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Physical and Engineering properties of Fertilizers Relevant to Design of a Precision Ferti Drill

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ABSTRACT: Fertilizers play vital role in the production of crop cultivation. The engineering properties such as physical and mechanical properties of fertilizers viz., Diammonium Phosphate (DAP), NPK complex, Single Super Phosphate (SSP), urea, Muriate of Potash (MOP) were measured in order to design and develop the tractor operated, target oriented ferti-drill for high density guava orchard. The physical properties were measured namely length, width, thickness, geometric mean diameter, bulk density, true density, angle of repose and coefficient of friction were measured. The highest length, breadth and geometric mean diameter (GMD) were noticed for Single Super Phosphate (SSP) i.e 4.20±0.52 mm, 3.56±0.43 mm and 3.59±0.39 mm respectively and NPK complex had the highest thickness as 3.26±0.51 mm. The highest bulk density and true density were observed in case of Muriate of Potash (MOP) i.e 1123.91±4.19 kg m^{-3} and NPK complex i.e 1989.28±836.39 kg m^{-3}, respectively. The Muriate of Potash (MOP) had the maximum angle of repose as 39.82±0.98˚. The rubber surface had the highest coefficient of static friction i.e 38.60±1.42, 38.30±1.25, 30.10±0.73, 39.20±1.13 and 37.10±0.99 for DAP, NPK Complex, SSP, Urea and MOP respectively. The glass surface had the lowest coefficient of static friction i.e 25.30±1.05, 25.20±0.91, 22.10±1.10, 24.50±0.52 and 31.20±1.61 for DAP, NPK Complex, SSP, Urea and MOP respectively. The determined physical properties and engineering properties were used to design and develop the precision fertilizer applicator.

Keywords: Fertilizers, Engineering properties and Physical properties.

INTRODUCTION

Fertilizers also called plant food elements. Fertilizers replace the nutrients that crops remove from the soil. India is the third largest producer (16.36 Mt) and consumer (27.40 Mt) of fertilizer in the world with an average consumption of 129.8 kg.ha^{-1} (Anon., 2013). Traditional farming practices relied on massive fertilizer application of agricultural chemicals to increase the yield. Mass application of chemicals in agriculture practice resulted in, contamination of the environment, soil degradation and deposition of harmful residue on agricultural products (Talha *et al.*, 2012). In the recent days consumers demands for safe agricultural products, which are grown using minimum fertilizer application as per the sustainable farming practice. Conventionally, fertilizers are being applied by the farm labours; these are not uniform in nature or not uniformly distributed to the plants within the field. Basic goal of agricultural research in the developed countries, where high-yielding varieties are used with massive application of agricultural chemicals and also care is taken to reduce the contamination levels in the field (Iida *et al.*, 2001). Granular fertiliser needs to be accurately delivered to the plants at prescribed application rates to accomplish the desired outcome (Swisher *et al.*, 2002). Hence design and development of precision fertilizer applicators are the need of hour. This paper discusses the physical and engineering properties of fertilizers relevant to design of precision fertilizer applicator.

MATERIALS AND METHODS

The research work was carried out ICAR-Indian Institute of Horticultural Research, Bengaluru, Karnataka located at a latitude of 13º 58′N, longitude of 78′E and 890 m elevated above mean sea level. The essential raw materials required for experiment was procured from local market.

Physical properties of fertilizer granules. The most commonly used fertilizers for crop production were

Diammonium Phosphate (DAP), NPK complex, Single Super Phosphate (SSP), urea, Muriate of Potash(MOP). The physical properties of granular fertilizers were measured in this study by using standard procedure.

Linear dimensions of fertilizer

Size is necessary to describe any object defined with some dimensional parameters. The geometric dimensions of fertilizer granules namely, length, width and thickness were determined. One hundred fertilizer granules from each fertilizer were selected randomly and the geometric dimensions were measured by using digital Vernier calliper (Mitutoyo DIGIMATIC CALIPER 500-144CN-10) (Mitutoyo Corporation, Japan) having least count 0.01 mm (Mohsenin, 1986).

Geometric mean diameter (D_p)

The geometric mean diameter (D_p) was calculated by using the following relationship (Mohsenin, 1986).

$D_p = (LWT)^{1/3}$

Where,

L = Length, mm,

W = Width, mm and

T = Thickness, mm

Bulk density

The volume of hopper depends upon the bulk density of granular fertilizer. Bulk density of granular fertilizer is the ratio of its mass to total volume. The bulk density was calculated using the equation (Mohsenin, 1986). The procedure was replicated for ten times and the mean values were reported.

$$\text{Bulk Density } (g.cc^{-3}) = \frac{\text{Weight of the granularfertilizer (g)}}{\text{Volume of the granular fertilizer (cc)}}$$

True density

True density defined as the ratio of mass of the sample to its true volume and it was measured usingthe liquid displacement method (Mohsenin, 1986). The solvent Toluene (C_7H_8) was used to determine the true density of fertilizer granule. A 50 ml of toluene was filled in a 100 ml measuring cylinder and 10 g of granular fertilizer was taken to determine the true density. The sample was immersed in a jar containing toluene liquid. The displaced volume of toluene was recorded for each sample. Observations were taken for twenty samples and the mean considered as the characteristics value of density of fertilizer granules. True density was calculated using the following expression described by Mohsenin (1986).

[True volume of fertilizer] = [Final toluene level]-[Initial toluene level]

$$\text{True Density } (g.cc^{-3}) = \frac{\text{Weight of the granularfe rtilizer (g)}}{\text{Volume of the granular fertilizer (cc)}}$$

Angle of repose

Angle of repose is one of the important engineering property needed for the design of hopper system. The container having dimension of 130 × 130 × 210 mm was used to measure angle of repose of fertilizer granules. A removable vertical plate placed between one side of the metal container having dimensions of 130 × 210 × 5 mm. The container was filled with the fertilizer granules, levelled and then the vertical plate was quickly slid upwards allowing the fertilizer granules to flow down. The angle of repose was calculated by considering maximum depth of free fall surface of the sample and length of the box. The angle of repose of the sample was calculated using the formula given below (Mohsenin, 1986). The procedure was replicated ten and the mean was calculated.

$$\text{Angle of repose} = \tan - 1\left(\frac{H}{L}\right)$$

Where

H= height of sample, mm

L= length of sample, mm

Coefficient of static friction(μ_s)

The coefficient of static friction (μs) is very important in the field of bulk storage, quality and handling of agricultural industry. The coefficient of static friction (μs) of fertilizer granules was determined with respect to each of the following six structural materials such as plywood, galvanized iron sheet, rubber, glass, aluminium and mild steel sheet. The granular fertilizers were placed in a M.S sheet two sided open box having dimensions of 50 × 50 × 50 mm on the test surface at the top edge. The inclined surface was tilted until the samples begin to move leaving the inclined surface. The angle of inclination to the horizontal was measured directly on the instrument scale and it was taken as angle of internal friction. The tangent of the above angle was taken as co-efficient of friction between the test surface and fertilizer granules sample. The procedure was repeated ten times for each structural material with each fertilizer granules. The coefficient of friction was calculated as the tangent of the angle using the equation given below (Mohesenin, 1986)

$\mu_s = \tan \theta$

Where,

μ_s = Co-efficient of static friction

θ = Angle of inclination of material surface, (˚)

RESULTS AND DISCUSSION

Physical and engineering properties of granular fertilizers. The linear dimensions, geometric mean diameter, bulk density, true density, angle of repose and coefficient of static friction for granular fertilizer were measured and average values were tabulated. However, urea was very small in size and MOP was in powder form. Hence the linear dimensions viz, length, breadth, thickness and geometric mean diameter were not reported in this paper.

Linear dimensions. Linear dimensions namely length, breadth and thickness were measured and presented in Table 1. The length of fertilizer viz., DAP, NPK complex and SSP ranged from 3.88±0.60 mm to 4.20±0.52 mm. Whereas, the breadth ranged from 3.47±0.57mm to3.56±0.43mm. Similarly, the thickness of granular fertilizer ranged from 2.89±0.54 mm to 3.26±0.51 mm. The geometric mean diameter of granular fertilizer ranged from 3.44±0.53 mm to3.59±0.39 mm, respectively. Similar results were obtained by Gurjar *et al.* (2017).

The maximum length, breadth and geometric mean diameter of granular fertilizer was observed in case of SSP (4.20±0.52 mm, 3.56±0.43 mm and 3.59±0.39 mm). Whereas, the thickness was found highest in case of NPK complex (3.26±0.51 mm).

From Table 2, it was inferred that lengths of DAP (4.08 mm) and SSP (4.21 mm) were on par and highest followed by NPK Complex (3.88 mm). The breadth of fertilizers were on par. It was also observed that NPK complex (3.26 mm) had the highest thickness followed by SSP (3.09 mm) and DAP (2.89 mm). The geometric mean diameter of fertilizers were on par.

Table 1: Geometric properties of different fertilizer.

Sr. No.	Property	Fertilizer		
		DAP	NPK Complex	SSP
1.	Length, mm	4.07±0.63	3.88±0.60	4.20±0.52
2.	Breadth, mm	3.47±0.57	3.53±0.52	3.56±0.43
3.	Thickness, mm	2.89±0.54	3.26±0.51	3.09±0.32
4.	Geometric mean diameter,mm	3.44±0.53	3.54±0.52	3.59±0.39

Table 2: ANOVA for Linear dimensions of fertilizers.

Sr. No.	Fertilizer	Length, mm	Breadth, mm	Thickness, mm	Geometric mean diameter, mm
1.	DAP	4.08^{a}	3.48	2.89^{c}	3.44
2.	NPK Complex	3.88^{b}	3.54	3.26^{b}	3.523
3.	SSP	4.21^{a}	3.56	3.09^{a}	3.59
4.	'F' value	*	NS	*	NS
5.	CD (0.05)	0.16	14.57	0.13	12.32

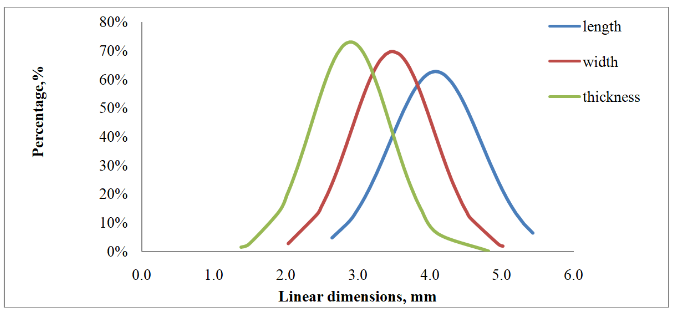

Fig. 1. Frequency distribution curves of linear dimensions of DAP fertilizer.

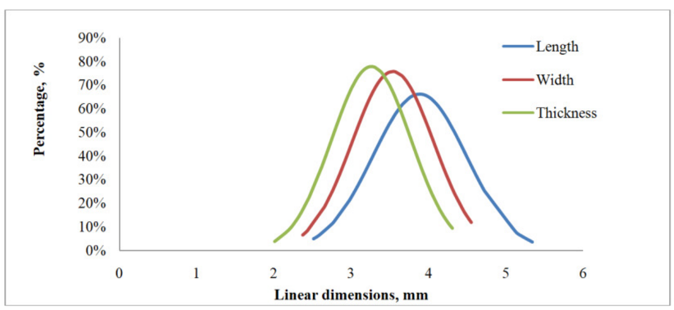

Fig. 2. Frequency distribution curves of linear dimensions of NPK Complex fertilizer.

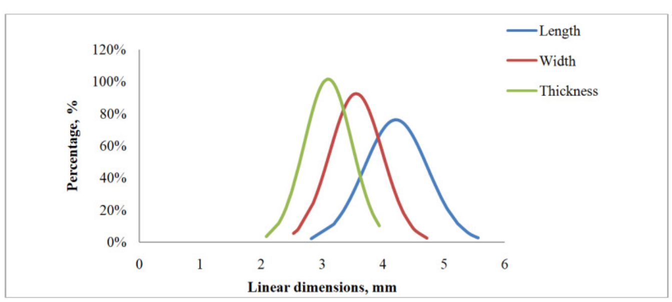

Fig. 3. Frequency distribution curves of linear dimensions of SSP fertilizer.

In case of DAP fertilizer, 62% fertilizer had length of 4.5 mm, 70% fertilizer had width of 3.5 mm and 75% fertilizer had thickness of 3.0 mm (Fig. 1). In case of NPK complex fertilizer, 60% fertilizer had length of 4.0 mm, 70% fertilizer had width of 3.5 mm and 75% fertilizer had thickness of 3.0 mm (Fig. 2). In case of SSP fertilizer, 70% fertilizer had length of 4.5 mm, 90% fertilizer had width of 3.5 mm and 98% fertilizer had thickness of 3.0 mm (Fig. 3).

Bulk density and true density. The bulk density and true density of the selected granular fertilizers were presented in Table 3. From the table it was observed that bulk density of selected fertilizer viz., DAP, NPK Complex, SSP, Urea and MOP ranged from 753.769±11.40kg $m^{-3}$to 1123.91±4.19 kg m^{-3}. Similarly, true density ranged from 1203.57±180.02 kg m^{-3} to 1989.28±836.39 kg m^{-3}.

The highest bulk density was observed in case of MOP i.e 1123.91±4.19 kg m^{-3}. Similarly, the highest true density was noted in case of NPK complex i.e1989.28±836.39 kg m^{-3}.

Table 3: Gravitational properties of different fertilizer.

Sr. No.	Property	Fertilizers				
		DAP	NPK Complex	SSP	Urea	MOP
1.	Bulk density, kg m^{-3}	976.43±3.85	1112.02±13.62	1008.86±6.76	753.77±11.40	1123.91± 4.19
2.	True density, kg m^{-3}	1379.76±264.9 9	1989.28±836.39	1950.00±217.94	1203.57±180.02	1817.85±325.15

Table 4: ANOVA for Bulk density and True density of fertilizers.

Sr. No.	Fertilizer	Bulk density, kg m^{-3}	True density, kg m^{-3}
1	DAP	976.43^{d}	1379.76^{b}
2	NPK Complex	1112.02^{b}	1989.29^{a}
3	SSP	1008.86^{c}	1950.00^{a}
4	Urea	753.77^{e}	1203.57^{b}
5	MOP	1123.91^{a}	1817.86^{a}
6	'F' value	*	*
7	CD (0.05)	7.99	281.52

From Table 4, it was inferred that bulk density was highest for MOP(1123.91kg m^{-3}) followed by NPK complex (1112.02kg m^{-3}), SSP (1008.86 kg m^{-3}), DAP (976.43 kg m^{-3}) and urea (753.77kg m^{-3}) fertilizer. It was also observed that true density of MOP (1817.86kg m^{-3}), NPK complex (1989.29kg m^{-3}) and SSP (1950.00kg m^{-3}) were on par and highest followed by DAP (1379.76kg m^{-3}) and urea (1203.57kg m^{-3}).

Angle of repose. The angle of repose for selected granular fertilizers was determined and presented in Table 5. From the table, it was observed that the angle of repose of selected fertilizes namely DAP, NPK Complex, SSP, Urea and MOP ranged from 32.46±1.42° to 39.82±0.98°. The maximum angle of repose was observed for MOP i.e39.82±0.98° and minimum for NPK Complex i.e 32.46±1.42°. Similar types of results were reported by Mandal and Thakur (2010).

From Table 6, it was observed that, the angle of repose for all the fertilizers under study was significantly different. The angle of repose of MOP (39.83°) was highest followed by SSP (37.69°), DAP (35.29°), Urea (33.32°) and NPK Complex (32.47°).

Coefficient of static friction. The coefficient of static friction for selected granular fertilizers was determined and presented in Table 7.

Table 5: Angle of repose for different fertilizer.

Sr. No.	Property	Fertilizer				
		DAP	NPK Complex	SSP	Urea	MOP
1.	Angle of repose, °	35.29±0.58	32.46±1.42	37.69±0.43	33.32±0.68	39.82±0.98

Table 6: ANOVA for angle of repose of fertilizers.

Fertilizer	DAP	NPK Complex	SSP	Urea	MOP	'F' value	CD (0.05)
Angle of repose	35.29^{c}	32.47^{e}	37.69^{b}	33.32^{d}	39.83^{a}	*	0.81

Table 7: Coefficient of static friction of different fertilizer for different surfaces.

Sr. No.	Property	Fertilizer				
		DAP	NPK Complex	SSP	Urea	MOP
1.	Mild steel	34.60±2.01	35.00±1.56	27.10±1.10	34.30±1.88	35.90±0.99
2.	Wood	31.05±1.16	30.20±0.91	24.10±0.87	27.60±1.71	33.90±0.73
3.	Galvanized iron	32.10±1.64	31.40±0.69	27.00±1.24	29.10±0.56	34.00±0.81
4.	Rubber	38.60±1.42	38.30±1.25	30.10±0.73	39.20±1.13	37.10±0.99
5.	Glass	25.30±1.05	25.20±0.91	22.10±1.10	24.50±0.52	31.20±1.61
6.	Aluminium	31.50±1.84	29.20±1.22	28.70±0.67	26.90±0.87	31.40±1.17

The coefficient of static friction for rubber surface was highest as compare to other surfaces. i.e38.60±1.42, 38.30±1.25, 30.10±0.73, 39.20±1.13 and 37.10±0.99 for DAP, NPK Complex, SSP, Urea and MOP respectively. This was due to surface roughness of rubber (Ezzat *et al*., 2007). The coefficient of static friction for glass surface was lowest as compare to other surfaces i.e25.30±1.05, 25.20±0.91, 22.10±1.10,24.50±0.52 and 31.20±1.61 for DAP, NPK Complex, SSP, Urea and MOP respectively. This was due to the smoother surface of glass (Murase, 1984).

Table 8: ANOVA for coefficient of static friction.

coefficient of static friction					
Fertilizer / Material surface	**DAP**	**NPK Complex**	**SSP**	**Urea**	**MOP**
Mild steel	34.60	35.00	27.10	34.30	35.90
Wood	31.05	30.20	24.10	27.60	31.20
Galvanized iron	32.10	31.40	27.00	29.10	34.00
Rubber	38.60	38.30	30.10	39.20	37.10
Glass	25.30	25.20	22.10	24.50	31.20
Aluminium	31.50	29.20	28.70	26.90	31.40
Factors	**F' value**		**CD(0.01)**	**SeM**	
Fertilizer	**		0.57	0.156	
Material	**		0.63	0.171	
F×M	**		1.40	0.383	

From Table 8, it was inference that the effect of material on coefficient of friction was highly significant. It was observed that glass has the least coefficient of friction followed by wood, aluminium, galvanized iron, mild steel and rubber. The glass is fragile in nature and wood has ability of absorbing moisture. Hence, these materials are not suitable for fabrication of fertilizer hopper. Next least coefficient of friction was observed for aluminium, but it is reactive with fertilizers as well as high cost. Hence, galvanized iron which had the next least coefficient of friction was considered for fabrication of hopper.

DISCUSSION

The fertilizers are mixed at recommended rate and then applied to the field. Presently the fertilizers are mixed manually. Hence, the suitable fertilizer mixer need to be developed which will be used in precision fertilizer applicator. The uniformity of fertilizer mixing is represented in terms of uniformity coefficient. As the fertilizers are solvable in nature. The mixed fertilizers are need to be separated physically to determine the coefficient of uniformity. From the above study, it was observed that as the fertilizers have different size, the mixed fertilizer can be separated by using suitable screens to compute the coefficient of uniformity. From Table 5, it was observed that the side slope of fertilizer hopper should be more than 40˚ to achieve the free flow of the fertilizers.

CONCLUSIONS

The physical and engineering properties of selected granular fertilizers were studied for design of precision fertilizer applicator for crop cultivation. The size of fertilizers were significantly different. Hence, separation of fertilizers after mixing to compute the coefficient of uniformity by physical method is possible. As the highest angle of repose to be 39.82˚. The fertilizer hopper should be designed having a side slope greater than 40˚. The material should be galvanised iron as it had the least coefficient of friction among the materials considered under study compared with nature. However, it is recommended that stainless steel and non-reactive coating suitable fertilizer may be studied and its for hopper.

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Conflict of Interest. None.

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