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IMPROVEMENT OF SOLID SPREADER BLADE DESIGN USING DEM APPLICATIONS

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I hereby declare that all information and results reported in this thesis have been obtained by my part as a result of truthful experiments and observations carried out by the scientific methods, and that I referenced appropriately and completely all data, thought, result information which do not belong my part within this study by virtue of scientific ethical codes.

07/08/2020

Atakan SOYSAL

ÖZET

DEM UYGULAMALARI İLE KATI GÜBRE DAĞITIM RÖMORKU BIÇAK TASARIMININ İYİLEŞTİRİLMESİ

Atakan SOYSAL

Yüksek Lisans Tezi, Makine Mühendisliği Anabilim Dalı
Tez Danışmanı: Prof.Dr. Pınar DEMİRCİOĞLU
2020, 43 Sayfa

Klasik bıçak tasarımlarının daha çok makine arkasında gübre serpmeye uygundur. Bu sebeple gübreleme işlemini tamamlamak için gereken zaman ve yakıt sarfiyatı fazladır. Homojen ve geniş alanda dağılım sağlandığında hem zaman hem de yakıt tasarrufu sağlanmış olacaktır. Bunların yanında gübreleme verimi de artacaktır.

Bu çalışmada, tarım arazilerini gübreleme için kullanılan katı gübre dağıtım römorklarının serpme genişliğini artırmak ve homojen bir dağılım elde etmek için bıçak tasarımının iyileştirme çalışmaları sunulmuştur. Bu yeni tasarım hem bilgisayar ortamında hem de sahada test edilmiştir. Bıçak tamburları eğilerek gübrenin daha uzağa atılması sağlanmış ve bıçak yüzeylerini artırarak birim zamanda atılan gübre miktarı artırılmıştır.

Dağılımı izlemek için araziye toplama kutuları yerleştirilmiştir. Traktöre bağlı makine üç farklı ilerleme hızında çalıştırılarak (4, 5 ve 6 km/h) belirlenen rotada kutuların üzerinden geçirilmiş ve kutularda biriken gübre miktarı gözlemlenmiştir. Denemelerde sepere edilmiş katı gübre (%65 nem) ve kompost (%50 nem) olmak üzere iki farklı karakteristikte gübre kullanılmıştır. Bu malzemelerin hacim ağırlıkları ise sırasıyla 720 kg/m^3 ve 600 kg/m^3 olarak ölçülmüştür. Dağıtım tamamlandıktan sonra her bir kapta toplanan gübre tartılmış ve varyasyon katsayısı hesaplanmıştır. Efektif serpme genişliği, testin yapıldığı tüm traktör hızlarında 13 metre olarak tespit edilmiştir.

Anahtar Kelimeler: Arazi Uygulamaları, Dağıtım Genişliği, DEM Analizi, Düşey Bıçaklı Dağıtıcı, Katı Gübre Römorku.

ABSTRACT

IMPROVEMENT OF SOLID SPREADER BLADE DESIGN USING DEM APPLICATIONS

Atakan SOYSAL

M. Sc. Thesis, Department of Mechanical Engineering
Supervisor: Prof. Dr. Pınar DEMİRCİOĞLU
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Since the conventional blade designs are more suitable for spreading manure behind the machine, the time and fuel consumption required to complete the fertilization process is high. When homogenous and wide area distribution is achieved, both time and fuel will be saved.

In this study, improvement studies of the blade design are presented to increase the spread width of solid fertilizer distribution trailers used for fertilizing agricultural lands and to obtain a homogeneous distribution in land. This new design has been tested both in the field and in the computer environment. The blade drums were bent and the fertilizer was thrown further, and the amount of fertilizer thrown in unit time was increased by increasing the blade surfaces.

Collection boxes were used to monitor the distribution in the land. The machine driven by a tractor was operated at three different feed speeds (4 km / h, 5 km / h and 6 km / h), passed over the boxes in the determined route and the amount of fertilizer accumulated in the boxes was observed. In the trials, two different fertilizers were used, which are separated solid manure (65% moisture) and compost (50% humidity). The volume weights of these materials were measured as 720 kg / m³ and 600 kg / m³, respectively. After the distribution is completed, the fertilizer collected in each container is weighed and the coefficient of variation is calculated.

Key Words: DEM Analysis, Distribution Pattern, Field Application, Solid Spreader, Vertical Beater.

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Also, I would like to thank my friends Cansu Uymaz and Tuğçe Keskin whom I had the chance to meet during my study. Their efforts and help with my studies are invaluable. I would like to acknowledge the efforts of my dear friend Sertaç İpek for his help with my study.

In addition, production of vertical beaters and field tests for this study were carried out in headquarters and test area of EYS Metal San. ve Tic. Ltd. Şti. in Aydın Astim Organized Industrial State. I would also like to thank them for giving me the opportunity.

Last but not least, I would like to give all my special thanks to my beloved mother. Without her support, I wouldn't be who I am and where I am right now.

Atakan SOYSAL

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LIST OF SUBSCRIPTS

$\bar{X}$: mean

B : effective working width

n : quantity of box in distribution width

P : amount of manure

Q : manure distribution norm

S : standard deviation

V : linear speed of the machine

W : weight of dried solid manure

W_o : weight of solid manure

x_i : manure weight in each box after folding technique

Cv : coefficient of variation

LIST OF ABBREVIATIONS

DEM	: Discrete Element Method
DM	: Dry Matter
PTO	: Power Take off
TSE	: Türk Standartları Enstitüsü (Turkish Standards Institute)

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1. INTRODUCTION

Development of plants depends on the presence of enough nutrients in the soil. Soil contains many mineral substances in its structure, but their amounts are not always sufficient or available to plants. Especially the lands on which plants are grown become poor in terms of nutrients (Anonymous, 2014). Plants take these elements into their bodies and use them in the synthesis of organic compounds and biochemical events necessary for growth and metabolism activities (Çokuysal, 2010). The nutrients essential for plant development are called essential nutrients. These are carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, iron, manganese, copper, zinc, molybdenum, boron and chlorine. Plants cannot maintain their normal development when any of these are not available (Anonymous, 2014). Plant nutrients can be divided into two parts, macro elements and micro elements. Plants need large amounts of macronutrients compared to micronutrients and they contain these elements in large quantities. Plants need very little amount of nutrients in the micro nutrients group and they contain these elements in very low amounts (Çokuysal, 2010).

-Macro-nutrient elements: carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium and sulphur.

- Trace element or micronutrient elements: iron, manganese, copper, zinc, molybdenum, boron and chlorine.

The substances that stimulate the development in organic inorganic plants taken from the soil by the plant until the end of the maturity period in germination of the seed is called manure. According to Adolif Mayer, “In order to increase the amount of product to be obtained from the agricultural land, all the substances given to the soil are called manure. Manures are divided into 2 classes as shown in the Table 1.1 (Oğuz, 2008).

Table 1.1. Types of Manure.

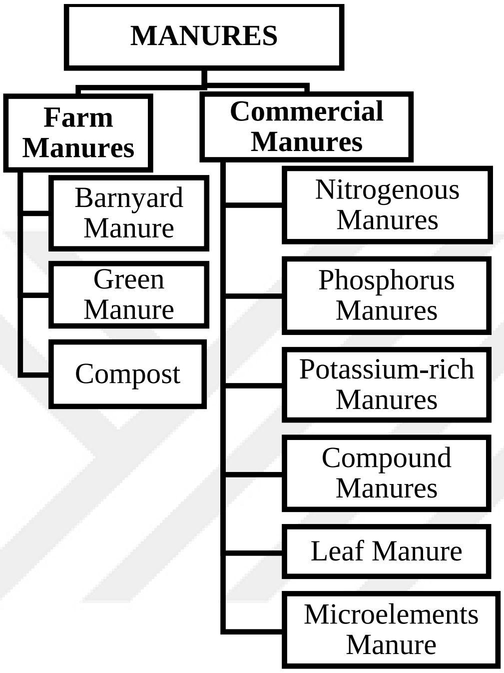


Figure 1.1. Compost Manure

2. LITERATURE REVIEW

2.1. Classification of Fertilizers

Different researchers classified the fertilizers in different ways, taking into account the criteria. These criteria and classifications are summarized below.

- Fertilizers taking into account their availability:
  - **Natural Fertilizers:** Barnyard fertilizers, green fertilizers, blood flour, bone meal etc.
  - **Artificial Fertilizers:** Ammonium sulfate, ammonium nitrate, potassium nitrate etc.
- Fertilizers according to the forms of plant nutrients in fertilizers:
  - **Organic Fertilizers:** Barnyard manure, green fertilizers, blood flour, bone meal etc.
  - **Mineral Fertilizers:** Chilean saltpeter, ammonium nitrate, potassium nitrate, etc.
- Fertilizers taking into account the agricultural enterprise where the fertilizers are made:
  - **Plant Fertilizers:** Fertilizers obtained in agricultural enterprises; barnyard manure, compost, human droppings etc.
  - **Commercial Fertilizers:** Fertilizers purchased from outside but not purchased in the agricultural enterprise; fertilizers containing one or more nutrients and produced for commercial purposes.

However, due to the purchase and sale of fertilizers obtained in the enterprise, this classification has largely lost its validity.

- Finally, some researchers fertilizers:
  - **Organic Fertilizers:** They contain plant nutrients in an organic way.
  - **Chemical Fertilizers:** These are fertilizers containing one or more nutrients in their composition and produced by chemical methods.

Manuring is a very special production factor in order to ensure growth and development in crop production, increase yield and quality, and improve the quantity and quality of the product taken from the unit area (Çokuysal, 2010).

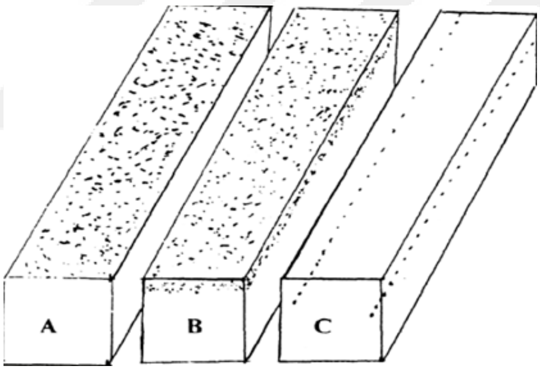
Manuring ;

a) In the form of application to the soil

b) In the form of application to the plant (plant leaf)

c) In the form of application to soilless cultivation environments

It is done in three ways as above (Taban, 2020).



Direct application of solid fertilizers to the soil:

A. Application by sprinkling on the soil surface,

B. Mixing the fertilizer with the soil after sprinkling it on the soil surface,

C. Application to band.

When considered in terms of Turkey, a substantial part of organic matter is insufficient scope of our soil. Lack of organic matter, on the other hand, speeds up the deterioration in the soil. Increasing the organic matter coverage of soils and improving soil properties are among the priority issues (Lampkin, 2002; Schoenau, 2006).

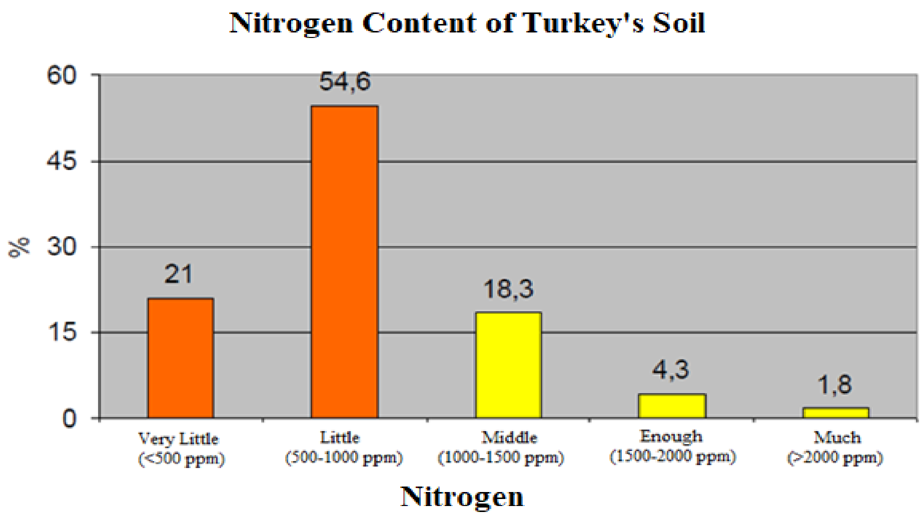


Figure 2.1. Nitrogen Content of Turkey's Soil(Taban, 2020).

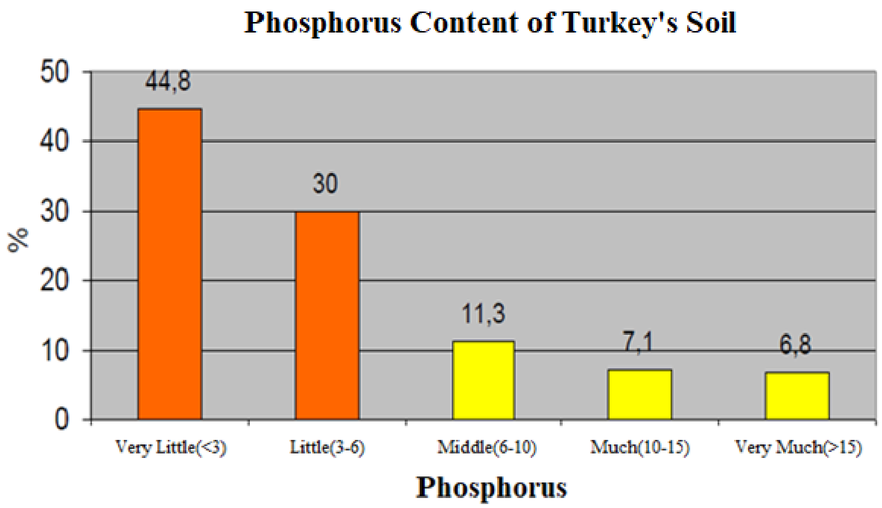


Figure 2.2. Phosphorus Content of Turkey's Soil(Taban, 2020).

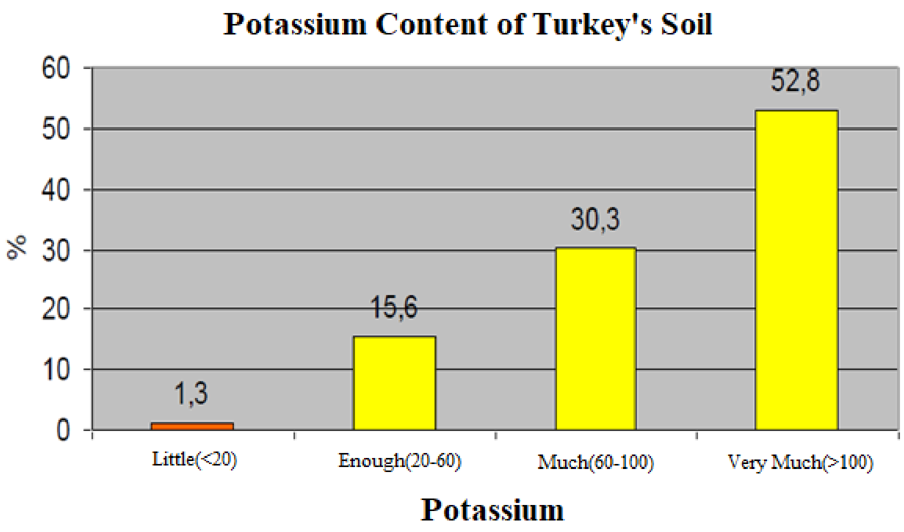


Figure 2.3. Potassium Content of Turkey’s Soil(Taban, 2020).

The ability of the plant to achieve a good development in the soil in agricultural production activities is related to the physical and chemical properties of the soil environment in which it grows. The most frequently used method in correcting the physical properties of the soil and ensuring its continuity is the addition of materials of organic origin to the soil (Bender et al., 1998).

Organic manures provide nutrients when compared to commercial manure, as well as have a function to correct the physical, chemical and biological properties of the soil (Derya, 2013).

Farm manure, poultry waste, bird manure, green fertilizers, composts, garbage, food industry waste, sugar industry waste are the most important organic fertilizers (Anonymous, 2014).

2.2. Functions of Organic Substance on Soil

- It reduces the negative environmental effects of pesticides, heavy metals and many pollutants in the soil.

- It increases the usefulness of many nutrients, especially nitrogen, phosphorus and sulfur, and accelerates the development of plants and soil organisms.
- Helps cluster of soil grains and reduces the risk of erosion.
- It helps plant development by increasing the water holding and aeration capacities of soils (Taban, 2020).

Various organic materials can be used to eliminate organic matter deficiency and improve the properties of soils. Vegetable residues remaining after harvest, farm residues, barnyard fertilizers, urban residues, industrial wastes and similar materials can be used directly or after composting (Pascual et al., 1997; Madejon et al., 2001; Kütük et al., 2003; Bhattacharyya et al., 2003). Barnyard manure is a fertilizer matured by taking liquid and solid feces of bovine or ovine animals together with a qualified substrate and compacting them in layers in a suitable environment, covered with a covered surface, which does not allow fluid loss. In terms of the content of barnyard fertilizers, poultry, ovine and last cattle manure come in quality ranking (Aydeniz et al., 1993).

- N, P, K contents of different animal fertilizers are given in Table 2.1.

Table 2.1. N, P, K Contents of Different Animal Fertilizers (Follet et al., 1981).

Manure	**Nutritional element,% dry matter.**		
	N	**P**	**K**
Cattle manure	2.0 (1.0)*	1.0 (0.5)	2.0 (1.0)
Horse manure	1.7 (1.0)	0.3 (0.2)	1.5 (0.9)
Sheep manure	4.0 (1.0)	0.6 (0.2)	2.9 (0.7)
Pig manure	2.0 (1.0)	0.6 (0.3)	1.5 (0.8)
Chicken manure	3.9 (1.0)	2.1 (0.5)	1.8 (0.5)

* The numbers in parentheses show the proportional values of P and K when N = 1.0.

The barnyard manure also has value due to the microelements it contains. As seen in Table 2.2, Mn, Zn, B and Cu are remarkable in barnyard manure.

Table 2.2. Micro element content of stable manure (Simpson et al., 1981).

Micro elements	**Amount, g**
Mangan (Mn)	50-100
Zinc (Zn)	20-40
Boron (B)	10-15
Copper (Cu)	10-12
Molybdenum (Mo)	0.4-0.7
Cobalt (Co)	0.8-1.2

When the barn manure is added to the soil, the net mineralization affects the C / N ratio. Materials with a higher C / N ratio have a higher value in the construction of soil organic matter and in the supply of nutrients for the long term.

Table 2.3. Nutrient Contents of Some Organic Materials.

Source	**% N**	**% P_2O_5**	**% K_2O**	**Beneficial**
Barnyard Manure	0.5-1.0	0.15-0.20	0.5-0.6	Middle
Chicken Manure	2.87	2.90	2.35	Medium-fast
Compost	1.5-3.5	0.5-1.0	1.0-2.0	Slow
Horse Manure	0.3-2.5	0.15-2.5	0.5-3.0	Middle
Bone Dust	0.7-4.0	18.0-34.0	0.	Slow-medium
Blood Powder	12.0	1.5	0.57	Medium-fast
Seaweed	0	0	4.0-13.0	
Wood Ash	0	1.0-2.0	3.0-7.0	Fast
Cotton Seed Meal	6.0	2.0	1.0	Slow

All organic residues of vegetable and animal origin from the agricultural enterprise or outside the enterprise are used in composting. Vegetable stems, leaves, weeds, kitchen residues are suitable for compost making. These materials are prepared to be mixed in a place where the base is compressed and mixed well (Soyergin et al. 2003)

Table 2.4 specifies the features required for an ideal compost.

Table 2.4. Properties of An Ideal Compost (Anaç and Okur 1998).

Features	Desired Values
C:N ratio	25-30
Particle size	10 mm in ventilated systems, 50 m in long heaps and natural ventilation conditions.
Moisture content	% 50-60
Air flow	Oxygen content should be between 10-18%.
Heat	55-60°C
pH	5.5-9.0
Stack height	If natural ventilation is to be carried out, piles of 1.5 m height, 2.5 m width and desired length are made.
Microbiological activity	Cellulotic fungi and biofertilizers.

Composting is widely applied worldwide to organic wastes including manure. It is an aerobic process that biologically degrades livestock manure into humus and maintains nutrients in compost by high temperature fermentation through the function of microorganisms (Nigussie et al., 2017). In composting, organic matters degradation depends on the C/N ratio of feedstock. The suitable C/N for composting is about 30; higher C/N ratio may prolong the process while a low C/N ratio means that available nitrogen is in excess and may be lost as NH3 with odor (Chen et al., 2011).

Table 2.5. Basic Composition of Different Livestock Manures (Bernal et al., 2009).

Parameter	Beef Manure	Pig Manure	Chicken Manure
Water Content (%)	87.44	71.20	55.00
Organic Matter (%)	79.37	-	-
Total Carbon (%)	43.81	36.20	35.00
Total Nitrogen (g/kg)	19.40	27.40	43.70
Total P (g/kg)	4.20	-	18.40
C/N	22.16	13.20	8.01
Total K (g/kg)	14.40	-	35.20

Table 2.5 lists the composition of different kinds of manure. Livestock manure normally has a low C/N ratio, which can be adjusted by adding bulking agents with more organic carbon (Bernal et al., 2009).

2.3. Fabrication and Application of Composites

- During composting, some of the high level carbon (C) in the fresh feces becomes free as CO_2 and the C / N ratio decreases by 12 to 20 in fertilizer.
- Some plant foods in organic form in fresh feces turn into forms that plants can utilize.
- Initially, nitrogen, which is high in fresh feces, decreases to levels that will not harm plants.
- The temperature rises up to 60-80 degrees due to the active breakdown in the compost pile, while pathogens (bacteria, viruses, fungi, etc.) and fly, worm and disease-causing organisms die.
- Some unsuitable features (reaction, salinity, etc.) of fresh animal feces are also made suitable during the composting process.
- The composted animal feces (manure) is easy to store, transport and apply in the field.
- Its irritating odor was largely lost during composting.
- Since the nutrients reach a stable structure during composting, the risk of disappearance is eliminated (Taban, 2020).

2.4. Manuring Techniques and Machines

The main task of manure spreading machines is to distribute the fertilizer uniformly to the field. Excessive manuring causes the vegetative component to increase in the plant, and the NO_3 and similar plant foods that are not used by the plant are washed deeply with rain or irrigation water and mixed with the ground water. Incomplete manuring decreases product yield and quality (Ergüneş, 2009).

Table 2.6. Manure Machine Types (Akıncı, 2020).

1. Organic Manure Dispensing Machines	1. Liquid Farm Manure Dispensing Machine	
	2. Solid Farm Manure Dispensing Machine	
2. Inorganic Manure Dispensing Machine	1. Solid (Mineral) Manure Spreading Machine	a. Chest Manure Distribution Machine
		b. Precision Manure Distribution Machine
		c. Centrifuge Manure Distribution Machine
	2. Liquid and Gas Manure Dispensing Machine	

2.5. Discrete Element Method

In general, three basic methods are used to model the interaction between the agricultural machine and the soil. These methods are experimental, analytical and numerical methods. Although experimental modeling methods are useful methods to provide practical information in a short period of time, they cannot be used efficiently because the experimental processes are time consuming and expensive and the results are only valid for specific situations (Raji, 1999).

Depending on the developments in computer technology, numerical methods have begun to be used to overcome the shortcomings of experimental and analytical methods. The most used of these methods are finite elements (Kushwaha and Shen, 1995; Fielke, 1999) and computational fluid dynamics (Karmakar and Kushwaha, 2005; Karmakar et al., 2009).

Some researchers emphasize that the discrete elements method can be used to more accurately calculate the forces occurring in the machine-to-ground communication and model the soil motion as well, by eliminating the deficiencies in the finite element and computational fluid dynamics methods (Shmulevich et al., 2007; Chen et al., 2013; Ucgul et al., 2014; Bravo et al., 2014).

The discrete element method was developed by Cundall and Strack (1971). The basic principle of this method is based on the interaction between two discrete particles. The interaction between the particles and the resulting forces are calculated with formulas controlled by physical laws. After calculating the forces between the two particles, the next positions and orientations of the particles are calculated by integrating Newton's second law of motion. In the discrete element method, the forces are considered to only spread to other particles closest to the particles (Anonymous, 2020a).

The Discrete Elements Method (DEM), which has a common use for calculating the movements of granular materials; mining, mineral processing, food, material handling, metallurgy, etc. in many areas; movements of granular materials, effects on each other and on structures they contact (eg wear), mechanical effects (eg torque), electrostatic interactions, heat transfers, etc. makes it possible to make calculations.

In this way, optimization of processes, equipment design, detailed examination of interactions, etc. It is used as an auxiliary engineering tool in studies (Orhan et al., 2019).

2.5.1. Model Description

The behaviors of individual particles in the system are modeled using a mesh-free method and the behavior of the bulk is predicted. The sequence of a DEM simulation is shown in Figure 2.14.

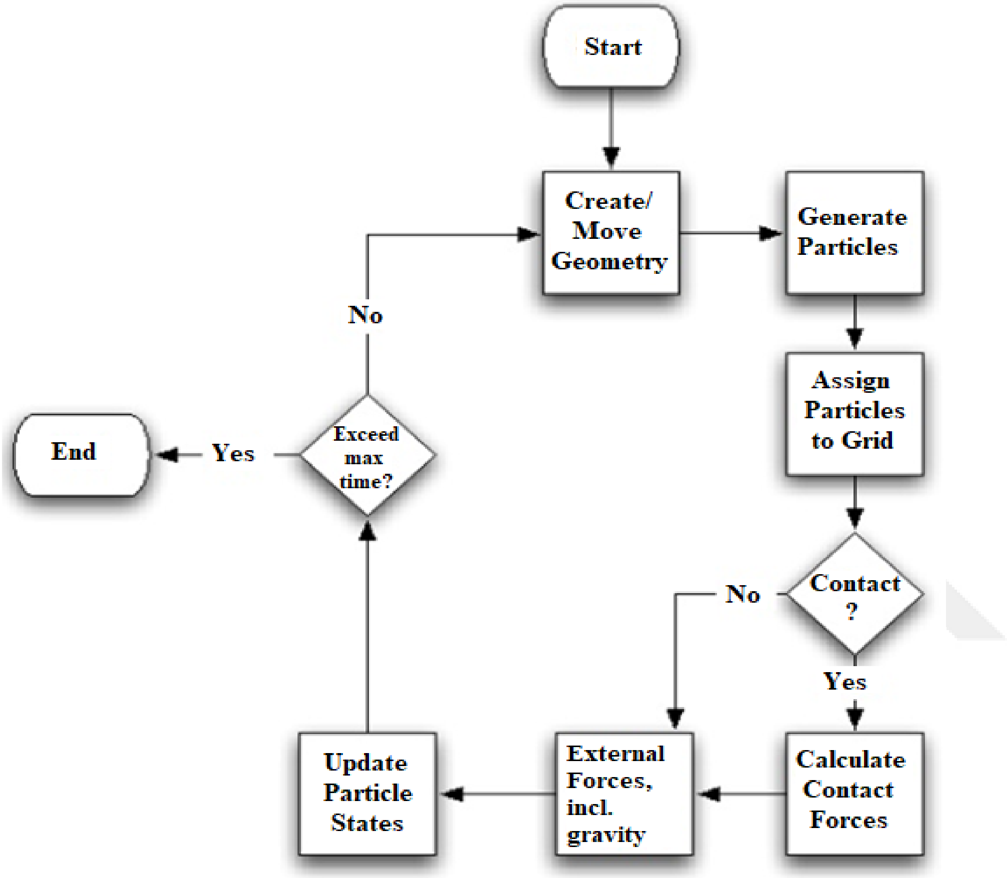


Figure 2.4. Basic DEM simulation flow chart (Anonymous, 2020b).

2.5.2. Applications

DEM is a versatile tool for modeling particulate material behavior in pharmaceutical, chemical, food, ceramic, metallurgical, mining, and other industries. DEM applications include the following categories:

Particle packing involves processes such as pouring or deposition under gravity (such as sandpiling), vibration after deposition of particles, and compaction.

Particle flow may occur under gravity only (as in the case of a hopper) or under gravity and other driving forces (such as for mixers and mills).

Particle-fluid interaction occurs in transport of granular material within a fluid flow, during wavelike motion, and during fluidization (wherein fluid flows upwards through a bed of particles).

DEM can provide insight for many situations that are difficult to investigate with other computational methods or with physical experiments (Anonymous, 2020c).

2.6. Rocky DEM

Rocky is a 3D Discrete Element Modeling (DEM) particle simulation software that accurately simulates the flow behavior of bulk materials with complex particle shapes and size distributions, for typical applications such as conveyor chutes, mills, mixers, and other materials handling equipment. Several capabilities set Rocky DEM apart from other DEM codes, including its Multi-GPU solver, truly non-spherical particle shapes, the ability to simulate particle breakage and flexible fibers, fully integrated with ANSYS simulation software, and more.

Getting a uniform spread pattern with solid spreaders are vital to minimize consumption of time and fuel. If the spread pattern is narrow or not uniform, operator must take more turns in the field which will lead to higher fuel consumption and longer operation time. Therefore the blades on vertical or horizontal beaters needs to be designed effectively. In this study, a beater blade will be designed in a CAD application and the model will be analyzed using a DEM application. Rocky DEM application will be used for the analysis.

3. MATERIAL AND METHOD

3.1. Materials Used

3.1.1. CAD and DEM Applications Used In Analysis

Autodesk Inventor and Rocky DEM applications were used in the study. Blades were designed in Inventor and the model was exported in STL file format to be compatible with Rocky DEM. A sample layout of Rocky DEM is given in Figure 3.1. Data menu is shown on the left side of application window. All settings and parameters are available in this menu. Motion preview is shown at the center of application. On right side, animation and results menu are available. Details of design is given in section 4.3.

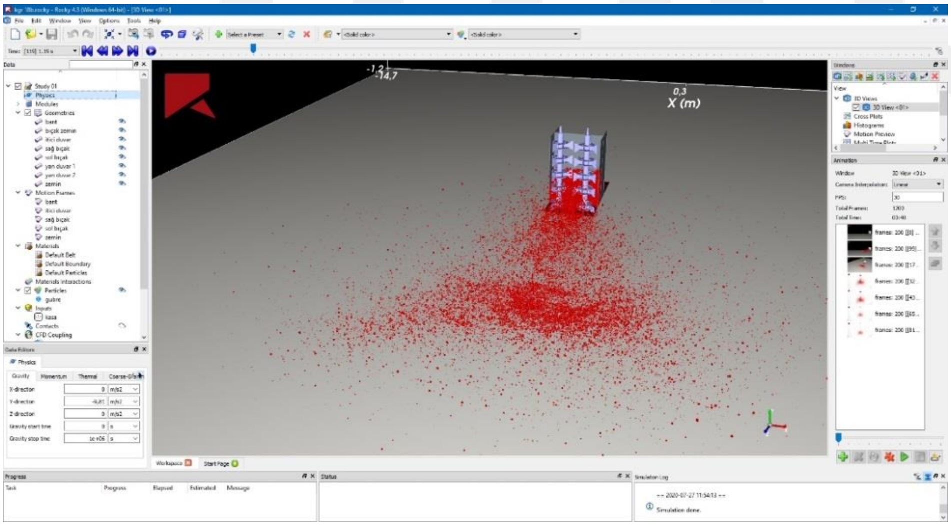


Figure 3.1. Layout of Rocky DEM

3.1.2. Test Field

Test field of a local factory in Aydın Astim organized industrial site was used for test. Test field was a flat terrain as shown in Figure 3.2.

Figure 3.2. Field of test

3.1.3. Manure Used in Test

Required solid manure was collected from a local farm in Aydın. Separated solid manure and compost were used in the test. Milking cow manure with %9 dry matter ratio (%DM) was first separated by a screw press separator before application. After separation, dry matter ratio increased to %35 while moisture was decreased to %65. Second sample was composted in an in-vessel compost machine. Then it was piled and mixed regularly for maturation. Dry matter ratio of second sample was %50 after maturation.

3.1.4. Solid Spreader With Dual Vertical Beater

A domestic production solid spreader with 12 m³ capacity was used in application. Chassis and components of the machine was designed and manufactured by EYS Metal company in Aydın Astim organized industrial site.

3.1.4.1. Trailer

Solid spreader units are basically customized trailers. Trailer used in test has single axle, two rubber wheels and is driven by a tractor. A dual vertical beater with a single frame is attached at the rear of trailer. Until spreading solid manure in land, the manure is stored in trailer. While transferring manure to land for application, a hydraulically controlled frame covers the reat exit of trailer and keeps manure inside as a static pile. During operation, this cover will be lifted by tractor’s hydraulic controls and discharge of solids will be allowed. A general view of the trailer used in this application is given in Figure 3.3.

Figure 3.3. General View of a Solid Spreader

Technical details of solid spreader is given in Table 3.1.

Table 3.1. Technical details of solid spreader

Overall Length	6585 mm	**Spread Direction**	Left, rear and right
Overall Width	2820 mm	**Beater Type**	Dual Vertical
Overall Height	3245 mm	**Tractor Power**	90 HP
Loading Capacity	12 m^3	**PTO Revolution**	540 & 1000 RPM
Weight	4250 kg	**Gearbox Revolution**	870 RPM

3.1.4.2. Distribution system

Distribution system consists of dual vertical beaters which are driven by a gearbox. The gearbox is driven by PTO. Tractor may run with either 540 RPM or 1000 RPM during operation. Dual vertical beaters are placed on a frame which is attached to rear end of trailer. Once the frame is removed from chassis, the unit can be used as a conventional trailer. Once the rear end cover is lifted by hydraulic cylinders, chain dragging system inside trailer will move solids to rear end.

Comparison of old and new vertical beater designs are given in Table 3.2.

Table 3.2. Comparison of technical details of previous and new vertical beater design

	Previous Design	**Improved Design**
Type	Screw	Screw
Quantity Of Beaters	2	2
Shaft Diameter	139 mm	139 mm
Shaft Length	1950 mm	1950 mm
Shaft Speed	350 RPM	870 RPM
Diameter Of Beater	670 mm	674 mm
Blade Placement	Horizontal and Vertical	Vertical
Beater Working Angle	0º	6º or 12º
Material	S235	S235

3.1.4.3. Feeding arrangement

A simple conveyor is available inside trailer and is driven by a hydro motor. Two gears were placed at the rear end of machine just before vertical beaters and gears are connected by a shaft. Same setup is used at front side of trailer. Front and rear gears are connected by a chain mechanism. Sheet bars are placed on chains with a uniform pattern and solid manure moves on these sheet bars towards rear end. General view of feeding conveyor is given in Figure 3.4.

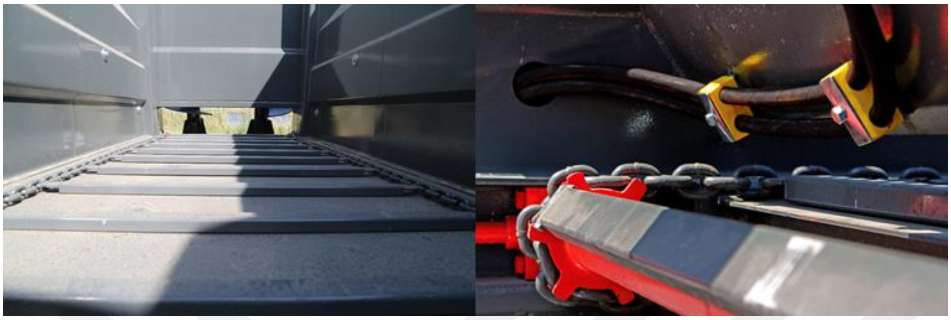


Figure 3.4. Conveyor mechanism inside trailer

3.1.4.4. Power transmission

Minimum 90 HP tractor is required to drive vertical beaters of the machine. Tractor can run with either 540 RPM or 1000 RPM. Horizontal rotation gathered by power take off of tractor is converted to vertical rotation by a gearbox at rear bottom of trailer with an exchange ratio of 1:1,61. When tractor is driven by 540 RPM, vertical beater speed is obtained as 870 RPM. Hydro motors which control feeding arrangement at bottom and rear end cover are connected to tractor's hydraulic system by hydraulic hoses. During test feeding conveyor was used at 0,06 m/s. Velocity of conveyor can be adjusted by tractor's hydraulic controls. Conveyor linear speed can be adjusted between 0,05 m/s and 0,18 m/s.

3.2. Method

3.2.1. Vertical Beater Design

Autodesk Inventor application was used to design new blades. Main idea was increasing distribution width as much as possible without sacrificing total mass per unit area. In addition durability and ease of replacement were also vital for design. Disks and blades are made of S235. Dimensions and general view of blade is shown in Figure 3.5.

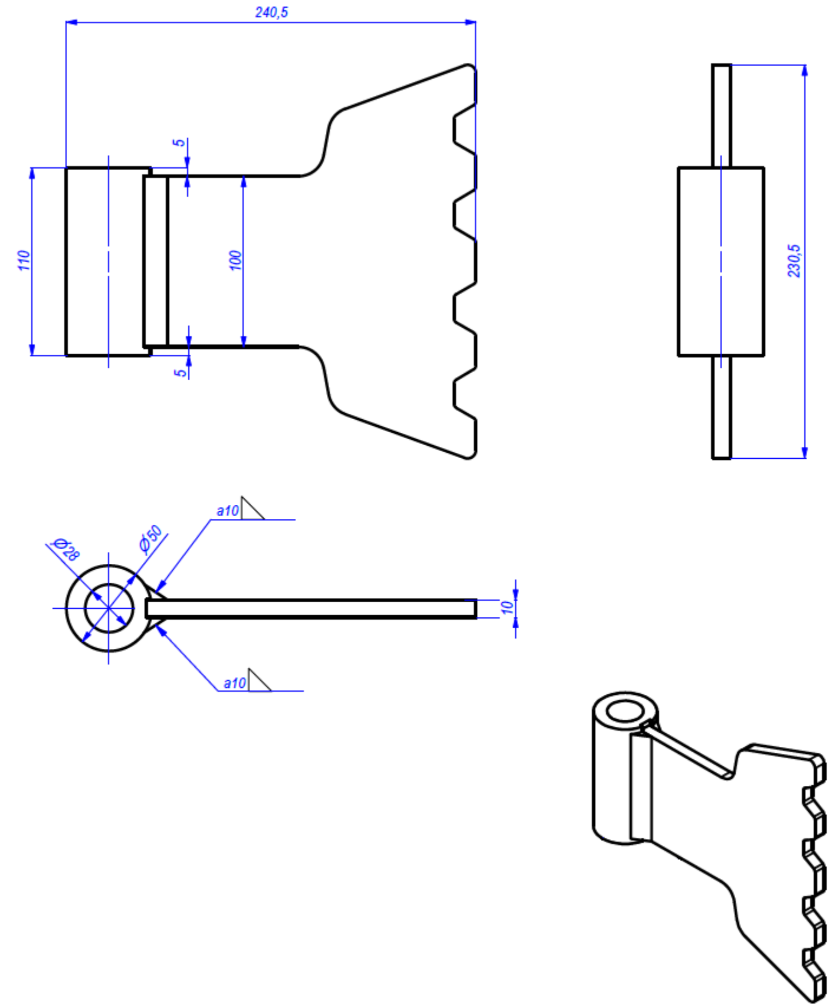


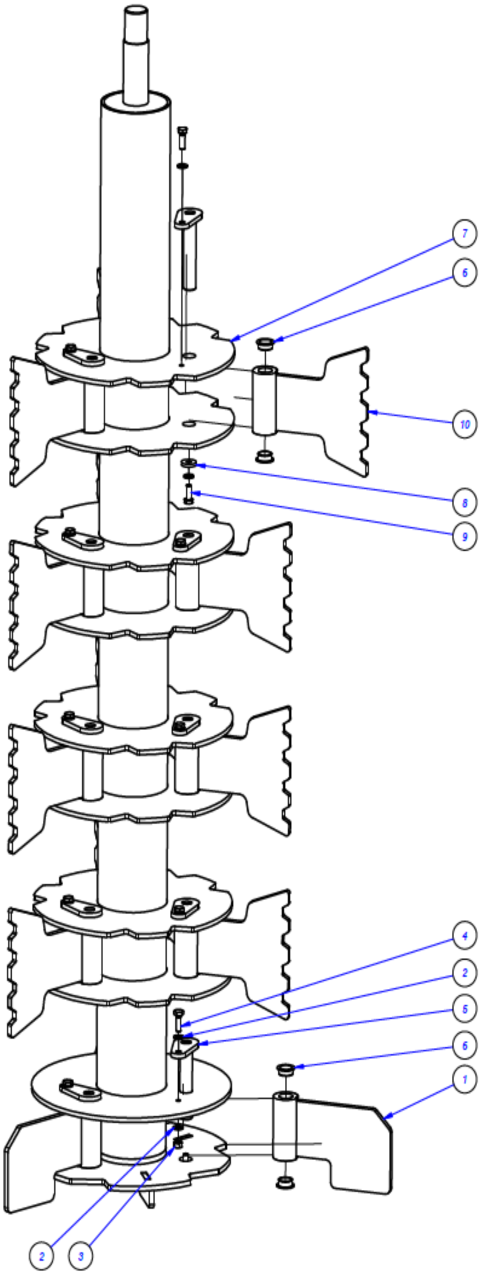
Figure 3.5. Details of New Blade

Ten disks were welded on the shaft as dual sets. Blades were installed between each dual disk by pins. Three blades were installed with 120° between them. Three blades at the bottom were designed as flat to scrape the surface. If a blade is damaged or bended, it can easily be replaced by removing the pin. Beater is shown as stand-alone and assembled on frame in Figure 3.6.

Figure 3.6. Blades Installed on Beater Frame

Exploded drawing of beater is given in Table 3.3.

Table 3.3. Exploded Drawing of Beater



ITEM NO	DESCRIPTION	QTY
1	Bottom Blade	3
2	M10 Washer	45
3	M10 Nut	15
4	M10x30 mm Screw	15
5	Blade Pin	15
6	Bush	30
7	Shaft with Disks	1
8	Pin Washer	15
9	M10x25 mm Screw	15
10	Blade	12

3.2.2. DEM Analysis

Vertical beater was designed in Autodesk Inventor application and it was imported to Rocky DEM in STL format for simulation. Compost particle was designed in the application and the trailer was filled with the particle by using volume fill method. Stickiness and moisture of the compost was adjusted in DEM application by setting adhesive forces. As the characteristics of compost was identified in the application, distribution pattern was simulated. A sample image of particles in the trailer is given in Figure 3.7. Technical drawings and comparison of previous and new design were given in section 4.2.

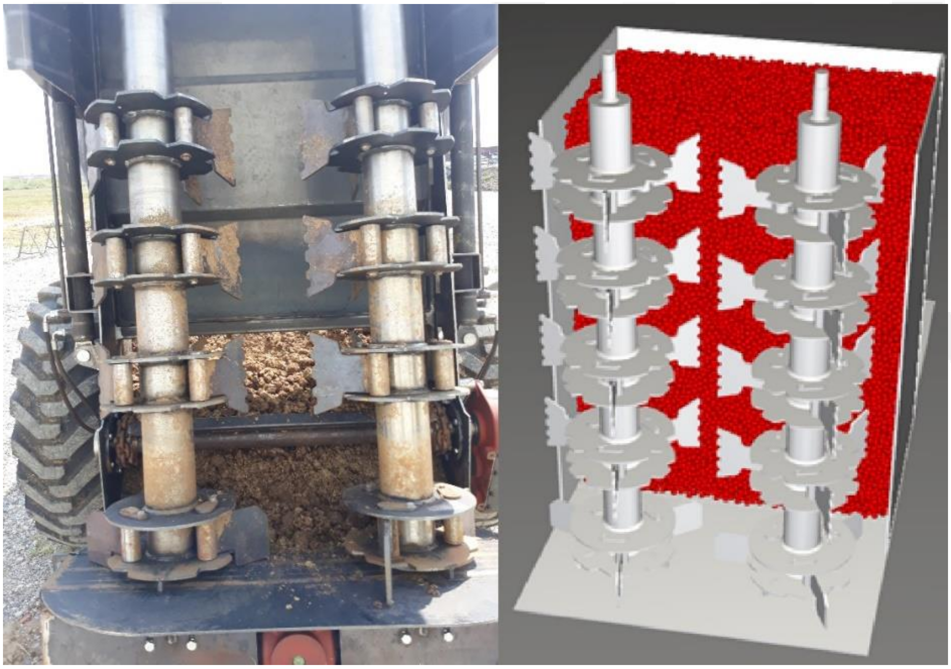


Figure 3.7. Compost Particle Injection in Solid Spreader

Data such as particle size, particle bulk density, moisture of compost particle and adhesive forces between particle-particle, particle-boundaries were used to create simulation.

Parameters entered in application are given in Table 3.4.

Table 3.4. Parameters used in DEM application

Particle Size	5 to 30 mm
Bulk Density	650 kg/
Adhesive Distance	0.02 mm
Force Fraction	0.7
PTO Speed	540 RPM
Gearbox Exchange Ratio	1.16
Gearbox Speed	870 RPM
Wind Speed	1 m
Tractor Velocity	4 km/h

3.2.3. Field Test

In order to receive national certificate of approval for the machine, the design must comply with TS EN 13080 standard. New blade design is used on solid spreader and the machine was tested according to standard with a committee of Turkish Standards Institution.

Forty eight plastic boxes with 600x300x250 mm (LxWxD) dimensions were used to collect distributed solid manure in test. Empty weight of each box were weighed and noted before test by using a precision scale. Then all boxes were placed at both sides of solid spreader's direction of movement. A pattern with 24 boxes on left, 24 boxes on right and three boxes on center was created. A 90 HP tractor was used in test. In order to measure time spent during operation, a chronometer was also used. Boxes are shown in Figure 3.8.

Figure 3.8. Test Layout and Box Placement

3.2.3.1. Moisture measurement

Two different methods were used to measure moisture of solid manure before the test. In order to receive the fastest measurement, an industrial moisture meter is used. Three different samples from solid manure were taken. 10 gr of each sample was dried in the moisture meter. Each measurement was completed around 70 minutes. Used moisture meter is shown in Figure 3.9.

Figure 3.9. Industrial moisture meter used in test

As the second method, an incubator is used. Two different samples were taken from solid manure and both samples were weighed. Both samples were dried in incubator at 105ºC for 24 hours. (Malgeryd and Wetterberg, 1996) The results in first method were confirmed with this measurement. After drying process, both samples were weighed again and moisture ratio was calculated based on below formula.

$$Moisture\ (\%) = \frac{W_o - W}{W_o} . 100$$

W: Weight of dried solid manure (g)

W_o: Weight of solid manure (g)

3.2.3.2. The specimens of tensile test

Start and end points of the test were marked on the land with flags. Once tractor started operation, a precision chronometer was also started. Once tractor passed the flag, chronometer was stopped. Depending on the time and distance, tractor’s speed is calculated.

3.2.3.3. Calculation of side distribution pattern

Plastic boxes were in two rows with 3 meters distance between each other to calculate side distribution pattern of the machine. Location of each box were given in Figure 3.8.

The boxes in the center of track were placed between tyres of solid spreader, thus velocity of machine is not interrupted or slowed down during test.

After tractor completed operation, each box was photographed and then weighed in precision scale. Results of weights were used to calculate coefficient of variation. Distribution was maximum at the center and as the distance to center increased, distribution dwindled down on sides. After a range on left and right side, there were no solid particles found. So folding technique is used before calculation of coefficient of variation (TSE, 1994).

Each measurement of weight were listed and graphed in excel by using below formula (TS EN 13080).

$$S = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(xi - \bar{x})^2}$$

$$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} xi$$

Where;

S is standard deviation

n is quantity of box in distribution width

x_i is manure weight in each box after folding technique

$\bar{X}$ is mean

After standard deviation was calculated, coefficient of variation was also calculated by using below formula.

$$Cv = \frac{S}{\bar{X}}$$

Where;

Cv is coefficient of variation

In order to comply with TS EN 13080 standard, coefficient of variation must be lower than %35. After calculation, results were compared with the standard.

3.2.3.4. Manure distribution norm of the machine

In order to receive distribution norm of the machine, below formula was used (TSE, 1994).

$$Q = \frac{0{,}06.P}{B.V}$$

Where;

Q: Manure distribution norm (ton/daa)

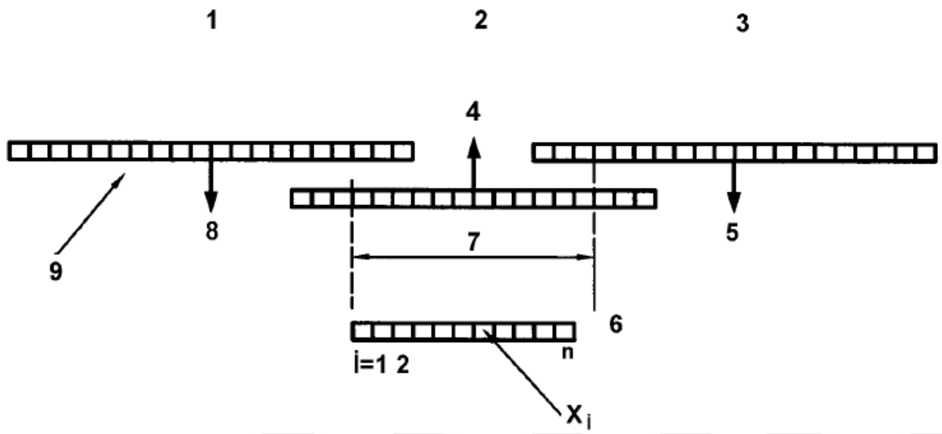
P: Amount of manure (kg/min)

B: Effective working width (m)

V: Linear speed of the machine (km/h)

3.2.3.5. Calculation of effective working width

Effective working width was calculated in Excel by gathered data on field. Coefficient of variation was calculated for every side distribution test where all effective working widths were between half of trailer width or distribution range and distribution range. Determination of working effective working with is shown in Figure 3.10.



1 First folding
2 Second folding
3 Third folding
4 Movement direction
5 Movement direction
6 Section used in calculation of Cv
7 Working width
8 Movement direction
9 Boxes to collect manure

Figure 3.10. Folding simulation used to calculate coefficient of variation for two way distribution

4. RESULTS AND DISCUSSION

4.1. Results of DEM Analysis

Results of DEM analysis was similar to results of field test. Efficient working width was found as 13 meters maximum. Distribution on left side was slightly higher than the right side in field test. The results were seen as opposite of field test. The distribution was higher on right side of the track. Particle size, direction and velocity of wind are also effective on this difference. Due to limitations with the analysis computer, minimum particle size was set to 5 mm. Coefficient of calculation was less than %35 up to 13 m working width. So the design complies with TS EN 13080 standard.

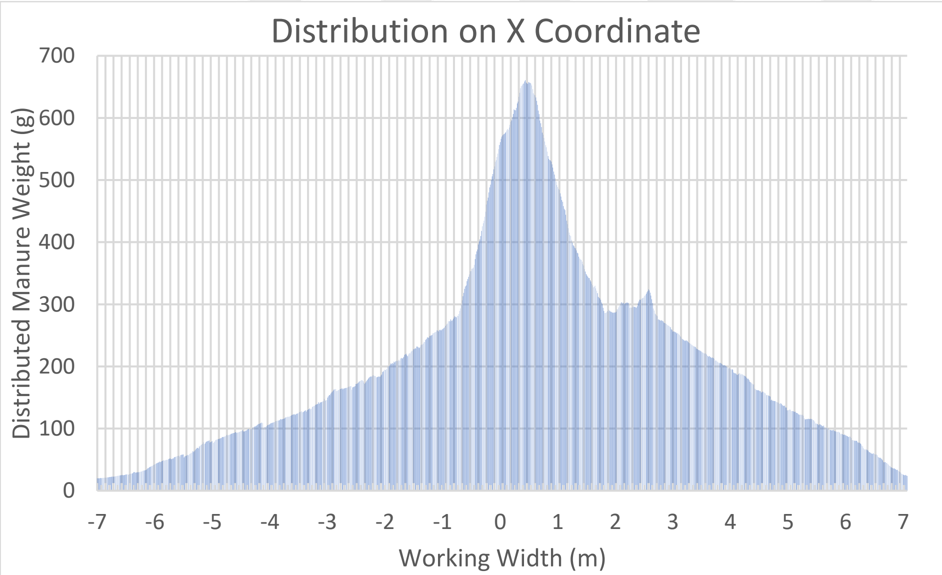


Figure 4.1. Working Width in DEM Analysis

4.2. Results of Field Test

The distribution was maximum at the center and was decreased as distribution range increased. So the amount of manure collected in outer boxes were decreased in a pattern compared to boxes in center. Different amount of manure was collected in each box.

Technical details of used manure in test are given in Table 4.1.

Table 4.1. Physical characteristics of manure used in test

Manure used in Test	Moisture Content	Bulk Density
Separated Solid Manure	%65	720 kg/m³
Compost	%50	650 kg/m³

4.2.1. Results of Field Test with Separated Solid Manure

As the test completed, a certain amount of manure was seen in every box. No empty boxes found after the test. As shown in Figure 4.2, maximum distribution was at the center of movement direction. As the range increased to left and right side, weight of collected manure decreased. Distribution on left side of the field was slightly higher than right side as shown in Figure 4.2.

Velocity of tractor was 8 km/h. Angle of vertical beater assembly was 12º and velocity of wind was measured as 1 m/s while maximum allowed value is 3 m/s. Rear end cover was lifted 700 mm for distribution. Coefficient of variation was calculated as %30.41 which was less than maximum limit (%35). So the design complies with TS EN 13080 standards. In addition, effective working width was calculated as 13 meters. Distribution difference between each side of field was observed as %3.88.

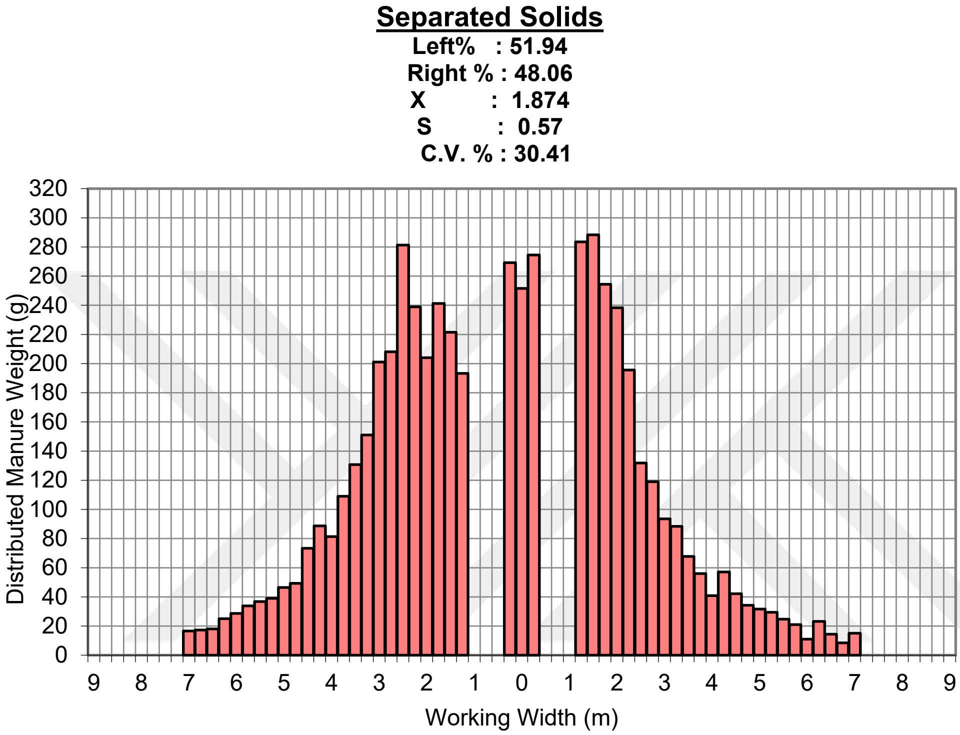


Figure 4.2. Transverse distribution, optimum working width, standard deviation after folding technique and coefficient of variation.

4.2.2. Results of Field Test with Compost

The test with compost was carried out with committee of Turkish Institute of Standards. Since the results were to be recorded, more tests were carried out compared to separated manure. Tests were conducted with half open and fully open rear cover and at three different speeds. Details of the tests are given in Table 4.2.

Table 4.2. Test details with compost

Manure Type	**Position of Rear Cover**	**Working Width**	**Distributed Manure (kg/min)**	**Manure (kg/da)**		
				4 km/h	5 km/h	6 km/h
Compost	Fully open	13	2181	2307	1846	1538
Compost	Half Open	13	1672	1776	1480	1230

5 km/h tractor speed was chosen to calculate distribution pattern. Calculated coefficient of variations for certain working widths are given in Table 4.3. Coefficient of variation for 13 meters working width was calculated as %33.24. As the value is smaller than %35, the design complies with TS EN 13080 standards.

Table 4.3. Coefficient of variation for different working width

Effective Working Width (m)	Coefficient of Variation (CV%)
8.5	10.36
9	14.27
9.5	9.88
10	8.01
10.5	11.22
11	17.17
11.5	21.83
12	26.06
12.5	29.97
13	33.24

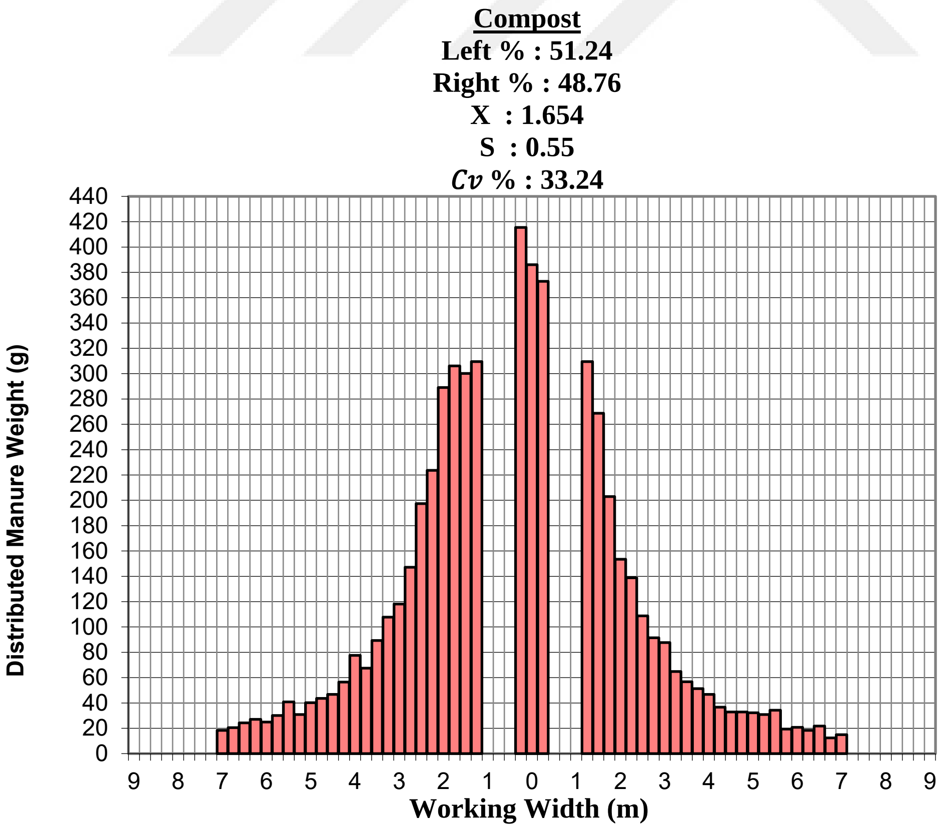


Figure 4.3. Transverse distribution, optimum working width, standard deviation after folding technique and coefficient

4.3. Comparison of Previous and New Design

Compared to old model, design of each blade has been changed completely. Ten horizontal disks were added on beater shaft. Three blades were placed between each dual set of disks with 120º between each blade. In previous design, each blade was fixed by screw and nut connection to shaft. In new design, each blade was connected by a pin to disks. Since the blades were fixed to shaft in old design, their rotation was limited to rotation of shaft. In addition to rotation by shaft, now the blades can also rotate at a limited angle in new design. This additional self-rotation of blades were achieved by using pin connection instead of screw and nut connection. When there are stones or any other solid particles in the manure, it may damage the blades. Since the blades were fixed in the old design, blades used to worn out fast and the force on screws were higher. Each blade can rotate at a limited angle freely in new design since they have an extra degree of freedom. When a stone hits the blades, the blade will free move at a limited angle and easily evade possible force caused by the stone. In addition dual vertical beater and the frame were installed with 12º angle on chassis of trailer. When the blades were mounted vertically, particles were launched horizontally. As the blades were mounted at an angle, horizontal launch turns to projectile motion. So the particles can spread further. Speed of tractor and blades are also vital. If tractor is moving too fast, then manure amount per unit area will not be enough. So operator needs to take more laps to fertilize the land.

General view of old and new distribution systems are given in Figure 4.4 and Figure 4.5.

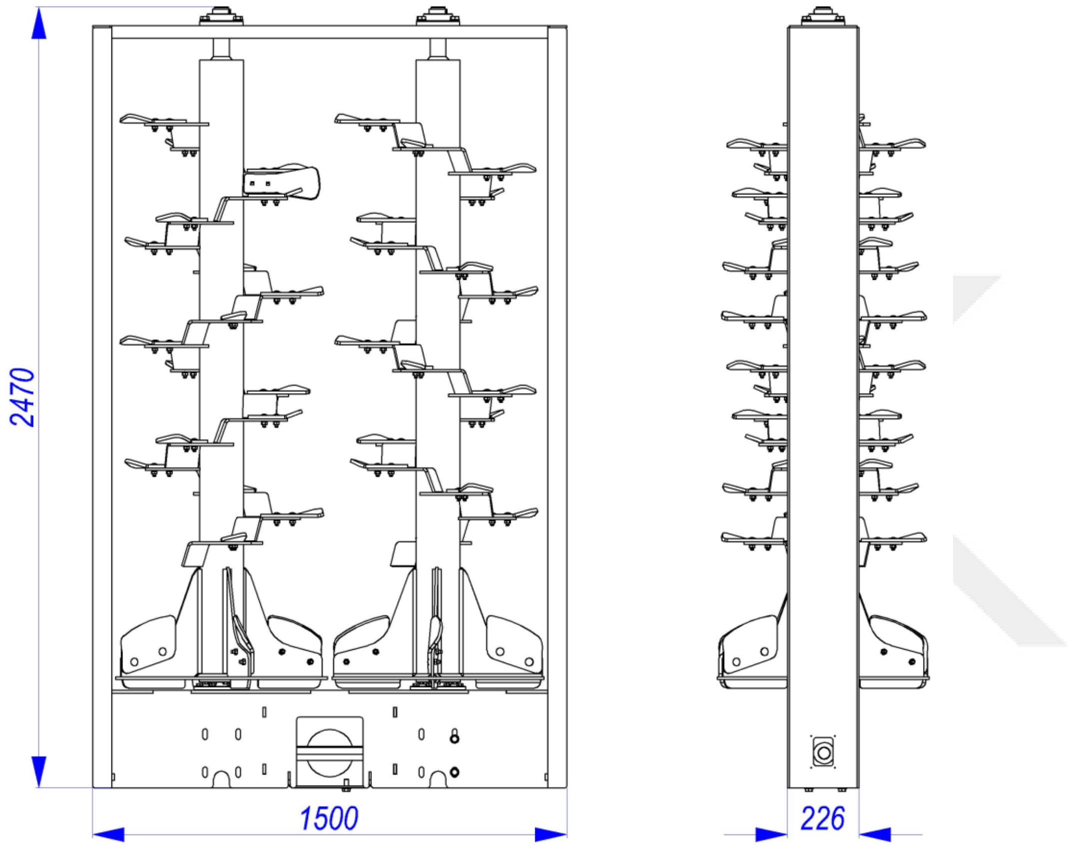


Figure 4.4. Previous vertical beater design

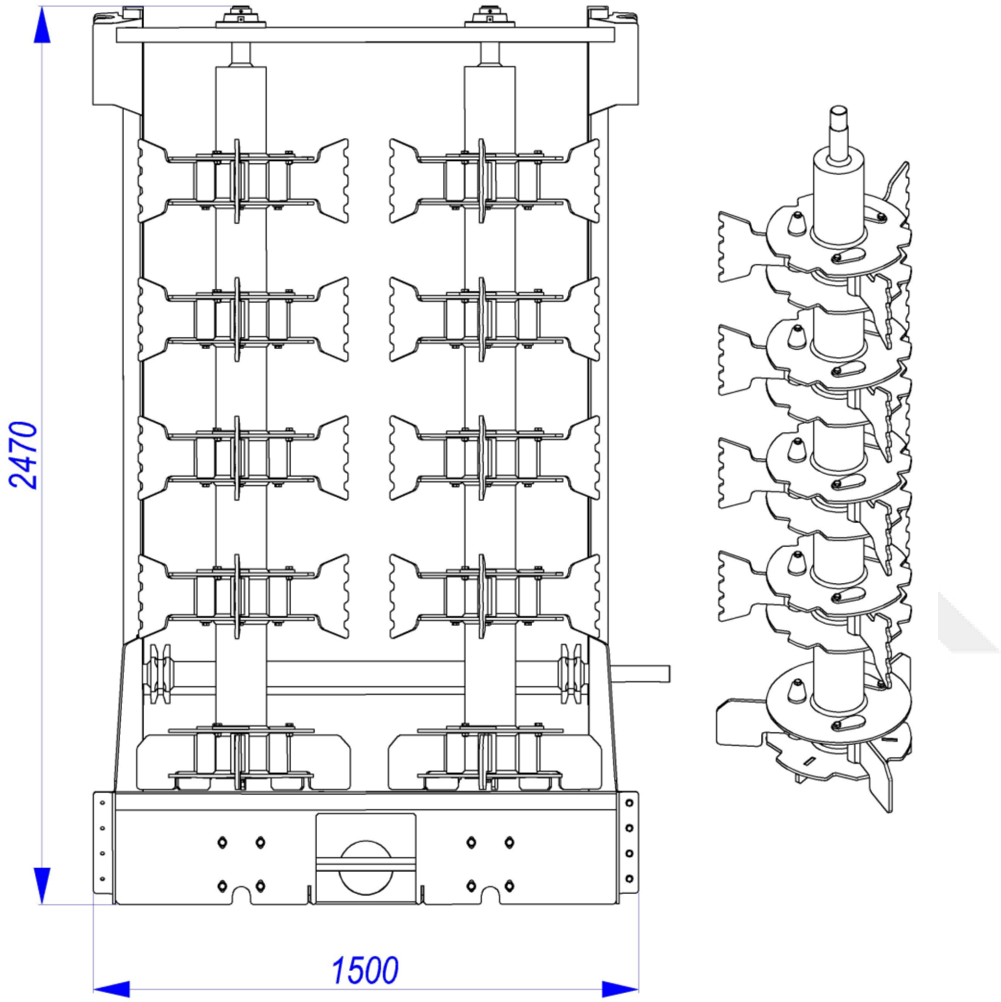


Figure 4.5. New vertical beater design

In old design, same blades were placed both horizontally and vertically. Purpose of placing blades in both axis were to achieve a uniform spread pattern. With original design, almost all of manure was spread at rear of trailer. Based on the results of first test, a certain angle were given to each blade. This improvement helped increase spread pattern on left and right side of trailer. However, the spread pattern was still not uniform. The results were out of acceptable limits of TS EN 13080 standard. Detailed drawing of previous design is given in Figure 4.6.

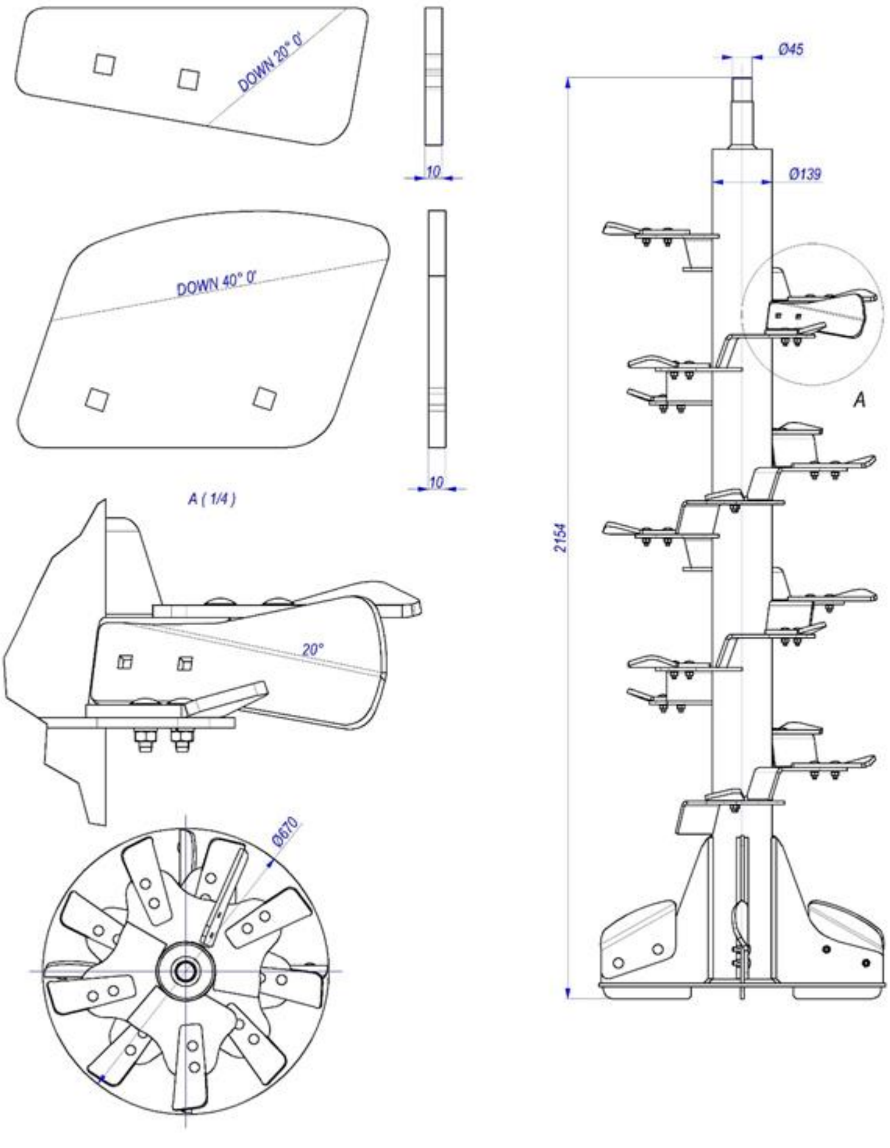


Figure 4.6. Blade details of previous vertical beater design

Total vertical surface area was higher in previous design, but distribution was mainly at the center. Gap between each design is higher compared to previous model, but the design was abandoned to increase homogenous distribution pattern.

5. CONCLUSION

5.1. Conclusion

Effect of vertical beater design on distribution width has been investigated in detail using DEM applications and with field test. Trials with TSE committee was continued for 10 hours. No replacements or maintenance was done on the machine during this period. This method gave the opportunity to observe possible damages and wear on the blades during trial.

In order to observe distribution, solid spreader was also used in a rough country. Due to minimized design and manufacturing tolerances, possible vibrations on the beaters were observed at minimum.

Effective distribution width was increased from 8 meters to 13 meters and coefficient of variation stayed below %35 up to 13 m working width. According to TS EN 13080 standards, the design is acceptable and is eligible to receive national certificate of approval. At current state, design is suitable to be used in industrial applications.

5.2. Recommendations for Future Work

This study has provided fundamental data on effect of beater design on distribution pattern. It also has highlighted the impact of stones on blades were greatly reduced since flexural strength is increased by new design.

Operation angle of shafts are also vital for the whole operation. When there is no operating angle on the U joint, the output yoke of the driven member, U joint and the drive shaft all travel together at a constant speed. When an operating angle is created at the front end of the drive shaft, the output of the U joint no longer travels in a perfect circle. Instead it travels in an ellipse. This forces the drive shaft to speed up and slow down to keep pace with the rotation of the output yoke creating tortional and inertial vibration. So the shafts needs to be at the same operating angle at all times to drive both beaters at the same speed.

Future work is proposed to investigate;

- It is recommended that more endurance tests be conducted that include different type of manure in different regions with different moisture as well.
- The results in the study has shown no visible damage or wear on the blades. By using different type of solid manure or compost, possible wear on blades should be observed.
- It has been shown that the difference of gearbox exchange ratio and speed of beaters also made a considerable increase in distribution pattern. In addition to blade design change, it is also recommended to observe effects of different gearbox exchange ratios and beater speeds on distribution pattern.
- It is recommended that analysis should be repeated by using a high-end computer and smaller particle sizes and different particle shapes and fibrous structure should be modeled.
- As distribution width increased, it will clearly reduce fuel and time consumption to fertilize the land. Exact time and fuel consumption should be calculated and tested in field.
- It is recommended to reduce gap between each vertical blade and observe distribution pattern.

REFERENCES

Akıncı, İ. 2020. Tarım Makineleri Ders Notları. Akdeniz Üniversitesi, Ziraat Fakültesi, Tarım Makineleri Bölümü

Anaç, D. ve B. Okur, 1998. Toprak Verimliliğinin Doğal Yollar ile Artırılması. Ekolojik (organik, biyolojik) Tarım. Ekolojik Tarım Organizasyonu Derneği (ETO), Bornova, İzmir.

Anonymous. 2014. Gübre Analizleri Yapma-2. Laboratuvar Hizmetleri, T.C. Millî Eğitim Bakanlığı.

Anonymous. 2020a. https://www.edemsimulation.com/content/uploads/2016/08/EDEM2.6_theory_reference_guide.pdf

Anonymous. 2020b. https://www.powderbulksolids.com/article/what-discrete-element-method-09-10-2014

Anonymous. 2020c. https://abaqus-docs.mit.edu/2017/English/ SIMACAEANL RefMap/simaanl-c-demanalysis.htm

Anonymous. 2020d. https://en.wikipedia.org/wiki/Ansys

Aydeniz, A., Brohi, A.R. 1993. Gübreler ve Gübreleme. Gaziosmanpaşa Üniversitesi Yayınları No:1. Ziraat Fakültesi Yayınları No:1, 1. Ders Kitapları Serisi 243249.

Bender, D., Erdal, İ., Dengiz, O., Gürbüz, M. ve Tarakçıoğlu, C. 1998. Farklı Organik Materyallerin Killi Bir Toprağın Bazı Fiziksel Özellikleri Üzerine Etkileri. International Symposium On Arid Region Soil. International Agrohydrology Research and Training Center, Menemen, İzmir, 506-510 ss.

Bernal, M.P., Alburquerque, J., Moral, R. 2009. Composting of animal manures and chemical criteria for compost maturity assessment: a review. **Bioresour. Technol. 100 (22)**, pp. 5444–5453.

Bhattacharyya, P., Chakrabarti, K., Chakraborty, A. 2003. Residual effects of municipal solid waste compost on microbial biomass and activities in mustard growing soil. **Archives of Agronomy and Soil Science 49**, pp. 585-592.

Bravo, E.L., Tijskens, E., Suárez, M.H., Cueto, O.G., Ramon, H. 2014. Prediction Model for Non-Inversion Soil Tillage Implemented on Discrete Element Method. **Computers and Electronics in Agriculture, 106**, pp. 120-127.

Chen, L., De Haro, M., Moore, A., Falen, C. 2011. The composting process: dairy compost production and use in Idaho CIS 1179. University of Idaho.

Chen, Y., Munkholm, L.J., Nyord, T. 2013. A Discrete Element Model for Soil-Sweep Interaction in Three Different Soils. **Soil and Tillage Research, 126**, pp. 34-41.

Çokuysal, B. 2010. Gübreleme Ders Notları. Ege Üniversitesi, Ziraat Fakültesi, Toprak Bölümü.

Derya, H. 2013. Tekirdağ İlinde Bulunan Bazı Ahırlardan Toplanan Olgunlaşmış ve Olgunlaşmamış Gübrelerin Besin Elementi İçeriklerinin Belirlenmesi ve Tarımsal Açıdan Değerlendirilmesi. Toprak Bilimi ve Bitki Besleme Anabilim Dalı, Yüksek Lisans Tezi.

Ergüneş, G. 2009. Tarım Makinaları. Ders Notu. pp. 262-272.

Fielke, J.M. 1999. Finite Element Modelling of the Interaction of the Cutting Edge of Tillage Implements with Soil. **Journal of Agricultural Engineering Research, 74(1)**, pp. 91-101.

Follet, R., Donahue R., Murphy, L. 1981. Soil and Soil Amendments. Prentice-Hall Inc.

Houser, M. 1995 .Small firm big player in software industry. Tribune.

Karmakar, S., Ashrafizadeh, S.R., Kushwaha, R.L. 2009. Experimental Validation of Computational Fluid Dynamics Modeling for Narrow Tillage Tool Draft. **Journal of Terramechanics, 46(6)**, pp. 277-283.

Karmakar, S., Kushwaha, R.L. 2005. Simulation of Soil Deformation around a Tillage Tool Using Computational Fluid Dynamics. **Transactions of ASAE, 48(3)**, pp. 23-32.

Kushwaha, R.L., Shen, J. 1995. Finite Element Analysis of the Dynamic Interaction between Soil and Tillage Tool. **Transactions of the ASAE, 37(5)**, pp. 1315-1319.

Kütük, C., Çaycı, G., Baran, A., Başkan, O., Hartmann, R. 2003. Effects of beer factory sludge on soil properties and growth of sugar beet (Beta vulgaris saccharifera L.). **Bioresources Technology, 90**, pp. 75-80.

Lampkin, N. 2002. Organic Farming. Old Pond Publishing. 104 Valley Road Ipswich, **IPI 4PA**, U.K.

Madejon, E., Lopez, R., Murillo, J.M., Cabrera, F. 2001. Agricultural use of three (sugar- beet) vinasse composts: effects on crops and chemical properties of a Cambisol soil in the Guadalquitvir river valley (SW Spain). **Agric. Ecosystem and Environ. 84**, pp. 55-65.

Malgeryd, J., WETTERBERG, C. 1996. Physical Properties of Solid and Liquid Manures and their Effects on the Performance of Spreading Machines. **Journal of Agricultural Engineering Research**. Sweden.

Nigussie, A., Bruun, S., Kuyper, T.W., Neergaard, A. 2017. Delayed addition of nitrogen rich substrates during composting of municipal wastes: effects on nitrogen loss, greenhouse gas emissions and compost stability. **Chemosphere 166**, pp. 352–362.

Oğuz, H. 2008. Toprak Bilgisi. Ders Notu.

Orhan, E.C., Harzanagh, A.A., Ergün, Ş.L. 2019. Numerical Modelling Of Industrial Screening (Part 1): Development and Validation Of Dem Model. **Scientific Mining Journal, 58(1)**, pp. 17-29.

Pascual, J.A., Ayuso, M., Hernandez, T., Garcia, C.A. 1997. Phytotoxicity and fertilizer value of different organic materials. **Agrochemical, 41**, pp. 50-62.

Raji, A.O. 1999. Discrete Element Modeliing of the Deformation of Bulk Agricultural Particles. PhD, University of Newcastle upon Tyne.

Schoenau, J.J. 2006. Benefits of Long-Term Application of Manure.

Shmulevich, I., Asaf, Z., Rubinstein, D. 2007. Interaction between Soil and a Wide Cutting Blade Using the Discrete Element Method. **Soil and Tillage Research, 97(1)**, pp. 37-50.

Simpson, K. 1991. Fertilizers and Manures. Longman Scientific and Technical, England, pp. 1-254.

Soyergin, S. 2003. Organik Tarımda Toprak Verimliliğinin Korunması. Gübreler ve Organik Toprak İyileştiricileri.

Taban, S. 2020. Gübre Bilgisi Dersi Notları. Ankara Üniversitesi, Ziraat Fakültesi Toprak Bölümü.

Ucgul, M., Fielke, J.M., Saunders, C. 2014. 3D DEM Tillage Simulation: Validation for a Sweep Tool for a Cohesionless Soil. **Soil and Tillage Research. 144**, pp. 220-227.

Ucgul, M., Saunders, C., Aybek, A. 2018. Ayrık Elemanlar Metodunun Tarım Makineleri Tasarımında Kullanımı Üzerine Bir Araştırma. **KSÜ Tarim ve Doğa Dergisi 21(3)**, pp. 304-311.

RESUME

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