A POTENTIAL RESEARCH AREA UNDER SHADOW IN ENGINEERING: AGRICULTURAL MACHINERY DESIGN AND MANUFACTURING

H. Kursat CELIK[1,*] Allan E. W. RENNIE[2], Ibrahim AKINCI[1]

[1,]Dept. of Agricultural Machinery & Technology Engineering, Faculty of Agriculture, Akdeniz University, Turkey*
[2]Lancaster Product Development Unit, Engineering Dept., Lancaster University, United Kingdom

Corresponding Author	*: Dr H. Kursat CELIK, Assoc. Prof.*
e-mail	*: hkcelik@akdeniz.edu.tr*
Tel	*: +90 242 310 65 70*
Fax	*: +90 242 227 45 64*
Address	*: Department of Agricultural Machinery & Technology Engineering, Faculty of Agriculture, Akdeniz University, 07070, Antalya, Turkey*

Abstract

As a branch of the global machinery industry, the agricultural (farm) machinery design and manufacturing or agricultural engineering industry has become one of the most important industries to be supported and focussed on in the era of hunger threats foreseen in the World’s future. In order to produce sufficient volumes of food from current limited agricultural land, well-designed machinery and high technology-supported mechanisation of the agricultural production processes is a vital necessity. However, although novel improvements are observed in this area, they are very limited. There is a lack of implementation of advanced engineering design and manufacturing technologies in this industry, therefore agricultural engineering could be considered a potential engineering research area with this in mind. This study aims to highlight the potential, gaps, sector specific challenges and limitations of the agricultural engineering research area at a macro level. Under consideration of the sector-specific indicators, the study revealed a major result: there is an insufficient level of sector-specific research on implementation strategies for up-to-date design and manufacturing technologies.

Keywords: Agricultural Mechanisation, Agricultural Engineering, Farm Equipment Market, Food Production, Technological Trends, Advanced Design and Manufacturing.

INTRODUCTION

One of the most prevalent issues facing us in modern times is the rapidly increasing World population which is expected to reach 8.5 billion by 2030, 9.7 billion in 2050 and by 2100 the world's population is predicted as 11.2 billion, approximately 33 percent higher than the current 2019 population of more than 7.5 Billion (UN, 2017). As such, a key question is posed: How to feed the global population in the era of hunger threats which is not difficult to foresee in the world's future growth? The answer is clear - producing sufficient food to meet the demands of population growth, which leads us to focus on the agricultural sector.

Agriculture, also known as farming, can be defined as the production of food, fibre, animal feed, and other goods by means of growing and harvesting plants and animals. The English word 'agriculture' derives from the Latin *ager* (field) and *colo* (cultivate) signifying, when combined, the Latin *agricultura*: field or land tillage. The word 'agriculture' is defined in The Oxford English Dictionary (1971) as "The science and art of cultivating the soil, including the allied pursuits of gathering in the crops and rearing live stock; tillage, husbandry, farming (in the widest sense)" (Harris and Fuller 2014). In any sense, agriculture is related to the core of food production and is a prerequisite for civilisation and sustainable life for human beings since the first records of civilisation history.

The origins of agriculture are visible to us today only from archaeological digs and studies of foraging societies and groups that survive into the Twentieth Century and the findings show to us that farming first developed in the "fertilecrescent" of Mesopotamia, where the local flora and fauna included the wild progenitors of the main domesticated food crops and animals (Tauger 2011). Although all crops were produced and prepared by human and animal power for these first-known farming applications, archaeological findings also indicate the use of several tools in the agricultural production phases such as primitive tillage and sharp cutting tools. This shows that humans have been working on the mechanisation of agriculture since the first agricultural applications.

Mechanisation of the agricultural domain can be defined as the process of using different kinds of highly efficient machineries compared to primitive or traditional equipment used in the agricultural production phases. In addition to new patterns of crop rotation and livestock utilisation, the importance of such mechanisation was well understood during the Green Revolution in the world. The term Green Revolution refers to the renovation of agricultural practices beginning in Mexico in the 1940s. The beginnings of the Green Revolution are often attributed to Norman Borlaug, an American scientist interested in agriculture and then Green Revolution technologies spread worldwide in the 1950s and 1960s. Significant effects on increasing the amount of calories produced per decare of agricultural fields were also observed (Sarkar 2016; Briney 2019).

With the Green Revolution, agriculture workers laboured six days a week, from sun up to sun down, just to keep their crops growing, therefore working in agriculture was not just a job, but often a lifestyle for families (Pollard 1981). Because of the difficulties associated with agricultural work, it became necessary to innovate the agricultural industry, such that the agricultural revolution helped contribute to the industrial revolution through innovations and inventions that altered how the farming process worked (FoWC 2019). After three revolutions were experienced in the industry in 1784, 1870 and 1969 respectively, these days we also refer to the fourth revolution: Industry 4.0 where it encompasses a range of new technologies that combine the physical and digital worlds. There was no doubt since the first emergence of industry 4.0 that this would also effect the agricultural production and agricultural engineering industry: Agriculture 4.0.

The agricultural engineering industry or agricultural machinery design and manufacturing industry (AMD&MI) is the part of the industry that design, produce and maintain agricultural tractors, agricultural machinery systems and agricultural tools/equipment used in the agricultural production phases. This branch is considered to be part of the global machinery design and manufacturing industry.

During the aforementioned industrial revolutions, although innovative developments in the AMD&MI were witnessed, they were very limited, not spread worldwide and it would be difficult to talk about a parallel technological and engineering advancement with other industrial branches of material science, machinery design and manufacturing industries. Most especially, it is seen the lack of implementation of advanced engineering design, manufacturing and automation technologies in the AMD&MI sector (relative to the other machinery industries).

Most of the agricultural machinery manufacturers are classified as small and medium-sized enterprises in Turkey (AEA 2017; Ileri 2018) as they are in many other countries. It would be true to say that this industry does not have a high level of competitive power in the global marketplace. Again, one of the most important reasons is that the use of advanced engineering design, manufacturing and automation technologies has not become a mainstream requirement for them in producing high quality functional agricultural machinery systems. However, related statistics also indicate that the AMD&MI has hidden potential for professional commercialism and being a profit centred sector. Hence, agricultural engineering research areas could be considered as potential engineering research areas.

In this study, initial discussions were conducted in consideration of some of the key statistics related to agricultural indicators and the agricultural machinery market globally and then focused specifically on Turkey's current situation, as this industry and research area in Turkey shows promise because of the agricultural production potential of the country.

AGRICULTURAL AREA

Agricultural area can be defined as the sum of areas considered as arable land and permanent crops and permanent pastures. China is the top country by agricultural area in the world. As of 2016, the agricultural area in China was 518 552 thousand hectares, that accounts for 11 % of the world's agricultural area (approximately). The top five countries (others are the United States of America, Australia, Brazil, and Russian Federation) account for 37.5 % of it. Total Agricultural area in Turkey and in the United Kingdom is 38 327 and 17 345 thousand hectares respectively, in 2016. The world's total agricultural area was estimated at 4.87 billion hectares in 2016 (FAOSTAT 2019; Knoema, 2019). Predictions state that there is still scope for further expansion of agricultural land. However, there is also a perception, at least in some quarters, that there is no more, or very little, land to bring under cultivation (FAO 2019). A threatening indicator here is that the agricultural area in the world has been decreasing when considered against the increase in the world's population. When the last 20 years data is considered, it is seen that the total agricultural area was 4.91 billion hectares in 1996, 4.95 billion hectares in 2000 and 4.87 billion hectares in 2016. The corresponding total global population was 5.83 billion in 1996, 6.14 billion in 2000 and 7.45 billion in 2016. This shows that the agricultural area per person was 0.81 hectares in 2000 and 0.65 hectares in 2016. This means that agricultural area experienced 20 % decrease against 18 % increase in world population between the years 2000 and 2016 approximately. The graphical representations related to this situation are given in Figure 1.

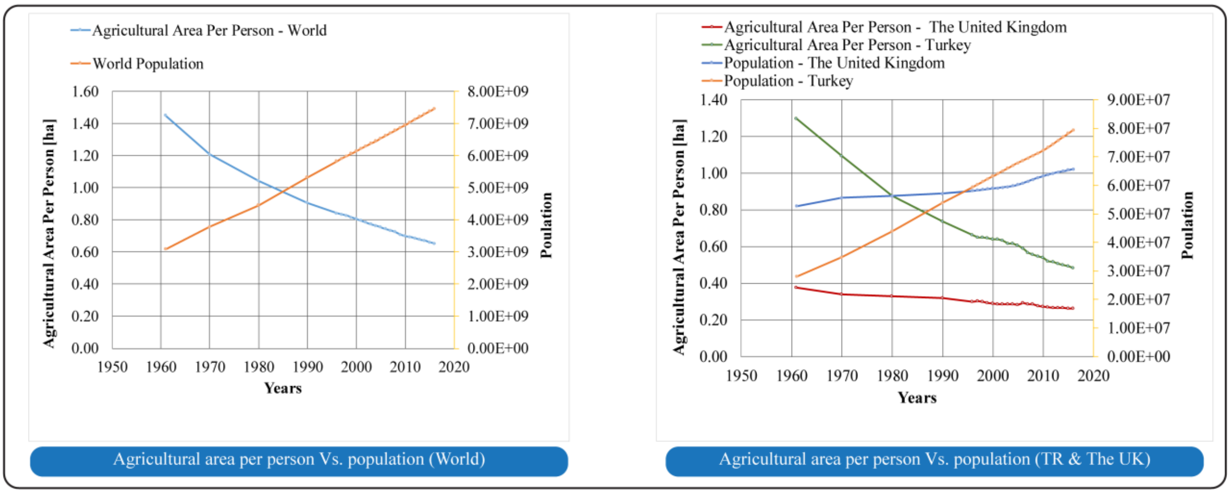


Figure 1. Agricultural Area per person Vs. World population (1961 - 2016)

URBAN AND RURAL POPULATION

Related statistics shows that the world's population was predominantly rural for decades (more than 60%), however, the most recent data indicates that there is a change in this situation. Today, more than half of the population (54 %) is urban and it is predicted that more than two-thirds of all people may be living in urban areas by 2050 (FAO 2017). Rapid population growth changes the population structure as well. In this structure, it can be seen that most of the younger generation are expected to live in sub-Saharan Africa and South Asia, particularly in rural areas, where jobs will likely be difficult to find. Related reports from FAO highlight that without sufficient employment opportunities, this population trend may lead to a more rapid rate of outmigration which may be considered as a potential problem for world's future (FAO 2017). Another point in urbanisation is its impact on food consumption patterns. Higher urban income tends to increase demand for processed foods, as well as animal-source food, fruit and vegetables, as part of a broad dietary transition. Graphical representation of the population growth, urban and rural population projections globally are given in Figure 2.

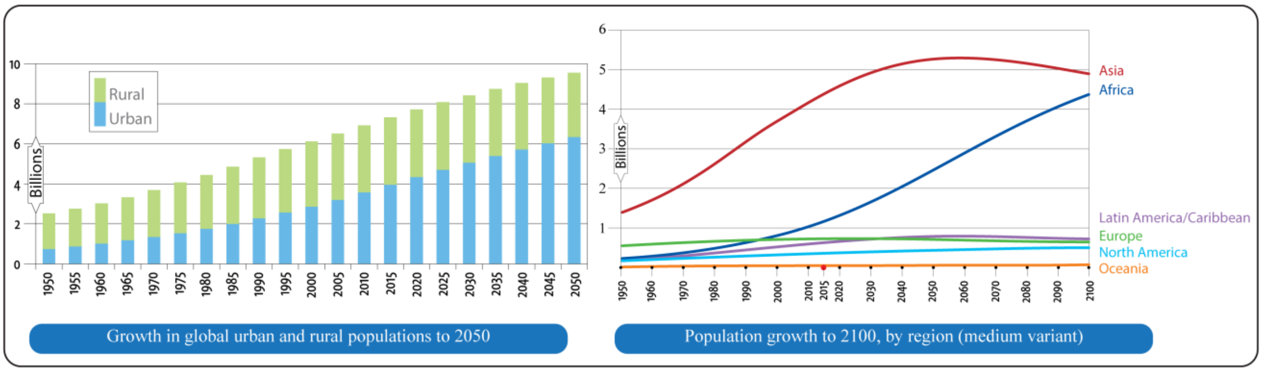


Figure 2. Population growth, urban and rural population projections (FAO 2017).

AGRICULTURAL PRODUCTION AND THE DEMAND FOR FOOD

The High-Level Expert Form in 2009 revealed the following projections: feeding a world population in 2050 would require raising overall food production by some 70% until 2050. Additionally, the reports highlighted that agricultural production in the developing countries would need to almost double. The facts show that annual cereal production, for instance, would have to grow by almost one billion tonnes, meat production by over 200 million tonnes to a total of 470 million tonnes by 2050, 72% of which would be in developing countries, up from the 58% today. The demand for other food products that are more responsive to higher incomes in the developing countries (such as livestock, dairy products and vegetable oils) will grow much faster than that for cereals. Feeding the world population adequately would also mean producing the kinds of foods that are lacking to ensure nutrition security (FAO 2009). Another important problem is the number of undernourished people in the world which has been on the rise since 2014, reaching 821 million in 2017 and estimated to reach 900 million by 2023 (FAO 2018; Ileri 2019). A large proportion of the world population is affected by micro-nutrient (vitamin and mineral) deficiencies. This is often called "hidden hunger" because there may be no visible signs (FAO 2018). The FAO projections for food demand for the different commodities mention that the per capita food consumption (kcal/person/day) will grow significantly. The world average would reach 3000 kcal by 2015 and exceeding 3000 kcal by 2030. These changes in the world averages will reflect all the rising consumption of the developing countries, whose average will have risen from the 2680 kcal in 1997/99 to 2850 kcal in 2015 and close to 3000 kcal in 2030. In addition to projections for food production and consumption volumes, water issue is another significant problem. The statistical projections also indicate that in 2025, 1.8 billion of the world population and in 2050, half of the world population would experience limitations to reach water sources (Ileri 2019). Some selected data which shows current and future projections for food production, food consumption and the number of undernourished people in the world are given in Figure 3.

Figure 3. Current situation and future projections of food production, food consumption and the number of undernourished people in the world (FAO 2009; FAO 2018a).

AGRICULTURAL MECHANISATION LEVEL

Agricultural mechanisation involves the use of tools, implements and machines to improve the efficiency of human time and labour. Mechanisation is a crucial input for agricultural production and one that has historically been neglected within the context of developing countries for a long time (Negrete 2018). Most especially when considering the hunger threats on the world's future, one of the key achievements would be use of modern, well-engineered machinery systems in order to produce higher-yield products per hectare from limited agricultural areas. The mechanisation level of the countries in agricultural production can be explained through specific indicators such as total number of agricultural tractors, average tractor power, tractor numbers/power per unit of agricultural area, number of agricultural machineries (implements), mass of the agricultural implements per tractor, tractor operating hours per year, etc. Most especially, agricultural tractors are the main technology and mobile power source for the farmers. According to the most recent data, it would not be wrong to assume that in most countries, the situation regarding the number of agricultural tractors remains largely the same as it was in 2000. The FAO statistics show that Europe was the leader in the number of operational tractors between the years 1961 and 2000 (FAO, 2018b).

In Turkey, 37.8 million hectares of area is in use for agricultural production. 81% of the farms in Turkey have less than 100 decares, classified within the group of small enterprises. Cereals and fruits are the most common products grown in Turkey. Cereals (66.4%), fruits (14.3%), vegetables (3.4%) and flowers are grown in agricultural areas totalling 23.4 million hectares (fallow area is 15.7%) (TUIK 2019). There is promising potential for agricultural production in Turkey, however, the level of existing mechanisation is not promising. Akdemir (2013) reports that, although the agricultural mechanisation level in Turkey looks greater than most of its neighbours, its mechanisation level is still behind most developed countries according to agricultural mechanisation indicators. Oguz *et al* (2017) reports that tractor operating hours per year in developing countries is 1000 hours and the mass of the agricultural implements per tractor is more than 10 tonnes, with corresponding values in Turkey equating to 350 hours and 4.5 tonnes respectively. The number of agricultural machinery per tractor is approximately 5 units, with average tractor power of 43.3 kW, average farm size is 59 decare and the number of tractors per thousand hectare of agricultural area is 41 units in Turkey. The corresponding values in developed countries are 15 units, 77 kW, 174 decare and 81 units respectively. Additionally, the number of combine harvesters per thousand hectares is only 0.7 units in Turkey, this indicator being 14 units in the EU member states, 4 units in the USA and 3 units in Canada (Oguz *et al* 2017). Using 2018 statistics, the total number of agricultural tractors, total number of agricultural machinery and total number of combine harvesters in use in Turkey are 1.33 million units, 11 million units and 17.3 thousand units respectively (TUIK 2019). This data can be considered an indication of insufficient mechanisation levels in Turkey. In relation to tractor population, some the key graphical representation of related data is given in Figure 4.

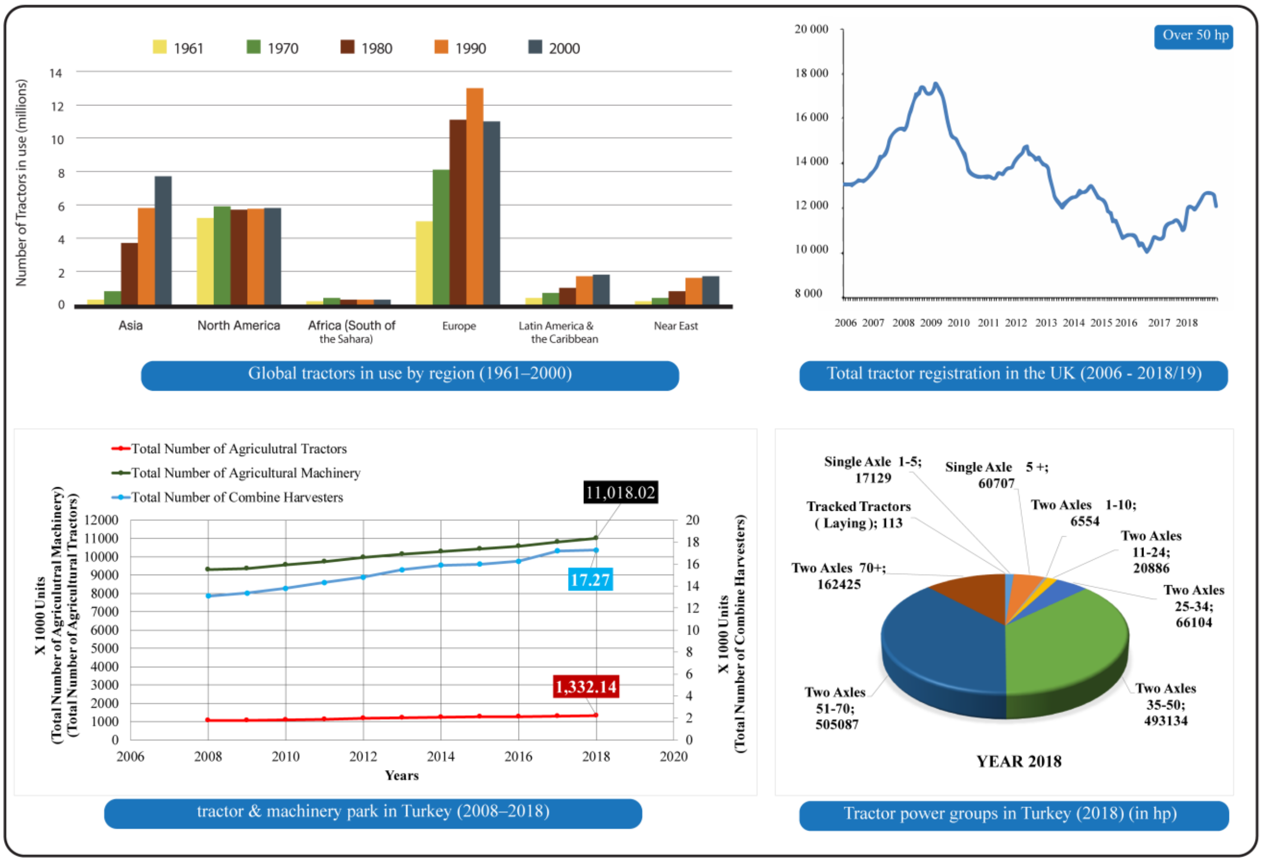


Figure 4. Tractor population

AGRICULTURAL MACHINERY DESIGN & MANUFACTURING INDUSTRY (AMD&MI)

The machinery industry is an essential sector producing investment goods among the industrial sectors and thus has a strategic importance. According to NACE-Rev2 (Nomenclature des Activités Économiques dans la Communauté Européenne), manufacture of agricultural and forestry machinery is a sub-branch of "The manufacturing of machine and equipment not elsewhere classified" (Tuncel and Polat 2016). Parameters related to agricultural tractors is the key indicator of the agricultural mechanisation level of the countries, hence the agricultural tractor market is the leading market in the agricultural machinery industry. The Global Agricultural Tractor Market was valued at USD 55.37 billion in 2018 and is expected to register a CAGR of 5.8% during the forecast period of 2019-2024. China and India have been at the forefront in the number of tractors being sold with approximately 1.3 million tractors in China and over 600,000 tractors in India every year (Mordor Intelligence 2019). Increasing farm mechanisation rates, especially in developing countries, coupled with increasing costs of farm labour can be considered a supportive factor for this growth. However, fragmentation of land holdings and the heavy dependence of the market on commodity prices would be a limiting factor in this situation. Charts related to size of the global agricultural tractor market is given in Figure 5.

Categorisation of agricultural machinery can be made with consideration to the agricultural practice size in the world: Large-Scale, medium-scale and small-scale. Ozogul (2018) reports that large-scale machinery manufacturing practices can be found in USA and Canada, medium-sized machines are manufactured in Europe both by European companies and companies affiliated to US companies. Mexico, Brazil and Argentina can also be included in this category. The leader of the small-scale equipment market is Japan. On the other hand, South Korea, India, Taiwan and China could increase their share in small-scale machinery manufacturing.

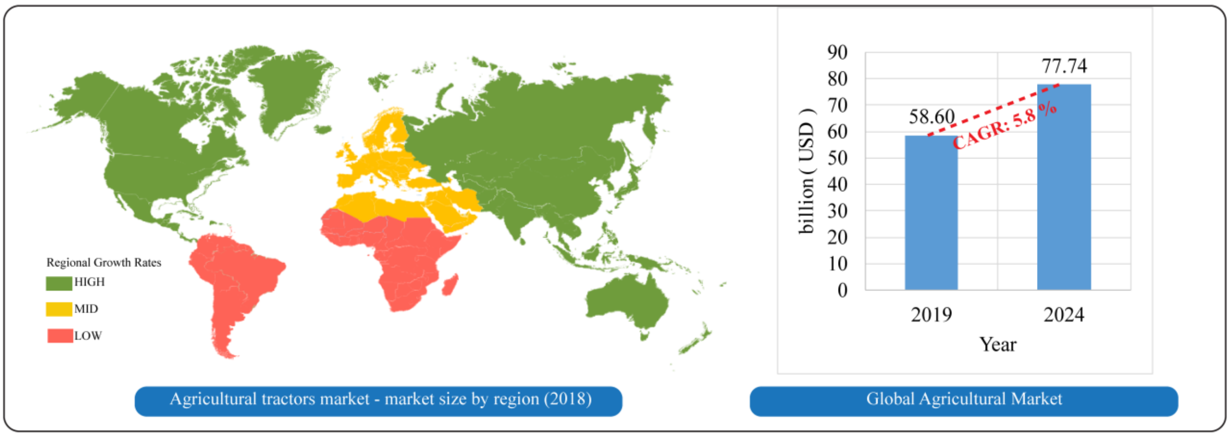
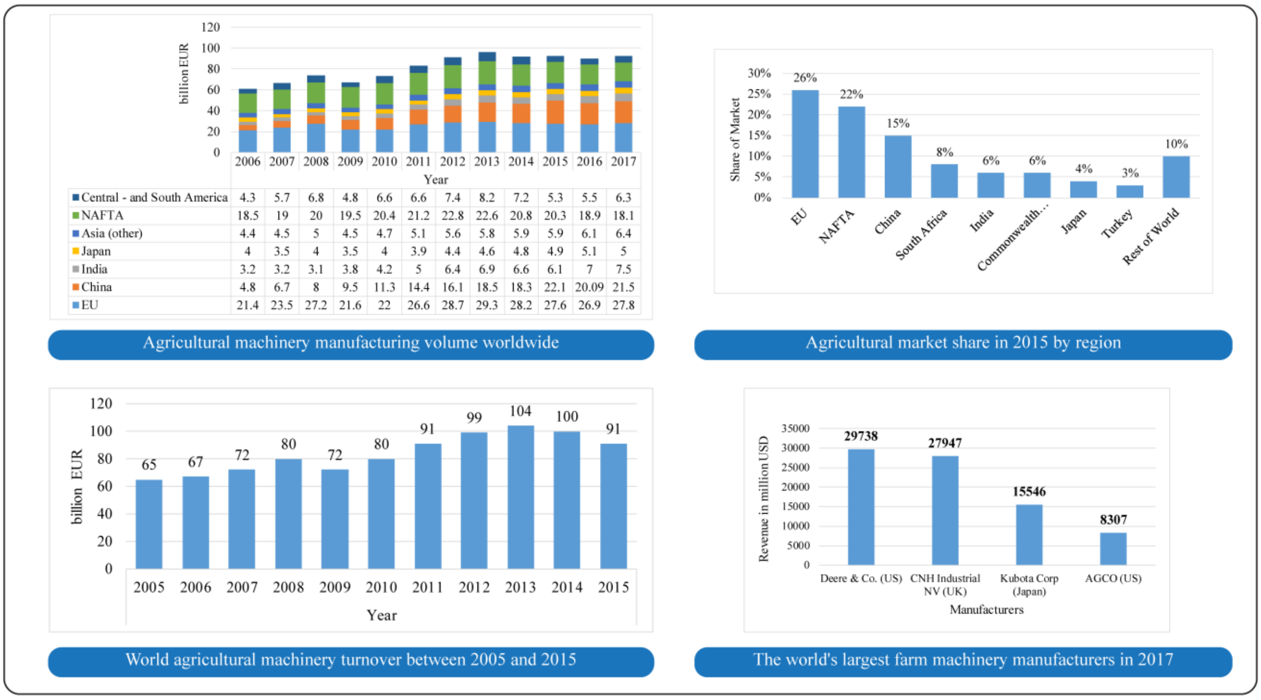


Figure 5. Global Agricultural Tractor Market

Another key indicator of the mechanisation level is agricultural equipment/machinery statistics. According to regional agricultural practice capacity, the market share varies. The global agriculture equipment/machinery market is expected to reach USD 243.4 billion by 2025, according to a report by Grand View Research Inc. The report predicts that global agriculture equipment is expected to grow at a CAGR exceeding 7% from 2016-2025, due to technological advancements in agriculture, automation and robotics (GVR 2019). It is observed in Figure 6 that the world's largest agricultural machinery manufacturers in 2015, based on revenue, is the Deere Corporation who generated approximately USD 30 billion in revenue and was ranked highest. The EU has the top market share according to regional statistics in 2015 (Kiss *et al* 2018; Statista 2019).



	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Central - and South America	4.3	5.7	6.8	4.8	6.6	6.6	7.4	8.2	7.2	5.3	5.5	6.3
NAFTA	18.5	19	20	19.5	20.4	21.2	22.8	22.6	20.8	20.3	18.9	18.1
Asia (other)	4.4	4.5	5	4.5	4.7	5.1	5.6	5.8	5.9	5.9	6.1	6.4
Japan	4	3.5	4	3.5	4	3.9	4.4	4.6	4.8	4.9	5.1	5
India	3.2	3.2	3.1	3.8	4.2	5	6.4	6.9	6.6	6.1	7	7.5
China	4.8	6.7	8	9.5	11.3	14.4	16.1	18.5	18.3	22.1	20.09	21.5
EU	21.4	23.5	27.2	21.6	22	26.6	28.7	29.3	28.2	27.6	26.9	27.8

Figure 6. Global Agricultural Machinery Market

In addition to market share statistics, worldwide agricultural machinery export and import values are important parameters in order to understand the capacity of the sector. Table 1 gives the export and import values between 2013-2015 (Ozogul 2018). Data given in Table 1 shows that China, USA and Germany are the top three countries in export respectively. Import values indicate that the top three countries are USA, Germany and France respectively. Turkey takes 31st place and 30th place in export and import activates of the global agricultural machinery market, respectively.

Table 1. World agricultural machinery export and import values by country

World agricultural machinery export by country (Value: Million USD)					World agricultural machinery import by country Value: Million USD)				
	Country	**2013**	**2014**	**2015**		**Country**	**2013**	**2014**	**2015**
1	China	2209	2342	2282	1	USA	4181	4324	4067
2	USA	1578	1620	1504	2	Germany	3169	3118	2584
3	Germany	1451	1498	1331	3	France	3342	3071	2556
4	Japan	715	690	625	4	Canada	2971	2660	2236
5	Netherlands	672	673	568	5	England	1499	1855	1638
6	South Korea	560	573	527	6	Russian Federation	2288	1900	1079
7	France	581	581	506	7	Australia	966	1013	1013
8	Hong Kong	535	524	499	8	Belgium	1150	1183	1013
9	England	548	511	466	9	China	826	820	885
10	Italy	518	530	459	10	Poland	957	981	852
11	Canada	457	474	407	11	Mexican	694	737	771
12	Belgium	469	473	400	12	Netherlands	897	902	722
13	Mexican	380	397	381	13	Italy	672	721	645
14	Singapore	410	410	347	14	Austria	767	743	638
15	Russian Federation	527	498	334	15	Swedish	660	723	633
16	Swiss	358	311	292	16	Spain	570	586	542
17	Taiwan	305	313	280	17	Czech Republic	563	585	532
18	Spain	311	319	278	18	Denmark	662	640	527
19	India	337	318	264	19	Ukraine	761	475	448
20	Saudi Arabia	378	347	213	20	Japan	338	381	397
31	Turkey	152	158	144	30	Turkey	444	322	283
	Grand total	**82254**	**81215**	**69893**		**Grand total**	**40760**	**40109**	**34654**

Like many countries, in Turkey, the machinery sector is one of the growth sectors of the manufacturing industry. In order to represent the Turkish machinery sector worldwide, the Turkish Mechanical Industry Platform turned into a Federation in 2014 (MAKFED). 16 sub-sectoral associations which represent machinery manufacturers are members of MAKFED. The latest report from the Turkish Machinery Exporters Association in Turkey (MAIB) shows that Turkey is the 18th largest economy in the world and the 6th biggest economy in Europe, according to gross domestic product (GDP) in 2018. GDP, which was USD 200 billion in 2001, more than tripled and reached USD 851 billion by 2018. GDP per person in Turkey which was USD 3500 in 2002 soared to USD 10546 in 2017. Machinery is the second largest sector in Turkey’s export portfolio. Production in the Turkish machinery sector more than doubled in 10 years. Turkey exports to more than 200 countries (including free zones). Turkey’s machinery export, Germany, USA, England, Italy and France are among the top five countries in 2018. Turkey’s machinery export, which was USD 8.1 billion in 2009, has reached USD 17.1 billion in 2018 (MAIB 2019). The statistics related to Turkey’s general machinery export share are given in Figure 7.

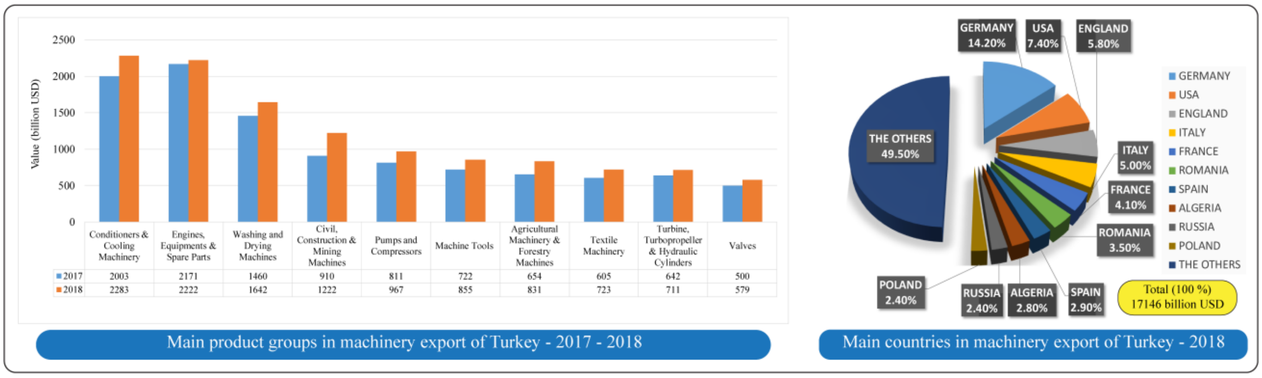


Figure 7. Turkey´s general machinery export share by country

According to sub-sectoral machinery exporters (MAIB 2019), Turkish AMD&MI takes 7th place in Turkey in 2018. 130 different types of agricultural machinery and equipment include agricultural tractors (tillage machinery, tools and equipment, fertiliser machines and equipment, seeding machinery and equipment, mowers, livestock machines and equipment, combine harvesters, postharvest processing machines and equipment, irrigation equipment, etc.) are produced under the AMD&MI in Turkey. According to the Turkish Ministry of Industry and Technology (entrepreneur information system, 2017) under NACE 2830, approximately 20 thousand people work in the AMD&MI and there are 1161 manufacturers in total in this sector. In Turkey, most of the agricultural machinery manufacturers are classified as small and medium-sized enterprises. In addition to tractors and accessories export value (approximately USD 150 million), sectoral export value has reached approximately USD 830 million in 2018 and export range was expanded to 120 different countries. In the export range of the AMD&MI, the top three countries are USA, Azerbaijan and Italy in recent years (Figure 8). The import share of Turkey in this sector also has significant value. Total import share in 2015 was USD 283 million and top three importer countries are USA, Germany and Canada (TRMoE 2016; MAIB 2019; TARMAKBIR 2019).

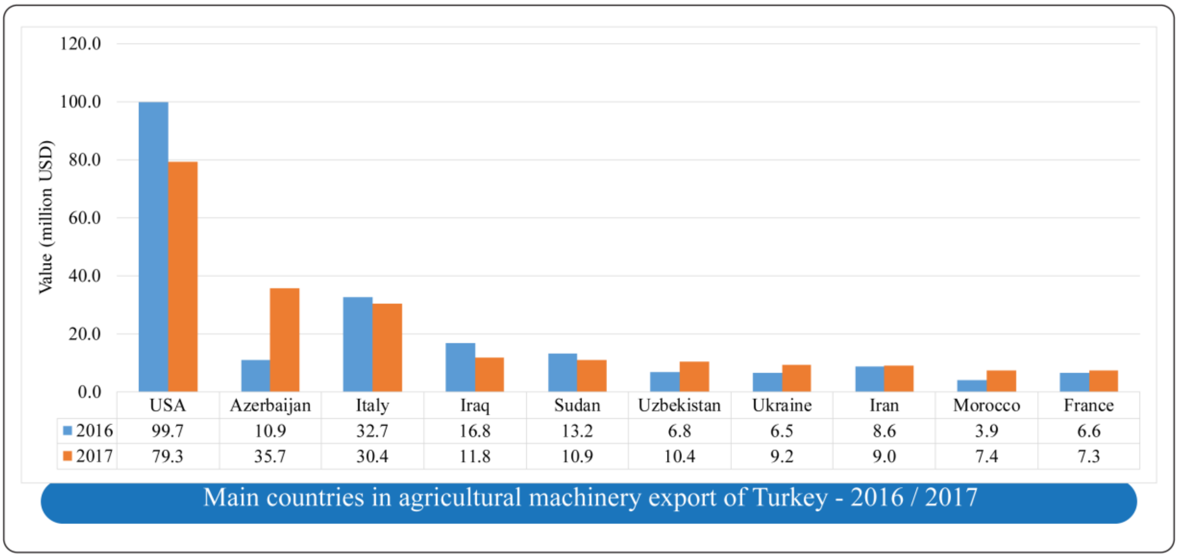


Figure 8. Turkey’s agricultural machinery export share by country

TECHNOLOGICAL TRENDS, ITS EFFECT ON THE AGRICULTURAL PRODUCTION AND LIMITATIONS

It is well known that the research and development activities in industry have a vital role and the major trigger mechanism in technology development and future trends are dependent on market, manufacturers visions and capability and legislation. Most especially, innovative developments in AMD&MI within recent years showed that trends are mostly focusing on Industry 4.0 aspects such as precision agriculture, mobile and web applications for agriculture, digitalising crop varieties and yield, forecasting farm weather and modelling, Geographical Positioning Systems and Geographic Information System (GNSS/GIS) applications, remote sensing, automated tractors and farm equipment, robotics, data mining and warehousing, and Internet of Things (IoT). Many countries such as USA, Canada, The Netherlands, England, and Germany have already applied some of these advanced technologies in agricultural production, and have been able to improve their agricultural technology, reducing the total cost of agricultural production, and increasing farm size successfully. The graphical representation of the agricultural "treadmill" based on present day technological boosts achieved through mechanisation, plant breeding for high-yielding varieties, the use of agrochemicals and genetic engineering, etc. is given in Figure 9 (Chen 2018). In addition to the digital and sensor based electronics technology, adaptation of advanced design and manufacturing technology is another important issue in AMD&MI. Ozogul (2018) mentions this issue under further development of machinery: optimisation of machinery where they take place as one of the routes in order to reach the objectives in effective agricultural production (Figure 9).

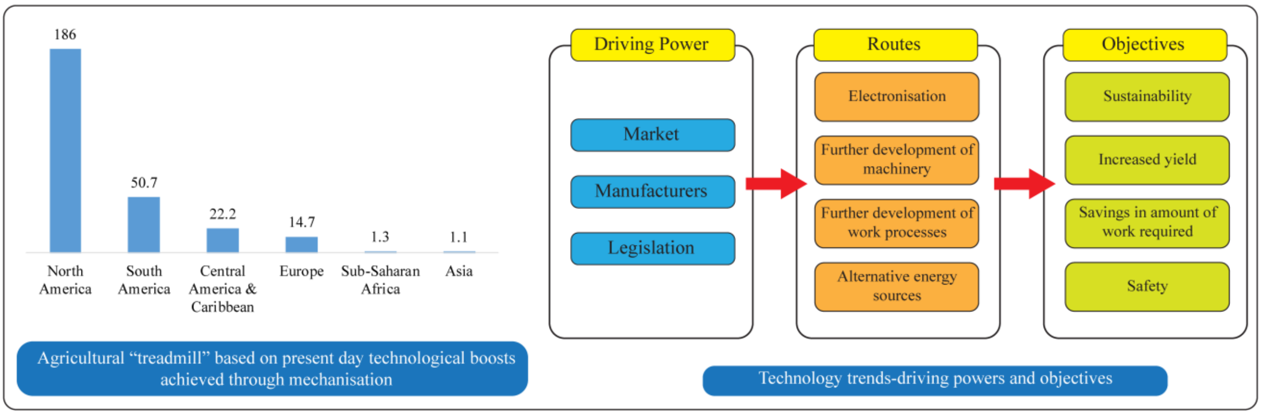


Figure 9. The agricultural treadmill and Technology trends-driving powers and objectives.

Compared with developed countries, there are significant limitations to the application of these present-day technologies in the mechanisation of agricultural production units in many parts of Africa, Asia and Latin America, this situation is same for the Turkish AMD&MI. The machinery industry is an engineering-based industry, however, Turkey is not a country which provides sufficient resources for macro-scale R&D in this context (Tuncel and Polat 2016). Although some exceptions could be seen in the sector, it would be true to say that use of advanced engineering and manufacturing applications based on R&D in the realisation of new products or unique product development is clearly absent in the AMD&MI in Turkey. Within this frame, some of the future predictions regarding sectoral needs are specified in the agricultural machinery sector report: (1) utilising higher capacity agricultural machinery for agricultural production; (2) informatics and mechatronics applications; (3) R&D, innovation and university-industry collaborations; and (4) expectation for a decrease in the number of small manufacturing companies related to AMD&MI in Turkey, which are also highlighting the capital potential of the sector (Ileri 2018).

The fact here is that the AMD&MI in Turkey suffers from a lack of professional leadership and management in modern technology, and the ability to tackle problems in optimal design and manufacturing issues. Some of the major reasons for this can be listed as follows: (1) Lack of investment in technology implementation; (2) Lack of qualified and/or trained staff in this technological field; (3) Advanced Computer Aided Design/Engineering (CAD/CAE) and manufacturing technologies are still in their infancy within the sector; (4) Insufficient level of sector-specific research highlighted benefits to be derived from utilisation; (5) Insufficient level of sector-specific research on implementation strategies for up-to-date design and manufacturing technologies; (6) Family-based institutionalised companies which show resistance to change. Further, it is seen that a sector-specific systematic approach cannot be established without showing the advantageous benefits from previous research related to design optimisation and advanced manufacturing processes such as Additive Manufacturing (AM) technology within the agricultural machinery sector.

AM (or 3D printing) is a promising technology trend today, and since the late 1980s, AM has been penetrating the world of manufacturing. Today all classes of engineering materials, such as plastics, metals, ceramics, and even non-traditional materials, such as food, drugs, human tissue, and bones, can be processed using AM technology (Gebhardt and Hötter 2016). AM usage in various industries is on the rise, steadily increasing over recent years. In order to highlight the trend in AM in different research areas, 150 scientific research papers in total covering the years between 2005 and 2019 were reviewed in this study (Science Direct and Google Scholar search engines). The results showed that there is a rise in the number of publications in recent years. The number of papers were 12, 24, 32 and 67 respectively in 2015, 2016, 2017 and 2018 in different research areas, however, there were no research publications related to the agricultural machinery research area. When considering the major manufacturing industries, statistics show that the use of AM technology is rapidly increasing and manufacturing industry is adopting this technology to itself (Figure 10) (Ultimaker 2019). In this context, integration/implementation of an advanced design strategy and AM technology in manufacturing processes for the development of AMD&MI is a necessity, not an option and that meeting current and future needs in developing countries including Turkey, is required.

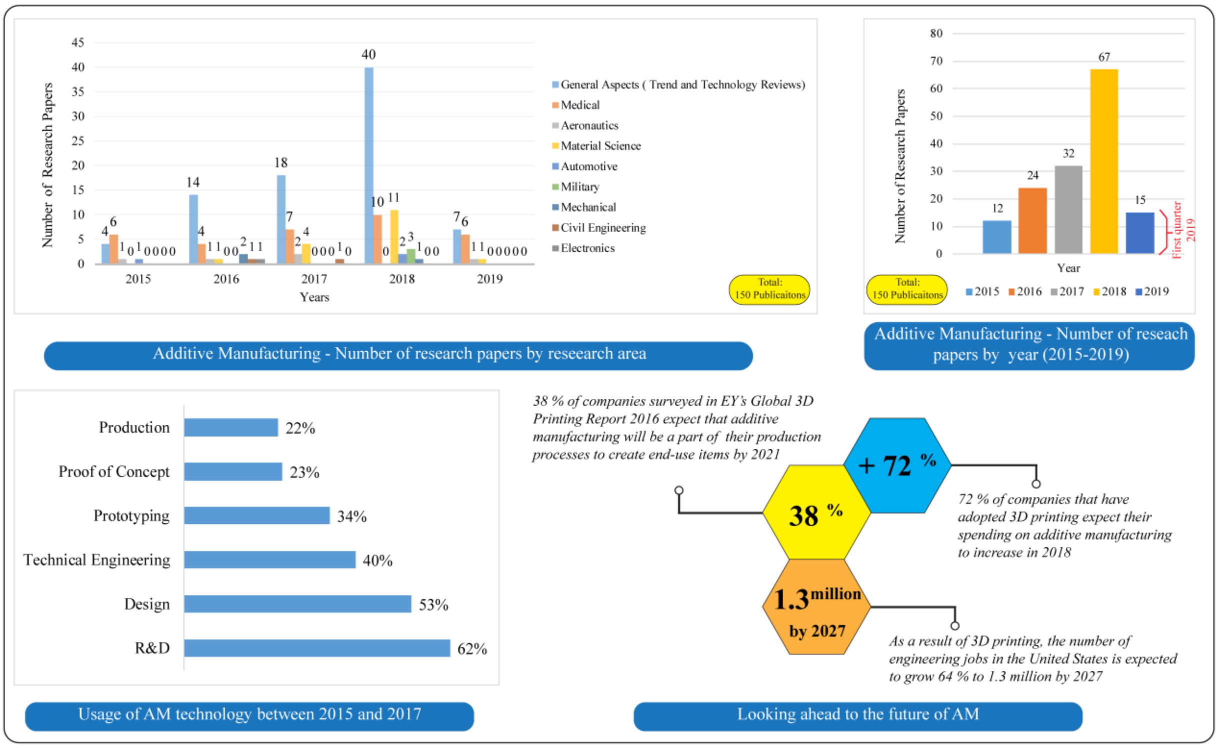


Figure 10. Trend manufacturing technology: Additive Manufacturing

CONCLUSIONS

The statistics and future projections given above underline some of the key facts: Agricultural area per person has an increase against the growth in population; the increase in urban population future projections indicate less labour in rural areas for agricultural production; the number of undernourished people in the world has been on the rise since 2014, significant rise in food production and yield of agricultural fields have to be realised in order to mitigate against the hunger threat. As a result of urbanisation in the world population, hiring labour for agricultural work is becoming expensive, farmers are looking for cheaper alternatives by adopting machinery. There is no doubt that, in order to produce sufficient volumes of food from currently available agricultural land, well-designed machinery and high-technology supported mechanisation for agricultural production is one of the most vital necessities. In this context, it would be true to say that AMD&MI should be equipped with advanced design and manufacturing technologies so that they can manage to provide high-technology, precision and higher capacity machinery systems for efficient agricultural production in our limited production-capable land. The FAO reports that the research agenda for the future will be more comprehensive and complex than in the past because the resource base of agriculture and the wider environment are so much more stretched today compared with the past. Effective exploitation of advances in information, communication and agricultural machinery design and manufacturing technology will be necessary. Agricultural mechanisation is not an end in itself, but a means of development. As an example of a prime manufacturing trend, the adoption of AM technology in the workplace will continue to expand into varying industries. These types of advanced design and manufacturing technologies should urgently be adopted by AMD&MI in order to realise well-designed and optimised agricultural machinery systems which would help to increase the yield of agricultural production in limited areas. Therefore, having a certain level of R&D activities is important. Under consideration of the sector specific indicators reviewed in this study, the major results reveal that there is an insufficient level of agricultural mechanisation and sector-specific research on implementation strategies for up-to-date design and manufacturing technologies in the AMD&MI, most especially in Turkey, like many developing countries.

Acknowledgements

This study is an originally prepared full text research which is the extended version of an abstract publication of Journal of Material Science and Nanotechnology (2019, Vol. 3: 22) and the abstract was presented in 2nd International Conference on Materials Science and Materials Chemistry (ICMCMS 19) (March 20-21, 2019, London, United Kingdom). Additionally, the authors wish to acknowledge that this study is partly supported financially by The Scientific Research Projects Coordination Unit of Akdeniz University (Turkey).

REFERENCES

AEA (The Agricultural Engineers Association). (2017): Market Report 2017- Overview of the agricultural engineering market 2017, Available at http://www.aea.uk.com/news-home

AEA (The Agricultural Engineers Association). (2019): Tractor Statistics, Available at: https://aea.uk.com/industry-insight/tractor-statistics

Akdemir, B. (2013): Agricultural mechanization in Turkey. IERI Procedia, 5: 41-44.

Briney, A. (2019): All you wanted to know about the green revolution, ThoughtCo, Available at: https://www.thoughtco.com/green-revolution-overview-1434948

Chen, G. (2018): Advances in agricultural machinery and technologies. New York, CRC Press.

FAO. (2009): Global agriculture towards 2050, Food and Agriculture Organisation of the United Nations, High Level Expert Forum (12-13 October 2009, Rome , Italy), Available at: http://www.fao.org/fileadmin/user_upload/lon/HLEF2050_Global_Agriculture.pdf

FAO. (2013): World Agriculture: Towards 2015/2030 - an FAO Perspective, Food and Agriculture Organization (FAO), Available at: http://www.fao.org/3/y4252e/y4252e.pdf

FAO. (2017): The future of food and agriculture-trends and challenges, Food and Agriculture Organisation of the United Nations, ISBN 978-92-5-109551-5 Rome, Italy.

FAO. (2018a): The state of food security and nutrition in the world 2018 - Building Climate Resilience for Food Security and Nutrition, Food and Agriculture Organisation of the United Nations, Rome, Italy. Available at: http://www.fao.org/3/I9553EN/i9553en.pdf

FAO. (2018b): Sustainable agricultural mechanization: A framework for Africa, Food and Agriculture Organisation of the United Nations and the African Union Commission, Addis Ababa, Available at: http://www.fao.org/3/CA1136EN/ca1136en.pdf

FAO. (2019): Crop production and natural resource use, Food and Agriculture Organisation of the United Nations, Available at: http://www.fao.org/3/y4252e/y4252e06.htm

FAOSTAT. (2019): Agricultural land statistics, Food and Agriculture Organisation of the United Nations, Available at: http://www.fao.org/faostat/en/#data/RL/visualize

FoWC (Foundations of Western Culture). (2019): Effects of Agriculture on the Industrial Revolution, Foundations of Western Culture course, University of Wisconsin-Green Bay, Available at: http://foundations.uwgb.org/agriculture/

Gebhardt, A., Hötter, J-S. (2016): Additive Manufacturing- 3D Printing for Prototyping and Manufacturing, Ohio, Hanser.

GVR. (2019): Agriculture equipment market, Grand View Research Inc. (May 2017 statistics), Available at: https://www.oemoffhighway.com/market-analysis/industry-news/agriculture/news/20860794/agriculture-equipment-market-to-be-worth-2434-billion-by-2025

Harris, D.R. and Fuller, D.Q. (2014): Agriculture: definition and overview. In Encyclopaedia of Global Archaeology (Claire Smith, Ed.). New York, Springer.

Ileri, M.S. (2018): TARMAKBIR (The Turkish Association of Agricultural Machinery & Equipment Manufacturers) Sector Report 2018 for Turkish Agricultural Machinery Industry (05.02.2018). Available at: http://www.tarmakbir.org

Ileri, M.S. (2019): TARMAKBIR (The Turkish Association of Agricultural Machinery & Equipment Manufacturers) Sector Report 2018 for Turkish Agricultural Machinery Industry (22.02.2019). Available at: http://www.tarmakbir.org

Kiss, P., Hajdú, J., Máthé, L., Dobos, J., Magó, L. (2018): Analysis of the towed agricultural machinery manufacturers in Europe. Hungarian Agricultural Engineering, 33:5-10.

Knoema. (2019): Agricultural area & arable land, Available at: https://knoema.com/atlas/topics/Land-Use/Agricultural-area-and-arable-land/Agricultural-area

MAIB (2019): Turkish industry spotlight, Turkish Machinery Export Association, Available at: https://www.makinebirlik.com/En/Page/sektor

Mordor Intelligence. (2019): Agricultural tractor market - growth, trends, and forecast (2019 - 2024), Available at: https://www.mordorintelligence.com/industry-reports/agricultural-tractor-market

Negrete, J.C. (2018): Agricultural mechanization key to recovery of agriculture of developing countries. ACTA Scientific Agriculture, 2.12: 168-169.

Oguz, C., Bayramoglu, Z., Agizkan, S., Agizkan, K. (2017): Agricultural Mechanization usage level in agricultural enterprises-Case of Konya Province. Selcuk J Agr Food Sci, 31 (1), 63-72.

Pollard, S. (1981): Peaceful conquest: the industrialization of Europe 1756-1970, Oxford, Oxford University Press.

Sarkar, C. (2016): Agricultural mechanization in west Bengal a comparative study of Bardhaman and Dakshin Dinajpur districts, PhD Thesis, Department of Economics, University of North Bengal.

Statista. (2019): The world's largest farm machinery manufacturers in 2017, Available at: https://www.statista.com/statistics/461428/revenue-of-major-farm-machinery-manufacturers-worldwide/

Tauger, M.B. (2011): Agriculture in world history, Routledge. New York, Taylor & Francis Group.

TUIK. (2019): Statistics of Agricultural machinery and Equipment, Turkish statistical Institute, Available at: http://tuik.gov.tr/VeriBilgi.do?alt_id=1006

Tuncel, C.O. and Polat, A. (2016): Sectoral system of innovation and sources of technological change in machinery industry: an investigation on Turkish machinery industry. Procedia - Social and Behavioural Sciences, 229: 214-225.

Turkish Republic Ministry of Economy (TRMoE). (2016): Agricultural Machinery and Equipment Sectoral Report, Available at: https://ticaret.gov.tr/data/5b87000813b8761450e18d7b/Tarim_Alet_ve_Makinalari.pdf

Ultimaker (2019): Developments and trends in 3D printing, Available at: https://ultimaker.com/download/74242/Developments%20and%20trends%20in%203D%20printing.pdf

United Nations (UN). (2017): Department of Economic and Social Affairs, Population Division (2017). World Population Prospects: The 2017 Revision, DVD Edition.