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Evaluation of some physical properties of cattle manure

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Abstract

Cattle manure, which is obtained from cattles and is a biological material, goes through many basic processes such as collection from animal shelters, transportation, storage and distribution as animal fertilizer. The physical properties of manure are of great importance in the manure processes and the design of farm manure machinery. In this study, animal manure with and without bedding was considered as material. Manure bedding was selected from sawdust and straw. Among the characteristics effective in the mechanization of the applications; dry matter ratio, volumetric weight and natural repose angle were determined. As a result, it was determined that the type of bedding used, manure moisture content and repose angle were effective on the physical properties of manure. In addition, it was found that the dry matter ratio of farm manure changed with the type of bedding used and the dry matter content of straw-based manure was higher. When the volumetric weights were examined, the average volumetric weight of the manure without bedding was 857.48 kg/m³, the sawdust manure was 653.84 kg/m³ and the straw manure was 590.37 kg/m³. Moreover, it was obtained that the angle of repose values was lower in the bedding manure.

Introduction

Agricultural mechanization systems have processes that come into contact with biological materials and interact with natural environments such as soil and water during the agricultural process. Farm manure equipments are also a tool and machine that are considered in both animal husbandry mechanization and soil fertilization mechanization. On the other hand, the chemical, physical and mechanical properties of cattle manure must be known from the animal shelters to the collection, transportation and application to the soil as fertilizer when necessary. These properties are also the basic characteristics required for the design parameters of the mechanization tools that interact and the optimization of manure processes.

Farm manure used without considering its physical and chemical properties creates great pollution especially in air, water and soil resources. In order to make better use of manure, reduce pollution risks and apply a manure usage technique determined according to standards, it is essential to know its physical properties. In the process of collecting, storing and transporting manure from the barn, it is necessary that the facilities used be designed in accordance with the basic properties of the manure in order to preserve

plant nutrients, obtain energy and prevent environmental pollution (Yaldız, 1996).

In the use and management of organic and animal fertilizers, the principles to be followed at institutional and legal levels have been determined in our country. The most prominent of these is the 'Implementation Directive on Organic Fertilizers and Soil Enrichers Produced from Animal By-Products and Their Derivative Products'. In this legislation, the necessary conditions for some physical and chemical properties addressed in the management and dispatch of animal fertilizers are given; pH, EC and moisture values are considered as important physical parameters (Anonymous, 2024a). In addition, there are many action plans and legislation adopted by the European Commission on this subject. The European Union Directive 91/676/EEC is used regarding the production methods of farm manure in enterprises in terms of nitrogen cycle, environmental factors and pollution. In the position paper related to this directive, the product and quality criteria of the animal manure to be obtained, storage and transportation conditions, biogas production, soil application and certification necessary legal and technical conditions are reported (Anonymous, 2024b).

In agricultural product processing, the volume and specific gravity values of materials are considered as important parameters (Mohsenin, 1980). In the transmission of agricultural materials, physical properties such as bulk density, angle of repose, moisture content and fluidity have been emphasized (Deligönül, 1995). It has been reported that dry matter content has gained importance in the transmission of farm manure and in processes such as phase separation. It has been indicated that these characteristics determine the rate at which these types of materials will be diluted and the capacity of the facility in the transmission of liquid menure with pumps (Safley and Fairbank 1983). Some physical characteristics of dairy and beef cow manure are given in Table 1 (Anonymous, 1985).

In the sources where the testing principles and methods of agricultural mechanization systems are determined to the design and test parameters for scrapers, manure separators, discharge pumps, farm manure mixers, biogas plants, liquid farm manure injection systems and farm manure spreaders used in cleaning liquid and solid feces in barns. Among the design and test parameters, the bulk density, dry matter ratio and repose angles of farm manure were considered (Anonymous, 2024c), (Onurbaş et al., 2011).

Table 1. Manure production and characteristics of dairy and beef cows (Anonymous, 1985)

Animal type	Animal weight (kg)	Manure production (kg/day)	Bulk density of manure (kg/m³)	Total dry matter content (kg/day)
Dairy cow	113	9	994	1.2
	227	19		2.4
	454	37		4.7
	635	52		6.6
Beef cow	227	14	962	1.6
	340	20		2.4
	454	27		3.1
	567	34		3.9

In a study conducted by Özbek et al.,(2015) the effects of mineral fertilizer and liquid barn manure applications with a grain sowing machine on grain yield were investigated. It was reported that the positive effects of liquid barn manure on soil structure and yield were due to the fact that it provided the most suitable environment for manure nutrients, soil compaction and aeration. The properties of the liquid barn manure used in the study were given as bulk density 1.04 ton/m^3, knematic viscosity 1.5 mm^2/s, pH 6.98 and EC value 17.1 ms/cm (Özbek et al., 2015).

Material and Methods

Material

The manure of dairy cows in the Cattle Farm of the Animal Husbandry Department of the Faculty of Agriculture of Ankara University was used as farm manure. The values of the bedding used and the total manure amounts taken from the animals are given in Table 2. The manure collected from 26 cows in 1 day was mixed with a shovel to ensure homogeneity. After that, it was freely filled into tin cans with dimensions of 24x24x35 cm.

Table 2. Total amounts of litter and manure used in the experiments

Material	Amount (kg)
Sawdust [1]	9.2
Straw [2]	6.2
Manure without bedding	66.1
Sawdust + Manure	60.3
Straw + Manure	72.5
Total manure	198.9

[1]: Poplar sawdust, [2]: Wheat-Barley straw

In order to determine the physical properties of the collected manure, 3 experimental groups (manure without bedding, manure with sawdust and manure with straw) were created. A total of 15 tin cans of material were prepared for the measurements, with 5 replications in each group. 10 kg of manure was filled into each can.

Method

One-day manure wastes of cattles were filled into tin cans on the same day. The aim here was to determine the physical properties of immature fresh manure. Considering the agricultural mechanization processes, the manure is in an immature fresh form during the stages of collection, loading, transportation, separation and transfer to storage areas of farm manure. The mature form of this animal waste is valid during its use in biogas and compost facilities and its use for fertilizer purposes. Therefore, the scope of this study was the physical measurements of the fresh manure form, which can be considered the first stage in farm manure mechanization.

In this study, some basic physical properties of farm manure, which has a rather heterogeneous structure, such as dry matter ratio, volumetric weight and natural repose angle (static and dynamic), were determined. In addition, the relationships between these properties were examined.

Determination of dry matter ratio

Each fertilizer sample was dried in a 105 °C oven for 24 hours. The amount of water in the material was taken as m_w and the amount of dry matter as m_{dm} ; the dry matter ratio (DMR) (%) was found with the following formula number 1 (Ayık 1984):

$$DMR = \left(\frac{m_{dm}}{m_w + m_{dm}}\right) * 100 \qquad (1)$$

Determination of volumetric weight

Volumetric weight (VW) (kg/m³) was found by dividing the weight values of manure placed in equal amounts (10 kg each) into each can by the volume they occupy place. The volume they occupy was calculated by measuring the distance between the upper surfaces of the manure freely poured into the can and the upper surface of the can.

Determination of natural repose angle

Natural repose angle is measured as static and dynamic repose angle:

1. *Finding the static repose angle:*

The fertilizers, which are emptied into a cylinder with a volume of five liters and open on both sides, are emptied on a horizontal plane in a free state without shaking, and a conical heap is formed. The height of this cone, (h), and the lateral side length of the cone (l) are taken as hypotenuse. The angle that the cone makes with the horizontal (βs) (°) is defined as the static angle of repose and is found from equation no. 2 (Deligönül 1995, Sağlam and Dikilitaş 1998, Tunalıgil and Eker 1985):

$$Sin\,\beta s = h / l \qquad (2)$$

2. *Finding the dynamic repose angle:*

The dynamic natural heaping angle (repose angle) is determined by taking into account the vibration movement of the horizontal plane in the vertical direction. With a theoretical approach, the dynamic repose angle (βd) is taken as 70% of the static repose angle (βs). Accordingly, the dynamic repose angle is calculated with equation number 3 (Mohsenin 1980):

$$\beta d = 0.7\ x\ \beta s \qquad (3)$$

Results and Discussion

Results Regarding the Dry Matter Ratio of Manure

The determined dry matter values are given collectively in Table 3. Accordingly, it was concluded that the dry matter ratio of farm manure changes with the type of bedding used. In the calculations, the dry matter content of straw manure was found to be higher; with an average value, it was determined that the non-bedding manure contained 16.79% dry matter, sawdust manure 20.03% dry matter and straw manure 20.42% dry matter. After all, the dry matter ratio of bedding manure is higher than that of non-bedding manure.

Results Regarding Volumetric Weight

The volume weight of the material is effected by the properties such as bedding material, density and humidity. Materials such as straw and straw absorb moisture well, but since they have a flexible structure, they create voids in the manure mass, causing the volumetric weight to decrease. The volumetric weight of 1 m³ of 80-87% moist and straw manure is 780-980 kg. As the bedding in its composition increases, the volume weight and humidity ratio decrease (Önal 1995).

Among the manure tested, the volume weights of the samples taken from sawdust manure were found to

be lower (Table 4). The average volume weight of the manure without bedding was calculated as 857.26 kg/m³, sawdust manure as 590.51 kg/m³ and straw manure as 653.78 kg/m³. It was determined that the non-bedding manure occupies less volume than the bedding manure and is heavier.

The relationship between volumetric weight (VW) and dry matter ratio (DMR) was determined statistically through variance analysis; the analysis results are shown in equation number 4 and Table 5. According to the results obtained, the difference between dry matter ratio and volumetric weight was found to be statistically significan ($p<0,05$).

$$DMR = 28.7 - 0.0137\, x\, VW$$

and; $r^2 = 79.4$ (4)

Results Regarding Natural Angles of Repose

Table 4. Volumetric weights of manure with and without bedding

Gübre	Sample no.	Manure volume (m³)	Volumetric weight (kg/m³)	Mean of volumetric weight (kg/m³)	S.D
Manure without bedding	M1	0.0119	840.34	857.47	15.31
	M2	0.0114	881.06		
	M3	0.0118	850.34		
	M4	0.0116	862.07		
	M5	0.0117	853.52		
Sawdust manure	SAW1	0.0169	592.07	597.67	18.56
	SAW2	0.0161	619.96		
	SAW3	0.0167	614.07		
	SAW4	0.0173	577.03		
	SAW5	0.0171	585.21		
Straw manure	ST1	0.0155	644.33	655.38	19.27
	ST2	0.0146	684.46		
	ST3	0.0158	632.91		
	ST4	0.0152	658.62		
	ST5	0.0152	656.60		

Table 5. Variance analysis of the relationship between dry matter ratio and volumetric weight

Variable	S.D	Sum of Squares	Mean of Squares	F Value	p (%)
Regression	1	37.057	37.057	50.11	0.00
Error	13	9.614	0.740		
Total	14	46.671			

The magnitude of repose angle depends on the frictional abilities of the material particles with each other, in other words, on their viscosity. As viscosity increases, this angle decreases and increases as friction increases (Deligönül 1995). Malgeryd and Wetterberg (1996), who grouped the relationship between the visually defined consistency of the manure and the angle of repose, divided the manure into 8 main groups: Normally dry manure (35^0-40^0), solid manure (30^0-35^0), slurry-like manure (20^0-30^0), compact manure (15^0-20^0), normal manure (10^0-15^0), mushy manure (5^0-10^0), pulp manure (around 5°) and liquid manure ($<5^0$).

The repose angle of the manures without bedding, with sawdust bedding and with straw bedding measured in the study are shown in Table 6. Accordingly, the angle of repose angle values of the non-bedding manure were found to be higher, while those of the bedding manures were found to be lower. Among the bedding manures, sawdust manure had a higher angle of repose. The average static angle of repose values were calculated as 23.04^0 for the non-bedding manure; 21.55^0 for the sawdust manure, and 18.54^0 for the straw manure.

As a result, many factors affect the physical properties of manure, such as the type of animal, its nutritional content, age and weight; the moisture

Table 6. Farm manure repose angle values

Material	Sample no.	Static repose angle (β_s) (^{0})	Dynamic repose angle (β_d) (^{0})	Mean of dynamic repose angle (^{0})	S.D
Manure without bedding	M1	23.22	16.25	16.13	1.66
	M2	26.25	18.38		
	M3	20.45	14.32		
	M4	24.22	16.95		
	M5	21.04	14.73		
Sawdust manure	SAW1	21.83	15.28	15.09	0.67
	SAW2	23.02	16.11		
	SAW3	20.45	14.32		
	SAW4	21.23	14.86		
	SAW5	21.23	14.86		
Straw manure	ST1	19.86	13.90	12.98	0.56
	ST2	17.73	12.41		
	ST3	18.11	12.68		
	ST4	18.50	12.95		
	ST5	18.50	12.95		

content of manure, its fluidity, the way it is collected and stored, the type of bedding used in animal shelters and even the ambient temperature. This study has concluded that the physical properties of bedding and non-bedding manure differ from each other and that the type of bedding used also affects these properties. As the results of this research, the physical properties of manure and their average values are given collectively in Table 7.

During the research process, due to the sawdust and straw in their content, it was easier to collect and transport bedding manures with high dry matter content. On the other hand, while the fluidity feature of bedding-free manure provides an advantage, it was observed that it caused stickiness and contamination on the surfaces it contacted; it also caused leakage and loss of liquid material. Although the average dry matter ratios of bedding manure are approximately close to each other; both the volumetric weight (590.37 kg/m³) and the angle of repose values (βs = 18.54^0 and βd = 12.98^0) of the straw-based manure were lower than those of the sawdust manure. The average volumetric weight of the sawdust manure was measured as 653.84 kg/m³; the static and dynamic repose angle values were βs = 21.55^0 and βd = 15.09^0, respectively.

In the literature research on farm manure, mostly studies were found examining the chemical properties of manure, nutritional values, yield effects on soil and

Table 7. Average values of some physical properties of cattle manure

Properties	Manure without bedding	Sawdust manure	Straw manure
Average dry matter content (%)	16.79	20.03	20.42
Volumetric weight (kg/m³)	857.48	653.84	590.37
Static repose angle (^{0})	23.04	21.55	18.54
Dynamic repose angle (^{0})	16.13	15.09	12.98

plants, pathogens and microbes in its content and environmental greenhouse gas effects. Academic studies conducted in terms of mechanization systems that come into contact and interact with biological materials are quite insufficient. Some of the existing designs were made based on the results of academic studies conducted abroad. For this reason, throughout the entire agricultural production chain, there is a need to evaluate the biological, chemical, rheological and physical properties of cattle manure in our country. Using this data, it will be easier to design, construct and disseminate national farm manure mechanization tools.

In addition to the limited production of agricultural tools and machines used in farm manure mechanization in our country; it is also possible to say that domestic manufacturers cannot develop designs that comply with the standards in this regard. When the number of agricultural machinery test reports, which can be considered as an indicator of production levels, is examined; in the 2018-2023 period, it was determined that among the total of 7845 test reports certified, there were only 83 test reports (approximately 1.1%) belonging to farm manure mechanization vehicles (Anonymous, 2023).

As a result, farm manure is a biological resource that we benefit from in a very wide area as a natural fertilizer source for soil and plant nutrition, and as a source of electricity and fuel energy for natural gas production. The manure management process of this biological resource is a critical activity for the economic and environmental sustainability of large cattle farms. In a study, it was reported that the annual approximate cost per cow in the most common usage methods for manure was 306 US dollars. While manure provides valuable nutrients for soil health and plant production in one aspect, it also causes high costs and greenhouse gas emissions in the collection, transportation and manure processing. It has been stated that there is a great need for the development and implementation of mechanization technologies that optimize all these benefits and minimize their harmful effects (Wang, H. et al., 2019).

In continuation of this research, it is suggested that the effects of animal biology, chemical composition of manure, environmental parameters such as temperature and humidity on the physical properties of manure should be investigated in a well-rounded approach. The physical, rheological, chemical and technical design parameters to be determined in this field will form the basis for the establishment of valid legislation and standards for farm manure properties in manure management processes in our country.

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Ethical statement

Any animal experiment was made in this research.

Conflict of Interest

The authors declare that they have no known competing financial or non-financial, professional, or personal conflicts that might appear to influence the work reported in this paper.

Author Contributions

ZDA: Data Curation, Formal Analysis, Investigation, Methodology, Supervision, Resources, Writing -original draft, Writing -review and editin. **ÖA**: Conceptualization, Decision to publish, References, Computer hardware and applications, Gramarly Editing.

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