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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

Aysel Yazıcı[1,*]

[1] *Manisa Celal Bayar University, Turgutlu Vocational School, Department of Machine and Metal Technologies, 45400, Turgutlu-Manisa, Türkiye.*
[*] *Corresponding author (Sorumlu Yazar): A. Yazıcı, e-mail (e-posta): aysel.yazici@cbu.edu.tr*

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ABSTRACT

The aim of the study is to present the course of scientific developments of wear studies in soil tillage tools and to evaluate basic constraints in transferring the research results to the farm systems and the solution proposals. In this study, the studies conducted to analyze and reduce the wear losses in soil tillage tools in the last century are presented chronologically. Hereby, in the first stage of the study, it is aimed to present the course of scientific developments in this field. In the second phase, the reflection of the scientific research results in the agricultural sector was evaluated for Turkey. As a result of the investigation, it is observed that the developments in the field of materials science have been reflected in research aiming to improve the wear resistance of agricultural tillage tools and studies generally have focused on heat treatments and coatings. It is understood that the level of the economic prosperity of small-medium-sized farms, and the poor financial structures of small-medium-sized machinery manufacturers are the most important constraints in transferring the research results to the farm systems. As a result of the study; development of policies to strengthen the weak economic purchasing power of small-medium scale farms, and the weak financial structures of small-medium scale machinery manufacturers, and to reduce costs using new production technologies suitable to automation can be suggested.

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ÖZ

Çalışmanın amacı, toprak işleme makineleri konusunda yapılan aşınma çalışmalarının bilimsel seyrini sunmak ve araştırma sonuçlarını çiftlik sistemlerine aktarılmasında karşılaşılan temel kısıtlamaları ve çözüm önerilerini değerlendirmektir. Bu çalışmada, son yüzyılda toprak işleme makinelerindeki aşınma kayıplarını analiz etmek ve azaltmak için yapılan çalışmalar kronolojik olarak sunulmuştur. Çalışmanın ilk aşamasında bu alandaki bilimsel gelişmelerin seyrinin sunulması amaçlanmıştır. İkinci aşamada, bilimsel araştırma sonuçlarının tarım sektörüne yansıması Türkiye açısından değerlendirilmiştir. Yapılan incelemeler sonucunda, malzeme bilimi alanındaki gelişmelerin toprak işleme araçlarının aşınma direncini geliştirmeye yönelik araştırma çalışmalarına yansıdığı ve çalışmaların genellikle ısıl işlemler ve kaplamalar konuları üzerinde yoğunlaştığı görülmektedir. Küçük-orta ölçekli çiftliklerin ekonomik refah düzeyi ve küçük-orta ölçekli makine üretici firmaların zayıf finansal yapılarının araştırma sonuçlarının çiftlik sistemlerine aktarılmasındaki en önemli kısıtlar olduğu görülmektedir. Sonuç olarak; küçük-orta ölçekli çiftliklerin zayıf ekonomik satın alma gücünü, ve küçük-orta ölçekli makine üreticilerinin zayıf finansal yapılarını güçlendirmeye yönelik politikaların geliştirilmesi ve makine üretim maliyetleri azaltmak için otomasyona uygun yeni üretim teknolojileri kullanımı önerilebilir.

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1. INTRODUCTION

The development of tillage dates back to ancient times when agriculture began. During those times, sticks and stones were used for the tillage works. There are also pieces of evidence indicating that plough was used in Mesopotamia and the Egyptian Nile Delta 3-4 thousand years before Christ (Rehkugler, 2011). The emergence of the modern plough in the early 1800s (Kendall, 1959; Gilbert, 2010; Rehkugler, 2011) and the introduction of the first steel plough in 1837 (Kendall, 1959; Rehkugler, 2011) made a breakthrough in tillage. The explanation of interactions between the soil and the tillage tools and the wear losses in the tillage tools that cause the economic loss of millions of dollars each year has been an issue attracting the interest of researchers. The first Ph.D. thesis entitled "A study of the Plow-bottom and Its Action on The Furrow Slice" on tillage in Agricultural Engineering was written by White in 1917 (Rehkugler, 2011). The first studies on the wear of tillage tools date back to the early 1920s (Hoffman, 1922). The wear that occurs in the tillage implements varies depending on many parameters such as chemical composition of the material used, mechanical and microstructure properties of the used material, surface roughness, soil type, particle shape, size, soil strength and compactness, soil density, moisture content of soil, rock and gravel content, tillage speed and depth, geometry of the tool, and impact angle between the soil and the tool (Yu and Bhole 1990; Owsiak, 1997; Natsis et al., 1999). According to the study conducted by Schulze (1969), to examine breakdown and repair expenses in agricultural machinery, the most important factor causing a depreciation in agricultural machinery is wear. Among the types of damage determined in agricultural tools and machinery, wear is ranked first with a 42.5% share (Önal et al., 1994). Wear losses in tillage tools do not only result in economic losses caused by material, energy and labour losses. One of the most important problems caused by wear in tillage tools is that the tillage cannot be done in accordance with agrotechnical demands. The ploughshares, which are worn but insisted on being used without being replaced, speed up the formation of the plough pan since they cannot cut the soil and do only pushing. The blunted cutting edges of tillage tools are one of the factors that cause compaction in the soil. It is known that plough pan formation leads to a decrease in plant production efficiency by negatively affecting the plant root development, soil ventilation, water movement in soil and microbiological activities in soil (Soane, 1970; Barnes, 1971; Ulusoy, 1981).

The force needed to cut the soil, soil properties (e.g., humidity, density, adhesion, cohesion, and internal friction angle of the soil), interaction characteristics between the tool and soil (e.g., rake angle and friction angle), geometry of the tool, and tillage parameters (e.g., work width, tillage depth, and tillage speed) are known to change as a function. The worn tillage tools and increasing cutting edge thickness increase the need for draft force (Gavrilov and Koruschkin, 1954; Fielke 1996; Natsis et al., 1999) and fuel consumption (Karatish, 1955; Natsis et al., 1999; Derafshpour and Mogaddam, 2013). With the wear of ploughshare, the need for draft force increases by as much as 30% (Gavrilov and Koruschkin, 1954). Fielke (1996) reports that the ploughshare, whose sharp edge is blunted, can increase the draft force by up to 80%. It also becomes difficult for the worn ploughshare to hold on the groove.

Wear can be described as removing of materials from the surface due to interaction with another surface. The basic and most important types of wear are abrasive wear, adhesive wear, fatigue wear, and corrosive wear (Burwell, 1957/58). In a tribosystem, wear varies depending on dynamic, environmental, and material parameters. During wear, the interaction between the metal material and the soil can be said to be quite complex. The soil generally cannot be characterized as a rigid body, and the evidence of cutting and scratching indicates that the forces within even small areas are highly complex and of varying magnitude. During a tillage process, dynamic parameters of an abrading system contain the stresses on the sliding surface and the duration, and rate of sliding so far as it affects the temperature and stability of the sliding surface (Gill and Berg, 1967). The material parameters of the tillage tools that affect the abrasive wear are the hardness, strength, toughness, and surface roughness of the material. There are also parameters that are related to the environmental-soil and that affect wear. These are soil grain-related parameters (size, amount, and sharpness), the water content of the soil, compactness, and pressure of the soil, and presence of some materials (e.g. plant roots, trashes, and rocks) in the soil. Abrasive wear losses constitute the highest cost among the other types of wear. Adhesive wear is influenced by surface tension, surface characteristics of the tool material, and environmental-soil parameters such as soil type, soil moisture. The corrosive wear is affected by the properties of the material (chemical content, grain size, hardness, microstructure, and phases), residual stresses occurring in the material as a result of heat treatments and other production processes, and environmental conditions such as soil temperature, soil moisture, acidic-basic properties.

This study aims to present the course of wear studies related to tillage tools and to evaluate the difficulties and constraints in transferring the research findings to the agricultural sector.

2. HISTORICAL BACKGROUND AND THE CURRENT STATUS OF THE WEAR RESEARCH FOR TILLAGE TOOLS

The main studies carried out in the last century to determine and improve the life of the tillage tools are presented in chronological order, together with the topic of research, in the Table 1. It is observed that the developments in material science have been reflected in research aiming to improve the wear resistance of agricultural tillage tools. As can be seen from the Table 1, studies have focused on heat treatments and coatings aimed at improving the microstructure and surface characteristics of the material. Generally, as can be seen from the research results, improved the microstructure and surface characteristics increase the wear resistance of tillage tools. However, today, conventional heat treatment (quenching) is still the most widely used technique for improving the mechanical properties of tillage tools.

It is understood that studies focusing on determining the impact of the geometry and manufacturing forms of tillage tools on wear remains more limited (Table 1). Tillage tools are generally manufactured by the cutting from steel sheets and sometimes casting. In the manufacturing of the tillage tool, many process steps such as cutting of the part in the desired dimensions, opening holes for countersunk bolt and screws, heat treatment, giving the final shape to the part, hardening and tempering follow each other. As a result of this, traditional manufacturing processes are labour-intensive and take a long time. While Yazici (2011b) examined the wear behaviour of ploughshare produced through hot stamping from the filled steel mile, Yazıcı and Çavdar (2017) investigated the wear behaviour of the test samples produced through sintering from powder metals and boronized. Although such techniques may already seem more expensive, the transfer of the developments in production technologies to the agricultural sector will allow the modernization and automation of the production systems. This, in turn, will reduce costs in the long run. In recent years, studies focusing on interactions of the tillage tools and the modelling of wear are also conducted (Singh et al., 2011; Goel 2013; Skirkus and Jankauskas, 2015; Bedollaa et al., 2018; Zhang et al., 2018; Cucinotta et al., 2019). Realistic wear models will shed light on the technical, economic, and design optimization.

Table 1. Research carried out in the last century to determine and improve the life and performance of the soil tillage tools

Name of researchers and year of study	*Name of paper*	*Topic of research*
Hoffman, 1922	"Wearing Tests of Plowshares"	Material - Wear
Gallwitz, 1930	"Werkstoffe und abnutzung von pflugscharen"	Speed, Type of abrasive, Moisture content, Operating angle and depth, Composition and hardness of the material -Wear
Nichols, 1930	"Dynamic properties of soil affecting implement design"	Dynamic properties of soil -Design
Nichols, 1931	"The dynamic properties of soils, II. soil and metal friction"	Friction; metal-soil, Friction coefficient
Kühne, 1931	"Vergleichende untersuchungen an schar-werkstoffen"	Tillage speed - Wear
Zink et al, 1936	"Results of studies of the cutting edges of tillage implements"	Cutting Edges, Heat treatments, Soils conditions, Hardness -Wear
Kummer, 1938	"The dynamic properties of soil: A study of the nature of physical forces governing the adhesion between soil and metal surfaces",	Adhesion
Carleton and Martin, 1945	"Sharpening and hard surfacing plow and lister shares"	Types of plowshares, Share treatments, Hard-surfacing materials - Wear
Mitsuhasi et al, 1950	"Study of wear of steel against soils"	Soil moisture, Velocity, Cutting angle, Load - Wear
Gavrilov and Koruschkin, 1954	"The underside chamfer of plough shares"	Draught force - Wear
Mohsenin, 1956	"Development of an accelerated wear test for tillage tool materials and its application to ordinary cast iron and nodular iron"	Material (Carbon content), Suitable Shape and Size - Wear
Tribble, 1958	The teflon covered mouldboard plow	Teflon covered plough ear -Wear
Cooper and McCreery, 1961	"Plastic surface for tillage tools"	Teflon coating- Wear
Stroppal, 1961	"Über die Güte, den verschleiss und die schneiden form fabrikneuer pflugschare"	Cutting edge properties - Wear
Koszeghy, G. 1964	"Some questions of investigations on rotary cultivators"	Blade wear -Operating speed
Fox and Bockhop, 1965	"Characteristics of a teflon-covered simple tillage tool"	Teflon coating - Wear

Name of researchers and year of study	*Name of paper*	*Topic of research*
Richardson, 1967	“The wear of metallic materials by soil-practical phenomena”	Soil conditions - Wear
Marin and Tomescu, 1972	“Increasing the wear resistance of working member of the rotary tillers”	Overlay welding - Wear
Silveira, 1973	“Desgastes em cultivadores”	Soil moisture - Wear
Mutaf and Ulusoy, 1977	“Toprak işleme aletlerinin iş organlarında kullanılan bazı çeliklerin farklı ısıl işlemlere göre laboratuar ve tarla şartlarında aşınma dirençleri”	Material, Hardness - Wear
Quick et al., 1979	“Effects of speed and other parameters on lineal share wear”	Tillage parameters - Wear
Ulusoy, 1981	“Bazı Toprak işleme alet ve makinelerinde iş ooorganının aşınması üzerinde araştırmalar”	Tillage tools - Wear
Foley et al., 1984	“The use of alumina ceramic to reduce wear of soil-engaging components”	Alumina ceramic coating - Wear
Karamış, 1985	“Investigation on the wear of workpiece in soil tillage tools”	Tillage parameter, Soil moisture, Hardfacing, Tempering temperature, Surface roughness - Wear
Murthy, 1988	“Abrasive wear of cultivator shovel in soils”	Soil type, Soil moisture, Heat treatment, Material (carbon content)- Wear
Foley et al., 1988	“Wear of ceramic protected agricultural subsoilers”	Alumina ceramic coating- Wear
Quirke et al., 1988	“An evaluation of the wear behaviour of metallic materials subjected to soil abrasion”	Medium-carbon and high-carbon heat treated steels - Wear
Gupta et al, 1989	“Performance evaluation of wide cutting tillage tools of different geometry for dryland farming”	Geometry of tillage tools, Rake angles, Tillage depths - Draught
Kushwaha et al., 1990	“Investigation of agricultural tools with plasma sprayed coatings”	Metallic-glass coatings, Friction coefficient - Soil forces
Kushwaha and Shen, 1991	“Investigation of wear of agricultural tillage tools”	Materials- Abrasive medium (sand and soil) - Wear
Fielke et al., 1993	“Comparison of tillage forces and wear rates of pressed and cast cultivator shares”	Soil type and condition- Wear - Draft forces.
Milos et al, 1993	“Abrasive wear of agricultural machinery parts”	Soil conditions - Wear
Ali and Ezzat, 1994	“Wear of tillage tools coated by thermoplastic coatings”	Polyamide and polyethylene coatings- Wear
Zhang and Kushwaha, 1995	“Wear and draft of cultivator sweeps with hardened edges”	Coating - Wear
Fielke, 1996.	“Interactions of the cutting edge of tillage implements with soil”	Cutting edge geometry -Tillage forces - Soil movement
Zheng et al., 1996	“Wear resistance of cultivator tine (part 2) - Effects of tine parameters on wear resistance”	Tine parameters (hardness, shapes, coating materials, coating locations and shank types) - Wear
Kurchania, 1997	“Abrasive wear of cultivator shovels affected by soil, tool and operating parameter”	Soil, Tool and tillage parameter - Wear
Owsiak, 1997	“Wear of symmetrical wedge-shaped tillage tools”	Material, Heat treatment (quenching + tempering) - Wear
Ferguson et al., 1998	“Wear of cultivator shares in abrasive South Australian soils”	Heat treatment, Soil conditions - Wear
Owsiak, 1999	“Wear of spring tine cultivator points in sandy loam and light clay soils in southern Poland”	Soil type, Spring tine point -Wear
Salokhe et al., 1999	“Effect of Enamel Coating on the Performance of a Tractor Drawn Rotavator”	Enamel coating - Wear
Banaj et al, 2000	“Material wear of cultivator shovels”	Material - Wear
Bhakat, et al., 2004	“Metallurgical life cycle assessment through prediction of wear for agricultural grade steel”	Material, Hardness - Wear
Gupta et al., 2004	“Performance evaluation of different types of steel for duck foot sweep application”	Material, Heat treatment -Wear

Name of researchers and year of study	*Name of paper*	*Topic of research*
Jia and Ling, 2005	"Reduction of soil resistance through the use of a composite coating"	Material, Composite coating - Wear
Mohsenin and Womochel, 2005	"Wear tests of plough share materials"	Material - Wear
Bayhan, 2006	"Reduction of wear via hardfacing of chisel ploughshare"	Hardfacing (shielded metal arc welding) - Wear
Er and Par, 2006	"Wear of plowshare components in SAE 950C steel surface hardened by powder boriding"	Boronizing- Wear
Chahar, 2006	"Studies on wear characteristics of cultivator shovels"	Material (C content), Hardfacing, Tillage speed and depth, Soil moisture - Wear
Bhakat et al., 2007	"Characterization of wear and metallurgical properties for development of agricultural grade steel suitable in specific soil conditions"	Material, Heat treatment - Wear
Bobobee et al., 2007	"Wear rate of animal-drawn ploughshares in selected Ghanaian soils"	Material chemical composition, Share hardness, Soil physical factors- Wear
Bobobee and Gebresenbet, 2007	"Effect of cutting edge thickness and state of wear of ploughshare on draught force and heart rates of Sanga oxen in Ghana"	Cutting edge thickness, Draught force - Heart rates of oxen
Fouda and Tarhuny, 2007	"A Study on ploughshares wearing behavior under conditions of sandy loam soil"	Hardness, Share position, Soil moisture - Wear
Karoonboonyanan et al., 2007	"Wear resistance of thermally sprayed rotary tiller blades"	WC–Co and Al_2O_3/TiO_2 (+NiAl) coating - Wear
Kelly et al., 2007	"Pulsed DC titanium nitride coatings for improved tribological performance and tool life"	Titanium nitride coating - Wear
Mahapatra, 2007	"Wear characteristics of rotavator tynes for power tillers"	Materials (carbon contents), Abrasive particle size, Soil type, Rotovator tine type- Wear
Horvat et al., 2008	"Reduction of mouldboard plough share wear by a combination technique of hardfacing"	Hardfacing (shielded metal arc welding and high-frequency induction welding) - Wear
Natsis et al., 2008	"Influence of local soil conditions on mouldboard plougshare abrasive wear"	Soil conditions - Wear
Korucu and Arslan, 2008	"The effect of wear rate of cultivator shares and operating speed on draught force requirements"	Cultivator share types, Operating speeds- Draught
Kaur et al., 2011	"Studies on the wear performance of different materials of rotary blades"	Materials (low alloy steel, high carbon spring steel), Blade type, Soil type, Working period - Wear
Nalbant and Palalı, 2011	"Effects of different material coatings on the wearing of plowshares in soil tillage"	Chromium, nickel nitride and titanium plating coating - Wear
Yazıcı, 2011a	"Wear behavior of carbonitride-treated ploughshares produced from 30MnB5 steel for soil tillage applications"	Carbonitriding- Wear
Yazıcı, 2011b	"Investigation of the reduction of mouldboard ploughshare wear through hot stamping and hardfacing processes"	Hardfacing (shielded metal arc welding and gas metal arc welding) and Manufacturing form (Hot stamping)- Wear
Kang et al., 2012	"Wear Behavior of Thermal Spray Coatings on Rotavator Blades"	WC-Co-Cr, Cr3C2NiCr and Stellite-21 Coating- Wear
Yazıcı, 2012	"Investigation of the wear behavior of martempered 30MnB5 steel for soil tillage"	Martempering - Wear
Bednář, et al., 2013	"Suitability of technical materials for machinery subsoilers for soil tillage"	Material, Hardfacing - Wear
Derafshpour and Mogaddam, 2013	"Investigation of blade's wears of chisel plow in a silty clay soils"	Tillage depth, Operation area- Wear- Fuel consumption
González et al., 2013	"Wear of rotary plows operating in a tropical clay loam soil"	Tillage implements- Wear
Hrabe and Müller, 2013	"Research of overlays influence on plough-share lifetime"	Hardfacing (overlay welding)-Wear
Alwan and Hussan, 2014	"Study the effect of heat treatment on abrasive wear with silt clay loam soil texture"	Heat treatment- Wear
Kang et al., 2014	"Wear behavior of hardfacings on rotary tiller blades"	Hardfacing (gas tungsten arc welding) - Wear
Kolomeichenko and Titov, 2014	"Investigation of hardness of tillage tools being hardened by Carbo-Vibro-Arc method with paste application"	Hardfacing - Wear

Name of researchers and year of study	*Name of paper*	*Topic of research*
Jankauskas et al., 2014	"The method of hardening soil rippers by surfacing and technical-economic assessment"	Hardfacing - Wear
Chernoivanov et al., 2015	"Features of wear of agricultural machinery components strengthened by Fe_n B-Fe-B composite boride coatings"	FenB–Fe–B boride coatings - Wear
Hrabě, et al., 2015	"Evaluation of techniques for ploughshare lifetime increase"	Hardfacing (overlay welding) - Wear
Zhang et al., 2015	"Abrasive wear characteristics of subsoiler tines with bionic rib structure surface"	Materials, Bionic ridge structure, Sobsoiler tine - Wear
Vlăduţoiu et al., 2015	"Increasing agricultural machinery active parts durability by hardening"	Hardfacing - Wear
Arifa et al, 2015	"Improvements of harrows wear resistance"	Material, Sharpening angle, Hardfacing - Wear
Abd El-Hameid, 2016	"Development of a mathematical model to predict wearing and energy requirements of some treated tillage tools"	Heat treatment and coatings - Wear
Kostencki et al., 2016	"Durability and wear geometry of subsoiler shanks provided with sintered carbide plates"	Coatings (with sintered carbide plates and by pad welding) - Wear
Pyndak and Novikov, 2016	"Tribotechnical and energy assessment of parts of working members of cultivating machines after carburizing and laser hardening"	Carburizing, Hardfacing - Wear
Zein El-Din et al., 2016	"Effect of new hard facing materials of tillage tools on draft and roughness"	Carbon nanotube, Hard chromium composite, Surface roughness - Draft force requirements
Yazıcı et al., 2017	"Effect of carbonitriding on corrosion resistance of steel 30MnB5 in two acidic environments"	Carbonitriding, Quenching-Corrosive wear in soil condition
Yazıcı and Çavdar, 2017	"A study of soil tillage tools from boronized sintered iron"	Manufacturing form (Sintering), Boronizing, Quenching - Wear
Yazıcı et al., 2017	"Corrosion resistance and mechanical properties of quenched and tempered 28MnCrB5 steel in two acidic environments"	Quenching - Corrosive wear in soil condition
Tabrizi et al., 2017	"Analytical and experimental draft force evaluation of plastic coated chisel tines"	Ultra-high molecular weight polythene coating- Wear - Draft force
Stawicki et al., 2017	"Tribological properties of plough shares made of pearlitic and martensitic steels"	Material - Wear
Waheed and Ezzat, 2017	"Wear of tillage tools coated by thermoplastic coatings"	Polyamide and Polyethylene coatings - Wear
Březina et al, 2018	"Application of ductile iron in the manufacture of ploughshares"	Heat treatment - Wear
Stawicki et al., 2018	"Wear resistance of selected cultivator coulters reinforced with sintered-carbide plates"	Coatings - Wear
Singh et al., 2018	"Effect of heat treatment on wear rate of different agricultural grade steels and associated cost economics"	Materials, Austenization temperature, Tempering temperature - Wear
Singh et al., 2018	"Effect of hard-faced Cr-alloy on abrasive wear of low carbon rotavator blades using design of experiments"	Hardfacing - Wear
Novikov et al., 2018	"Composition and Tribological Properties of Hardened Cutting Blades of Tillage Machines under Abrasive Deterioration"	Carburizing and Laser hardening - Wear
Marani et al, 2019	"Effect of nano coating materials on reduction of soil adhesion and external friction"	Nano-coated material-Soil conditions - Friction and adhesion
Malvajerdia et al., 2019	"Protection of CK45 carbon steel tillage tools using TiN coating deposited by an arc-PVD method"	Titanium nitride (TiN) coating - Wear
Sukumaran et al., 2019	"From single asperity to real scale in the wear of agricultural tine"	Real-scale test in the field, in-lab macro-scale test, and micro-scale single asperity test - Simulation of wear
Singh et al., 2020	"Tribological Performance of Hardfaced and Heat Treated EN-47 Steel Used for Tillage Applications"	Hardfacing, Carburizing- Wear
Singh et al., 2020	"Abrasive wear behavior of newly developed weld overlaid tillage tools in laboratory and in actual field conditions"	Hardfacing- Wear

3. DIFFICULTIES IN REACHING THE RESEARCH FINDINGS TO THE AGRICULTURAL SECTOR AND SOLUTION PROPOSALS

Despite approaches such as conservation agriculture (conservation agriculture: CA; covers no or minimum mechanical soil disturbance, biomass mulch soil cover, and crop species diversification applications) that aims to reduce field traffic, carbon footprint, fuel, and machinery operating costs, tractor tillage-based systems continue to be the basis of the farm machinery industry. According to Kassam et al., (2019), in 2015-2016, CA applications were conducted in only 12.5% of the total cultivation areas worldwide. The choice and use of wear-resistant materials, and again the use of high-cost coatings, also necessitates an economic optimization. For economic reasons, it is not always possible to use the most durable materials or coatings. Constraints and solution proposals for the transfer of research results into practice for reducing wear in tillage machines can be gathered under three main headings in relation to the stakeholders of the subject; structural problems of farms, structural problems of firms producing tillage machines and policies regulating the sector.

3.1. Structural problems of the farms

There are many large and small scale farms operating in the agricultural sector around the world. Farm sizes vary from a few decares to thousands of hectares. In total farm numbers, there is a significant share of small and medium-sized farms. According to the FAO (2015) report, in the world, the rate of farms doing agriculture in less than 2 hectares of land is 98% in China, 90% in Egypt and Ethiopia, 80% in India, 50% in Mexico, and 20% in Brazil. 80.7% of agricultural enterprises in Turkey are in business-size-groups smaller than 100 decares, and the land that these businesses hold in their hands accounts for 29.1% of the total land (TARMAKBİR, 2019). The poor economic purchasing power of small medium-sized farms limits the purchase of relatively expensive tools and equipment.

3.2. Structural problems of manufacturers

Agricultural machinery manufacturers are of a variety of sizes, ranging from small and medium-sized enterprises to multinational corporations. When looking at the structures of the companies that produce tillage machines, it is seen that the companies operating in the sector have very different scales. Large-scale firms have R&D culture to increase competitiveness and market share in both national and international markets and they benefit from research findings, information, and technology more (many also have their own R&D department). However, this is mostly unlikely for small-medium-sized machine manufacturers which are in a large number. In agricultural tools and machinery industry, making production in large numbers and small-scale enterprises, which are financially inadequate, negatively affects the R&D process and innovation-based production at the sectoral level. There is no employment of technical personnel in small-medium-sized companies or it is insufficient (TARMAKBİR, 2019). On the other hand, companies that manufacture and sell machines are under pressure to provide both advanced-quality and affordable products to the market.

3.3. Policies regulating the sector

In order to promote, support, and subsidize the agricultural sector, policies are produced by the states and various international organizations. But the budgets of allotted resources are limited, and state support is also closely related to economic development levels of the states. According to "Agricultural Policy Monitoring and Evaluation 2018" report of the OECD, producer subsidies increased rapidly over the past 15 years, from $255 billion in 2000–02 to $484 billion in 2015–17 in the 10 non- OECD (a mix of developing and emerging) economies, and was driven by a 16-fold increase in producer support in China. In all nine other non-OECD countries examined by the report in question, this support increased from $ 11 billion to $ 24 billion (OECD, 2018). Particularly, support and subsidies are not at the desired level in low and middle-income countries. Additionally, subsidies are generally received by wealthier farmers.

3.4. Solution Proposals

The following solutions can be highlighted, particularly for improving the welfare levels of small-medium-sized farms and machine manufacturers;

- Policies for farms; in accordance with regional-geographical conditions, development of policies that will raise the level of socio-economic welfare of farmers (development of rural development policies, strengthening agricultural production and trade policies for small and partial enterprises, arrangements supporting cooperative and organization), machine-equipment supports, promoting the use of common machinery, development of machine parks (the use of machines through leasing will reduce costs), virtual removal of farm boundaries to enable the use of highly equipped high capacity machines, subsidized agricultural loans, providing effective agricultural advisory services to farmers, and farmer training policies are important (TAGEM 2018; TARMAKBİR 2019). It can be suggested to raise awareness of farmers about choosing of machine that has wear-resistant tillage tools by preparing geographical maps showing soil abrasiveness, and to provide technical consultancy support to farmers as well as financial support for purchasing the machine.

- Policies for machine manufacturers; encouraging the companies with instruments such as R&D, renovation of their technological-production infrastructure, and technical personnel employment support, forming policies supporting university-industry cooperation that may be an important complementary element for R&D (TARMAKBIR, 2019), development of projects for transferring the research findings to the sector, development of policies to encourage companies to cluster and specialize can be suggested. Information production and information transfer (nationally, regionally, and internationally) should be encouraged in cooperation between public-universities-private sectors. The fact that machine manufacturers expand through mergers and acquisitions, adopt export-oriented strategies, and have broad sales networks will increase their competitiveness in the market. Only the firms whose economic-financial indicators have improved can turn to R&D investments.

4. CONCLUSION

The following issues can be highlighted as a result of this study focusing on the review of the wear studies on tillage tools and evaluation of the difficulties-constraints of the transferring of the results of those studies to the agricultural sector in Turkey;

- Development of policies to strengthen the weak economic purchasing power of small-medium scale farms, and the weak financial structures of small-medium scale machine producers,
- Development of policies that reduce environmental harm, reduce costs, and encourage the transfer of simple and logical new information and technologies to the sector,
- Development of realistic wear models, implementing approaches that increase wear resistance in tillage tools, and that reduce fuel consumption, and the use of new production technologies suitable for automation that reduce costs can be suggested.

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