increased sand content.

The resistance of a tool to abrasive wear is strongly influenced by its hardness. Homberg and Rostek (2014) stated that the material hardness should be approximately 1.3 times higher than that of the attacking abrasive particles to minimize wear. However, increased hardness does not necessarily result in improved wear resistance. Excessive hardness may reduce toughness and increase susceptibility to brittle damage. Consequently, the balance between hardness and toughness determines which wear mechanisms dominate under field conditions (Yazıcı 2024). Considering these aspects, the limited performance of the LBS coating may be related to a combination of insufficient coating adhesion and inadequate mechanical properties of the coating system. In particular, an unfavorable balance between hardness and toughness could have accelerated coating degradation under abrasive soil conditions. In addition to abrasive soil properties, coating adhesion and material hardness, the choice of alloy may also have influenced the overall wear behavior. While composite materials such as wolfram carbide (WC-Co-Cr) or chromium carbide nickel (Cr3C2-NiCr) exhibited high wear resistance, this was not the case for aluminum oxide (Al2O3) coatings (Kang et al. 2012, Karoonboonyanan et al. 2007). This suggests that the wrong alloy was used for abrasive wear in this study.

Furthermore, the laboratory results can only be applied to real field tests to a limited extent. The abrasive medium used in the laboratory tests does not reflect the complex soil properties (Curley and Joseph 2017). This means that certain alloys achieve positive effects under laboratory conditions with consistent abrasion stress. However, under practical conditions in the field, they cannot withstand the stresses of the soil. More comprehensive data collection under practical conditions could be ensured in the future by adding sensors. This could include optical sensors (e.g., 3D scanners, photogrammetry), acoustic sensors (e.g., recording vibrations), or sensors that directly record measurements from the tractor (e.g., traction force requirements, fuel consumption). Furthermore, sensors for the continuous analysis of layer thickness could be installed. All this collected data could thus provide insights into the wear behavior and geometric changes of the cultivator tines. In addition, it would be conceivable to incorporate cyclic impact loads into the standard abrasion test. This would likely bring the test somewhat closer to realistic conditions. This includes high dynamic loads and shock movements (Homberg and Rostek 2014). Yu and Bhole (1990) already pointed out that ASTM G65 is not a good test standard for preliminary tests due to the use of a standardized dry sand mixture as an abrasive medium.

Furthermore, the small number of samples could limit the statistical significance of the results. Nevertheless, the observed trends show a clear tendency that is comparable to previous studies.

Conclusions

The results of this work show that thermal coating using Fe-based arc spraying did not increase the tool life. Both ML and LC of the untreated and thermally coated tools were at a similar level. Therefore, the established hypothesis cannot be confirmed. In some cases, the coated tools even exhibited higher wear rates, which indicates premature material collapse. In addition, the surfaces of the tool material were subject to high abrasive stress due to the soil types (sL, Ls). Although the LBS coating exhibited high wear resistance under laboratory conditions, it could not be confirmed under practical field conditions. This indicates, above all, a lack of transferability of the results from the laboratory to the field. Overall, the results show that it is possible to extend the tool life if influencing factors such as material composition, soil properties, hardness values and alloy type were taken into account to a greater extent. However, under practical conditions, there are numerous influencing factors that affect the wear of tool surfaces. It is not possible to take all influences into account. In order to be able to make statements about the performance of thermal coatings, further field tests under realistic soil and load conditions are necessary.

References

Aramide, B.; Pityana, S.; Sadiku, R.; Jamiru, T.; Popoola, P. (2021): Improving the durability of tillage tools through surface modification—a review. The International Journal of Advanced Manufacturing Technology, 116(1-2), pp. 83–98, https://doi.org/10.1007/s00170-021-07487-4

ASTM International (2021): Standard Test Method for Measuring Abrasion Using the Dry Sand/Rubber Wheel Apparatus. Version G65-16R21, https://store.astm.org/g0065-16r21.html, accessed on 26 May 2026

Bührke, J.; Schramm, F.; Frerichs, L. (2018): Geometriediskrete Belastungsmessung an einem Grubberwerkzeug. agricultural engineering.eu 73(2), pp. 39–51, https://doi.org/10.15150/lt.2018.3181

Curley, M.; Joseph, T. G. (2017): Cyclic loading and a modified ASTM G65 abrasion test. Wear 390-391, pp. 346–354, https://doi.org/10.1016/j.wear.2017.09.005

Denisenko, M.; Deviatko, O.; Mushtruk, M.; Kanivets, N.; Tuziuk, M. (2025): Theoretical Prerequisites for Increasing the Durability and Service Life of Working Bodies of Tillage Machines Advances in Design, Simulation and Manufacturing VIII. In: Proceedings of the 8th International Conference on Design, Simulation, Manufacturing: The Innovation Exchange, DSMIE-2025, June 17–20, 2025, Porto, Portugal - Volume 1: Manufacturing Engineering, Cham. https://doi.org/10.1007/978-3-031-95211-1_2

Fouda, T; El-Tarhuny, M. (2010): A Study on Plowshares Wearing Behavior under Conditions of Sandy Loam Soil. Jordan Journal of Agricultural Sciences 6(3)

Handler, F.; Riegler, T.; Rechberger, C. (2015): Verschleißschutz bei Grubberscharen. Bauernzeitung Agraranzeiger.at Nr. 15, 9. April 2015, https://www.josephinum.at/dam/jcr:c0a0f066-01be-4e29-9cf2-62bf460de107/1496.pdf, accessed on 26 May 2026

Homberg, W.; Rostek T. (2014): Hochleistungsaktivelemente für landwirtschaftliche Maschinen aus ultrahochfestem Stahl. Düsseldorf, Verlag und Vertriebsgesellschaft mbH

Jacob, S.; Ádám, K.; Patrick De, B.; Kannaki Shanmugham, P. (2017): Wear mechanisms prevalent in agricultural tines. Mechanical Engineering Letters 15, pp. 87-93, http://hdl.handle.net/1854/LU-8550975

Kang, A. S.; Grewal, J. S.; Jain, D.; Kang, S. (2012): Wear Behavior of Thermal Spray Coatings on Rotavator Blades. Journal of Thermal Spray Technology, 21(2), pp. 355–359, https://doi.org/10.1007/s11666-011-9709-y

Karoonboonyanan, S.; Salokhe, V. M.; Niranatlumpong, P. (2007): Wear resistance of thermally sprayed rotary tiller blades. Wear 263(1-6), pp. 604–608, https://doi.org/10.1016/j.wear.2006.12.072

Kushwaha, R. L.; Chi, L.; Roy, C. (1990): Investigation of agricultural tools with plasma-sprayed coatings. Tribology International, 23(5), pp. 297–300. https://doi.org/10.1016/0301-679X(90)90002-7

Lemecha, M.; Ligier, K.; Napiórkowski, J.; Vrublevskyi, O. (2024): Analysis of Tribological Properties of Hardfaced High-Chromium Layers Subjected to Wear in Abrasive Soil Mass. Materials 17(14), 3461, https://doi.org/10.3390/ma17143461

Listauskas, J.; Jankauskas, V.; Žunda, A.; Katinas, E.; Gargasas, J. (2024): Estimation and modelling the wear resistance of plough points and knife coulters by discrete element method. Wear 556-557, 205508, https://doi.org/10.1016/j.wear.2024.205508

Malvajerdi, A. S. (2023): Wear and coating of tillage tools: A review. Heliyon 9(6), e16669, https://doi.org/10.1016/j.heliyon.2023.e16669

Mamkagh, A. M. (2019): Review of Fuel Consumption, Draft Force and Ground Speed Measurements of the Agricultural Tractor during Tillage Operations. Asian Journal of Advanced Research and Reports 3(4), pp. 1–9, https://doi.org/10.9734/ajarr/2019/v3i430093

Möhrke, L.; Hauer, M.; Biswal, P.; Gericke, A.; Henkel, K.-M. (2024): Hard-Facing Coatings for Agriculture Tools. In: ITSC 2024, ASM International, pp. 570-579, https://doi.org/10.31399/asm.cp.itsc2024p0570

Nalbant, M.; Palali, A. T. (2011): Effects of different material coatings on the wearing of plowshares in soil tillage. Turkish Journal of Agriculture and Forestry 35(3), pp. 215–223, https://doi.org/10.3906/tar-0904-30

Natsis, A.; Petropoulos, G.; Pandazaras, C. (2008): Influence of local soil conditions on mouldboard ploughshare abrasive wear. Tribology International 41(3), pp. 151–157, https://doi.org/10.1016/j.triboint.2007.06.002

Owsiak, Z. (1997): Wear of symmetrical wedge-shaped tillage tools. Soil and Tillage Research 43(3-4), pp. 295–308, https://doi.org/10.1016/S0167-1987(97)00020-2

Renfert-Deitermann, D. (2018): Hartmetall gegen Panzerung. profi Sonderdruck 07/2018, https://betek.de/fileadmin/user_upload/profi_0718_Lemken.pdf, accessed on 26 May 2026

Revell, W. (2026): psych: Procedures for Psychological, Psychometric, and Personality Research (version 2.6.3), 10.32614/CRAN.package.psych

Saygılı, Y. S.; Aygün, İ.; Urkan, E.; Çakmak, B. (2025): Investigation of Material Hardness Values of Active Elements of Some Domestic Production Tillage Equipment and Agricultural Machinery. ÇOMÜ Ziraat Fakültesi Dergisi 13(1), pp.165–171, https://doi.org/10.33202/comuagri.1629690

Sidorov, S. A.; Mironov, D. A.; Mironova, A. V.; Ryabov, V. V. (2021): Increasing the Wear Resistance and Other Life Characteristics of Materials of Tillage Tools. Metallurgist 65(5-6), pp. 593–601, https://doi.org/10.1007/s11015-021-01195-w

Singh, J.; Chatha, S. S.; Sidhu, B. S. (2017): Influence of soil conditions on abrasion wear behaviour of tillage implements. International Journal of Latest Trends in Engineering and Technology, Special Issue AFTMME-2017, pp. 258-263, https://www.ijltet.org/pdfviewer.php?id=925&j_id=4263, accessed on 26 May 2026

Singh, J.; Chatha, S. S.; Sidhu, B. S. (2020): Abrasive wear behavior of newly developed weld overlaid tillage tools in laboratory and in actual field conditions. Journal of Manufacturing Processes 55 pp. 143–152, https://doi.org/10.1016/j.jmapro.2020.03.040

Sponagel, H. (2005): Bodenkundliche Kartieranleitung. Stuttgart, Schweizerbart

Swanson, P.; Ruff, A.; Bayer, R. (1993): Comparison of Laboratory Abrasion Tests and Field Tests of Materials Used in Tillage Equipment. In Tribology: Wear Test Selection for Design and Application (Vol. STP1199-EB, pp. 0), ASTM International, https://doi.org/10.1520/stp15966s

Wang, Y., Li, D.; Nie, C.; Gong, P.; Yang, J.; Hu, Z.; Li, B.; Ma, M. (2023): Research Progress on the Wear Resistance of Key Components in Agricultural Machinery. Materials 16(24), 7646, https://doi.org/10.3390/ma16247646

Wanzek, T.; Keiluweit, M.; Baham, J.; Dragila, M. I.; Fendorf, S.; Fiedler, S.; Nico, P. S.; Kleber, M. (2018): Quantifying biogeochemical heterogeneity in soil systems. Geoderma, 324, pp. 89–97, https://doi.org/10.1016/j.geoderma.2018.03.003

Yazıcı, A. (2021): Review of Wear on Tillage Tools: Constraints in Transferring of the Research Findings to the Agricultural Sector and Solution Proposals [Toprak İşleme Araçlarında Aşınma Konusunun Değerlendirilmesi: Araştırma Bulgularının Tarım Sektörüne Aktarılmasındaki Kısıtlamalar ve Çözüm Önerileri]. Tarım Makinaları Bilimi Dergisi 17(2), pp. 74–85, https://izlik.org/JA67WD99GA

Yazıcı, A. (2024): Wear on steel tillage tools: A review of material, soil and dynamic conditions. Soil and Tillage Research 242, 106161, https://doi.org/10.1016/j.still.2024.106161

Yu, H. J.; Bhole, S. D. (1990): Development of a prototype abrasive wear tester for tillage tool materials. Tribology International 23(5), pp. 309–316, https://doi.org/10.1016/0301-679X(90)90004-9

Authors

Moritz Gombert (B.Sc.) is a Master’s student at the University of Rostock - Faculty of Agriculture, Civil and Environmental Engineering, **Dr. Susanne Demba** is a researcher at the Professorship for Agricultural Process Engineering of the University of Rostock - Faculty of Agriculture, Civil and Environmental Engineering, **Dipl.-Ing. Kai Potthoff** is a researcher at the Fraunhofer Institute for Large Structure in Production Engineering IGP, **Prof. Dr.-Ing. Wilko Flügge** is the head of the Professorship for Manufacturing Technology at the University of Rostock - Faculty of Mechanical Engineering and Marine Technology as well as the head of the Fraunhofer Institute for Large Structure in Production Engineering IGP, **Prof. Dr. habil. Sandra Rose** is the head of the Professorship for Agricultural Process Engineering at the University of Rostock - Faculty of Agriculture, Civil and Environmental Engineering, Justus-von-Liebig-Weg 6b, D-18059, Rostock, Germany, e-mail: sandra.rose@uni-rostock.de.