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Hydraulic Folding Possibility in Semi-Mounted Reversible Moldboard Plows

Yarı Asma Döner Kulaklı Pulluklarda Hidrolik Katlanma Olanağı**

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ABSTRACT

The plow frequently used in soil cultivation, is a soil cultivation machine that turns over hardened and compacted soil, aerates it, and makes it more suitable for growing plants. Reversible plows, which provide straight plowing, are multi-bottom (5, 6 and more bottom) and, due to their weight, are attached to the tractor in a semi-mounted or towed instead of a three-point hitch. In this study, the possibility of converting semi-mounted reversible plows into mounted type reversible plows by hydraulic folding was examined, taking into account the road conditions and field conditions, preparation status in the field, and turning situations in the field. It is well known that semi-mounted reversible plows pose traffic safety risks during road transport and result in longer turning times in the field. That it is more costly because there are too many hydraulic system parts in their structures. In this study, using the SolidWorks software, plows of various bottom sizes and bottom numbers were designed, and the distance between the center of gravity of the plow and the three-point hitch system of the tractor was determined, and then the appropriate folding that would not cause the tractor to rearward tipping was achieved. This folding configuration was designed after determining its suitability to the tractor's drawbar pull, ensuring that the reversible moldboard plough can be effectively operated in the field. The reaction force of the tractor front wheels was measured using both theoretical moment calculation and SolidWorks software. In addition, the strength analysis of the hydraulic folding components of the plow was performed with SolidWorks software, which uses the Finite Element Method in its structure.

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ÖZET

Toprak işlemede sıklıkla kullanılan pulluk, sertleşen ve sıkılaşan toprağın devrilerek kabarmasını, hava almasını ve toprağın bitki yetiştirme için daha elverişli olmasını sağlayan bir toprak işleme makinesidir. Düz sürüm imkanı sağlayan döner kulaklı pulluklar çok gövdeli (5, 6 ve daha fazla gövdeli) olduklarından ağırlıklarından dolayı traktöre üç nokta asma şekli yerine yarı asma ya da çekili olacak şekilde bağlanmaktadır. Bu çalışmada, yarı asma döner kulaklı pulluklar ile asma tip pullukların yol durumu ile iş durumu, tarlada hazırlık durumu, tarlada dönüş durumları dikkate alınarak yarı asma döner kulaklı pullukların hidrolik katlama ile asma tip döner kulaklı pulluklara dönüştürme olanağı incelenmiştir. Yarı asma döner kulaklı pullukların trafikte yol güvenliğini riske soktuğu ve tarlada dönüşlerin daha uzun sürdüğü bilinmektedir. Ayrıca yarı asma pullukların yapılarında çok fazla hidrolik sistem parçaları bulunduğundan daha pahalı oldukları bilinmektedir. Söz konusu çalışmada SolidWorks yazılımı kullanılarak çeşitli gövde büyüklüğünde ve çeşitli gövde sayısında pulluk modelleri çizilerek pulluğun ağırlık merkezinin, traktörün üç nokta asma düzenine olan mesafesi tespit edildikten sonra traktörü şahlandırmayacak olan uygun katlanma şekli sağlanmıştır. Bu katlanma, döner kulaklı puluğun tarlada çekilebilecek traktörün çeki kuvvetine uygun olarak tespit edildikten sonra yapılmıştır. Teorik statik moment hesabı ve de SolidWorks yazılımı kullanılarak traktör ön tekerleklerine gelen tepki kuvveti ölçülmüştür. Ayrıca pulluktaki hidrolik katlanma bileşenlerinin mukavemet analizleri, yapısında Sonlu Elemanlar Yöntemini kullanan SolidWorks yazılımı ile yapılmıştır.

1. INTRODUCTION

Agricultural production has existed since humankind's first step towards civilization and is the main reason for the transition to settled life. Since the transition to settled life, human beings have engaged in agriculture both for the animals they benefit from and for their own nutritional needs. The increase in human population and technological development over time have led to changes in the methods, systems, tools, and machines used in agricultural production. Thus, in addition to meeting needs, agriculture also enabled the start and development of trade. After the Second World War, with foreign aid, classical agricultural production methods were gradually abandoned, and a rapid transition toward agricultural mechanization began. Thus, the number of tractors in Türkiye has increased; agricultural machines that use the tractor's tractive power and hydraulic lifting functions and will contribute to agricultural mechanization have also begun to be used (Avşar and Avşar, 2016).

There are tillage methods and sequences to prepare the soil for plant production. These are listed as primary and secondary tillage machines. The plow, one of the primary tillage machines, is a widely used tillage machine in countries around the world and in Türkiye. It carries out cutting, relief and tilting of the soil in order to provide suitable soil conditions for the growth of the plant (Mattetti et al., 2017).

In tillage, flat plowing is done to keep the field level smooth. Flat plowing is the process of constantly turning the soil in the same direction in the field. The aim here is to eliminate the irregularity (herringbone or open line) that occurs in the field in classical plowing. Thus, the field leveling will be smooth; problems such as ponding in the field, dryness, and soil erosion will be eliminated (İşler and Kılınç, 2016). Reversible plows are used to perform flat plowing (Figure 1). Despite the advantages of conventional tillage, reversible moldboard plows used in this method have certain drawbacks, such as excessive weight and high costs (Culpin, 1986).

Figure 1. Reversible moldboard plow (Alpler Pulluk, 2024).

While classic plows and reversible plows with up to 4-5 bottoms can be attached to the tractor and transported in a three-point hitch system (Figure 2), reversible plows with 5 or more bottoms can be attached to the tractor in a semi-mounted or trailed mode.

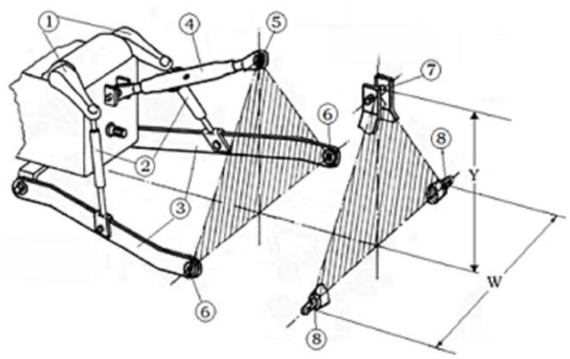


Figure 2. Three point hitch (Gülsoylu and Çakmak, 2016) (1. lifting arms, 2. hanger arms, 3. Lower binding arms, 4. upper link arm, 5. upper link port, 6. Lower hitch points, 7. machine top link point, 8. Machine upper link point).

Since multi-bottom reversible plows are much heavier than classical plows, when they are attached to the tractor in a three-point hitch system, they may cause the front wheels of the tractor to lose contact with the ground, which is called "rearward tipping". This rearing eliminates healthy and safe steering. For this reason, multi-bottom reversible plows are attached to the tractor in a semi-mounted or trailed. However, these plows have to have more hydraulic cylinders and components compared to three-point hitch type reversible plows, and this makes the plow more costly. In addition, it takes a lot of time to put the plow into road position and into field position in the field. In addition, the semi-mounted reversible plow or trailed reversible plows requires more space to make safe turns in the field and spends more time for these turns (Figure 3).

Figure 3. Semi mounted- trailed type reversible plow end of field turn.

Factors such as the time it takes for the tractor to return to the field and the fuel consumed, the cost of the tillage machine, and the way the tillage machine is transported from the farm to the field affect the efficiency of agricultural production. Efficiency in agricultural production is influenced by numerous factors, including irrigation, fertilization, chemical use, seed quality, labor, machinery utilization, transportation, storage, marketing, input and product prices, land structure, farm size, and climatic conditions (Bayramoğlu, 2010).

The aim of this study is to demonstrate that multi-bottom reversible plows can be attached to tractors as a three-point hitch type with hydraulic folding in order to reduce these losses that negatively affect productivity.

2. MATERIALS AND METHODS

In this study, new drawings of hydraulic folding reversible plows with 5 bottoms and 12, 14 and 16 in. moldboard sizes (Table 1), tractor test reports from TAMTEST and Nebraska tractor test laboratories are discussed (Table 2). The tractor's center of gravity was determined according to the tractor front axle and rear axle loading in these reports.

The last two bottoms of the realistically drawn plows were designed to fold forward, thereby shifting the center of gravity closer to the tractor (Figure 4). The centers of gravity of these plows, both in folded and unfolded positions, were determined using the SolidWorks software. By considering the tractor's rear axle center as the moment reference point, a moment analysis was conducted to determine the extent to which the plow affects the load on the tractor's front axle.

SolidWorks software, which can perform engineering analyzes using the design and finite element method was used. SolidWorks simulation results are approved by DIN- Aerospace Standards Committee (SolidWorks, 2024).

Figure 4. Hydraulic folded reversible moldboard plow (Original).

Table 1. Technical information of hydraulic folding plows

Plow type *	*Mass (kg)*	*Working width (mm)*	*Moldboard spacing (mm)*	*Center of gravity ** location (mm)*		*Plow length (mm)*
				Plow is open	*Plow is folded*	
5-12	1273	1500-1600	850	1800	1244	4660
5-14	1477	1700-1800	915	1879	1326	4990
5-16	1791	2000-2100	950	1986	1389	5180

* The moldboard size of the plow is specified here.

** Distance between the plow centre of gravity and the tractor lower link arm connection centres (In open-closed state)

Table 2.TAMTEST ve Nebraska Tractors Tested in Tractor Laboratories – 1 (TAMTEST, 2018; Nebraska, 2025).

Num	*Tractor Model*	*Power (kW)*	*Total Weight (Without Additional Weight - With Cabin) (kg)*	*Front Axle Load (kg)*	*Rear Axle Load (kg)*	*Wheelbase (mm)*	*B+e (mm)**
1	Hattat 295 DT	68	3875	1655	2220	2285	1020
2	Massey Ferguson -5709 S	70	4670	1835	2835	2550	1165
3	Massey Ferguson -5709 M	70	4185	1655	2530	2315	1080
4	John Deere 5095M	70	4575	1717	2858	2350	1045
5	Hattat 305 DT	75	3865	1645	2220	2285	1020
6	Massey Ferguson -5710 S	77	4669	1835	2834	2550	1165
7	John Deere 5105M	78	4575	1717	2858	2350	1045
8	New Holland T5.110	79	4825	1890	2935	2380	1176
9	Massey Ferguson -5711 S	81	4690	1850	2840	2550	1165
10	John Deere 5115m	85	4441	1701	2740	2350	1060
11	Massey Ferguson -5713 S	86	4710	1865	2845	2550	1165
12	New Holland T4.120	88	3815	1525	2290	2285	1070
13	Massey Ferguson -5712 S	88	4680	1815	2865	2550	1165
14	Massey Ferguson -6712 S	88	5400	2325	3075	2675	1110
15	John Deere 5120M	88,5	4575	1717	2858	2350	1045
16	John Deere 6R 110	89	6460	2620	3840	2580	1150
17	John Deere 5125M	92	4513	1683	2830	2350	1060
18	New Holland T6050	93	5425	2160	3265	2630	1180
19	New Holland TR6.135	93	5700	2350	3350	2660	1240
20	John Deere 5130M	96	4575	1717	2858	2350	1045
21	John Deere 6R 120	97	6460	2620	3840	2580	1150
22	New Holland TR6.150	104	5700	2350	3350	2660	1240

* Distance between tractor lower link arm pin center and rear axle center.

The tractor traction force corresponding to the working width of the 5-bottoms 12-in. reversible plow was calculated multiple times with the Microsoft Excel program, depending on the soil structures. It was deemed sufficient for the tractor to have 77 kW tractive power to meet this traction force. Since this reversible plow is heavier than the classic type plow, the tractor that will lift this plow will not have enough force in contact with the ground on the front wheels of the plow and it will rear up. To compensate for this negative situation, a hydraulic folding plow was designed with the SolidWorks software so that the last two furrows of the plow fold over the first three furrows. The center of gravity of the folded plow was determined again with the SolidWorks software. Moment analysis performed on the center of gravity of the plow has been used to examine whether the front wheels of the tractor provide sufficient force to the ground and ensure safe steering movement.

2.1.Tractor and Reversible Moldboard Plow Match

Tractors in some power groups and their hydraulic lifting capacities are given in Table 3. The tractors in this table are best-selling tractors in Türkiye.

Table 3. Tractor power and hydraulic lift data (“Başak Traktör”, 2023; “Hattat Traktör”, 2023; “Massey Ferguson”, 2023; “New Holland Agriculture”, 2023; “Tümosan ”, 2023)

Tractor power (kW)	*Lifting Capacity (kg)*	*Weight / Without additional weight(kg)*	*Wheelbase (cm)*
55 – 66	2200 - 3565	3600 – 3900	240
66 – 81	3565 - 4700	3700 – 4200	242
81 – 96	4700 - 6000	4200 – 4800	243-250
96 – 110	6000 - 6600	4800 –5000/5800	250-264
110 – 132	6600 - 8600	5000 –6950/7300	264-288
132 – 176	8647 - 9600	7300-7700	288

Note: The data in this table is the technical information of the tractors produced by the most well-known tractor manufacturers. There is no statistical data in this table.

Tactor tractive power requirement and plow technical information are given in Table 4.

Table 4. Plow Draft Power Requirement

Plow type	***Plow Draft Power Requirement (tractor forward speed 7 km.h^{-1}) (kW)***		***Working width (mm)***	***Tractor Motor Power Requirement (kW)***	
	Middle heavy soil	***Heavy soil***		***Middle heavy soil***	***Heavy soil***
5 Bottoms 12"	40.4	49.7	1600	62.2	76.5
5 Bottoms 14"	45.4	55.9	1800	69.8	86
5 Bottoms 16"	53.0	65.2	2100	81.5	100.3

Note: The data in Table 4 represents the tractor power requirements calculated using Equations 1, 2, and 3, considering the working width of the plow. The data in this table does not contain any statistical information.

The designed plow was drawn with actual measurements, taking into account the technical information of "Ünlü Ziraat" (2023). The plow traction power requirement was calculated by taking into account the information in Table 4 and based on the tractor advance speed of 7 km h^{-1}. In this calculation, the working width was taken in meters, and the specific tractive force was found by taking the tractor progress speed as 1.94 m s^{-1}, which is the equivalent of 7 km h^{-1}, and multiplying it with the specific tractive force (Equation 1). Keçecioğlu and Gülsoylu determined that the maximum traction power that the tractor can develop can be up to 65% of the tractor's effective engine power (Keçecioğlu and Gülsoylu, 2002). This ratio is taken into account for the tractor power requirement calculation in Table 4 although the traction requirement in theoretical calculations is as shown in Table 4. This tractor drawbar pull power will increase with the operator, front and rear additional weights that will be added to the tractor later.

$$\eta_{trak} = \frac{P_M - (P_{trans} + P_R + P_{\dot{I}})}{P_M} = \frac{P_Z}{P_M} = 0.5 \ldots\ldots 0.65 \quad (1)$$

P_{trans}: Transmission loss power,
P_M: Tractor effective engine power,
P_R: Rolling resistance loss power,
$P_{\dot{I}}$: Tractor skid loss power,
P_Z: Tractor traction power,
η_{trak}: Tractor effective engine power efficiency.

Specific traction power information corresponding to various soil structures is given in Table 5.

Table 5. Specific plow traction force required in various soil species (Öztekin, 2006)

Soil Species	***Specific soil resistance (N dm^{-2}), (5 km h^{-1} at the speed of progress)***	***Required specific traction force (N m^{-1}), (30 cm in depth of work)***
Light	220-350	9000
Light-medium heavy	250-400	10000
Medium-heavy	300-550	13000
Medium heavy – heavy	350-600	16000
Heavy - too heavy	600-1200	20000-30000

Note: This Table presents the required draft force data for a plow operating at a depth of 30 cm under various soil conditions. The data in this Table does not contain any statistical information.

Tractor power requirement and plow draft power requirement in Table 4 were calculated with Equation 2 and Equation 3. The data in Table 2 were used in this calculation.

$$P_Z = P_M.(0.65) \tag{2}$$

$$P_Z = F.V = F_{ö}.b.(1.94 \text{ m s}^{-2}) \tag{3}$$

b: Plow work width (m) (taken from Table 1),
$F_{ö}$: Required specific traction force (kN m^{-1}) (30 cm work depth-medium heavy soil, taken from Table 5),
V : Tractor progress speed (7 km h^{-1}= 1.94 m s^{-1}),
F : Plow traction force (kN),
P_Z: Required traction power (kW),
K : Horsepower – Kilowatt conversion coefficient (1.36).

$\boldsymbol{P_Z = F.V = F_{ö}.b.(1.94 \text{ m s}^{-1}) =}$
$\boldsymbol{(16 \text{ kN m}^{-1}).(1.6 \text{ m}).(1.94 \text{ m s}^{-1})}$
$\boldsymbol{P_Z = 49.66 \text{ kW}}$
$\boldsymbol{P_Z = P_M.(0.65)}$
$\boldsymbol{P_M = 76.41 \text{ kW}}$
$\boldsymbol{P_M = (76.41 \text{ kW}).(K)}$
$\boldsymbol{P_M = 104 \text{ hp}}$

The effective engine power of the tractor found here, 76.41 hp, is the tractor power requirement required by the plow with a working width of 1600 mm in medium heavy-heavy soil.

2.2. Hydraulic Folding Reversible Plow Analysis for 77 kW Tractor

As seen in Table 4, the tractor power that can pull a 5-bottoms 12” plow in heavy soil conditions is 76.5 kW. Since there was no tractor with this power, a Massey Ferguson 5710 S with a similar power of 77 kW was chosen (Table 2). Technical information about this tractor is given in Table 6.

Table 6. Massey Ferguson 5710 S tractor technical information (TAMTEST, 2018; Massey Ferguson, 2024)

Power	77 kW	***Wheelbase***	2550 mm
Maximum torque	430 Nm	***Total weight (additional weightless-cabinet)***	4669 kg
Transmission	4 WD (four wheel drag)	***Front bag weight***	10x40 kg
Lifting capacity	4700 kg	***Rear additional weight***	6x45 kg

Note: The data in this table includes the technical specifications of the Massey Ferguson 5710 S tractor. The data in this Table does not contain any statistical information.

The plow was attached to this tractor first in an unfolded state (Figure 5) and then in a folded state, and the reaction force on the front wheels was analyzed.

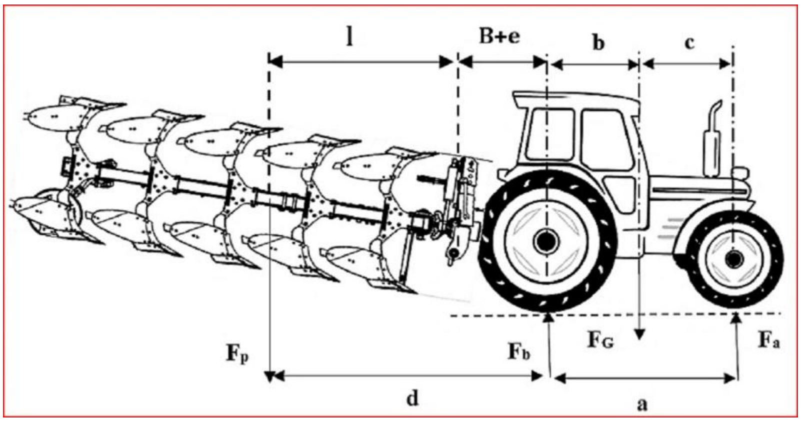


Figure 5. 5-bottoms reversible moldboard plow mounted on tractor as three-point hitch

F_a**:** Reaction force on the front axle when the plow is mounted as three-point hitch (kg),

F_b**:** Reaction force on the rear axle when the plow is mounted as three-point hitch (kg),

G **:** Tractor weight (4669 kg: without additional weight; 4300 kg: with front additional weight),

W**:** Plow weight (1273 kg, Table 1),

b**:** Position of the rear axle in the horizontal component to the tractor center of gravity (1002 mm),

c**:** Position of the front axle in the horizontal component to the tractor center of gravity (1548 mm),

a**:** Wheelbase (2550 mm),

l**:** Position of the plow center of gravity in the horizontal component to the tractor three-point hitch,

d: Distance of the plow's center of gravity from the tractor rear axle (d= l+(B+e)**=** 1799+1165 mm)**.**

B**:** Lower coupling arms length (1125 mm, Figure 10)

e: Distance of lower coupling arms joint center to rear axle (40 mm, Figure 6)

Here, the length "l" was found using the SolidWorks program. After determining the center of gravity by Solidworksplow, the horizontal distance between the center of gravity and the axis of the lower coupling arms were calculated by SolidWorks software.

Figure 6 and Table 7 show the distance between the pin centers of the lower coupling arms and the center of the tractor rear axle (Gülsoylu and Çakmak, 2016).

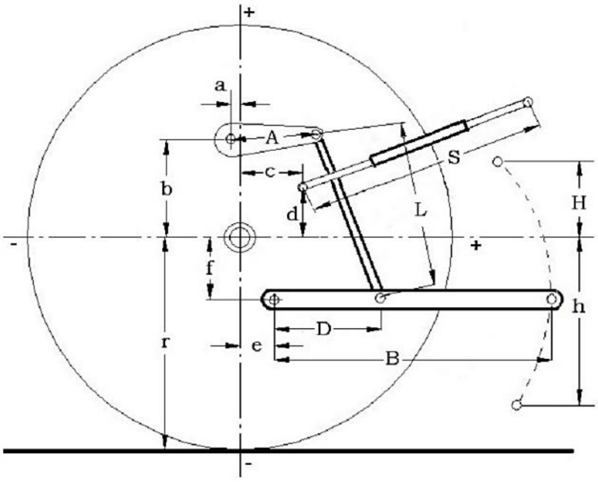


Figure 6. Tractor three-hitch point dimensions (Gülsoylu and Çakmak, 2016).

Table 7. Tractor three-hitch point dimensions (Gülsoylu and Çakmak, 2016).

Code	***Measurement (mm)***	***Description***
B	1125	Lower link arm length
e	40	Horizontal distance from the lower link arm pivot to the wheel center axis

Note: The data in this table represents the dimensions illustrated in Figure 6

As a result of the research conducted, information has been obtained indicating that the average distance between the center of gravity of the front additional weight and the front axle is approximately 500 mm, utilizing various tractor brands (Figure 7).

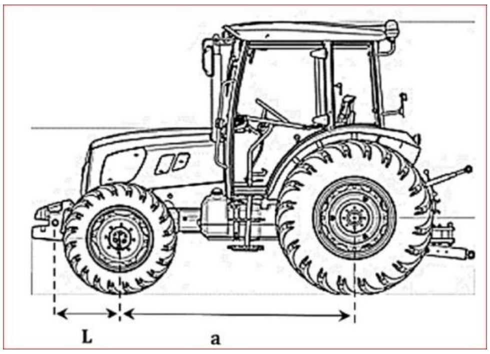


Figure 7. Distance between front additional weight and front axle

L: Distance between front additional weight and front axle = 50 cm,

W_c: Additional front weight = 400 kg,

a : Wheelbase (mm).

The center of gravity of the 5-bottoms 12" reversible plow designed with SolidWorks (determined with SolidWorks) is given in Figure 8.

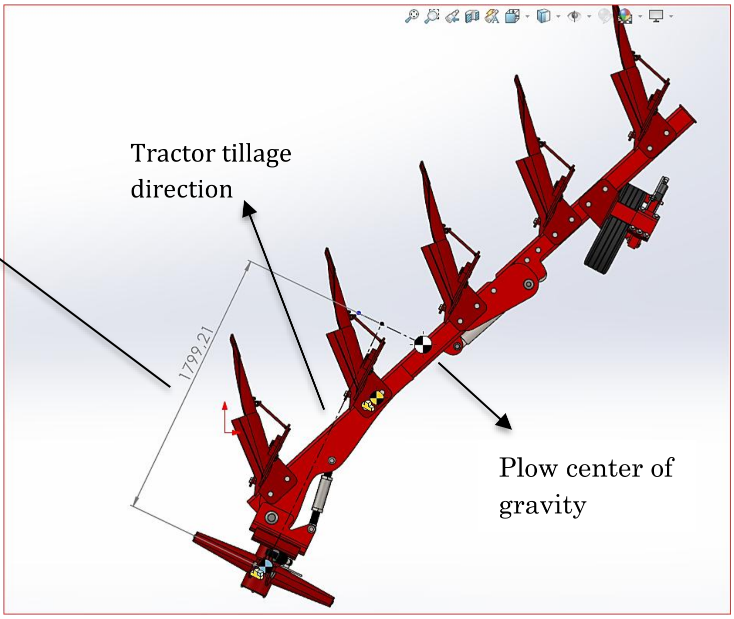


Figure 8. Center of gravity of 5-bottoms reversible moldboard plow (Original).

The free body diagram describing the situation when the plow is attached to the tractor as a three-point hitch is shown in Figure 9.

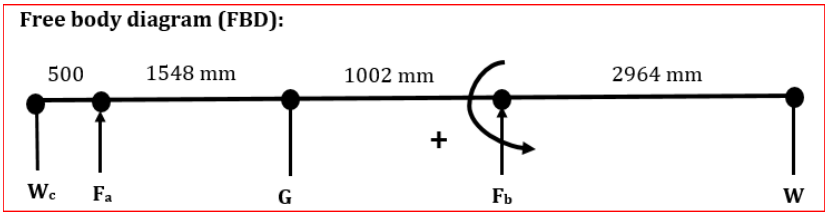


Figure 9. Free body diagram of a 5 bottom 12” reversible plow attached to the tractor.

The rear axle point of the tractor was accepted as the center of rotation (Equation 4).

$$\Sigma(MF_b) = 0 \tag{4}$$

$\Sigma(MF_b) = 0$
$\Sigma(MF_b) = -(2964 \text{ cm}).(W) - (\text{Fa}).(2550 \text{ mm}) + (G).(1002 \text{ mm}) + Wc.(3050 \text{ mm}) = 0$
$-(2964 \text{ cm}).(1273 \text{ kg}) - (Fa).(2550 \text{ mm}) + (4669 \text{ kg}).(1002 \text{ mm}) + (400 \text{ kg}).(3050 \text{ mm}) = 0$
$\boldsymbol{Fa = 833.4 \text{ kg}}$

For safe steering performance, the load acting on the tractor front axle must be at least 20% of the total tractor weight (Yıldız et al., 2025). Here, since the front axle reaction force of 833 kg is far from **933 kg**, **which is 20% of the tractor weight**, steering will not be safe in dynamic situations with the load on the front axle. In this case, when the plow is unfolded, the tractor will lift this plow as three-point hitch when turning at the end of the field. However, it is necessary to increase the load on the tractor front axle in order to ensure safe steering during the transfer of the reversible plow from the farm to the field in the form of three-point hitch. To achieve this, it is necessary to fold the plow hydraulically and bring the center of gravity of the plow closer to the tractor. Hydraulic folding of the 5 bottoms reversible plow was carried out using the movement and mechanism functions of the SolidWorks software, folding components and fasteners. This folding was made in such a way that the last two bottoms are 165° on the first three bottoms. The center of gravity of the plow was determined using the SolidWorks software after folding (Figure 10).

Plow’ s Center of gravity: 1201.54 mm

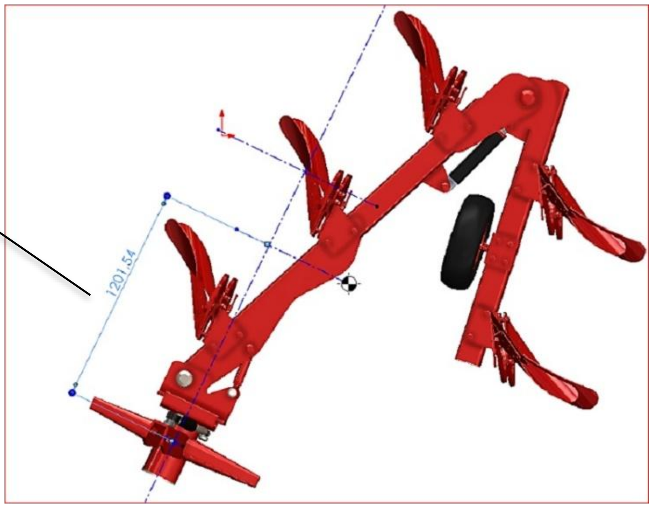


Figure 10. Hydraulically folded plow (Original).

When the center of gravity of the folded plow is used in Equation 4, the reaction force on the front axle is: **Fa = 1111 kg**. With this value, the reaction force on the front axle increases by 33%. In this case, steering will be safer. In this way, when the plow is folded hydraulically, the tractor will have safer steering when climbing the ramp.

2.3. Analysis of the Fasteners of The Hydraulic Folding Plow During Tillage Using the Finite Element Method (FEM)

The Linear static analysis program included in the SolidWorks Premium software was used to show whether the loads on the connection bolts and pins of the two furrows on the folding side of the hydraulic folding plow are safe during tillage at a depth of approximately 25 cm in heavy soil conditions. This program performs analysis using the Finite Element Method (Figure 11).

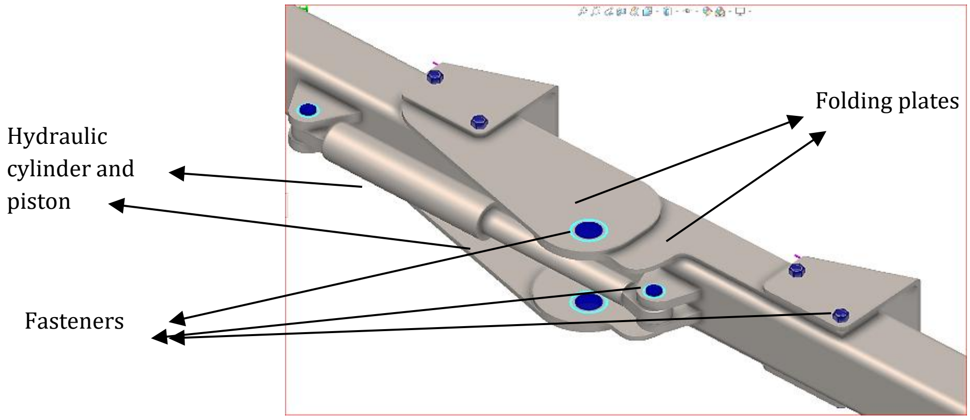


Figure 11. Hydraulic folding plates and fasteners (Original).

The mechanical properties of folding plates are given in Table 8.

Table 8. Mechanic properties of folding plates and fasteners.

Plate properties			Bolt properties	
Plate thickness (mm)	15	20	Bolt diameter (mm)	M18
Plate material	AISI 4340 Steel	Alloyed steel	Bolt quality	10.9
Elasticity modulus (GPa)	205	205	Elasticity modulus (GPa)	205
Tensile strength (MPa)	745	723	Tensile strength (MPa)	1000
Yield strength (MPa)	470	620	Yield strength (MPa)	900
Poisson's raito	0.285	0.285	Poisson's raito	0.285

Note: The data in this table represents the technical specifications of the folding plates, fasteners, and links that connect the front and rear chassis of the folding plow. The data in this Table does not contain any statistical information.

2.4. Assumptions Made for Linear Static Analysis with the Finite Element Method

Certain assumptions are made during the static analysis preparation phase. These assumptions aim to obtain accurate results.

- Average specific soil resistance is accepted for very heavy soil specified in Table 9 (120 kN m^{-2}).
- It was assumed that the entire load coming to the moldboard is transferred to the plow chassis and clamps.

- The plow profile chassis material was assumed to be the same as the plate material.
- The draw force in the direction of the plow draft, which is the horizontal force that forces the connection bolts and pins to shear, was taken into account (Figure 11).
- Analysis will be made for 2 bottoms on the hydraulic folding chassis.

Table 9. Specific soil strength coefficients (Öztekin, 2006).

Soil characteristics	**Specific soil strength – k (kN m^{-2})**
Light soil	20-30
Medium heavy soil	40-50
Heavy soil	60-90
Too heavy soil	90-150

Note: The data in this table represents the resistance of various soil characteristics. The data in this table does not contain any statistical information.

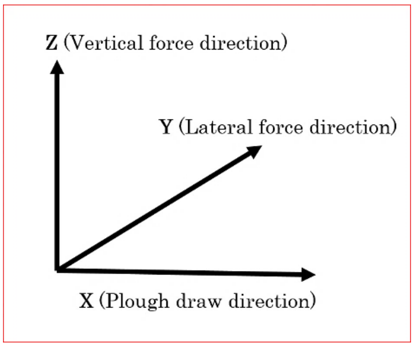


Figure 12. Directions of force acting on the plow (Değirmencioğlu et al., 1998).

The traction force acting on a furrow is specified in Equation 5.

$$F_x = k.b.t + \varepsilon v^2 \quad (5)$$

k: Specific soil strength for too heavy soil (120 (kN m^{-2}),
b: Nominal working width for 12" furrow (30.5 cm),
t: Plowing depth (25 cm),
εv^2: Linear static analysis independent of speed (0).

$F_x = k.b.t + \varepsilon v^2 = 120 \text{ (kN m}^{-2}\text{)}. (30.5 \text{ cm}). (25 \text{ cm}) + 0 = 9.15 \text{ kN}$

Here, it was assumed that there is a load of 9.15 kN on each furrow and that this load comes in the direction of draw on the fasteners attaching the body to the chassis. Since the plowing depth is accepted as 25 cm, the force applied in the vertical direction was considered zero and the lateral force was accepted as 1.4 kN on average (Keçecioğlu and Gülsoylu, 2002).

<u>Linear static analysis steps:</u>

AISI 4340 steel material was assigned to parts other than pins and bolts. 9.15 kN force and 1.4 kN force were applied to the clamps connecting the furrow to the chassis, in the direction of the plow draft, separately for each clamp (Figure 13).

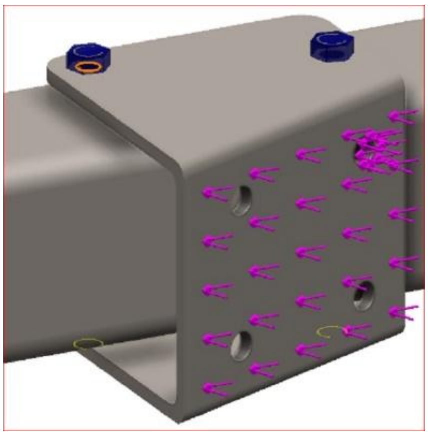


Figure 13. Forces of applied to the clamp.

In this analysis based on the Finite Element Method, a total of 721,573 nodes, 545,655 elements and 2,048,625 moving degrees of freedom were obtained for the mesh (Figure 14).

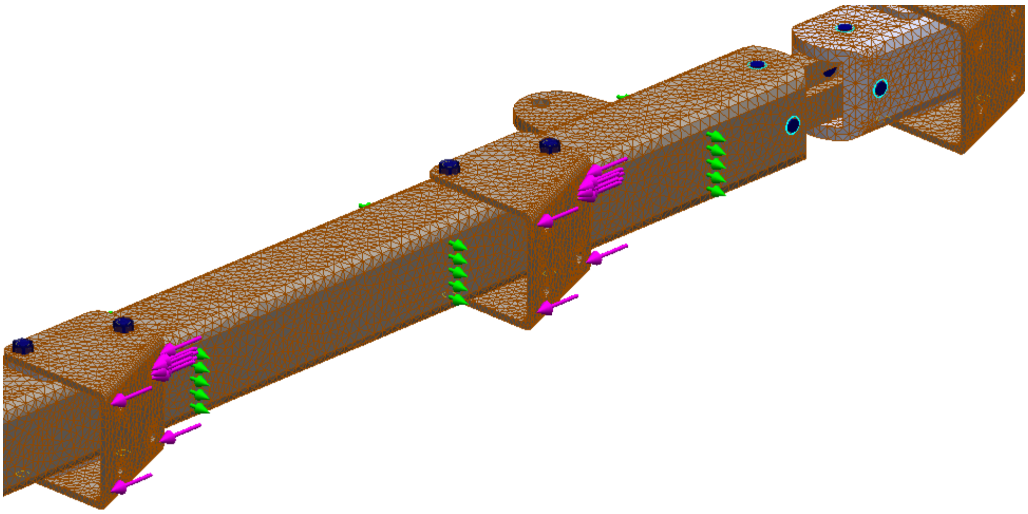


Figure 14. Applied mesh structure.

The safety coefficient calculation for the maximum stress occurring is given in Equation 6.

$$S = \frac{\sigma_{em}}{\sigma_{max}} \quad (6)$$

S: Safety coefficient,
σ_{em}: Allowable stress (Yield strength),
σ_{max}: Maximum stress.

3. RESULTS AND DISCUSSION

The tractor front axle loading for a 5-bottoms 12" reversible plow connected to a 77 kW tractor with a three-point hitch in both the hydraulically folded and extended positions is shown in Table 10. This table also includes the SolidWorks static analysis results for the tractor front axle loading.

Results of the front reaction force of the tractor with 5–bottoms reversible moldboard plow is three-point hitched were given in Table 10 and 11. When these tables are examined, it becomes clear that while the front axle load of most tractors before hydraulic folding does not meet the legal 20% load limit. After hydraulic folding, the front axle load either approaches or exceeds this legal limit. Thus, after hydraulic folding, the tractors ensure safe steering.

Table 10. Results of the front reaction force of the tractor with 5–bottoms reversible moldboard plow is three-point hitched.

Num	***Tractor Model***	***Power (kW)***	***Plow open front axle load (kg)***	***Plow closed front axle load (kg)***	***Tractor front ballast (kg)***	***Plow type***	***20% of Tractor Weight (kg)***	***A****	***B*****
1	Hattat 295 Dt	68	670	979	480	5-12"	775	86	126
2	Massey Ferguson -5709 S	70	834	1111	400		934	89	119
3	Massey Ferguson -5709 M	70	558	863	400		837	67	103
4	John Deere 5095m	70	662	962	400		915	72	105
5	Hattat 305 Dt	75	660	969	480		773	85	125
6	Massey Ferguson -5710 S	77	834	1111	400		934	89	119
7	John Deere 5105m	78	662	962	400		915	72	105
8	New Holland T5.110	79	783	1080	400		965	81	112
9	Massey Ferguson -5711 S	81	849	1126	400		938	90	120
10	John Deere 5115m	85	637	938	400		888	72	106
11	Massey Ferguson -5713 S	86	912	1189	440		942	97	126
1	Hattat 295 Dt	68	366	724	480	5-14"	775	47	93
2	Massey Ferguson -5709 S	70	550	871	400		934	59	93
3	Massey Ferguson -5709 M	70	254	606	400		837	30	72
4	John Deere 5095m	70	364	712	400		915	40	78
5	Hattat 305 Dt	75	356	714	480		773	46	92
6	Massey Ferguson -5710 S	77	550	871	400		934	59	93
7	John Deere 5105m	78	364	712	400		915	40	78
8	New Holland T5.110	79	478	821	400		965	50	85
9	Massey Ferguson -5711 S	81	565	886	400		938	60	94
10	John Deere 5115m	85	339	686	400		888	38	77
11	Massey Ferguson -5713 S	86	628	948	440		942	67	101

*The ratio of the front axle load to cover 20% of the overall weight with the plow open.

**The ratio of the front axle load to cover 20% of the overall weight with the plow closed.

Table 11. Results of the front reaction force of the tractor with 5–bottoms reversible moldboard plow is three-point hitched.

Num	*Tractor Model*	*Power (kW)*	*Plow open front axle load (kg)*	*Plow closed front axle load (kg)*	*Tractor front ballast (kg)*	*Plow type*	*20% of Tractor Weight (kg)*	*A**	*B***
12	New Holland T4.120	88	106	464	400	5-14"	763	14	61
13	Massey Ferguson -5712 S	88	578	898	440		936	62	96
14	Massey Ferguson -6712 S	88	1458	1763	660		1080	135	163
15	John Deere 5120m	88.5	364	712	400		915	40	78
16	John Deere 6r 110	89	1363	1680	400		1292	106	130
17	John Deere 5125m	92	321	668	400		903	36	74
18	New Holland T6050	93	1406	1717	810		1085	130	158
19	New Holland Tr6.135	93	1580	1887	810		1140	139	166
20	John Deere 5130m	96	558	906	560		915	61	99
21	John Deere 6r 120	97	1459	1776	480		1292	113	137
22	New Holland Tr6.150	104	1580	1887	810		1140	139	166
12	New Holland T4.120	88	-383	85	400	5-16"	763	-50	11
13	Massey Ferguson -5712 S	88	128	547	440		936	14	58
14	Massey Ferguson -6712 S	88	1035	1435	660		1080	96	133
15	John Deere 5120m	88.5	-108	347	400		915	-12	38
16	John Deere 6r 110	89	921	1335	400		1292	71	103
17	John Deere 5125m	92	-153	302	400		903	-17	33
18	New Holland T6050	93	968	1375	810		1085	89	127
19	New Holland Tr6.135	93	1140	1542	810		1140	100	135
20	John Deere 5130m	96	86	541	560		915	9	59
21	John Deere 6r 120	97	1016	1430	480		1292	79	111
22	New Holland Tr6.150	104	1140	1542	810		1140	100	135
12	New Holland T4.120	88	-1	308	400	6-12"	763	0	40
13	Massey Ferguson -5712 S	88	484	761	440		936	52	81
14	Massey Ferguson -6712 S	88	1367	1631	660		1080	127	151
15	John Deere 5120m	88.5	259	560	400		915	28	61
16	John Deere 6r 110	89	1270	1544	400		1292	98	119
17	John Deere 5125m	92	216	517	400		903	24	57
18	New Holland T6050	93	1315	1584	810		1085	121	146
19	New Holland Tr6.135	93	1491	1757	810		1140	131	154
20	John Deere 5130m	96	453	754	560		915	50	82
21	John Deere 6r 120	97	1365	1639	480		1292	106	127
22	New Holland Tr6.150	104	1491	1757	810		1140	131	154

As a result of SolidWorks Linear Static Analysis, it was seen that the maximum stress in the Von Mises stress indicator created by the program was at the attachment points attaching the clamp to the chassis and this value was approximately 128 MPa (Figure 15-a). The shear and axial forces acting on the M18 bolts nodes the 12" 5-bottoms of the plow to the chassis are given in Figure 15-b. The axial force was measured as 7476 N and the shear force was measured as 4808 N. In this study, the required draft force for the plow and the Von Mises stresses occurring on the plowshare were compared with experimental study "Comparative Analyses of the 4WD Tractor Performance with Two Different Moldboard Plow Bottoms by Using FEM" conducted by Ergech and Tahir (2008).

The safety coefficient calculation for the maximum stress occurring is given in Equation 6.

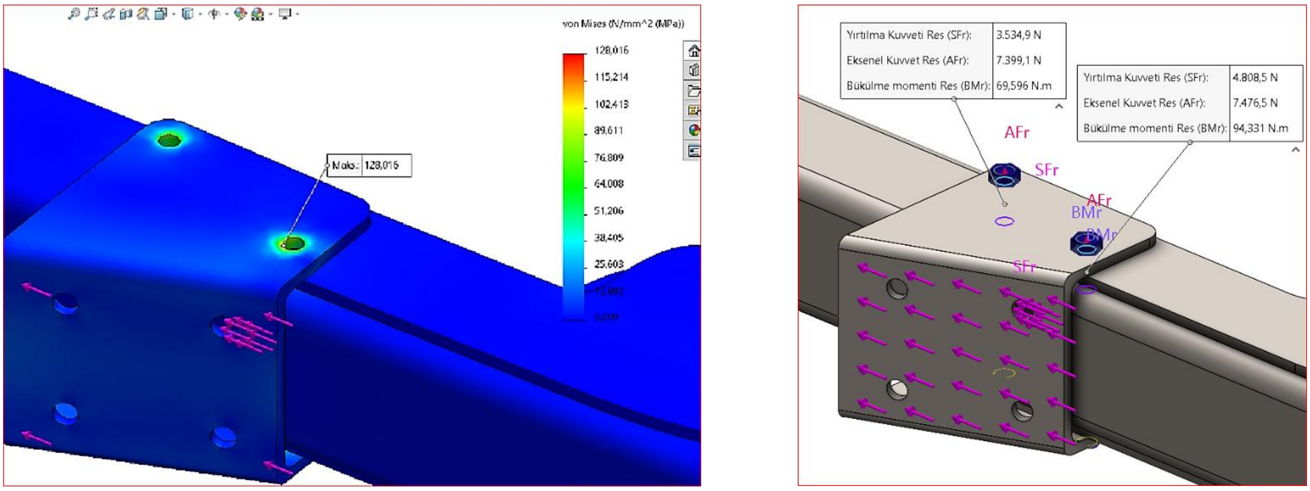
S: Safety coefficient,

σ_{em}: Allowable stress (Yield strength) (460 MPa),

σ_{max}: Maximum stress (128 MPa)

$$S = \frac{\sigma_{em}}{\sigma_{max}} = \frac{460(\text{MPa})}{128(\text{MPa})} = 3.59$$

$S = 3.53$ (The system is 3.59 times secure).



(a) (a)

Figure15.(a, b) Stresses occurring in the chassis, clamps and fasteners during tillage.

<u>Linear static analysis for the plate holding the rear chassis and equipment when folding:</u>

These plates are two, upper and lower. The weight of the two 12 in. bottoms and the depth wheel remaining in the folding part rests on these plates. Considering the weight of the 5-bottoms 12 in. plow, it is predicted that the average weight of the 2-bottoms and the depth wheel on the rear chassis were around 700 kg. However, since the load on the fasteners and the plate increase due to shaking, the estimated load was chosen as 1000 kg. This load is shared between the upper and lower plates located between the chassis members and acts on the plates only during the opening and closing stages of the hydraulic folding mechanism. Since these plates are two, static analysis was applied for only one plate and half the load. The loads and stresses occurring on the folding plate and fasteners during tillage with a 5-bottoms 12 in. reversible moldboard hydraulic folding plow are presented in Table 12.

Table 12. Stresses and loads occurring in fasteners.

Loads and stresses on hydraulic folding plow linkage elements				
Part name	***Applied load (N)***		***Von Mises maximum stress (MPa)***	***Yield stress (MPa)***
Folding plate	500 N		123.71	460
Clamp bolt slot x 2	12200N, 1400N		183.3	460
Clamp bolt x 2 (10.9)	Tear force (direction of shear stress) (N)	Axial force (N)		900
	8083	6375		

4. CONCLUSIONS

In this study, it was addressed that multi-bottom reversible moldboard plows, when mounted on tractors via the three-point hitch, should be mounted in their hydraulically folded position in order to prevent tractor rearing. Multi-bottom reversible moldboard plows, realistically modelled in SolidWorks and their centres of gravity determined, were evaluated with respect to the test reports of 22 tractors (68 kW – 104 kW) from TAMTEST and Nebraska Tractor Test Laboratories. The analysis considered both unfolded and hydraulically folded conditions of three-point hitch mounting, in order to determine whether the front axle load of the tractor was sufficient for safe steering. The findings indicated that hydraulically folded plows, when mounted via the three-point hitch, ensure safe steering (since the front axle load must account for at least 20% of the tractor's total mass to maintain steering safety). Furthermore, the durability of hydraulic folding linkage components during field operation was analysed using SolidWorks finite element method (FEM) simulations, and the results demonstrated adequate strength. Future studies may investigate whether the hydraulic folding mechanisms of larger reversible plows (with six or more bodies) can provide sufficient strength and reliability under field tillage conditions.

REFERENCES

Alpler Ziraat Aletleri San. ve Tic. A.Ş. (2023, March 18). *Reversible moldboard plow*. http://www.alpler.com.tr/urunler/1078/asilir-tip-doner-kulakli/1043/doner-kulakli-pulluk.aspx

Avşar, D., & Avşar, G. (2016). New technological developmentsfor machines used in agricultural production in Turkey (Verbal statement). *4th International Symposium on Innovative Technologies in Engineering and Science (ISITES2016)*, 40-49.

Başak Traktör. (2023, September 29). *Field tractors*. https://basaktraktor.com.tr/

Bayramoğlu, Z. (2010). Agricultural productivity and its importance. *Selçuk Tarım ve Gıda Bilimleri Dergisi*, *24*(3), 1-23.

Culpin, C. (1986). *Farm Machinery* (10. Edition). *HarperCollins,* London, 450 p.

Değirmencioğlu, A., Çakır, E., Gülsoylu, E., & Keçecioğlu, G. (1998). Stress analysis on plow roofs using Finite Element Method (Verbal statement). Tarımsal Mekanizasyon 18. Ulusal Kongresi.

Ergech, A., & Tahir, H. T. (2008). Comparative analyses of the 4WD tractor performance with two different moldboard plow bottoms by using FEM. *Journal of Agricultural Sciences*, *14*(02), 183–192.

Gülsoylu, E., & Çakmak, B. (2016). Effect of tractor and machine three-point hitch dimensions on load lifting capacity. *Journal of Agricultural Machinery Science*, *12*(4), 235-242.

Hattat Traktör (2023, October 29). *Tractor models*. https://hattattraktor.com/traktorler/hattat-traktor/hattat-t4000-stage-5

İşler, N., & Kılınç, M. (2016). Field agriculture. *Tarla Bitkileri Merkez Araştırma Enstitüsü Dergisi*, *25*(2).

Keçecioğlu, G., & Gülsoylu, E. (2002). *Soil cultivation machines* (1. Edition). Ege Üniversitesi Ziraat Fakültesi Yayınları, İzmir, Türkiye, 265 p.

Massey Ferguson (2023, September 29). *Tractors*. https://www.masseyferguson.com/tr_tr/product/tractors/mf-4700-m.html

Mattetti, M., Varani, M., Molari, G., & Morelli, F. (2017). Influence of the speed on soil-pressure over a plow. *Biosystems Engineering*, *156*, 136-147.

New Holland Agriculture (2023, September 28). *Tractors*. https://www.newholland.com.tr/traktorler/tdd-bluemaster-tmr

Öztekin, S. (2006). Agricultural machinery 2 (1. Edition). Nobel Kitabevi, Adana, Türkiye, 432 p.

SolidWorks. (2024, June). *SolidWorks Simulation*. https://www.SolidWorks.com/tr/product/SolidWorks-simulation

Tümosan (2023, September). *Field tractors*. https://www.tumosan.com.tr/tr/urun-kategori/tarla

Ünlü Ziraat (2023, June). *Reversible moldboard plow*. https://www.unluziraat.com.tr/klavuzlar/3 Soklu Kullanma Klavuzu %2829.08.2013%29.pdf

Yıldız, S. O., Olum, S. & Velioğlu, H. (2025). Tarım traktörlerinde hidrolik kaldırma kuvvetinin geriye devrilme (şahlanma) noktasına etkisi üzerine bir çalışma. *Mühendislik Bilimleri ve Tasarım Dergisi*, 13(1), 133-143. https://doi.org/10.21923/jesd.1452910

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