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Development of a manually operated organic and inorganic fertiliser applicator for smallholder farmers

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Abstract: This paper reports the design, fabrication and testing of a low-cost PVC-based manual fertiliser applicator (MFA) for the placement of granular and powdery fertilisers (organic and inorganic) at a required soil depth and plant spacing. The MFA consists of a spring-loaded trigger mechanism, a connecting tube and a knapsack plastic tank for the fertiliser storage, holding between 8.0–12.0 kg of fertiliser depending on the fertiliser's characteristics. The MFA was tested using four common fertilisers (NPK, SSP, Urea and organic manure) at different fertiliser moisture contents (3, 4, 5 and 6% w.b.). The results reveals that the MFA performed effectively in the fertiliser's discharges although it was significantly affected by the moisture content and fertiliser type. However, the MFA performed optimally when the moisture content was not above 4% (w.b.) giving optimal discharge values of 3.82, 3.45, 1.88 and 1.70 g per application for the NPK, SSP, urea, and pulverised organic fertilisers, respectively, at 4–7 cm application depths. Operators can, however, effectively determine the depth of placement and the number of applications during use based on agronomic recommendations.

Keywords: volatilisation; MFA; NPK, SSP; urea

Adequate fertiliser application techniques and utilisation are regarded as key factors in ensuring better yields in the face of degrading soil nutrients. Fertiliser application methods are very important to achieve the desired output. Fertilisers are applied to the soil to supply plant nutrients especially when the native soil nutrients are inadequate to meet plant nutrient requirements (John et al. 2006). The role and contributions of smallholders' agriculture to food production cannot be overemphasised. According to the United Nations (2015), smallholder farmers supply a large percentage of Africa's total food needs. They provide around 80% of the food consumed in both Asia and sub-Saharan Africa. It is, therefore, important to ensure that productivity at this level of agricultural production is given the required boost in terms of inputs and efficiency of their farm activities.

Consequently, application of fertilisers to augment the soil nutrients is an essential activity in ensuring a profitable smallholder crop production. Srivastava et al. (1993), asserted that fertilisers may be applied before planting, during soil tillage or the seed bed preparation time, during planting and after germination during the active growth period. Fertiliser applications in smallholder production systems are of-

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ten undertaken manually and this comes with much drudgery. In most smallholder farms, the application of a fertiliser is undertaken on the surface level via methods such as top and side dressing (placement), broadcasting, foliar feeding, etc. either by hand or by using crude tools and implements. Traditional fertiliser broadcasting, in which fertilisers are cast across the surface of crop fields by hand, a method that cannot control the rate of nutrient frequency, has been observed to result in inefficient fertilisation (Atikur-Rahman and Dunfu 2018). The surface placement of fertilisers has also been associated with nutrient losses from runoff and nutrient volatilisation (Umesha et al. 2017). Report by the International Fertilizer Development Center (IFDC 2013) also observed that fertiliser applications by broadcast method increase production costs by roughly 33% and greenhouse gases by 60% while also decreasing yields by roughly 15–18%.

In some developing countries, farmers have been noted to apply fertilisers to their cropland without measurements leading to excessive and indiscriminate applications (Tucker 1979). This has continued because of a lack of adequate tools, training and much needed innovations, this, in turn, leads to the over-fertilisation and, in some cases, is responsible for the increased soil acidity. Over-fertilisation is associated with high levels of residual nutrient elements in the soil, especially nitrates which potentially contribute to groundwater and atmospheric pollution as a result of leaching and volatilisation (Swietleik 1992). Excessive fertiliser applications have also been noted to cause physical, chemical, and biological damage to the soil and decrease the soil fertility (Sofyan et al. 2019).

According to Bouwman (2002), ammonia volatilisation (AV) is the major pathway of nitrogen losses from farmlands. In the case of manure applications, the nutrient losses arising from AV could increase depending on the prevailing environmental conditions and management techniques. In some parts of the world, agricultural systems are estimated to account for approximately 89% of the total NH_3 volatilisation (FAO 2014). Although animal production accounts for the major share of the total agriculture-related NH_3 volatilisation, the N loss from fertilised fields also plays a pivotal role in NH_3 volatilisation. Meisinger and Jokela (2000) reported that nitrogen losses can range from close to 100% for surface applications of fertiliser with optimal conditions for volatilisation to a few percent when manure is injected or incorporated directly into the soil. Fertilisers, therefore, are more efficiently utilised when incorporated in the soil at an appropriate depth.

As of present, most application methods of organic and inorganic fertilisers into the soil in smallholder operations are still applied as surface applications as mechanised fertiliser applicators are unaffordable for smallholders, which increases the constraints faced in smallholder farming production systems.

This study, therefore, aimed to develop, fabricate and test a hand-held, low-cost and polyvinyl chloride (PVC)-based manual fertiliser applicator (MFA) to place granular and powdery fertilisers (organic and inorganic) at a required soil depth and distance to the plants without exposure to the environment at each application.

MATERIAL AND METHODS

Design philosophy. The MFA was conceived in the search for a technically simple and easy to operate device capable of the efficient application of a fertiliser at a pre-defined depth and quantity using locally available materials. It also takes into account comfort in terms of ergonomics especially for the youth, women and adult smallholder farmers who would be the potential end users.

Machine description. The MFA basically consists of a spring loaded trigger mechanism on a handle connected to the outer member of two concentric PVC pipes with a shutter at the discharge end of the inner pipe (Ø 27.1 mm). A plastic serrated connecting tube is connected to the base of a plastic cylindrical knapsack type – storage tank of an 8.0–12.0 kg capacity for the fertiliser containment as shown in Figure 1. The fertiliser is gravity fed from the containment tank into the connecting tube where it is fed into the applicator's inner pipe where the trigger mechanism connected to the shutter helps to control the fertiliser discharge. The tip of the fertiliser applicator is connected to a furrow opening device which opens the ground to the required depth before the fertiliser is discharged and then effects a soil cover-up after the operation.

Preliminary investigation. Three samples of inorganic fertilisers [Nitrogen-phosphorus-potasium (NPK) – Indorama corporation, Nigeria; Single super phosphate (SSP) – TAK Agro, Nigeria; and Urea – Indorama corporation, Nigeria] were purchased from a local fertiliser distributor in Ibadan and allowed to absorb a moisture content determined at 3% (w.b.) using the thermo-gravimetric method.

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The samples were then allowed to absorb atmospheric moisture to three levels (4, 5 and 6% w.b.) to simulate the common conditions of fertilisers used by small holder farmers. The organic fertiliser (dried compost) produced for smallholder farmers' crop production was obtained from the Institute of Agricultural Research and Training. The compost was pulverised and also allowed to absorb atmospheric moisture until different (3, 4, 5 and 6% w.b.) moisture content levels were obtained using the thermo-gravimetric method. The different organic and inorganic fertiliser samples were then loaded into the MFA tank and readings were obtained on the discharge rates using a dry run method. The dry run method involved the operation of the manual device in a clean enclosed area on paper placed in a straight line. The device was then operated in such a way that the discharged fertiliser fell on the sheet of paper. The metered fertiliser samples were then collected and weighed on a sensitive scale (Falcon Electronic Model BL 3002, china). Each experimental run was replicated 3 times and the average value was calculated using the equation as shown below.

$$D_n = \frac{\sum X_i}{n} \qquad (1)$$

where: D_n – average fertiliser discharge; X – quantity of the fertiliser discharged per unit operation (g); i – $1 \rightarrow n$; n – number of the operation/test.

Choice of materials and fabrication of MFA parts. The materials used for the fabrication of the MFA were locally sourced to ensure affordability. The choice of materials was determined by taking the corrosive nature of the fertilisers to be handled by the applicator into consideration, the materials selected were mostly PVC, rubber, aluminium and plastic materials with the specifications given in Table 1.

Fertiliser tank. The tank was a cylindrical knapsack sprayer tank, where a hole was drilled at the bottom for the discharge of its contents. The choice of cylindrical material was to ensure that the material (fertiliser) flows without formation of pockets at the edges of the tank. The tank was then connected to the applicator assembly with the aid of a flexible plastic pipe.

Fertiliser tube. The fertiliser tube (Figure 1) consisted of a 75 cm long PVC pipe, 20 mm in diameter, fitted with a 15 mm reducing socket at one end. The other end was appropriately threaded and connected to the fertiliser release aperture. The fertiliser from the storage tank discharges into the fertiliser tube by gravity to the discharge chute (Figure 2) with an aperture size of 6.154 cm^2 when opened.

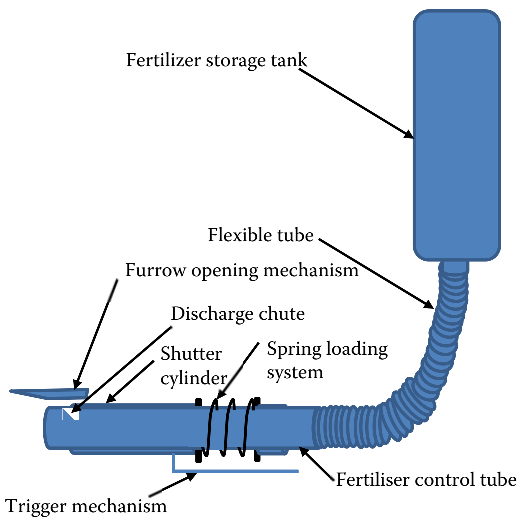

Figure 1. Sketch of the operational principle for the manual fertiliser applicator

Table 1. Major components and specifications of the manual fertiliser applicator

Component	Specification
Fertiliser storage tank	plastic, cylindrical, 8 L capacity
Furrow opening device	steel, L = 138.55 mm, W = 57.70 mm, clearance = 29.77 mm
Loading spring	steel, K = 0.97
Shutter cylinder	inner diameter = 27.3 mm, length = 3 750 mm
Flexible tube	serrated plastic tube, inner diameter = 21.55 mm outer diameter = 25.36 mm, length = 70 cm
Fertiliser control tube	CPVC, length = 75cm, outer diameter = 27.1 mm
Handle bar	aluminium with rubber coated handling portion, outer diameter = 24.02 mm
Discharge chute	area = 6.154 cm^2
Weight of applicator assembly	2.52 kg

L – lenght; W – width; K – spring constant; CPVC – Chlorinated polyvinyl chloride

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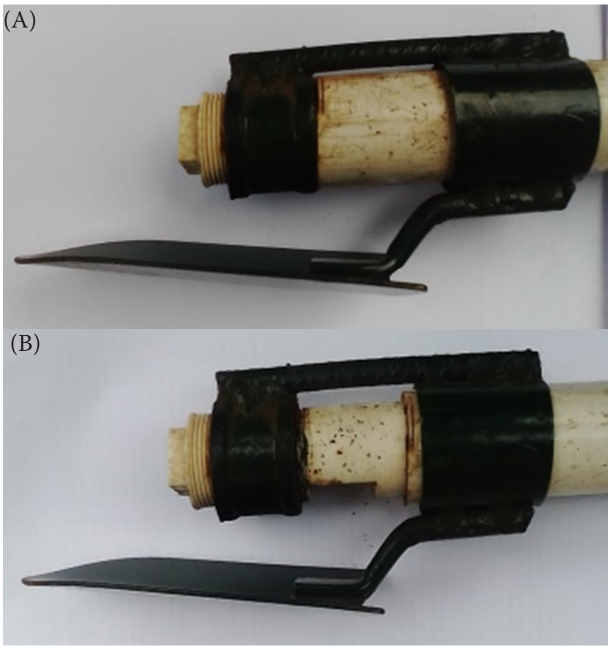

Figure 2. Discharge chute (A) closed and (B) open

Trigger mechanism. This consists of a metal spring with a constant value of 0.97, the spring was placed between the shutter cylinder of an inner diameter of 27.3 mm, which enabled a close fit with the fertiliser tube's outer diameter. The trigger handle was then attached to the shutter cylinder with the aid of connection made from ¾ PVC elbows, a pipe and an end cap. The end of the trigger mechanism aligned parallel to the handle bar of the applicator at a distance of 70 mm, this was to ensure the ease of operation and good ergonomics.

Handle bar. The handle bar was fabricated from an aluminium pipe; this reduced the weight considerably when compared with an iron pipe, and also offered a better corrosion resistance level. The handle bar was attached to the applicator assembly with the aid of a chromium plated steel clips.

Furrow opening device. The furrow opening device was fabricated from steel due to the nature of the task it needed to perform. The device was attached directly in front of the fertiliser release aperture in order to guide the placement of the fertiliser during application.

Performance evaluation procedure. The performance of the MFA was evaluated on the basis of a fertiliser delivery dosage at various moisture contents as well as the estimation of land coverage per volume of the loaded fertiliser. The delivery dosage was assessed by weighing the quantity of fertiliser delivered at various moisture contents for the different fertiliser types. All the measurements were carried out in triplicate.

Estimation of coverage for fertiliser applicator. The estimated number of applications expected from a fully loaded tank of MFA was determined using Equation (2) and the subsequent estimated land coverage was calculated with the aid of Equation (3).

$$Q = \frac{C_t}{D_n} \tag{2}$$

where: Q – estimated number of applications (plant stands); C_t – tank capacity (g); D_n – average discharge from the applicator for a specific fertiliser type (g).

$$L = \frac{Q \times 2.47}{10\ 000} \tag{3}$$

where: L – estimated coverage (acres).

Statistical analysis of data. The data collected were subjected to an ANOVA using the *R* statistical software package (version 3.6.1.) to determine the effect of the fertiliser type and moisture content on the MFA discharge. The means of the fertiliser discharges were separated using Duncan's multiple range tests (DMRT). The analysis was performed at a 5% significance level.

RESULTS AND DISCUSSION

Better ergonomics in operation

As required in the operation machinery involving the use of chemicals, concern for safety was considered. Better ergonomics is also a key advantage of the MFA when compared to the traditional methods where the farmer is required to bend over in order to apply fertiliser at each application. The MFA completely eradicates awkward bending positions while operating the manual fertiliser applicator (Figure 3). The operator is, however, required to wear safety boots, overalls to ensure minimum contact with the fertiliser as well as the use of a respirator to reduce risk of inhaling the fertiliser.

Discharge performance under varying moisture conditions

Chemical fertilisers. The comparison of the discharge rates of the MFA with varying moisture contents for each of the fertilisers (Figure 4) revealed that for both the NPK and SSP, the average discharge remained constant at 3.88 and 3.42 g, respectively, when the moisture content was between

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Figure 3. Manual fertiliser applicator in operation

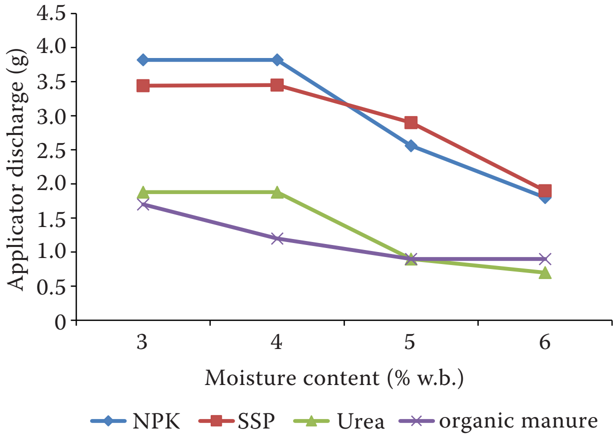

Figure 4. Variations in the applicator discharge with the different moisture contents

3 and 4% (w.b.), this trend, however, decreased when the moisture content was above 4%. Urea was also observed to have followed a similar trend of remaining constant between a 3 and 4% (w.b.) moisture content, the discharge was, however, at a lower value of 1.88 g was recorded with the Urea fertiliser at a moisture content between 3 and 4%. With an increasing moisture content, however, a discharge of 0.9 and 0.7 g was observed at a 5 and 6% moisture content, respectively. The observed reduction in the average discharge may have been due to the increased adhesion of the fertiliser particles as well as between the fertilisers and the contact surfaces as suggested by Massoudi (2001). This result also agrees with submissions by Camacho-Tamayo et al. (2001) who opined that an increase in the moisture content causes delays in the flow of fertilisers and, in certain conditions, hinders the particle movement by forming clogs.

Organic fertiliser. The pulverised organic fertiliser was observed to have followed a slightly different trend (Figure 4) as the discharge decreased with an increase in the moisture content until a fairly stable discharge rate of 0.9 g at a 5 and 6% moisture content (w.b.) was observed. The observed reduction in the organic manure flow with the increasing moisture content may have been caused by an increase in the liquid bridges and capillary forces acting between the particles of the powdered material thereby hindering the flow through the discharge tube as observed by various authors (Jenike 1964; Kamath et al. 1993; Schulze 1996; Horabik 2001).

Field performance of the manual fertiliser applicator

Tank capacity. The fertiliser holding capacity for the tank varied in terms of the average weight as shown in Table 2. This was due to the differences in the densities of the fertilisers. The super phosphate had the highest average weight while the organic manure had the lowest average weight. Another factor that may lead to a variation in the weight of the tank is the moisture content of the materials at the time of application.

Number of applications. The estimated number of placements per tank of the manual fertiliser applicator was highest (4 071 applications) for the full tank (7.67 kg) of Urea which would translate to an estimated land area of 0.12 acres for maize at a spacing of 25 × 75 cm. The MFA test also showed that NPK gave an estimated value of 2 335 placements which would translate to an area of 0.58 acres of maize at the same spacing. The MFA gave the lowest value of 1 676 applications at two applications of organic fertiliser per stand which translates to a land area of 0.41 acres of maize field being covered by just 5.7 kg of organic fertiliser.

Statistical analysis

The analysis of variance of the data sets conducted ($P \leq 0.05$) for the fertiliser discharges at the different moisture contents, as presented in Table 3, shows that the effect of the fertiliser type and moisture content were highly significant on the discharge of the fertiliser. This correlates with the fact that the MFA performed differently under the different fertiliser types and moisture contents.

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Table 2. Evaluation of the manual applicator performance

Parameter	Fertiliser type			
	Urea	NPK	SSP	organic manure
Tank capacity C_t (g)	7 670.00	8 920.00	9 710.00	5 700.00
Estimated number of placements** (Q)	4 071.00	2 335.10	2 814.50	1 676.50
Estimated area covered L (acreage)*	0.188	0.577	0.695	0.414

*Based on 25 × 75 cm maize spacing; **estimate for organic manure is based on two applications per stand

Table 3. ANOVA table

Source	*df*	Sum of squares	Mean square	*F* value	Pr (> *F*)
Fertiliser	3	463.61	154.583	8 695.22	< 0.2.2E–16***
Moisture	3	248.02	82.673	4 651.67	< 0.2.2E–16***
Fertiliser × moisture	9	32.08	3.564	200.55	< 0.2.2E–16***
Residuals	704	12.51	0.018	–	–

***highly significant at $P < 0.001$

Table 4. Comparison of the means for the discharge of the different fertilisers based on the moisture content

Fertiliser type	Moisture content (% w.b.)			
	3	4	5	6
NPK	3.82^a	3.82^a	2.56^a	1.8^b
SSP	3.44^a	3.45^a	2.9^b	1.9^b
Urea	1.88^a	1.88^a	0.9^b	0.7^b
Organic	1.7^a	1.7^a	1.2^a	0.9^b

Superscripts with the same letters along the row are not significantly different at $P \leq 0.05$

The interaction was also determined to have been highly significant. The separation of the means of the discharge using Duncan's multiple range tests (Table 4) revealed that there was no significant difference ($P \leq 0.05$) in the discharge of the applicator at the moisture contents of 3 and 4% (w.b.) for the SSP and Urea. The discharge was also observed to have exhibited a similar trend of not being significantly different at moisture contents of 2, 4 and 5% (w.b.) for the NPK and organic fertiliser. This shows that generally, for an optimum performance, the moisture content of the fertilisers should not exceed 4%. However, these values could still exceed 5% in extreme cases for the NPK and organic fertilisers.

CONCLUSION

The discharge of the MFA was significantly ($P \leq 0.05$) affected by the moisture content of the fertilisers. The results revealed that the applicator performed optimally when the moisture content was not above 4% (w.b.) giving optimal discharge values of 3.82, 3.45, 1.88 and 1.70 g per application for the NPK, Single Super Phosphate, Urea, and pulverised organic fertilisers, respectively. At different attempts, the MFA effectively placed the tested fertilisers at soil depths of between 4 and 7 cm. The authors, however, advise that operators effectively determine the depth of the placement during use following agronomic recommendations. The applicator offers an environmentally friendly and economical way of applying fertilisers for small holder farmers.

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