Development of a Battery-Operated Liquid Fertilizer Applicator with an Electronically Controlled Metering Device

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Abstract

Most farmers face high fertilizer prices and suffer economic losses due to uncontrolled fertilizer application on their farms. The common method of applying liquid fertilizer is with a watering can. The developed liquid fertilizer applicator is a battery-powered knapsack sprayer equipped with a program-based electronic metering device to deliver a more accurate amount of liquid fertilizer based on crop needs. The device includes a tank, pump, switch button, microcontroller, solenoid valve, liquid flow sensor, and lance. It was tested using two types of lance (injector-type and open-type) and compared to the traditional application method. Results showed that the uniformity coefficient exceeded the recommended 85%, with the open-type lance reaching 97.95% and the injector-type lance 96.09%. The device's actual field capacity was 248.70 m²/hr with the open-type lance and 134.96 m²/hr with the injector-type lance. Additionally, the injector-type lance's application rate and power consumption were 355.97 mL/m² and 9.26 Wh, respectively, while the open-type lance had 354.17 mL/m² and 5.17 Wh. These results indicate a higher uniformity coefficient, wider actual field capacity, and lower application rate compared to traditional methods, which had 72.74%, 110.15 m²/hr, and 538.58 mL/m², respectively. Therefore, the developed device improves liquid fertilizer application by efficiently dispensing the required amount, reducing labor and time, and cutting labor costs for the same field area compared to traditional methods.

***Keywords**:* fertilizer applicator, fertilizer injector, liquid fertilizer, microcontroller, precision agriculture

1. Introduction

Most farmers in the Philippines face high fertilizer prices. Consequently, they seek alternative methods to apply fertilizer, aiming to boost crop production while reducing costs. Numerous ways exist for applying fertilizer to crops, driven by the necessity of improving fertilizer absorption. Local farmers favor liquid fertilizer applications due to their comparatively higher effectiveness than direct granules and broadcasting methods, which lead to significant nitrogen losses through volatilization (Zheng *et al*., 2019). One method to apply liquid fertilizer to leafy vegetables is spraying. Other practical approaches for farmers to enhance liquid fertilizer utilization include soil injection of liquid chemicals and deep placement of fertilizers. Soil injection of liquid fertilizer allows for better nutrient treatment, concentrating on the crop's roots. Fertilizer application impacts initial crop growth and overall yield (Sundaram *et al*., 2017), influencing the production of amino acids that affect flavor and nutrition (Alcantara, 2015). However, excessive application of liquid fertilizer can be toxic to plants, making precise and appropriate fertilizer application essential (State of Hawaii, 2016). Nonetheless, accurate application of liquid fertilizer remains a significant issue for local farmers due to a lack of tools for precise measurement. This factor, along with a considerable labor requirement for crop care (80 man-days), contributes to high production costs (Tiw-an *et al*., 2020).

Liquid fertilizer injectors are devices used to apply water-soluble fertilizers, pesticides, plant growth regulators, wetting agents, and mineral acids during crop production. Since the introduction of injectors, growers have enjoyed an easy, time-saving, and labor-saving method of applying liquid chemical solutions to their crops (Pennisi and Kessler, 2017). Applying the correct amount of fertilizer to the soil for plant growth depends on the accuracy of the application rate and precision (Sugirbay *et al*., 2020). The unequal flow of fertilizers during distribution results in uneven fertilizer application in the soil, which impacts nutrient absorption in the plants.

When applying fertilizers to crops, it is essential to ensure that each plant receives adequate nutrients. Excess fertilizer application contaminates the environment, while nutrient deficits in nitrogen, phosphorus, or potassium hinder crop production. Over-application of nitrogen fertilizers leads to soil acidification, which reduces soil crusting potential by increasing the solubility of recycled surface silica (Si) (Beard *et al*., 2018).

In recent years, the Philippines has also developed a fertilizer injector that can apply fertilizer in either granular or liquid form. These designs are simple, effective, and efficient, as they have a lower tendency to lose fertilizer compared to broadcasting methods, where nutrients like nitrogen can be lost and not absorbed by plant roots (CTA, 1989). However, fertilizer injectors and applicators remain unavailable in the Philippine market. Although similar technology from abroad is accessible, adoption poses a challenge for farmers due to the high costs of investment, operation, and maintenance (Padhiary *et al*., 2025).

Figure 1. The traditional way of fertilizer application by local farmers

The development of an electronic metering device for battery-operated knapsack sprayers, intended for use as liquid fertilizer applicators, could ensure a more precise and optimal amount of liquid fertilizer. This allows plants to utilize the specified dosage crucial for their growth without the risk of over-fertilization that can harm them. The electronically-controlled metering device is programmed to release only the required volume of fertilizer based on the crop's needs, in contrast to the traditional method of applying liquid fertilizer with a watering can, as shown in Figure 1. Additionally, this device serves as an efficient tool that eases the burden on farmers compared to the conventional method of fertilizer application. This is supported by the observations of Zilpilwar *et al*. (2021), which noted minimal overall discomfort in the operator's body when using the battery-operated knapsack sprayer.

The study aims to develop a programmed metering device for a liquid fertilizer applicator, evaluate its performance on both injector-type and open-type lances, and compare it to the conventional method of fertilizer application regarding capacity, labor requirements, operation time, and labor costs. This study is vital in delivering the abovementioned significances. Additionally, it will contribute to the advancement of precision agriculture in the country by promoting fertilization at appropriate rates based on the need of the plants minimizing any excess application to keep water and nutrients in the root zone of the crops, hence facilitating maximum uptake efficiency.

2. Methodology

2.1 Concept of the Device

The development of the battery-operated knapsack liquid fertilizer applicator device was based on the criteria of the local farmers acquired in the interview conducted. The criteria considered during the design of the device are the following: the materials used should be locally available; the design should be simple and easy to operate; the materials used should be resistant to corrosion; the assembled parts should be easily replaceable; and the metering device should have a solenoid valve to dispense the required volume of fertilizer depending on the requirement of the crop.

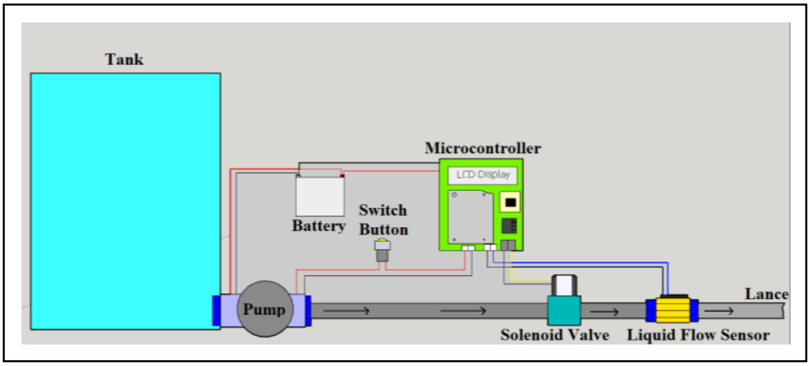

Figure 2. Schematic circuit diagram of the liquid fertilizer applicator

The developed device utilizes equipment and materials locally available such as the knapsack sprayer and other fittings. The schematic diagram (Figure 2) shows the flow of liquid fertilizer from the tank to the lance. The switch button activates the diaphragm pump to deliver liquid fertilizer to the lance. The microcontroller (ATmega328P, Arduino Uno R3, Italy), programmed to dispense the volume of 30 mL to 150 mL depending on the requirement of the crop, is connected to the solenoid valve (FPD-270A, CBLDF, China) and liquid flow sensor (114991172, Sensor Flow 1-25 LPM, China). When the liquid flow sensor detects the required volume was dispensed, the microcontroller commands the solenoid valve to shut off. The lance can be an open-type or injector-type depending on the needs of the farmer.

2.2 Materials

A battery-operated knapsack sprayer (YS-16GR, Yamada, Japan) was modified in this study as a liquid fertilizer applicator since most farmers utilize this technology in their farms. The tank has a maximum capacity of 16 liters made of polyvinyl chloride (PVC) plastic and it has a dimension of 380 mm x 215 mm x 535 mm. The device uses a diaphragm type pump with a working pressure of 0.15-0.4 MPa and is powered by a 12V/8Ah battery.

Figure 3. Microcontroller set-up

The knapsack sprayer was equipped with a locally available microcontroller set-up assembled in a local electronic shop shown in Figure 3. Arduino Uno is a microcontroller environmental board based on the Microchip ATmega328P that serves as the main controller of the device (Lualhati *et al*., 2022). It is fitted with a light crystal display (LCD) to show the selected setting and a potentiometer to adjust the volume to be dispensed from 30 mL to 150 mL.

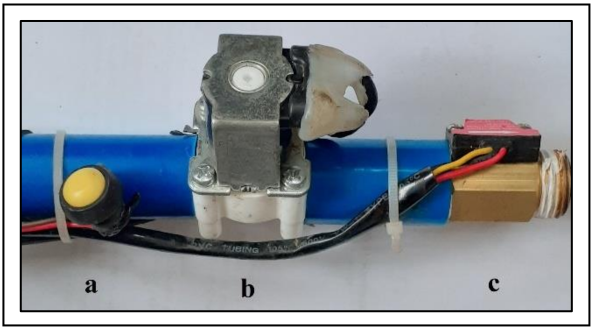

Figure 4. Liquid fertilizer applicator handle set-up: switch button (a); solenoid valve (b); and liquid flow sensor (c)

The tank is connected to the liquid fertilizer applicator handle set-up shown in Figure 4 which shows the switch button (a), the solenoid valve (b), and liquid flow sensor (c). The solenoid valve is an electromechanical device that controls, either shuts off or allows, the flow of liquid fertilizer (Bhattacharjee *et al.*, 2018). The liquid flow sensor consists of a plastic valve from which water can pass along a water rotor and a Hall Effect sensor that senses and measures the liquid flow.

Figure 5. Liquid fertilizer applicator lance: injector-type lance (a); and open-type lance (b)

The liquid fertilizer applicator handle set-up is attached with a lance. The two types of lance (Figure 5) used in this study are made of a stainless steel tube through which the liquid fertilizer passes. It has a length of 800 mm and has a diameter of 6.35 mm. The injector-type lance is operated by injecting it into the soil at a depth of 6 mm beside the crop to the root zone where the liquid fertilizers are discharged. The open-type lance when used is laid on the soil surface near the base of the crop allowing the measured volume to discharge from the 3 mm diameter opening to infiltrate to the root zone.

2.3 Principle of operation

The developed battery-operated knapsack liquid fertilizer applicator, powered by a 12VDC battery, is carried by an operator on his back. As shown in Figure 2, when the operator presses the switch button, the liquid chemical fertilizer will be pumped from the tank to the lance through a hose that passes through the liquid fertilizer applicator handle set-up. The liquid flow sensor measures the volume of liquid chemical fertilizer discharged which is predetermined by the microcontroller. When the required volume is detected by the liquid flow sensor, the solenoid valve will automatically close interrupting the flow of liquid fertilizer. After the liquid fertilizer is discharged from the lance, the lance is moved to the next crop, and the operation is repeated.

2.4 Preparation of Liquid Fertilizer

The liquid chemical fertilizer was prepared by diluting urea granules (46-0-0) in water. A 5.3 mm diameter by 9 mm high canister was used to measure the volume of urea granules based on the local farmer's practice. One can of urea granules (138 g) was diluted in 16 liters of water. This follows the ideal procedure of mixing the fertilizer and water uniformly before the solution is discharged (Pennisi and Kessler, 2017; Zhang *et al.*, 2022).

2.5 Laboratory Testing

Figure 6. Plastics cups set-up

A laboratory test in this study was done by setting empty plastic cups for every observation point in a plot simulating the actual planting row spacing and hill spacing set-up of farmers at Strawberry Farm, La Trinidad, Benguet (Figure 6). The plot has a dimension of 7,620 mm by 1,200 mm and the plastic cups have a spacing of 250 mm x 250 mm. The cups were used to collect the discharged 30 mL liquid fertilizer from the device. There are 160 plastic cups in each plot. The liquid fertilizer from the sampled plastic cups was measured using a graduated cylinder (PNS/BAFS 332:2022, 2022).

2.6 Field Evaluation

The liquid fertilizer applicator with a metering device was tested using an injector-type lance and an open-type lance. These were compared to the traditional fertilizer application as shown in Figure 1. The fertilizer used in the test of the device is urea (46-0-0) based on the traditional application of farmers in Strawberry Farm, La Trinidad, Benguet. The urea (138 g) was dissolved in 16 liters of water. It was applied to a prepared field with an area of 100 m^2 and a soil water content ranging from 14.13-16.39 %.

2.7 Equations Used

2.7.1 Effective Field Capacity

The effective field capacity measures a device's ability to apply liquid fertilizer in each area under actual field conditions. It was calculated using Equation 1 (PNS/PAES 166:2011, 2011).

$$C_{ef}=\frac{A}{T} \tag{1}$$

where C_{ef} = effective field capacity (m^2/hr); A = area covered (m^2); T = time of operation (hr)

2.7.2 Application Rate

The application rate was used to determine the distribution of fertilizer per unit area. It was determined using Equation 2 based on the discharge rate in (PNS/PAES 166:2011, 2011).

$$A_r=\frac{V}{A} \tag{2}$$

where A_r = application rate (mL/m^2), V = volume (mL) and A = area (m^2)

2.7.3 Uniformity coefficient

Application uniformity of fertilizer is critical (Bracy *et al*., 2003). The degree of uniformity of the performance of the liquid fertilizer applicator is determined by Equation 3 developed by Christiansen (1942) and modified by Mohamed *et al*. (2019). A uniformity coefficient of 85 percent or more is considered to be satisfactory.

$$C_U = 100\left(1.0 - \frac{\Sigma X}{mn}\right) \tag{3}$$

where C_u *= uniformity coefficient;* m *= average value of all observations (mL);* n *= total number of observation points;* X *= numerical deviation of individual observations from the average application rate (mL)*

2.7.4 Electrical Energy Consumption

The power consumption of the fertilizer applicator was determined by Equation 4 (Tam-awen *et al*., 2019; Dominguez and Basquial, 2025).

$$E_c = I \times E \times T_o \tag{4}$$

where E_c *= electrical energy consumption (W-hr);* I *= current rating, A;* E *= voltage rating, V;* T_o *= time of operation (hr)*

2.7.5 Cost Analysis

The cost analysis of the device in terms of payback period and break-even point is determined by Equation 5 (Abad *et al*., 2022) and Equation 6 (Valentin *et al*., 2016), respectively.

$$PP = IC/ANI \tag{5}$$

$$BEP = \frac{AFC}{CR - \frac{VC}{C}} \tag{6}$$

where PP = payback period; IC = investment cost; ANI = annual net income; BEP = break-even point; AFC = annual fixed cost; CR = custom rate; VC = variable cost

3. Results and Discussion

3.1 Liquid Fertilizer Applicator with Metering Device

The developed liquid fertilizer applicator is a converted knapsack sprayer equipped with a metering device. The metering device is a microcontroller connected with a light crystal display (LCD) and potentiometer programmed to dispense 30-150 mL of liquid fertilizer.

3.2 Performance Characteristics of the Liquid Fertilizer Applicator

3.2.1 Actual Field Capacity, m^2/hr

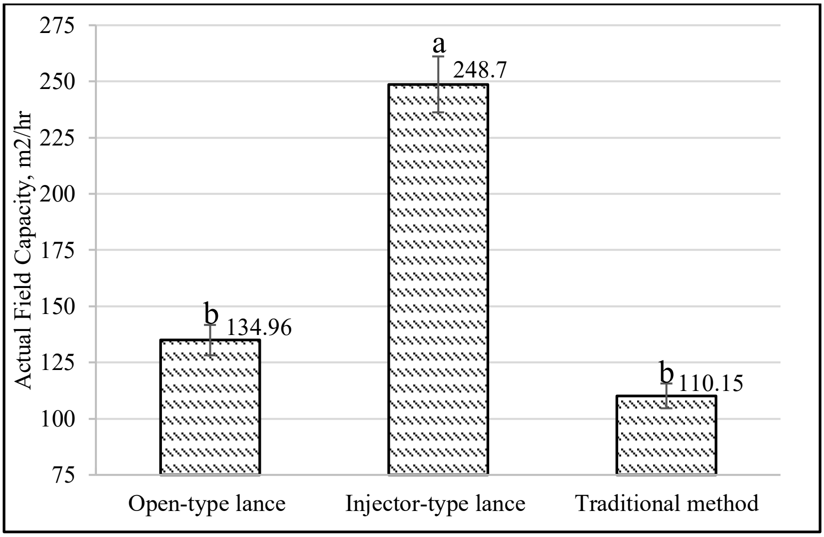

Figure 7. The actual field capacity of different liquid application methods

The actual field capacity of the liquid fertilizer application varies significantly between methods of application used (Figure 7). Open-type lance has an actual field capacity of 248.70 m^2/hr. The actual field capacity of the injector-type lance is 134.96 m^2/hr, which does not differ significantly from the traditional application method of 110.15 m^2/hr. These results are observed because following: the injector-type lance has to be injected into the soil while dispensing the liquid with the nozzle making it more difficult for the liquid to discharge out of the device; the traditional application requires estimation of every drop of liquid fertilizer to be dispensed from the watering can which was a little difficult to control during the operation thus causing it to take more time; and, the open spray lance easily dispenses an almost even amount of discharged liquid.

3.2.2 Application Rate, mL/m^2

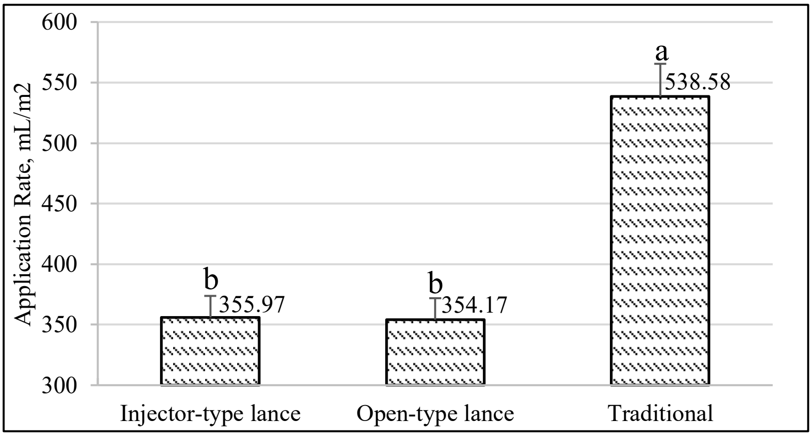

Figure 8. The application rate of different liquid application methods

Figure 8 shows a highly significant difference in the application rate of the traditional application method of 538.58 mL/m^2 compared to injector-type lance at 355.97 mL/m^2 and open type-lance at 354.17 mL/m^2. The injector-type lance and open-type lance showed similarly lower application rates. These results were observed because the volume of liquid fertilizer to be dispensed from the watering can must be approximated at every observation point which is difficult to control, especially in long hours of work

3.2.3 Uniformity Coefficients (%)

The traditional application method, as shown in Figure 9, with a uniformity coefficient of 72.74%, did not meet the minimum uniformity criteria of > 85% as recommended by the equation developed by Christiansen (1942). Though the injector-type lance has a uniformity coefficient of 96.09% which is significant to the open-type lance of 97.95%, the two types of lance used in the developed device are much better than the traditional method.

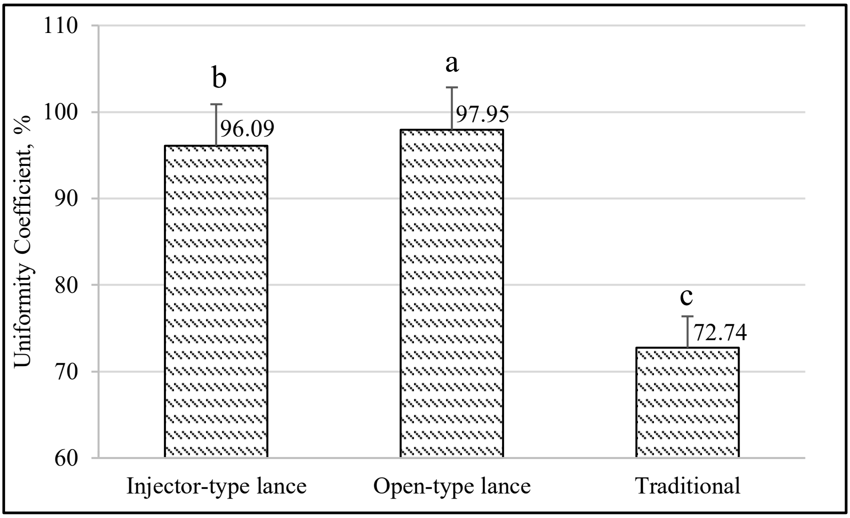

Figure 9. The uniformity coefficient of different liquid application methods

3.2.4 Power consumption (watt-hour)

The device is powered by a 12 V battery rated at 8 Ah. Power consumption using the two types of lance showed that the injector-type lance consumes 9.26 watt-hours of power while the open-type lance uses 5.17 watt-hours. This demonstrates that open-type lance consumes less power because the liquid fertilizer is not pressurized when dispense out of the device compared to injector-type lance.

3.3 Comparison of liquid fertilizer applicator and traditional method of applying liquid fertilizer

Table 1. Comparison of the liquid fertilizer application method in a one-hectare field area

Application Method	No. of Laborer	Time of Operation (hr)	Labor Cost (Php)
Injector-type lance	3	24	1200
Open-type lance	2	20	800
Traditional	5	18	2,000

Table 1 shows the comparison of the different liquid fertilizer application methods when used in a one-hectare field area. The field capacity, application rate, number of laborers, time of operation, and labor cost show that the developed device is more economical than the conventional method of applying liquid fertilizer.

3.4 Cost Analysis

Table 2 presents that the initial cost of the liquid fertilizer applicator was estimated to be Php 10,916.00 which includes all materials utilized and labor. The machine was estimated to operate for 5 hours per day. It has an annual operating cost is Php 12,883.20 and an annual net income of Php 31,756.80 at a custom rate of Php 2,000/ha. Based on these, the device must be utilized in a 1.80 ha field area per year to meet the break-even and a payback period of 4 months and 8 days (0.34 years).

Table 2. Cost analysis on the use of the liquid fertilizer applicator

Parameter	Value
Investment cost, Php	10,916.00
Custom rate, Php/ha	2,000.00
Annual Fixed Cost, Php	2,783.58
Variable Cost, Php	10,099.60
Annual Net Income, Php	31,756.80
Annual Operating Cost, Php	12,883.20
Annual Revenue, Php	44,640.00
Payback Period, yr	0.34
Break-Even Point, ha/yr	1.80

4. Conclusions and Recommendation

A liquid fertilizer applicator with an electronic-controlled metering device was developed using locally available materials to aid the farmers' need for efficiently controlled application of liquid fertilizer. The applicator consists of 6 major components; tank (converted knapsack sprayer), diagphram pump, switch, microcontroller setup, solenoid valve, liquid flow sensor, and lance (open-type and injector-type).

The developed device has performed significantly over the traditional method of fertilizer application in terms of actual field capacity, application rate, and uniformity coefficient. It has minimal power consumption and is more economical in terms of the number of laborers, time of operation, and labor cost.

Hence, the liquid fertilizer applicator with the metering device is effective in applying metered liquid fertilizer. It also helps farmers reduce drudgery and requires a short period of fertilizer application to the same field area compared to the traditional application method.

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