Performance simulation of a helical wet manure distributer machine

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Abstract: Considering the importance of organic manures, a novel helical wet manure distributer was developed in this study, that capable to speared manure with maximum distribution width at different moisture of manure. The machine performance was modeled as well. Main systems of machine were conveying system, distribution system and drawbar coupling system. Effect of speed of drum(450-950 rpm) and six level of particle mass of manure(5, 10, 20, 50, 80 and 100 g) on distribution width were considered. The power requirement of auger was calculated in different rotational speed of auger(90-660 rpm) and three level of manure-manure friction(0.45, 0.50 and 0.55). Drawbar power of machine was evaluated as well. The results showed that maximum distribution width was 14 m for mass of manure. Tractor speed was 5-10 km.hr-1 and consumed manure rate was 20-60 ton.ha-1.Volume of hopper was designed for 6m3. The maximum value of PTO power requirement and drawbar power obtained was 28.9kW and 8.5 kW, respectively.

Keywords: auger, manure, distribution width, performance modeling

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1 Introduction

Consumption of chemical fertilizers is increased exponentially throughout the world recently which causes serious environmental problems. Fertilization may affect the accumulation of heavy metals in soil and plant system. Plants absorb the fertilizers through the soil and they can enter the food chain. Thus, fertilization leads to water, soil and air pollution (Savci, 2012). The use of mineral fertilizers on continuous basis in tropical soils has been associated with reduced crops yield, increased soil acidity and nutrient imbalance (Adeleye et al., 2010). Organic manures play an important role in improvement of soil fertility, increase of crop yield and quality. Agricultural use of organic wastes can not only effectively depose of organic resources and realize nutrient cycling, but also has an important role in environmental protection and sustainable agriculture (Li and Liu, 2006). Organic manure, such as farmyard manure, green manure, organic amendment and municipal solid waste, has been used as a source of plant nutrients and organic matter to improve fertility conditions of agricultural lands for a long time (Dao and Cavigelli 2003). Generally, the physical, chemical, and biological properties were improved when manures incorporated into soils (Ould Ahmed et al., 2010). Several studies have shown the beneficial effects of animal manure on soil structural quality, by reducing bulk density, increasing porosity, water infiltration rate, saturated hydraulic conductivity and etc. (Hati et al., 2007; Fares et al., 2008; Uzoma et al., 2011).All over, beneficial advantages of manure depend on method of spreading. The spreading of manure is an important step in cultivation for agricultural production. Unsuitable method in spreading manure caused decreased crop production based on performed researches (Duhovnik et al., 2004).

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Regarding manure spreading importance, some researches were carried out for evaluation of optimal spreading conditions. Popa et al. (2009) designed a manure spreading machine of 4.5 m^3 volumes. This machine was designed to transporting and spreading the manure for cereal crops, technical plants vegetables and etc. it performed the transport of maximum 5 tons of manure and worked in aggregate with tractors of over 65 hp. Peeters et al. (2011) designed a manure spreader that included a vertical beater assembly for engaging and expelling manure that consist of a first vertical beater rotatable about first axis and included a shaft having a firstscrew flight (flighting)forming a left-handed helix and second screw flight forming a right-handed helix.

Mainly existing manure spreaders have been discharging and spreading manure from the end of hopper that this method reduces distribution width. Also little hopper in manure spreaders caused to increase number of transportation, consume energy and destruction of soil structure. Also mainly manure spreaders don’t suitable for wet manures. Furthermore the purpose of this research is development a new manure distributer machine and simulation of its performance that would be able to spread manure at wide area of field and has uniform patterns in transverse and longitude direction and would be suitable for manures with different moisture.

2 Material and methods

Principle of the manure spreader design was based on maximum distribution width. The machine was designed to be linked to drawbar and was powered via tractor’s PTO shaft. Main components of the machine were a hopper, two augers on the bottom of hopper, distribution unit and drawbar coupling system, transmission system (Figure 1, Figure 2). Manure was conveyed from rear and front of the hopper to the middle by augers and it’s distributed by centrifugal forces of drums. Advantages for this type of conveying include low cost, low maintenance and no limitation of use for wet manure.

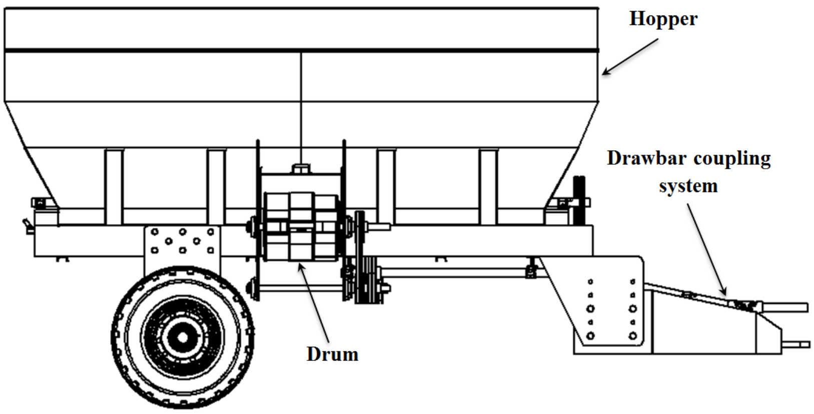

Figure 1 Side view of helical wet manure distributer

2.1.1Hopper

Trade-off for definition of hopper volume is based on two scenarios: a) More bigger hoppers causes to hard-layer in soil and b) a little hopper increases number of transportation that lead to more energy consumption, also increased number of transportation create hard layer in soil as well. So volume of hopper was determined by distribution rate in hectare. Slope of hopper’s sidewalls was designed based on internal friction of manure and friction between manure with walls of hopper. Required amount of manure is recommended 20-60 ton/ha according to type of soil and agricultural product (Mansouri-Rad, 2009). So the volume of hopper was determined 6m^3. Also the angle of hopper’s sidewalls was calculated as 45^{o}to be greater than coefficient of friction between manure and side-walls. For distribution manure under the hopper, two adjustable meshing plates were installed under the grips

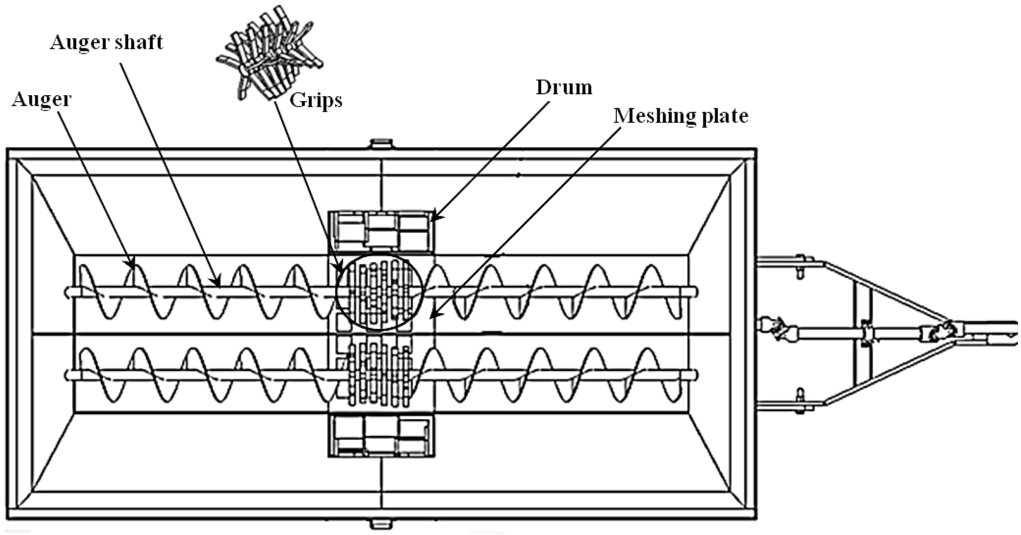

Figure 2 Top view of helical wet manure distributer and its component

2.1.2 Screw conveyor

The screw conveyor or auger consists of a shaft that carried helicoid screw flights on its outer surface. Auger moves manure in line with screw flights by rotation around shaft. Length of augers shaft were 2800mm. The auger shaft was equipped with some grips in the middle that were on screw shaft spirally and moved manure to outlet throat (Figure 2). The auger conveying capacity and power requirements depend on screw flight diameter, screw shaft diameter and pitch, speed, exposed intake length, incline and manure properties. The auger was powered via the main shaft using sprocket and chain.

A standard pitch auger is approximately equal to the screw flight diameter (0.9-1.5 times) that is suitable for horizontal and up to 20 °inclination angles (Figure3).

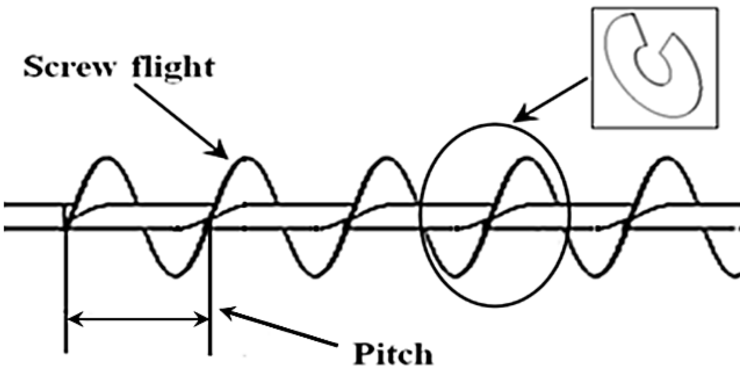

Figure 3A schematic diagram of a screw conveyor

For designing of auger, distribution width was 14m, also tractor speed and amount of manure application per hectare were 5-10 km/hr and 20-60 ton/ha respectively. Discharge flow rate (Q_t) was calculated based on distribution width, consumed manure and tractor speed. Then parameters of auger such as screw screw flight diameter (d_{sf}), screw shaft diameter (d_{ss}), pitch length (l_p) and screw rotational speed (n) were designed using the Equation 1 (Srivastava et al., 2006).

$$Q_t = \frac{\pi}{4}\left({d_{sf}}^2 - {d_{ss}}^2\right) l_p n \qquad (1)$$

In reality the actual volumetric capacity (Q_a) of an auger is considerably less than the theoretical capacity. This results in loss of volumetric efficiency. The volumetric efficiency (η_v) is defined as using Equation 2.

$$\eta_v = \frac{Q_a}{Q_t}.100 \quad (2)$$

2.1.3 Distribution unit

2.1.4 Power source and drive system

Manure spreader was powered from tractor PTO by universal joint. The PTO drives the main shaft and all other mechanism was powered by it. The drum was powered by a pulley and V-belt that was suitable for high rotational speed and low torque. The augers were powered from main shaft by duplex chain and sprocket. This power transmission system made suitable torque for low rotational speed.

2.2 Modeling machine performance

The manure particles were simulated as granular. Drum speed and distribution direction were determined using some theoretical and experimental parameters that was performed in laboratory of Department of Agricultural Machinery Engineering, Faculty of Agricultural Engineering and Technology, University of Tehran in August 2014. The rotational speed of drum was influenced by various factors, including density of manure (ρ_b), effective diameter of particle (d_p), density of air (ρ_a) and height of drum from ground (Z).The rotational speed of drum was calculated using Equation 3 (Srivastava et al., 2006).

Manure distribution system includes two drums in both sides of hopper and meshing plates on the apron of hopper (Figure 2). The drum consists of belts and rectangular plates that were on shaft (Figure 4). Manure was broadcasted on the field via centrifugal force that was applied by rotational motion of drums.

$$h = \frac{\ln(C\dot{h}_0 t+1)}{C} \quad (3)$$

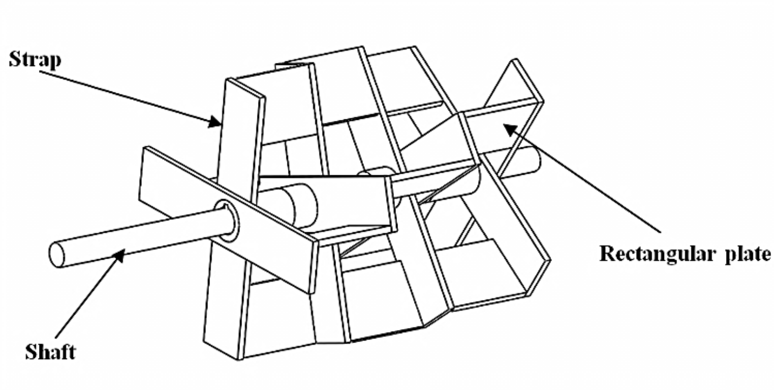

Figure 4 Drum and its components

Where $\dot{h}_0$ is initial velocity in horizontal direction (m/s), t is time for particle to fall that is calculated using Equation 4 and C is coefficient about air resistance that is calculated using Equation 6.

$$t = \frac{ln\left(Arg+\sqrt{Arg^2-1}\right)}{2C\sqrt{g/C}} \quad (4)$$

$$Arg = 2e^{2CZ} - 1 \quad (5)$$

$$C = \frac{0.75C_D\rho_a}{\rho_b d_p} \quad (6)$$

For calculating drawbar power of machine, the mass of machine with filled hopper was considered. Density of manure was in 1033- 1200 kg.m^{-3} range based on moisture content(Sadin et al., 2009) and tractor speed was 5-10 km.h^{-1}. Drawbar power of machine was determined using Equation 7. The rolling resistance of tire of machine was calculated using Equation 8 (Goering, 1992).

$$P_{db} = F.V \quad (7)$$

$$R_{tot} = w\left(\frac{1.2}{C_n} + 0.04\right) \quad (8)$$

C_n is wheel numeric and was calculated using following Equation 9:

$$C_n = \frac{CI.b.d}{w} \quad (9)$$

Where CI is cone index of soil that in several type of soil that varied from 200 to1500 kPa, b is width of the wheel (m) and d is diameter of the wheel (m).

The PTO power requirement of machine is included power of auger and drums. The power requirement of auger is depended on physical properties of manure and some parameters of auger that defined as Equation 10 (Srivastava et al., 2006).

$$P = 3.54 Q_a \rho_b g \left(2\pi n \sqrt{\frac{l_p}{g}}\right)^{0.14} \left(\frac{d_{sf}}{l_p}\right)^{-10.12} \left(\frac{l_i}{l_p}\right)^{0.11} (f(\theta))\mu^{2.05} \quad (10)$$

The power requirement of drum is included two parts: a) power requirement for idle rotational speed of drum (P_i) that is depended on Moments of inertia (I) and rotational speed of drum and b) power requirement for spreading of manure (P_s) that is computed using Equation 11 and Equation 12 respectively. Moment of inertia of drum was calculated using SolidWorks 2012 software.

$$P_i = \frac{1}{2} I \omega^2 \quad (11)$$

$$P_s = \frac{1}{2}\dot{m}V^2 - \frac{1}{2}\dot{m}{V_0}^2 \quad (12)$$

3 Result and discussion

Based on design principles that were described, the screw flight diameter, screw shaft diameter and pitch of auger were 250mm, 60mm and 250 mm, respectively. Relationship between variation of rotational speed of auger with tractor speed and manure application rate is shown in Figure 5. Based on relationship obtained, the rotational speed of auger increases with increase in speed of tractor and consumed manure per hectare.

The calculated radius of drum was 200mm. Each part of drum has four rectangular plates that located at 90 degree and rotated about shaft. Effect of different rotational speed of drums in range 450-950 rpm and six level of mass of manure's particle on the distribution width was simulated (Figure 6). The results showed that distribution width of machine increases with increase in the rotational speed of drum. Also increased mass of manure's particle decreased distribution width. Results showed that the distribution width of machine in the range of speed was more than 14m.

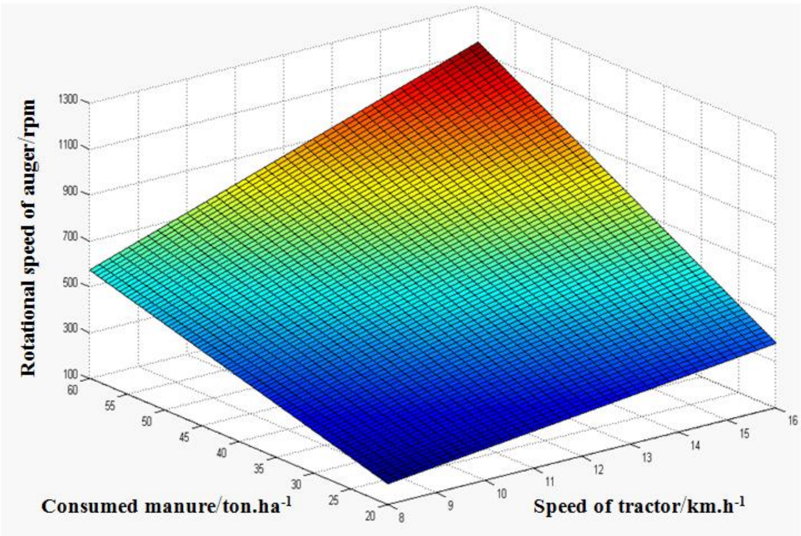

Figure 5 Effect of tractor's forward speed and amounts of manure application on the rotational speed of auger

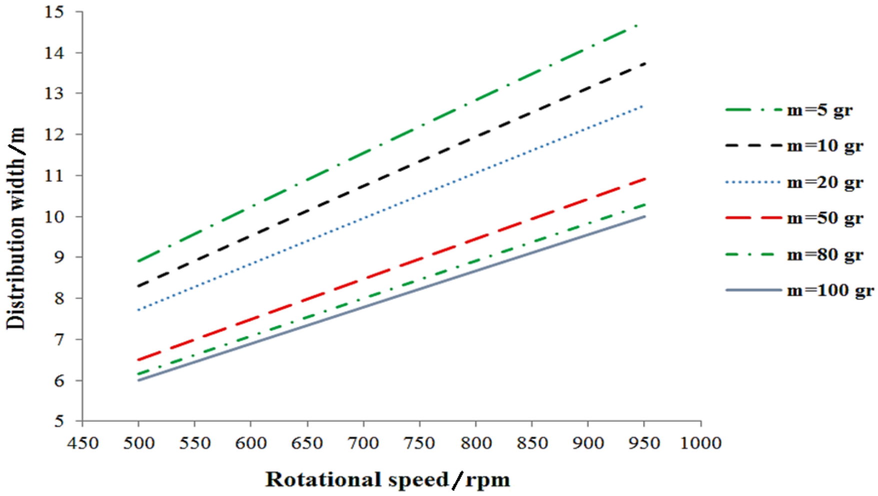

Figure 6 Effect of drum speed and particle mass of manure on distribution width of machine

The PTO power requirement of auger was calculated in three level of manure-manure friction (0.45, 0.50 and 0.55) and different rotational speed of auger in range 90-660 rpm (Figure 7). The results indicated that PTO power requirement increases by increasing rotational speed and coefficient of friction of manure. Also the maximum value of PTO power requirement obtained was 5.7 kW.

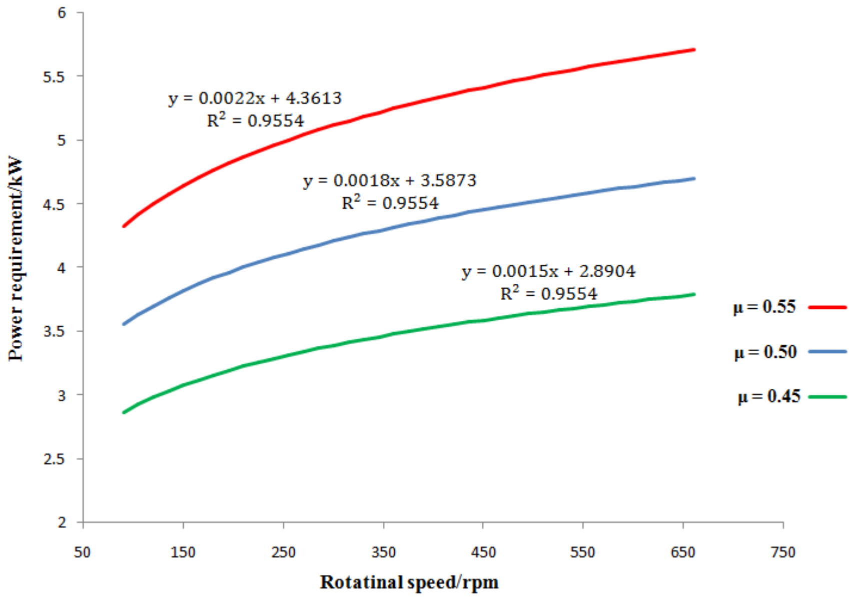

Figure 7 Effect of manure-manure friction and rotational speed of auger on PTO power requirement

The PTO power requirement of drums was computed in different rotational speed of drum at 450-950 rpm and two cases: a) power requirement for idle rotational speed of drum (Figure 8a) and b) power requirement for spreading of manure. The results showed that the PTO power requirement has exponentially relationship with rotational speed of drum. The power requirement for idle rotational speed of drum was low and majority of the power was used for spreading of manure. Also the power requirement for drum is more than auger, since the rotational speed of drum was greater than auger. The maximum PTO power requirement of drum was 26.66 kW.

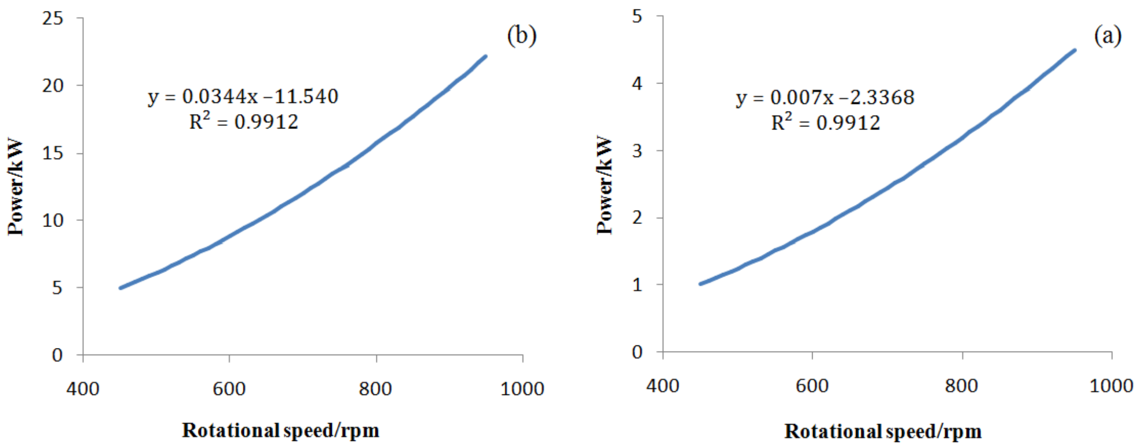

Figure8Effect of rotational speed of drums on power requirement for (a) idle rotational speed of drums and (b) spreading of manure

Drawbar power of machine was calculated in range of speed 5-10 km.h^{-1} that was common range of speed in field. Result showed that drawbar power of machine increased with increases in speed of tractor. Also drawbar power has linear relationship with speed of tractor. Maximum drawbar power obtained was 8.5 kW(Figure 9).

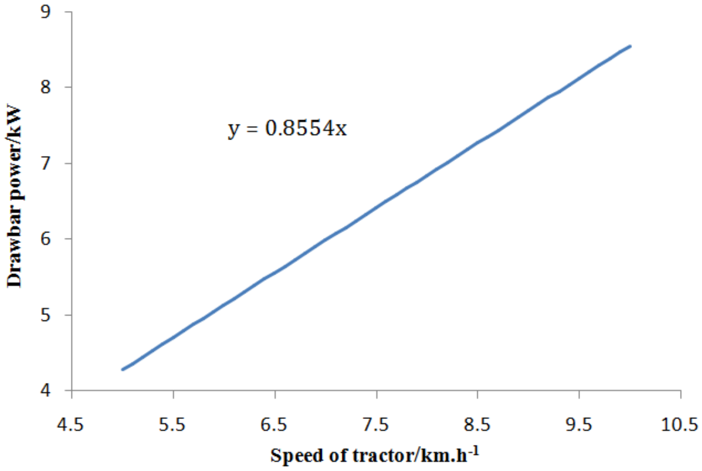

Figure 9 Effect of speed of tractor on drawbar power

4 Conclusions

In this study, design of a novel manure distributer machine that would be capable to spread manure with high moisture at wide area of field was presented. The important implement of machine included conveying system, distribution system and drawbar coupling system. The conveying system was designed based on tractor speed and the amount of consumed manure per hectare. Also modeling of distribution width of machine in different rotational speed of drum and 6 level of manure's particle with different mass was performed and the distribution system was designed based on maximum distribution width. Results showed that distribution width of machine was more than 14 m when the rotational speed of drum was 900 rpm. The PTO power requirement was calculated for different rotational speed of drum and auger. The result showed that the maximum value of PTO power for drum and auger was 23.2kWand 5.7 kW, respectively. Also the maximum value of drawbar power was 8.5 kW.

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Nomenclature

b	width of wheel (m)	P_i	power requirement for idle rotational speed (kW)
C_D	$26.38N_{Re}^{-0.845}+0.49$(for $N_{Re}\geq 1$)	P_s	power requirement for spreading of manure (kW)
CI	cone index of soil	Q_a	actual volumetric capacity ($m^3.s^{-1}$)
C_n	wheel numeric	Q_t	Theoretical volumetric capacity ($m^3.s^{-1}$)
d	diameter of wheel (m)	R_{tot}	total rolling resistance of machine (N)
d_p	effective diameter of particle (m)	t	time for particle to fall distance z (s)
d_{sf}	screw flighting diameter (m)	V	Speed ($m.s^{-1}$)
d_{ss}	screw shaft diameter (m)	V_0	Initial Speed($m.s^{-1}$)
F	Drawbar force (kN)	w	weight of machine (N)
g	acceleration of gravity ($m.s$-^{2})	Z	Vertical space of drum from ground (m)
I	Moment of inertia ($kg.m^2$)		
l_i	exposed screw intake length (m)		Greek symbols
l_p	pitch length (m)	η_v	volumetric efficiency
$\dot{m}$	Discharge flow rate ($kg.s^{-1}$)	μ	Manure-manure friction
n	screw rotational speed ($rev.s^{-1}$)	ρ_b	manure bulk density ($m^3.s^{-1}$)
P_{db}	drawbar power of machine (kW)	ω	Angular velocity ($radian.s^{-1}$)