Asian Research Journal of Agriculture

6(4): 1-10, 2017; Article no.ARJA.36964
ISSN: 2456-561X

Development of a Mechanical *Trichoderma harzianum* Soil Injector for Banana (*Musa acuminate*)

Roger C. Montepio[1], Ruel F. Tuyogon[1] and Ryan M. Abenoja[1*]

[1]*University of Southeastern Philippines, Brgy, Apokon, Tagum City, Davao del Norte, Philippines.*

Authors' contributions

This work was carried out in collaboration between all authors. All authors designed the study. Author RCM performed the statistical analysis and wrote the protocol. Author RFT wrote the first draft of the manuscript. All authors managed the analyses of the study and the literature searches. Author RMA revised the manuscript and all authors read and approved the final manuscript.

Article Information

DOI: 10.9734/ARJA/2017/36964
Editor(s):
(1) Tancredo Souza, Centre for Functional Ecology, Department of Life Sciences, University of Coimbra, Portugal.
Reviewers:
(1) Godwin Michael Ubi, University of Calabar, Nigeria.
(2) Tariq Mukhtar, Pir Mehr Ali Shah Arid Agriculture University, Pakistan.
Complete Peer review History: http://www.sciencedomain.org/review-history/21592

Short Research Article

Received 25th September 2017
Accepted 24th October 2017
Published 27th October 2017

ABSTRACT

Trichoderma harzianum is an antagonistic fungus and is widely recognized as a potential biological control agent against several soil-borne plant pathogens. Traditionally it was applied using basal or digging method. These are laborious, time consuming and low application accuracy. To improve these conditions, a mechanical soil injector was developed and evaluated. The fabricated prototype is 3 ft long and has a 1-inch diameter stainless injector. It weighs approximately 17 kilograms including the 16-liters backpack sprayer. The factor affecting the soil injection capacity was the pump power requirement. The volume of solution dispenses by the soil injector and field capacity was determined. The prototype was compared to digging and basal application method. Results showed that the prototype's average solution discharge ranges from 10-34 mL/sec having a field capacity of 424-890 plants/hour. Compared with the existing application method, it can deliver *Trichoderma harzianum* five times faster and has a marginal benefit cost ratio (MBCR) of 1.30.

Keywords: Fusarium; soil injector; Trichoderma; banana; organic.

**Corresponding author: E-mail: ryan.abenoja@usep.edu.ph;*
E-mail: roger.montepio@usep.edu.ph;

1. INTRODUCTION

1.1 Background of the Study

Fusarium wilt has been the problem of the local and international banana industry for the past three to four years. Reduction and loss of yield was merely due to dry spell that Davao Region suffered, but much of this loss was due to the devastation of Fusarium wilt. The area of damage is continuously increasing. For the past three year, several studies were conducted by private and government agencies. Still there is no exact solution to treat or prevent this disease.

Proper management was suggested to be the initial solution to control the spread of the disease. The University of Southeastern Philippines also conducted a study on the efficacy of *Trichoderma harzianum* and other microbial agents on the control of Fusarium wilt disease on 'Cavendish' banana. This study was conducted under greenhouse and field conditions. Among the treatments applied, *T. harzianum* had shown great potential in controlling Fusarium wilt disease. Several studies on different crops applied with *T. harzianum* significantly reduced the severity of Fusarium wilt disease [1] and [7].

T. harzianum is an antagonistic fungus and is widely recognized as a potential biological control agent against several soil-borne plant pathogens as recommended practices of [4]. Substrate could be made of rice hull, coco fiber and others. Currently, the application of this *T. harzianum* with substrate to the soil is by hand. Spreading of 100 grams of the *T. harzianum* substrate at 30 cm radius around the banana plant was the practice. Timing of application should be done when there is enough water in the soil or the surface soil is wet [6], thus the increase in population of *harzianum* will be realized. This fungus is very sensitive, they easily die without moisture. To effectively deliver this material into the soil and to keep them moisten, the ideal method according to [8] is through soil injection. *T. harzianum* in the form of powder and liquid bioformulation was found to be effective in controlling disease in field. Manual application at 4-inches below the surface soil is too laborious and time consuming. Added challenge is the accuracy of applying the recommended rate of 50 ml per plant. To solve this problem, a mechanical tool for *T. harzianum* soil injector with variable metering device must be needed to reduce the time of application and to deliver the exact amount. The device consists of a metering device, blade and injection mechanism which is portable and user-friendly. This study will uplift the mechanization level of the Philippine banana industry in controlling the Fusarium wilt disease.

1.2 Objectives

The study aimed to develop a mechanical *Trichoderma harzianum* soil injector to for effective and accurate application. The study specifically, aimed to:

1. Design the parts of the mechanical soil injector
2. Measure the performance of the machine in terms of discharge and injecting capacity
3. Compare the performance of the machine with the manual application
4. Perform a cost and return analysis

1.3 Conceptual Framework

Fig. 1 shows the conceptual framework of the study. The main constraints of the existing technology is the lack of appropriate tools/equipment intended for the application of *T. harzianum* 4 –inches below the ground. This results to high labor input, low capacity and precision of application. Therefore there is a need to develop a mechanical injector.

2. METHODOLOGY

Fig. 2 shows the process flow of the study. The process started in the review of traditional application method of the fungus and actual observation of the current practices. Conceptualization of design and model fabrication was then performed. Trial test was conducted. Several models did not work so some modifications were done to improve the machine.

2.1 Selection of Soil Application Method

Literature review and actual observation of traditional practice of fertilizer, fungicide and organic fertilizer or treatments of banana was performed. Result was presented in Table 1. It was found out that soil injection method has the highest application capacity, efficiency, ergonomics and lowest soil erosion.

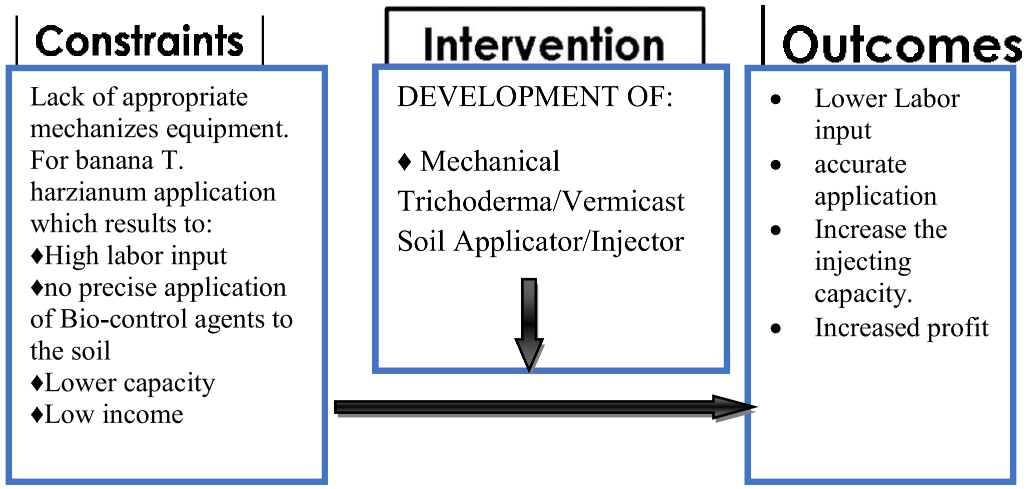

Fig. 1. Conceptual framework of the study

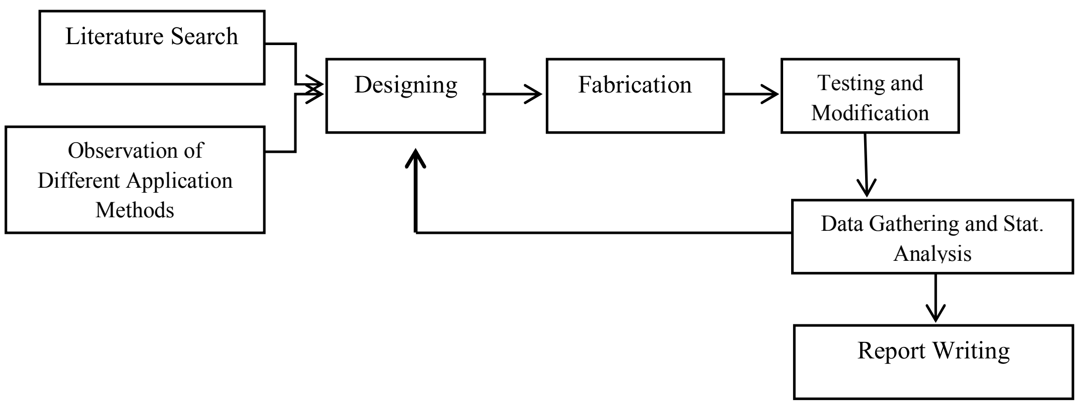

Fig. 2. Procedural framework of the study

Table 1. Advantage and disadvantage of the different soil application methods

Method of application	Capacity	Application accuracy	Ergonomics	Soil erosion
A. Digging method	×	×	×	×
B. Fertilizer applicator	×	✓	×	×
C. Soil injection method	✓	✓	✓	✓

Fig. 3. Different method of soil application (a) Digging method (b) fertilizer applicator method (c) Soil injection method

Fig. 4. Soil digger with moisten substrate

2.2 Design Concept and Materials

The materials used for the fabrication of the soil injector were made of a lightweight stainless steel.

The design criteria that were considered on the development of soil injector includes: (1) Soil injection method that can dispense either low to high viscous liquid material or powder form; (2) can resist certain amount of load, (3) has larger capacity than existing method (4) powered by battery for portability; (5) has provision of trigger type mechanism for the valve (closing/opening) to dispense the material into the soil and; (6) buzzer controlled with timer to meter the dispense material at desired setting amount.

The initial concept design was translated into plans with detailed specification as shown in Fig. 3(b) soil digger with moisten substrate. The moisten substrate of *Trichoderma* is placed in separate container and a metering device midway the soil digger and the container. With this initial concept a problem was found in the metering device and the delivery tube. The substrate will not flow at the delivery tube and into the outlets resulting to clogging.

The 2nd conceptualized design was also translated into plans with detailed specifications as shown in Fig. 3 (c). The concept is to deliver the desired solution (mixture of *Trichoderma* and water, about 50 to 100 mL depending on the extent of damage) to a depth of 4-inches around the plant based on literatures. *T. harzianum* is also effective when applied as liquid material.

Two stainless steel pipes (1/8 inch diameter) as injector needle spaced 10-inches that forms an arc around the plant was designed. The tip of the pipes was sharp enough to penetrate easily into the soil. At the distance of ¼-inch from the end of the pipe tip, a small outlet orifice with soil deflector was installed to serve as an outlet of the incoming solution material. A soil deflector was also installed at the tip so that soil will not cover the orifice during injection.

2.3 Determination of Flow Rate and Reliability/Repeatability: (Laboratory Test)

Four power settings of the battery-operated sprayer: lowest setting, 1/3 set, 2/3 set, and full setting were assessed and the discharge were measured. The power consumed for each setting was also monitored using DC power meter and recorded.

For each setting, a graduated cylinder was used to collect the volume of liquid solution discharge from the two needles of the injector per minute. The collected volume was then transferred to a conical flask for accurate measurement of the liquid solution. A digital stop watch was used as timer. The procedure was repeated three (3) times. The mean flow rate was calculated and presented in a tabular form/graphical form.

Further, reliability or repeatability test was also computed per setting. This can be determined by computing the standard deviation. Repeatability is defined as the standard deviation (SD) of the individual measurement. Results indicate that SD was fall below 5% in all level of pump power requirement (Fig. 5).

2.4 Determination of Application Rate: (Field Capacity)

A 16 liter tank was filled up with the solution (mixture of *trichoderma* and water). A 100 m^2 area (25 test plants equivalent- 2 x 2-m planting distance) was prepared for the test to determine the field capacity. Each test plants were applied at 25 g/ml solution. The total time to cover the area was recorded and computed to obtain the capacity (Ha/hr). Average application time per test plants was then also computed. All three methods of application: the manual, digger and injector following the same procedure.

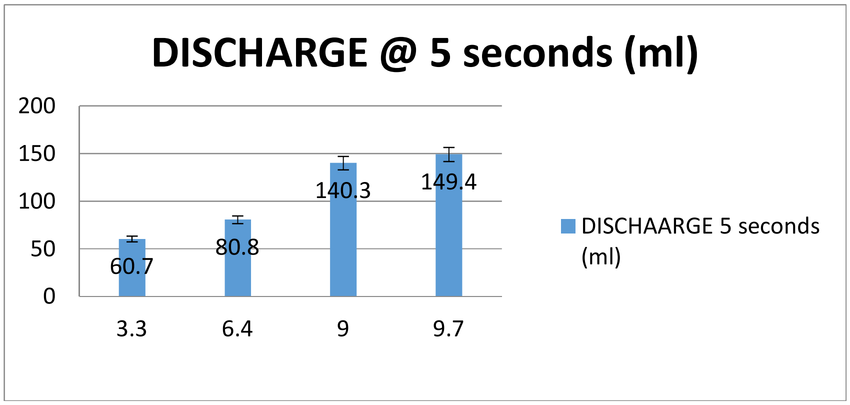

Fig. 5. Laboratory result for the repeatability test

2.5 Testing and Evaluation Stage

This includes pretesting, laboratory and field evaluation of the prototype.

Verifiable Indicators

1. Discharge = $\frac{\text{Total volume measured}}{\text{Total Time}}$

2. Field Capacity = $\frac{\text{Number of plants injected}}{\text{Total time of operation}}$

2.6 Cost and Return Analysis

The cost and return analysis of the mechanical soil injector is projected to be used in a 1 ha banana plantation (10,000 sq.) with a planting distance of 2 x 2 m with plant population of approximately 2,500 plants. Each bearing tree is estimated to provide 6 hands per bunches per year. Additional labour for manual *trichoderma* application is P 250.00 per man-day with effective working time of 7 hr. The ratio of savings for the labour using the mechanical soil injector was then divided to the annual total cost to determine the marginal benefits cost ratio.

3. RESULTS AND DISCUSSION

3.1 Mechanical Soil Injector

Fig. 6 shows the fabricated mechanical soil injector. The injector was made up of a stainless pipe having 3-ft length and 1-in diameter. The injector is connected to a battery operated pump with 16 L capacity. The motor pump of the backpack sprayer is powered by a 12 v DC battery with 2.2 Ampere maximum current controlled by a potentiometer. The source is a 12 v DC battery with a capacity of 7 aH. A hydraulic hose from the tank was connected to a spray gun that serves as the valve and metering device of the injector. The spray gun has depth control gauge and coupled with timer and buzzer as main metering device. To penetrate the soil at 4-in depth, the two stainless pipes with a diameter of 1/8 in. was attached to the 1 ft x 1 ft footrest to be push by the operator's foot. The two injection pipe has an orifice (opening) for dispensing the solution down into the soil. The tip end of the injector forms a half arrow that serves as the penetrating device and the soil deflector of the orifice, preventing soil from entering the injector.

3.2 Injector Discharge

Fig. 7 showed the calibration curve of the total volume dispense at the two needle outlets against the corresponding valve opening time at different pump motor power settings. Generally, volume dispense at the outlets is directly proportional to the power output of the motor pump. High volume dispense is due to the pressure supplied by the motor into the pump. Further, the calibration curve equation fit with 3.3 W setting linear relationship and non-linear relationship fit for 6.4 W, 9.0W and 9.7W with all equation had high coefficient of determination values (R^2). This means that the generated equation is useful to estimates the desired volume of solution to be injected into the soil. Using the calibration curve at full setting (9.7W) and at 0.9 s time of valve opening will discharge an equivalent volume of 50 mL. Meanwhile, the lowest setting (3.3W) can dispense 50 mL volume of solution for 4 s of valve opening.

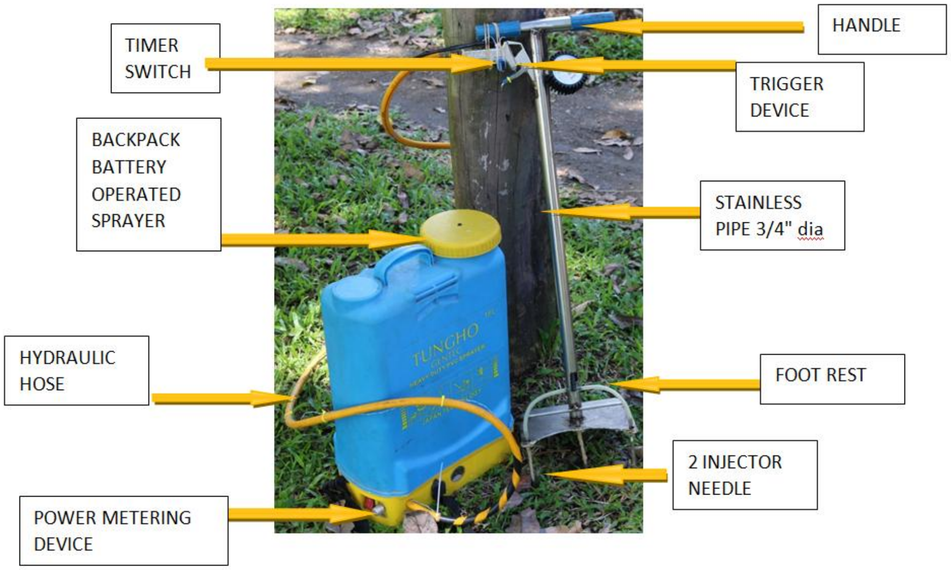

Fig. 6. Mechanical soil injector

The maximum discharge was carried out using the full throttle of the potentiometer having an average of 34 ml/s with a maximum power output of 9.7 W. On the other hand, the lowest power measured was 3.3 W with average discharge rate of 10 ml/s. It was found out that the power output of the soil injector had significant effect to the solution discharge. Tukey test result showed that among the four adjustment of power output the highest discharge was the output 9.7 W followed by 9, 6.4 and 3.3 W. Typical sprayers discharge ranges from11 to 15 ml/s which are higher than the obtained discharge. [1] reported that effect of power (Batteries), swath width, discharge rate and wind speed on droplet size and density of available sprayers. Considering the 7 Ampere hour battery and the motor pump with 2.2 Ampere, the maximum operating time of using the different power outputs from 3.3 to 9.7 W can be shown in Fig. 8.

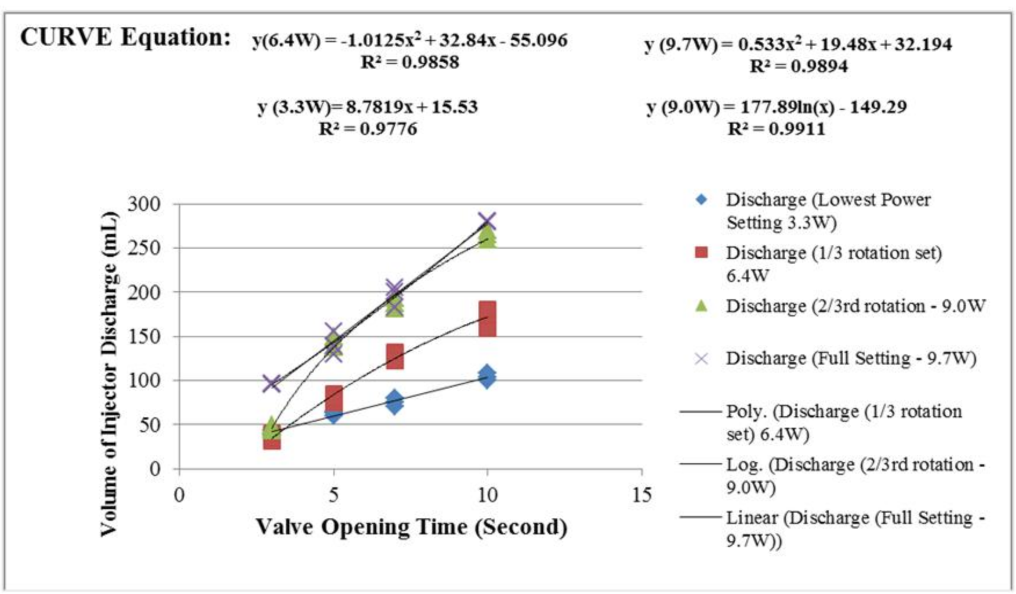

Fig. 7. Calibration curve at different pump-motor power setting (discharge-mL vs time-sec)

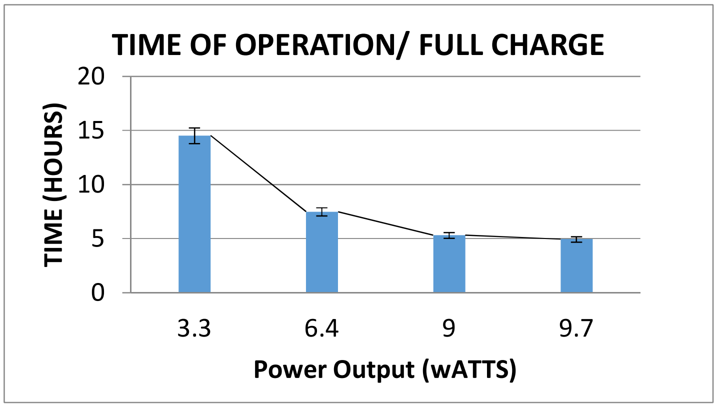

Fig. 8. Estimated time of operation per full charge

3.3 Field Capacity

Field capacity of the soil injector was evaluated in terms of number of plants injected per total time of operation. The four power settings of the battery operated backpack sprayer were assessed accordingly. Table 3 shows the injector field capacity at different power setting. Results shows that the highest and lowest capacities registered were at 9.7 W power output and the 3.3 W, respectively. Further, field capacity increases with an increase in power. This indicates that lesser time will be consumed on application per plant at full power setting. However with high power requirement, battery will be drained faster and can be operated only for about 6 to 7-hr. Thus, overnight charging is needed in order to utilize the battery the next day. On the other hand, when the lowest power setting is used the battery can supply the needed power for 2 days.

When the capacity was analysed using ANOVA, result showed that power setting affected the field capacity. Full setting (9.7 W) is significantly different from the two other setting. However, it

Table 2. Injector field capacity (plants/hr)

Injector field capacity (plants/hr) **				
Power (watts)	**R1**	**R2**	**R3**	**Mean**
3.3 (lowest setting)	456	384	432	424 c
6.4 (1/3rd set)	654	576	672	634 b
9 (2/3rd set)	822	780	840	814 a
9.7 (full setting)	858	942	870	890 a

*** Significant at a level of 1% of probability (p < .01)*
** Significant at a level of 5% of probability (.01 =< p < .05)*
ns Not-significant (p >= .05)

Table 3. Comparison of the capacity soil injector with the existing application method (four applications per tree @ 25 g/ml per application)

Time of operation per tree (SECONDS) **				
Method of application	**R1**	**R2**	**R3**	**Mean**
A. Manual (BOLO)	60	50	71	60.33 b
B. Fertilizer applicator	84	96	84	88 a
C. Soil injector	15.2	12.8	10	14.4 c

*** Significant at a level of 1% of probability (p < .01)*
** Significant at a level of 5% of probability (.01 =< p < .05)*
ns Non-significant (p >= .05)

was found out that the capacity of 9 W and 9.7 W has no significant difference. In this case, the 9 W power output generated by the motor pump is the selected and recommended for energy savings. Other factors that might affect the field capacity are the condition of the area including the soil moisture/soil compactness. Operation in well maintain area is expected to be faster since it will not affect the travel speed of the operator from plant to another plant. There are similar studies as stated by [2] that there is a chance of variation in the discharge capacity of operated backpack sprayer due to lack of constant walking speed of operator during the field operation. This problem was solved using a metering device which is manually triggered by the operator and a timer based buzzer that limits the amount of discharge for a given time setting.

3.4 Comparison of the Injector and Existing Method

Table 3 shows the comparison of the capacity of different method of *Trichoderma* application on banana. Result shows that the fertilizer applicator has the lowest application capacity. Soil injector can apply 100 ml of the solution into the soil in just 14.4 s. Soil injection method is 3 times faster than bolo, and almost 5 times faster than the digging method (fertilizer applicator). The performance of the soil injector was affected by the time of opening/closing the valve and the concentration of the solution (mixture proportion of the *Trichoderma* and water). The two most common performance factors related to direct injection systems [4] are lag time (delay time between injection and discharge) and mixing uniformity of the chemical with the carrier prior to discharge.

3.5 Economic Evaluation

Table 4 shows the cost and return analysis of the prototype projected based on a 1 hectare banana plantation. Results show that the marginal benefit cost ratio (MBCR) is 1.30.

Table 4. Cost and return analysis of operating the soil injector

Marginal benefit cost analysis	
Investment Cost	6000.00
Fixed Cost	
Depreciation (3 years)	900.00
Interest on Investment (25 %)	1650.00
Tax (0) and Insurance (1%)	60.00
TOTAL Fixed Cost	2610.00
Variable Cost	
Repair and Maintenance (10 %)	600.00
Labor Cost @ (Php 250/day)	1,760.39
Service Area	1 ha
# of banana tree per ha @ 2x 2 m spacing	2,500.00
Effective working time = 7 hours/day	
Mean injector capacity= 250 plants /hour	
Trichoderma Php 8.00/ pack	320.00
Water cost	7.50
Charging cost	4.32
TOTAL Variable Cost	2,692.21
TOTAL OPERATING COST (Prototype soil injector)	5,302.21
TOTAL OPERATING COST (Manual digging))	12,232.26
Mean manual digging = 60 plants/hour	
SAVINGS	10,144.37
TOC (Prototype without depreciation & Investment)	2,752.21

Marginal Benefit-cost ratio and net present value for 3 years life span and 1 ha service area

	Years				
ITEM	0	1	2	3	Total
Cash inflow (Total operating cost manual bagging)	-	0,144.37	10,144.37	10,144.37	30,433.11
Cash outflow					
Equipment cost	6,000.00				
Operating cost	-	2,752.21	2,752.21	2,752.21	8,256.63
Amortization (6000/3)	-	2,000.00	2,000.00	2,000.00	6,000.00
Total cash outflow (prototype operating cost)	6,000.00	4,752.21	4,752.21	4,752.21	20,256.63
Net cashflow (savings of using prototype)	(6,000.00)	5,392.16	5,392.16	5,392.16	10,176.48
Discount factor (25%)	1.00	0.80	0.64	0.51	
Present value benefits	-	8,115.50	6,492.40	5,193.92	19,801.81
Present value cost	6,000.00	3,801.77	3,041.42	2,433.13	15,276.32
Net present value	(6,000.00)	4,313.73	3,450.98	2,760.79	
Benefit/cost ratio					1.30

Depreciation and Interest on investment are not included in the cost stream to prevent double accounting

4. SUMMARY AND CONCLUSION

A mechanical soil injector was designed, fabricated. The discharge and field capacity were determined at different level of pump power requirement. The application capacity of the prototytpe was compared to the traditional application methods. The fabricated prototype is 3 ft long, has 1-in diameter injector and weighs approximately 17 kg including the 16 L backpack sprayer. Discharge ranges from 10-34 ml/min and has a field capacity of 424-890 plants/hr. The soil injector can be used for 14.54 hr - 4.95 hr using the lowest to highest power settings. The prototype was five times faster than the traditional methods. Cost and return analysis shows that the marginal benefit cost ratio (MBCR) was about 1.30.

5. IMPLICATIONS AND RECOMMENDATIONS

It is recommended that a machine evaluation and farmers' acceptability study should be conducted to determine other factors that affect the machine and operator's efficiency at farmers' field conditions. Efficacy of the solution concentration trials should be conducted since concentration affects the fluidity or viscosity of the solution. Comparative study on the efficacy of liquid injection of *Trichoderma* with the *Trichoderma* with substrate in soil media on treating fusarium wilt is needed.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Akrami M, Yousefi Z. Biological control of fusarium wilt of tomato (*Solanum lycopersicum*) by *Trichoderma* spp. as antagonist fungi. Biological Forum – An International Journal. Research Trend. 2015;7(1):887-892.
2. Ali MA, Abdul Nasir F, Khan H, Khan MA. Fabrication of ultra low volume (ULV) pesticide sprayer test bench. Pak. J. Agri. Sci. 2011;48(20):39-144.
3. Ashish P. Patil, Shivgauri V. Chavan, Amol P Patil, Mandar H Gee. Performance evaluation of solar operated snapsack sprayer. Agricultural Engineering Today. 2013;38(3).
4. Kerala Agricultural University. Package of practices recommendations: Crops. 12th Edition (eds. A. I. Jose et al.). Kerala Agricultural University, Trichur. 2002;278.
5. Luck JD, shearer SA, Luck BD, Payne FA. Evaluation of Rhodamine-WT dye/Glycerin mixture as a tracer for testing direct injection systems for agricultural sprayers. Applied Engineering in Agriculture. 2012;28(5):343–346.

6. Rahman, Ahsanur, Ferdousi Begum, Most, Rahman, Matiur, Miah, MA, N M. Ilias, G, Firoz Alam M. Isolation and identification of *Trichoderma* species from different habitats and their use for bioconversion of solid waste. Turkish Journal of Biology; 2011.
7. Sant D, Casanova E, Segarra G, Avilés M, Reis E, et al. Effect of *Trichoderma asperellum* strain T34 on Fusarium wilt and water usage in carnation grown on compost-based growth medium. Biol Control. 2010;53:291-296.
8. Sharma P, Sharma M, Raja M, Shanmugam V. Status of *Trichoderma* research in India: A review. Indian Phytopathol. 2014;67(1):1-19.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/21592