

Precision Metering System Design for Variable Rate Granular Fertilizer Applicator

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Received 2 June 2016 ; Accepted 17 July 2016 ; Published online 10 August 2016

Abstract A variable rate fertilizer metering mechanism was designed by changing the speed of the feed shaft. A microcontroller unit program with a Pulse Width Modulation (PWM) motor driver was used to run the feed shaft at varying speed. Two types of fluted rollers (straight and helical flutes) were used with varying numbers of flutes having same volume for each flute. The physical properties of di ammonium phosphate and single super phosphate granules were measured. The geometrical mean diameter of DAP and SSP were 4.48 ± 0.28 mm and

3.76 ± 0.33 , respectively. There were no significant differences between helical and straight fluted roller with varying numbers of flutes (6 and 8) for discharge rate. The discharge rate of SSP fertilizer was significantly higher than that of DAP.

Keywords Variable rate technology, PWM motor, Fluted roller, SSP, DAP.

Introduction

India is the third largest producer (16.36 Mt) and consumer (27.40 Mt) of fertilizer in the world [1] with an average consumption of 129.8 kg ha^{-1} . Conventional application of chemical fertilizer to the crops often results in very low yield at low fertility sites, whereas lodging of plants with increased biomass at high fertility sites which farmers find undesirable due to difficulty in harvesting. Uniform application of fertilizers, therefore, can result in under fertilization of some parts of a field and over fertilization in other parts. Under-fertilization may result in a yield loss and over-fertilization generally increases the crop yield up to an optimum level, but more fertilizer is less utilized or mobilized and also harmful to the environment [2].

Existing seed-cum-fertilizer drills are not capable of efficient metering and placement of fertilizers as recommended for variable application. Existing seed cum fertilizer drills draws power from spoked ground wheel which many times skid which is in the range of 15 to 20% [3]. Ground wheel skidding and inaccurate

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design of metering system is the major constrains of the existing seed cum fertilizer drill. The seed rate variability has been reported to the tune of 10—20%, which requires high seed rate and for achieving the desired plant population [3].

Precision application of input is very important for modern agriculture, as it allows the economical utilization of resources for optimization of productivity with least environment impact. Variable rate technology is helpful in optimizing the use of chemical fertilizer to meet site-specific requirement in the field. A variable rate fertilizer metering system may either be achieved by changing the active feed-roll length or varying speed of feed shaft. By changing the active feed-roll length, system application rate is adjusted, whereas in variable rate metering system, fertilizer rate can be changed by varying speed of the feed shaft. Keeping in view the need for variable metering system for site-specific fertilizer application, a research work was carried out to determine design values for variable rate metering mechanism and to find out the effect of different design parameter on discharge rate of fertilizers.

Materials and Methods

Physical properties of fertilizers

The physical form in which a fertilizer is produced is of considerable importance, both agronomically and in regard to satisfactory handling, transport, storage, and finally application to the field. Different physical properties were measured for two granular fertilizers di-ammonium-phosphate (DAP) and single super-phosphate (SSP) in the laboratory of the Division of Agricultural Engineering, IARI, New Delhi. The fertilizer was locally procured from market.

Dimension

Size of the fertilizer in terms of major, minor and intermediate diameters was measured using digital Vernier caliper (Mitutoya make). The dimensions of 50 randomly selected fertilizers for each variety were measured and their geometric mean diameter (GMD) was

determined. GMD was calculated by equation 1 [4].

$$\text{GMD} = \sqrt[3]{a * b * c} \quad (\text{Eq. 1})$$

Where, a = Major diameter, mm, b = Intermediate diameter, mm, and c = Minor diameter, mm.

Sphericity

The shape of fertilizer is expressed by its sphericity. Sphericity is a measure of shape character compared to a sphere of the same volume. Assuming that volume of solid is equal to the volume of tri-axial ellipsoid with intercepts *a*, *b*, *c* and the diameter of circumscribed sphere is the longest intercept of the ellipsoid, the degree of sphericity was calculated by equation 2 [4].

$$\text{DS} = \frac{\text{Geometric mean diameter}}{\text{Major diameter}} = \frac{\sqrt[3]{a * b * c}}{a} \quad (\text{Eq.2})$$

Where, DS = Degree of sphericity ; a = Major diameter, mm, b = Intermediate diameter mm, and c = Minor diameter, mm.

Angle of repose

The apparatus used for measuring dynamic angle of repose consisted of a funnel with an adjustable throat opening mounted on a stand. A circular plate, with four centering arms, was mounted in the funnel above the adjustable throat. The funnel was filled with fertilizer by keeping its adjustable throat closed. The throat was fully opened to allow free flow of fertilizer granules over and around the plate mounted beneath the funnel [4]. At the end of process, a heap-cone of the fertilizer granules was formed on the plate. From the heap-cone, base diameter and height of cone were measured. The angle of repose was calculated using the following relationship (Eq. 5) :

$$\theta = \tan^{-1} \left(\frac{2h}{d} \right) \quad (\text{Eq. 5})$$

Where, θ = Angle of repose, degree, h = Height of the cone, cm, and d = Base diameter, cm.

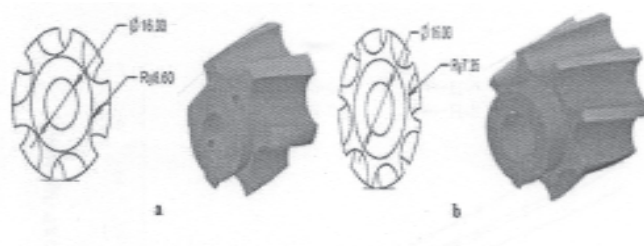


Fig. 1. Helical fluted roller with different number flute: (a) 6 and (b) 8.

Design of variable ratemetering mechanism

Metering mechanism is a critical component of seed / fertilizer–drill and its function is to discharge seed / fertilizer uniformly at the desired application rate with minimum damage. Most commonly used metering mechanism in seed-cum-fertilizer drills is fluted roller. Fluted roller types metering mechanism which have different number of flutes and flutes of different sizes was considered for metering of fertilizer. The design of roller diameter, exposure length flute diameter and number of flutes depends on the require application rate. As per the BIS [5], standard roller diameter was taken as : Diameter roller (mm) = 48, Length of roller (mm)=54.

Using this information, two different types of fluted roller (Helical and Straight) (Figs 1 and 2) made of high density poly ethylene (HDPE) with different number of flutes (6 and 8) were tested as given in Table 1. Considering constant volume of roller in

each revolution for particular number of flutes, as recommended for use in seed-cum-fertilizer drill, laboratory investigations was conducted. The design values of the prototype were finalized based on the result of the study [6].

Electronic control system

A micro controller (model ATMEGA8A) was used for desirable control the fertilizer metering system. This micro controller acted independently in controlling the rotational speed of the stepper motor.

Measuring system

The electric measurement system was developed and used to determine the relationship between PWM motor rotational speed and discharged fertilizer. The measuring system measured the two parameters ; PWM motor rotational speed and discharge rate. Fertilizer metered by the fluted roller feeder was received

Table 1. Design specification of fluted rollers.

Types of roller	Diameter of roller (cm)	Length of roller (cm)	Internal diameter (cm)	Flute length (cm)	Helical angle roller (degree)	Volume of roller (cm ³)	No. of flute	Diameter of flute (cm)	Volume of one flute (cm ³ / flute)	Spacing between two flute (cm)
Helical	4.8	5.4	1.6	4.2	15°	19.79	6	2	3.29	0.8
and Straight roller							8	1.5	2.47	0.4

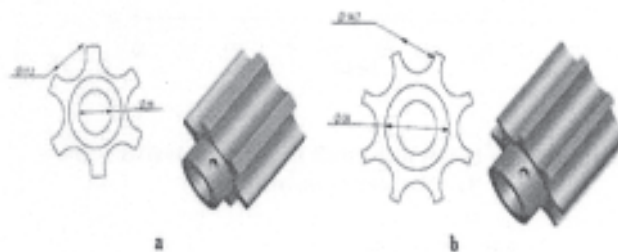


Fig. 2. Straight fluted roller with different number flute: (a) 6 and (b) 8.

in acuponan electronic balance with least count of 0.01 g [7].

Experimental setup

A 1.57 N.m. PWM motor was used to power the fluted rollers (Fig. 3). The roller rotational speed was varied within the range of 10–100 rpm. The experiments are conducted for two types of fluted rollers with 6 and 8 numbers of flutes and at 100% exposure length (4.2 cm). The unit was operated at 100% exposed length of the straight shaped flutes having 6 flutes with 5 kg of fertilizer placed in side the hopper. The rotational speed of the feed shaft was changed by micro-controller and initial speed was kept at 10 rpm. In second stage of experiment, the rotational speed of the fluted roller was increased to 20 rpm under similar conditions to measured is charge rate of the fertilizer. The rotational speed was increased continuously up to 100 rpm at an interval of 10 rpm. The straight shaped flutes were replaced with helical shaped flutes and same procedure was repeated for estimation of discharge rate of the fertilizer.

Results and Discussion

Dimension of fertilizers

The size of fertilizer granules is defined by major, minor and intermediate dimension of granules. The observations recorded for fertilizer are presented in Table 2. The average major, minor and intermediate diameters of DAP were 4.53 ± 0.37 mm, 4.29 ± 0.43 mm and

4.44 ± 0.34 mm, respectively. Whereas, the major, minor and intermediate mean diameters of SSP were found as 3.70 ± 0.32 mm, 3.78 ± 0.45 mm and 3.84 ± 0.55 mm, respectively. The geometrical mean diameter (GMD) of DAP and SSP were 4.48 ± 0.28 mm and 3.76 ± 0.33 , respectively. The GMD value of DAP was more by 6.61% from SSP.

Sphericity, bulk density and angle of repose of fertilizer

The shape of fertilizer granules was determined in terms sphericity as shown in Table 2. The average sphericity of DAP and SSP was 0.94 ± 0.02 and 0.93 ± 0.053 , respectively. The average bulk density of fertilizer granules DAP and SSP were 0.81 ± 0.025 g/cm³ and 1.36 ± 0.051 g/cm³, respectively. Mean values of angle of repose of fertilizer DAP and SSP were found to be $31.66 \pm 1.36^\circ$ and $28.37 \pm 1.75^\circ$, respectively. Angle of repose of DAP fertilizer was higher than SSP.

Effect of granules size on discharge rate

The rate of application depends on the granule size of the fertilizer. As the particle size increases the discharge rate decreases. For bigger size of fertilizer granules flow ability was affected due to more inter granular space. It was observed that fertilizer having average granule size of 3 to 5 mm had greater flow ability, and the distribution was found to be more uniform. The bigger granules having sizes of more than 6 mm

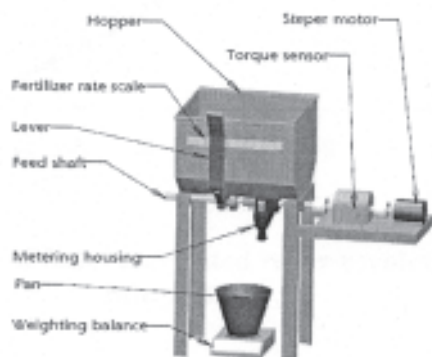


Fig. 3. Schematic diagram of variable rate fertilizer metering mechanism.

was found to clog the flutes of metering rollers. The average particle size of DAP and SSP was 4.48 ± 0.28 mm and 3.76 ± 0.33 , mm respectively, well within the range of 3 to 5 mm. Hence, the designed fluted rollers could ensure smooth flow of fertilizer granules.

Discharge rate for different rollers

Discharge rate was measured while operating at 100% exposure length for straight and helical fluted roller with 6 and 8 numbers of flutes respectively. There was no significant difference in discharge rate obtained when different types of fluted rollers were used at different revolution of feed shaft.

In wheat crop the DAP requirement is about 140 kg per ha. Assuming speed of operation of seed drill as $3\text{--}5 \text{ km h}^{-1}$ [5], width as 2 m and field efficiency of 85%, the approximate discharge rate of DAP comes about 1.12 to 1.87 kg min^{-1} . From Fig. 4 it can be deduced that for this discharge rate of 1.12 to 1.87 kg min^{-1} ; the revolution per minute of flute should be in the range of $50\text{--}80$. Similarly for SSP the requirement for wheat is about 390 kg ha^{-1} and the required discharge rate comes about 3.1 to 5.2 kg min^{-1} . To achieve this discharge rate the fluted roller revolution should be more than 100 rpm (Fig. 5) which was beyond the scope of this study. The revolution per minute of

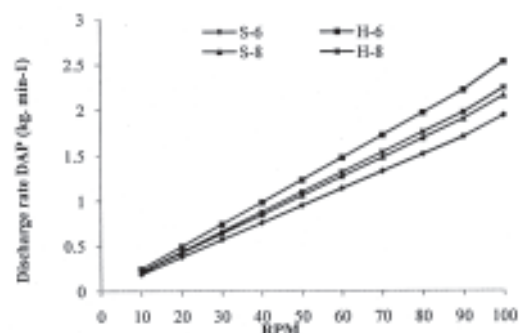


Fig. 4. Effect of shape of flutes and fluted roller revolution and on discharge rate of DAP.

fluted roller is in the range of $50\text{--}70$ from the ground wheel. Hence drilling of SSP fertilizer is not possible through ground wheel of seed drill. A different metering system which can provide higher RPM of the roller should be used. This can be achieved by using high RPM DC motor.

Conclusion

The average particle size of DAP and SSP was 4.48 ± 0.28 mm and 3.76 ± 0.33 mm respectively. The discharge rate of DAP was found to be less than that of SSP. It was observed that intermittent dropping is a problem with straight flute roller metering; hence helical fluted roller was designed and developed. There was no significant difference in discharge rate obtained when different types of fluted rollers were used at 100% exposure length. Also, there was no

Table 2. Geometric properties of different fertilizer.

Sl. No.	Property	Fertilizer	
		DAP	SSP
1	Length, mm	4.53 ± 0.37	3.70 ± 0.32
2	Breadth, mm	4.29 ± 0.43	3.78 ± 0.45
3	Thickness, mm	4.44 ± 0.34	3.84 ± 0.55
4	GMD, mm	4.48 ± 0.28	3.76 ± 0.33
5	Sphericity, fraction	0.94 ± 0.02	0.93 ± 0.053

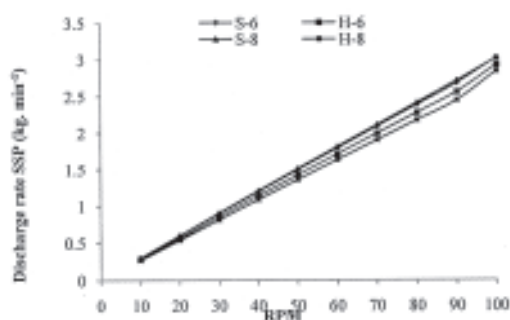


Fig. 5. Effect of shape of flutes and fluted roller revolution and on discharge rate of SSP.

significant difference between the rollers, but significant difference was found in discharge rate between DAP and SSP fertilizers. This metering mechanism eliminated the problem of ground wheel skidding. This will help in developing an applicator or can be used as a retrofit to existing machines for variable rate fertilizer application. However, a different metering system should be provided to achieve higher RPM of

the roller for SSP fertilizer.

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