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DEVELOPMENT AND TESTING OF WALK-BEHIND GRANULAR FERTILIZER APPLICATOR FOR PRECISE FERTILIZER APPLICATION

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ABSTRACT

The balanced use of fertilizer play vital role to maintain required nutrients level in the plants for their better growth. Currently, most of the fertilizer addition is carried out using manual broadcasting that reduces the fertilizer use efficiency due to non-uniform fertilizer distribution. Moreover, the excessive use of fertilizer not only results fertilizer wastage but also affect output quality of produce along with environmental pollution. Thus, in order to address these serious concerns and to increase fertilizer use efficiency, this research study was carried out for the development and testing of walk behind granular fertilizer applicator. The development of the applicator was carried out using locally available materials to reduce its capital cost. The performance evaluation of fertilizer applicator was carried out under laboratory and actual field conditions to determine various parameters like application rate, fertilizer missing index, fertilizer droppage rate, wheel slippage and field efficiency. The results showed that the average fertilizer rate for maize and cotton crop was found to be 69.17 and 157.05 kg/ha respectively. The fertilizer missing index was found to be zero. The average theoretical and effective field capacity was found to be 0.245 and 0.197 ha/h respectively with an average field efficiency of 81.52%. The average wheel slippage was calculated to be 8.78%.

Keywords: broadcasting, fertilizer applicator, fertilizer use efficiency, effective field capacity, field efficiency

INTRODUCTION

The soil structure in Pakistan is suitable for growing of fruits, vegetables and cash crops. The only limiting factor is to maintain the desired nutrient level for the plants by adding organic or inorganic fertilizers. The crop yield in the country can be increased to International standards by employing farm mechanization for different farming operations in which one aspect is to increase fertilizer use efficiency. The precise application of fertilizer helps to enhance the plant growth and crop yield. The lesser use of fertilizer results poor plant growth while over use of fertilizer results fertilizer loss, environmental pollution and poor quality of farm produce. The balanced use of fertilizer helps to increase profit of agricultural products (Li *et al*., 2019). Soil fertility potential could be improved by raising fertilizer use efficiency and more strategies are required to be planned for attaining more sustainability in production and outcomes (Burke *et al.,* 2019). Various evaluations of total nutrient concentrations NPK exhibit deviations occurring on maize crop yield. The crop productivity and fertilizer use in western Kenya at sidindi resulted that crop yield is highly responsive to fertilizer (Njoroge *et al.,* 2019). The suitable and effective methods need to be introduced for timely fertilizer application to boost up maize farming (Agyare *et al.,* 2014). A greater innovation in conventional fertilizer applicator is necessary for variable rate application and to enhance efficiency in fertilization (Ji *et al.,* 2009). The control system in variable rate technology is considered as an excellent idea for achieving accuracy in fertilizing rate (Yuan *et al.,* 2010). The innovative techniques like GPS along with map based variable rate technology is ideal to improve fertilizer use efficiency (Moreno *et al.,* 2016). The fertilizer metering system is one of the major operational characteristics that play a vital role in controlling and monitoring fertilizer rate (Tamayo *et al.,* 2009). The fertilizer placement deeply or near the plant root zone minimizes fertilizer loss through volatilization

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and ensures uniformity in distribution across the field (Rahman *et al.,* 2010). The design of metering system should be based on shape and size of fertilizer (Hermawan, 2018). The spreading pattern does not remain constant but is affected by each kind of fertilizer like fertilizers urea, potassium chloride and potassium sulfate (Yang *et al*., 2018). Particles having small size, less density and wide irregularity in shape are more affected by wind having speed of 3 m/s (Cool *et al*., 2016). By increasing gate cross sectional area, various parameters like volumetric efficiency, bulk density etc. might be improved (Ismaila *et al.,* 2011). The optimum distribution pattern of fertilizer particles is the key factor regarding healthy growth of a crop to achieve its appropriate maturity level (Grift and Kweon, 2006). The row to row and plant to plant spacing should be kept about 20cm and place urea at 6-8cm deep (Hossen *et al*., 2013). The production of vegetables per unit area can be maximized by applying precise and controlled amount of fertilizer (Ebrahim, 2011). According to a study carried out in Sri Lanka resulted that proper design of fertilizer applicator for coconut tree crop could save cost and time of 94 and 96.5% respectively as compared with traditional methods (Fernando *et al.*, 2013). Keeping in view the above discussion, this study was carried out for development and testing of walk behind granular fertilizer applicator for small scale farmers to replace conventional fertilizer application methods.

MATERIALS AND METHODS

The development of walk behind granular fertilizer applicator was carried out using locally available materials and existing sowing configurations. The major components of newly developed walk behind granular fertilizer applicator include main frame, direction control mechanism, drive mechanism, chain and sprockets mechanism, fertilizer storage box, fertilizer metering mechanism, fertilizer delivery unit. After successful development, its laboratory testing was carried out in terms of fertilizer missing index and fertilizer application rate while field testing was performed to determine fertilizer droppage per unit area, wheel slippage, effective field capacity and field efficiency.

Description of major components of fertilizer applicator

Main frame

The main frame was developed in such a way that all the other components like driving handle, drive wheel, fertilizer metering mechanism, fertilizer storage box etc. can easily be installed on it. The cast iron was used to make the main frame of the applicator so that the stresses and loads during field operation may be accommodated. The overall length of the main frame is 193cm. The isometric view of main frame is shown in Figure 1a.

Direction control mechanism

The direction control handle was used to control the movement of applicator in the field during fertilizer application. The length of direction control handle was kept to be 76.2 cm while spacing between both handles was 43 cm for easier control by the operator. The isometric view of direction control mechanism is shown in Figure 2b.

Drive mechanism

The drive mechanism plays a vital role for smooth running of applicator in the field. Thus, a front wheel having diameter of 40cm and two rear wheels each having diameter of 28cm was selected for easier operation and reduce wheel slippage. The spacing between two rear wheels was kept to be 26.50cm.

Chain and sprockets mechanism

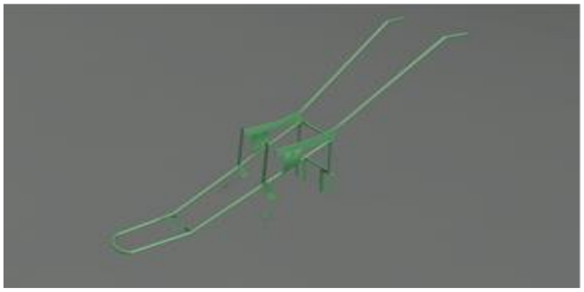
A suitable combination of chain and sprockets were used to drive the metering mechanism of the applicator. One sprocket having 16 teeth was connected with metering mechanism while other having 17 teeth was attached with the drive wheel. A roller type chain having a length of 130cm was used to drive the sprockets.

Fertilizer storage box

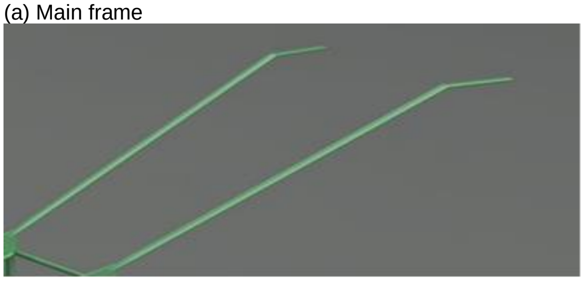
The fertilizer storage box was made of low weight material having storage capacity of 10 kg. The overall dimension of fertilizer storage box is 46×42×37cm. The isometric view of fertilizer storage box is show in Figure 1c.

Fertilizer metering mechanism

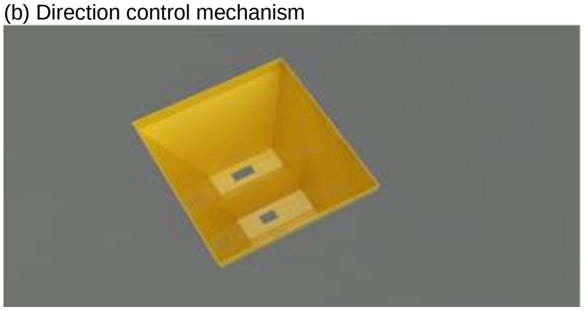
The metering mechanism is the key component to ensure proper fertilizer droppage through delivery tube. The metering unit was configured with various parts such as fluted roller, adjustable flap and slider cut off. The fluted rollers used in this applicator contained nine flutes. The isometric view of fertilizer metering mechanism is shown in Figure 1d. The fertilizer metering mechanism was attached with fertilizer delivery unit to drop the fertilizer at the required place in the field.



(a) Main frame



(b) Direction control mechanism



(c) Fertilizer storage box

(d) Fertilizer metering mechanism

Figure 1. Isometric view of major components of fertilizer applicator

The overall isometric view of newly developed walk-behind granular fertilizer applicator is shown in Figure 2.

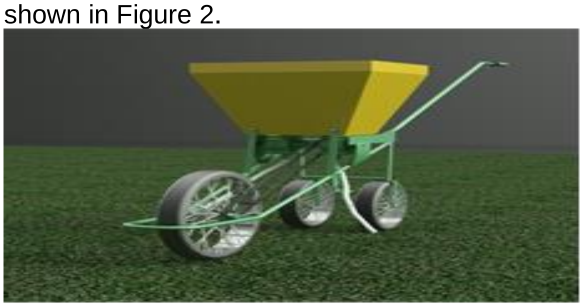


Figure 2. Isometric view of newly developed fertilizer applicator

Performance evaluation of applicator

After successful development of applicator, its laboratory and field testing were carried out under actual field conditions. This fertilizer applicator has ability to perform its function easily according to fertilizer requirement of any row crop. The laboratory and field-testing parameters include fertilizer missing index (FMI), fertilizer application rate (FR), fertilizer droppage per unit area, wheel slippage, effective field capacity and field efficiency.

Fertilizer missing index (FMI)

The fertilizer missing index was calculated using Eq. 1.

$$\text{FMI (\%)} = \frac{\text{N1+n2+n2)}}{\text{N}}$$

Where; FMI, N and n are missing index, total number of spacing and number of spacing in divisions respectively.

Fertilizer application rate (F.R)

Fertilizer application rate was calculated using Eq. 2.

$$\text{F.R} = \frac{(\text{Wf}+10)}{\text{A}}$$

Where; $W_{f,}$ and A are the total weight of fertilizer in grams and total experimental area in m^2 respectively while, F.R is fertilizer rate in grams/m^2.

Fertilizer droppage per unit area

The fertilizer droppage per unit area is calculated by taking the weight of fertilizer dropped in grams per m^2 area which is converted into kg per ha. The fertilizer droppage rate is controlled by adjusting the metering mechanism according to the requirement.

Wheel slippage

The wheel slippage was calculated using Eq. 3.

$$\text{S} = \frac{\text{Nth - Nac}}{\text{Nth}} \times 100$$

Where; S and N_{ac} are the wheel slippage and actual number of revolutions of ground wheel respectively while N_{Th} is theoretical number of revolutions of ground wheel.

Effective field capacity

The effective field capacity was calculated using Eq. 4.

$$\text{E.F.C} = \frac{\text{A}}{\text{T}}$$

Where; E.F.C, A, and T are effective field capacity in ha/hr, effective area covered by fertilizer applicator in ha and total time for covered area in hr respectively.

RESULTS

Laboratory testing

The applicator was tested in the laboratory to determine fertilizer missing index and fertilizer application rate to assess its feasibility for field operation.

Fertilizer missing index

The laboratory results showed that not a single particle of granular fertilizer was missed. The field testing of applicator also resulted zero fertilizer missing index. The average results of fertilizer missing index for maize and cotton crop are shown in (Table 1).

Table 1. Fertilizer missing index

S. No.	Crop fertilizer	Fertilizer missing index (%)
1.	Maize	0
2.	Cotton	0

Fertilizer application rate

The design of the fertilizer applicator was made in such a way that it is capable to perform fertilizer application for multiple crops. Different trials were carried out to observe any variation in application rate at varying speeds. The fertilizer application rate at different lever positions for maize and cotton crop is shown in Figure 3 and 4.

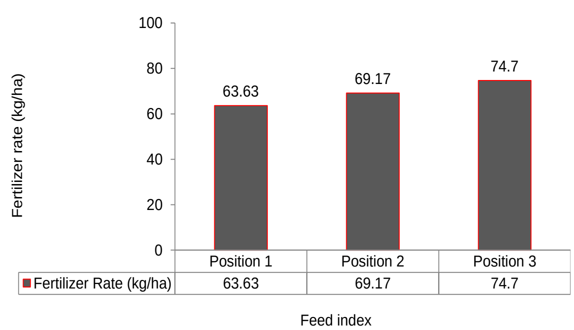


Figure 3. Fertilizer rate for maize crop

Field testing of fertilizer applicator

After laboratory testing, the performance of applicator was carried out under actual field conditions. The parameters tested during field operation include fertilizer droppage per unit area, wheel slippage, effective field capacity and field efficiency.

Fertilizer droppage per unit area

The experimental study area for maize and cotton crop was taken to be 0.00253 hectare in which fertilizer droppage was observed by changing gate area. The average fertilizer dropped was measured to be 69.17 kg/ha for maize crop, while it was 157.05 kg/ha for cotton crop.

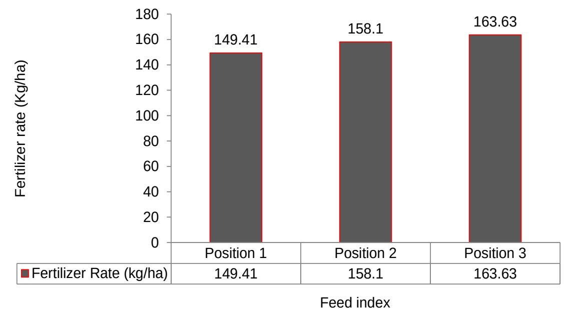


Figure 4. Fertilizer rate for cotton crop

Wheel slippage

The wheel slippage of applicator was calculated during actual field conditions. The wheel slippage at different forward speeds is shown in Figure 5. The results showed that the wheel slippage increases by increasing forward speed of the machine. The slippage value can be minimized by following some precautions regarding applicator speed and operational techniques. Some other factors like operator's experience, soil preparation etc. can also help to improve performance of fertilizer applicator.

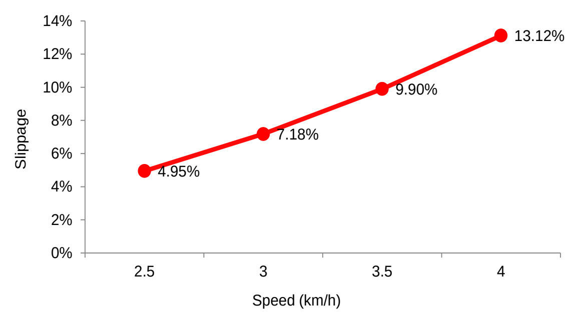


Figure 5. Wheel slippage at different forward speeds of applicator

Theoretical and effective field capacity

The theoretical and actual field capacity of granular walk behind fertilizer applicator was calculated with respect to maize crop and its calculations are shown in Table 2. The table shows that effective field capacity is dependent on speed of applicator and alters in accordance with forward speed of the applicator.

Furthermore, some other factors also affect its performance like applicator's operating conditions and handling etc.

Table 2. Calculation of field capacities

Time (min)	Speed (m/s)	Theoretical Field Capacity (T.F.C) in ha/hr	Effective Field Capacity (E.F.C) in ha/hr
	V = S/t	T.F.C = (S x W) / 10	E.F.C = Total covered area / Time
2.8	1.2	0294	0.245
3.1	0.95	0.232	0.189
3.5	0.81	0.198	0.158

Where; S is forward speed of machine in km/hr; W is the width of the machine; A is the total area covered in ha and t is the time consumed to cover total area in hours.

Field efficiency

The field efficiency at machine forward speed of 4.32, 3.42 and 2.92 km/hr was calculated to be 83.33, 81.46 and 79.79% respectively.

Economic analysis of fertilizer applicator

The capital cost of fertilizer applicator is PKR 25500. The economic analysis in terms of fixed and variable cost of fertilizer applicator resulted that the total fixed cost of applicator was calculated to be PKR 3.24 per hour while total variable cost of applicator was calculated to be PKR 102.42 per hour. The total cost of applicator was found to be PKR 105.66 per hour while in case of conventional broadcasting it is PKR 200 per hour.

DISCUSSION

The analyzed results showed that during laboratory and field testing of walk-behind granular fertilizer applicator the missing index was found to be zero. It is due to the fact that since the metering mechanism of the applicator is directly attached with the storage box, so all the fertilizer collected from the box is delivered to the fertilizer delivery unit by the metering mechanism, thus the missing of fertilizer was zero. The experimental results of applicator in terms of fertilizer application rate showed that the application rate increases in a linear trend by increasing the feed index from position 1 to 3 both for maize and cotton crop. The linear trend shows the accuracy of metering mechanism for better and effective fertilizer application. The maximum application rate was found to be 74.7 and 163.63 kg/ha for maize and cotton crop respectively. The fertilizer droppage rate was measured to be 69.17 and 157.05 kg/ha for maize and cotton crop by changing the grate area. The results showed that the applicator is capable to discharge varying amount of fertilizer based on the requirement of different crop by changing the grate area. The results of wheel slippage showed that the wheel slippage also increasing linearly by increasing the forward speed of the machine. The wheel slippage at 4 km/hr was found to be 13.12% which is within the recommended limit. Most of trailed machines are driven in the field between 2 to 5 km/hr forward speed. The recommended wheel slippage should be below 20% for trailed agricultural machinery. The effective field capacity of machine decreases by decreasing the forward speed of machine in the field. The effective field capacity at 4.32 km/hr was found to be 0.245 ha/hr which was decreased to 0.158 ha/hr at 2.92 km/hr. Thus it is imperative to select suitable forward speed of machine based on cropping pattern and soil condition to get maximum effective field capacity. The result of field efficiency at different forward speed of machine showed that the field efficiency ranged between 79.79-83.33% for the forward speed of varying from 4.32 to 2.92 km/hr. The variation in the field efficiency is not significant thus showing that the variation in forward speed has not significant effect on machine efficiency. The average field efficiency of machine was found to be 81.52% which shows the excellent operation of the machine in the field as the field efficiency of machine should be greater than 70% for better efficiency of the machine. The economic evaluation of applicator resulted that the user can save PKR 94.34 per hour by using this fertilizer applicator as compared with conventional fertilizer application method. Thus, the applicator is not only economical to use in comparison to conventional method, but it also enhances fertilizer use efficiency by the plants.

CONCLUSION

Currently, most of fertilizer application is carried out using manual broadcasting that result poor fertilizer use efficiency. Moreover, the excessive use of fertilizer not only affects the quality of farm produce but also result environmental pollution. In order to address these serious issues and to increase fertilizer use efficiency, this study was carried out for the development and testing of walk behind granular fertilizer applicator for small and medium scale farmers. The results showed that average wheel slippage was found to be 8.78%, average theoretical field capacity was 0.245 ha/h, average effective field capacity was 0.197 ha/h with average field efficiency of 81.52%. The average fertilizer rate for maize and cotton crop was found to be 69.17 and 157.05 kg/ha respectively. Thus, it is concluded that the newly developed fertilizer applicator is suitable for small and medium scale farmers to replace the conventional fertilizer application methods and enhance the fertilizer use efficiency.

AUTHOR'S CONTRIBUTION

S. Ahmed: Development of machine and data collection

A. Ghafoor: Study plan, supervision, and main author of the manuscript write-up.

M. A. Khan: Data analysis

M. U. Farid: Manuscript Editing and formatting

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