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Design, Development and Testing of a Direct Driven Two-wheel Tractor Operated Two-row Metering Mechanism for Sugarcane Fertilizer Applications

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ABSTRACT

Fertilizer application is an essential but costly management practice in sugarcane farming due to the labor scarcity for manual applications. A smallholder, accurate, easy to operate sugarcane fertilizer applicator will be suitable for overcoming such labor shortages. Therefore, the main objective of this research was to develop a tractive wheel-driven fertilizer metering mechanism to a two-wheel tractor mounted fertilizer applicator for evenly applying fertilizer in any field and at different speeds. The specific objective of this study was to evaluate the cost of fertilizer applications compared to manual applications. A metering mechanism was designed based on the sugarcane fertilizer recommendation of Sri Lanka. All the parts in contact with the fertilizer were fabricated using stainless steel to avoid the corrosive effect of fertilizer. Roller chains and sprockets were used as power transmission elements. Fertilizer dropping rates at different speeds of the tractor and the uniformity of fertilizer application (UFA) of developed fertilizer applicator were tested and compared to the manual application. Results concluded that the UFA of the new fertilizer applicator is 99.4% which is 13% higher than the manual broadcasting method (86.3%). Though the fertilizer dropping rate reduced slightly with the increasing speed, the speed of the fertilizer applicator did not significantly affect the fertilizer dropping rate. The cost of fertilizer application can be reduced by 55% using the newly developed fertilizer metering mechanisms attached fertilizer applicator.

1. Introduction

Fertilizer application is one of the essential, time-consuming, and costly management practices in sugarcane farming. There are three-stage fertilizer application practices in sugarcane farming: top dressing, 45 Days After Planting (DAP), and 90 DAP. Several methods are used for fertilizer application, mainly broadcast, placement, and deep placement [1]. In Sri Lanka, the manual broadcast is often practiced for apply Urea, Muriate of Potash, and Triple supper Phosphate according to the recommendations [2]. This method leaves more fertilizer available to weeds and enhances N losses [3]; thus, fertilizer application efficiency is very low. In the dry zone where sugarcane is grown, manual work availability is low due to low population densities, harsh climatic conditions, and remote locations from major cities [4–6]. In the Sri Lankan sugar industry, fertilizer application accounts for nearly 13% of sugarcane production costs [7]. Among these, a high cost is allocated only for labor for fertilizer application. Thus, a smallholder sugarcane fertilizer applicator will be a promising solution to overcome such labor shortages.

In 1997, Sugarcane Research Institute (SRI), Sri Lanka, developed a two-wheel tractor mounted fertilizer applicator [7] (Plate 1). Major limitations of this machine were; the application rate and distribution directly depended on the tractor speed, field condition, and operating condition because there was no proper fertilizer metering mechanism. When the fertilizer applicator changes its angle, the fertilizer dropping rate varied. The fertilizer dropping rate was considered the amount of fertilizer placed

in a unit distance (g/m). Also, most of the small-scale fertilizer applicators used in other countries [8–10] could not be adapted directly to Sri Lanka due to different fertilizer dropping rates because of different metering systems. Therefore, the general objective of this research was to introduce a tractive wheel-driven metering mechanism for even fertilizer application in any field condition with varying speeds. The specific objective of this study was to evaluate the cost of fertilizer applications compared to manual applications.

Plate 1: Fertilizer applicator previously developed by Sugarcane Research Institute Sri Lanka

2. Material and Methods

A Tractive wheel-driven fertilizer dropping mechanism (Figure. 1) was incorporated with a two-wheel tractor mounted fertilizer applicator. The mechanism comprised replaceable gear (Figure. 1 - T1) connected to the power tiller's main driving axle to extract power for operating the fertilizer applicator. Replaceable intermediate gears (Figure 1 - T2 and T3) were used to alter different gear ratios to maintain the fertilizer recommendation. The intermediate gears, T2 and T3, were connected to the same shaft; thus, both gears have the same rotation speed. The power from drive wheel gear (T1) to intermediate gear T2 was transferred through the chain drive. The fertilizer metering system consisted of eight hollow spaces (Figure 2) on the cylindrical cavity attached to the fertilizer hopper. The fertilizer metering system was driven by intermediate gear (T3). All the parts in contact with the fertilizer were fabricated using stainless steel to avoid the corrosive effect of fertilizer [11].

The fertilizer applicator was constructed at the engineering workshop in SRI. The dropping rate at different speeds and uniformity of fertilizer application (UFA) was tested compared to the manual conditions. The fertilizer applied area was measured to calculate the field capacity in mechanical (Fertilizer applicator) and manual conditions. The amount of fertilizer dropping on a 20 m distance was measured for four different speed conditions (four treatments) as four replicates (see Table 1).

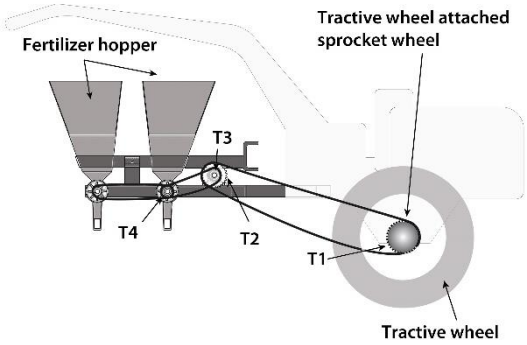

Figure 1: Tractive wheel-driven fertilizer dropping mechanism (not to scale)

Table 1: Conditions of the treatments

Treatment	Conditions
Treatment 1	Second gear in the low range (Average speed 0.5 m/s)
Treatment 2	Second gear in low range then change to the third gear low range (Average speed 0.9 m/s)
Treatment 3	First gear in the high range (Average speed 1.0 m/s)
Treatment 4	Second gear in high range then change up to fourth gear (Average speed 1.5 m/s)

Then, an experiment was conducted to verify whether the two-wheel tractor's speed affects the fertilizer dropping rate. A polythene sheet was laid on the sugarcane field to collect the fertilizer in each row when practicing manual application. The basket was temporarily mounted at the end of the fertilizer applicator's dispensing tube to collect the fertilizer when using the fertilizer applicator with the introduced metering system. Then UFA was calculated using equation No. 01 [12]. This calculation was done for both manual and machine application methods.

$$C_u = 1 - \frac{\sum(|X-\bar{X}|)}{n\bar{X}} \times 100 \text{ ---------- Eq. 01}$$

Where,

C_u: Christensen's coefficient of uniformity, %
$\bar{X}$: Mean weight of fertilizer, g
X : Weight of fertilizer in each box, g
n : Number of fertilizer samples

The total operational cost was calculated by considering machine depreciation, maintenance, hiring charges, and fuel cost [13]. The lifetime of the developed fertilizer applicator was considered as 15 years because there are 120 annual working days in both *Yala* and *Maha* cropping seasons. The machine salvage value was considered to be 26%

of the fabrication value. The annual repair and maintenance cost of the fertilizer applicator was 20% of the machine value. Then the cost of operation was compared with manual application.

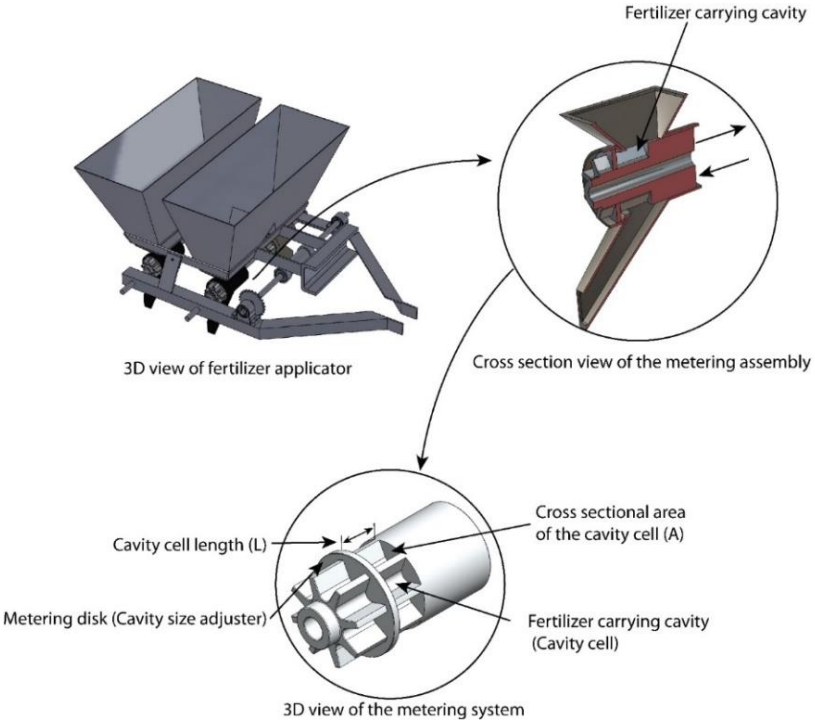

Figure 2: Arrangement of the Metering mechanism in fertilizer applicator

3. Results and Discussion

The developed fertilizer applicator was easily operated with the 12 hp, riding type, two-wheel tractors, and this is a commonly available farm power-producing machine in Sri Lanka. The dropping rate result was trended low with the power tiller's speed (Figure 3). However, optimum speed would be considered as about 0.8 m/s. The reduction of the fertilizer dropping with higher forward speed is due to less amount of fertilizer carried by the cavity cell. The fertilizer is collected by the cavity cell resulting from the gravitational force, thus, increasing speed cause to have less time to fill the cavity cell with fertilizer.

Table 2 shows the mean values of fertilizer dropping rate in both manual and mechanical operations. Those results reveal that the mean value of the co-efficiency of uniformity fertilizer application in both manual and mechanical conditions was 86.25% and 99.41%, respectively. The developed fertilizer applicator's metering mechanism increases the distribution of fertilizer all around the field uniformly. Because the entire metering cavity has the same volume and rotational speed, the metering cavity is directly proportionate to the rotation speed of the tractive wheel. When the different speeds as shown in Figure 3, It facilitates the application of 20 g/m (fertilizer recommendation given by SRI in 2020 for planting under irrigated conditions) of fertilizer to the field. With changes in the gear ratio in the metering mechanism, any given fertilizer recommendation can be applied for sugarcane farming.

Table 2: Variation of uniformity coefficient for machine and manual method

Replicate	Machine	Manual
1	99.2	88.1
2	99.5	90.2
3	99.7	80.3
4	99.3	86.4
Average	99.41	86.25

The field capacity of the machine was estimated as 0.484 ha/hr. The fabrication cost of the developed applicator was LKR 28,785. Machine depreciation was estimated as 4.07 LKR per hectare, assuming six working hours per day. Operator cost with hiring charges of the power tiller was considered 2,500 LKR per day without fuel charges. The fuel cost was 103 LKR per hectare, considering the current fuel price of 95 LKR per liter. The total cost of operation of the fertilizer applicator was 957 LKR per hectare.

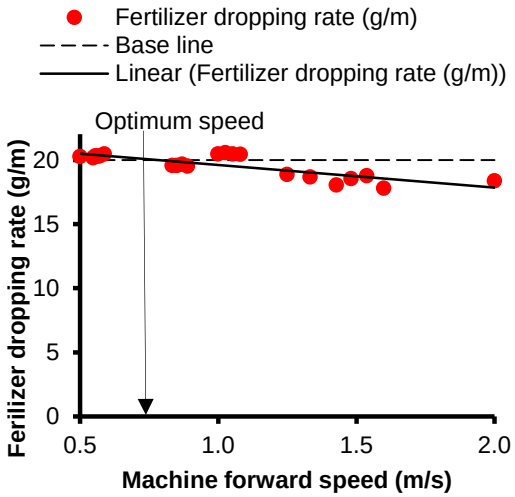

Figure 3: Amount of fertilizer dropped for 20 m distance in different speeds when the use of developed fertilizer applicator

Two labor units were required to apply fertilizer for one hectare land of sugarcane [14] at the current daily labor wage rate of 1085 LKR per day approved by the government of Sri Lanka. Accordingly, it was 2170 LKR for manual fertilizer application of one-hectare land. Therefore, it is clear that the cost of fertilizer application can be reduced by 55% by using the newly fabricated fertilizer application.

4. Conclusion

Tractive wheel-driven metering mechanism for 12 hp two-wheel tractor-mounted fertilizer applicator was developed and evaluated. The metering mechanism was effectively dispensing fertilizer at the rate of 20 g/m with an accuracy of 99% under the optimum speed of the two-wheel tractor (0.8 m/s). Thus, the applicator is useful for applying the first top dressing as it increases the efficiency and uniformity of application from 86% to 99% compared to existing manual application methods. The cost of fertilizer application can be reduced by 55% using the newly developed fertilizer metering mechanisms attached fertilizer applicator.

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