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Development of a Manually Operated Checkrow Seeder for Rice Production Systems

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ABSTRACT

The study focused on the development of a manually operated checkrow seeder for rice production systems. The machine was designed and fabricated in Alaminos City, Pangasinan. It was tested using the NSIC Rc 160 variety. Laboratory testing was done where the optimized and calibrated settings were determined. Using Design expert ® 11 for optimization, it was discovered that at a metering device hole diameter of 6 mm and 60% hopper capacity, the checkrow seeder can drop an average of 3.45 seeds per hill or 3 to 4 seeds per hill with only 3.14% damaged seeds, and 13.33 % missed hills. The results were verified through confirmation runs indicating that the generated predictive equations are reliable for the machine tests. The seeder was tested by male and female operators under actual field conditions. With the male operator, the seeder had an average of 3.23 seeds per drop, 14.06 mm seeding depth, 20% skipped rows with field efficiency of 93.13 %. With the female operator, the seeder had an average of 3.28 seeds per drop, 10 mm seeding depth, 16.67 % skipped hills with 56.25% field efficiency. In conclusion, the development of a manually operated checkrow seeder for rice production systems is possible in Alaminos City, Pangasinan. The machine can improve the method of rice establishment in the area.

Keywords: *Manual rice seeder, checkrow seeder, hopper capacity, seed drop per hill, damaged seeds*

INTRODUCTION

Agricultural mechanization is one of the factors that affect agricultural productivity. This is still a major concern in Philippine agriculture as a lot of farmers are still using traditional methods for rice production. A measure for this parameter is the mechanization level which is determined through several factors. In 2013, the measured mechanization level of the Philippines on rice - based farming systems was 2.31 hp/ha while 1.23 hp/ha for all crops (Dela Cruz & Bobier, 2013). As of 2020, the level of rice agricultural mechanization ranged from 3.351 hp/ha to 5.103 hp/ha or an average of 3.77 hp/ha (Amongo et al., 2020). These values are still low compared to other agricultural countries that are advancing with technology. The country is still considered as lowly mechanized and one of the causes is that there are farmers who are still using traditional methods for rice production. Several machines are already available in the market, but these are not always affordable and may be mismatched with the size and topography of agricultural lands.

The initial stages of rice production are very important as these affect the whole production stage. Land preparation needs to be properly done to provide the most suitable environment for the crop. In the country, the farmers are using direct seeding and manual transplanting methods. Transplanting is commonly used not just in the Philippines but in the entire Asia since it results in higher yield and lesser weeding activities ("Manual transplanting - IRRI Rice Knowledge Bank", n.d.). However, this method involves multiple steps that increases the labor costs which is also why the direct seeding method is still used.

The study was conducted in Alaminos City, Pangasinan where farmers are using both transplanting and direct seeding methods. For the direct seeding method, the broadcasting method is used. However, this method does not provide proper spacing for rice plants which is why the optimum yield is not achieved. Also, the use of other production machineries is difficult which limits the possibility of mechanizing other production operations. Even doing manual operations such as fertilizer application is not simple. In addition, the seeds are usually exposed which is why some of the planting materials are wasted from pests and runoff. Manual transplanting is labor intensive and is difficult to access during peak seasons.

The study focused on the development of the checkrow seeder which is specifically designed for rice production. It was designed as a low-cost machine that will help farmers to plant rice seeds using the direct seeding method where there is proper spacing, and the seeds are covered with soil. This can help lessen the labor time and allow production machinery to be used during the vegetative stage of the crop as well as prevent wastage of planting materials.

Rice production involves two general methods which are widely used in the Philippines. The first method is through transplanting where the rice seeds are sown into a nursery until they grow enough to be planted on the field. This is the most common method in Asia where seedlings are transplanted at 20 cm by 20 cm spacing and is done within 15 to 40 days after seeding ("Manual transplanting - IRRI Rice Knowledge Bank", n.d.). One of the main reasons for doing this is to attain proper spacing. With proper spacing, the use of machineries such as weeders and fertilizer applicators is possible during the growing stages of the crop. This method is either done manually or with the help of a mechanized transplanter. Manual transplanting is laborious and is prone to errors as the spacing may not be as accurate as needed ("Manual transplanting - IRRI Rice Knowledge Bank", n.d.). Mechanized transplanters are better at maintaining the proper spacing but are costly and uneconomical for small farms.

The second method is direct seeding which involves directly sowing the seeds (pre-germinated or not) into the field. This method is divided into two categories namely the dry direct seeding and wet direct seeding methods ("Direct seeding - IRRI Rice Knowledge Bank", n.d.). Dry direct seeding is further categorized into three methods namely the broadcasting, drilling, and dibbling methods. Broadcasting is the cheapest and most common method as it involves throwing the seeds by hand such that the seeds are scattered almost uniformly throughout the field. The seeds are then covered through a spike-toothed harrow to prevent the exposure to pests such as birds and rodents. In broadcasting, there is no proper spacing and the seeds are not completely covered which is not ideal for the crop. Drilling involves the use of seed drills or equipment that burrow the seeds into the ground and cover them at the same time. It has proper spacing between rows but not within hills. Dibbling is usually done in areas with slopes and is done by digging holes where the seeds are placed and covered.

Wet direct seeding involves two methods. The first method is also broadcasting but the seeds are pre-germinated. The second is drum seeding with the help of a drum seeder that has drums with holes where the seeds fall into the soil with row-to-row spacing like the seed drill. According to Agricultural Machinery Testing and Evaluation Center (AMTEC) (2005), the seeding rate is measured when it comes to a drum seeder unlike other seeders where the row and hill spacings are required. This means that there is no hill spacing and therefore does not follow the proper spacing for rice planting. The farmer also needs additional labor for covering the seeds since these are exposed when using a drum seeder.

For rice establishment operations in the Philippines, several machineries are available which are either locally made or imported. The most common locally made is the drum seeder which was developed by the International Rice Research Institute (IRRI) in Los Baños, Laguna (Bautista & Gagelonia, 1994). A unit costs from PhP 5,000 to more than PhP 10,000 depending on the type of material and number of rows. A manual rice hill seeder for wetland paddy was also developed by Lacayanga et al. (2009). It has five rows and could plant 44.78 kilograms of wetland rice paddy per hectare. It achieves a spacing of 21.38 centimeters and drops 9.82 seeds per hole. Bautista et al. (2019) also developed a seed drill for multiple crops that is mounted on a tractor. The machine has a capacity of 2 ha/day for rice and could plant 3 ha/day for mung bean. Mechanical transplanters and seeders designed by the Center for Agri-Fisheries and Biosystems Mechanization from the University of the Philippines Los Baños are also available. The Philippine Rice Research Institute (PhilRice) also created a transplanter which is a ride-on type (Doña & Mendova, 2017). It can also plant at 2 ha/day and was priced at PhP 750,000 per unit.

Although there are a lot of locally designed rice establishment machines, not all are commercially available. This is due to the small number of local manufacturers and results in the introduction of foreign-made machines. Imported seeders and planters come in different specifications. Single row seeders range from PhP 1,500 to PhP 25,000 while multi-row seeders could cost up to PhP 200,000. These seeders can be purchased online and shipped or are already available locally. The most common imported rice establishment machine is the transplanter which is either brand new or surplus. Brand new transplanters that are manual could cost from PhP 4,000 to PhP 30,000 while small ride -on types range from PhP 50,000 to PhP 100,000. Brand new four wheeled transplanters range from PhP500,000 to PhP 1,300,000 while used ones could cost about one-third (1/3) of the original price. Seed broadcasters are also available which randomly spread the seeds in the field.

Checkrow seeders for rice establishment are not commercially available in the Philippines. A checkrow seeder has equal and definite spacing within and between hills (AMTEC, 2001). If applied to rice production, the proper spacing will be achieved and this will make the use of other machineries easier. In addition, the optimum yield for the crops can be achieved since the competition for sunlight and nutrients is minimized.

A rice production system is an example of an agroecosystem. According to Marten (1987), some emergent properties of agroecosystems include productivity, stability, sustainability, equitability, and autonomy. The productivity of rice production systems is affected by the inputs and processes done during production. One of the factors that affect productivity is the method of crop establishment. Whether rice is established using direct seeding or transplanting method greatly affects its yield. Stability is achieved when the obtained yield becomes consistent through time. Changing the production methods affect stability where the yield may increase, or decrease compared to the previous yield. Sustainable rice production systems are challenging to achieve since demands are increasing through time. Organic rice production is one of the pushed methods to achieve sustainability (Johannes et al., 2019). Traditional rice production requires a high-water usage which is addressed in organic rice production systems. Equitability is still an issue in the Philippines since farmers do not own the same amount of land. The resources are also not the same since some farms are irrigated while others are still rainfed which limits their production rates. Based on the study, autonomy can be measured with respect to the ability of the farmers to produce rice by themselves without the help of entities such as the government or private organizations. Rainfed and irrigated production systems were compared, and farmers have more autonomy in rainfed systems since they become dependent when they are provided by the government with irrigation services.

Rice production systems have several effects on the environment. One of the apparent effects include the emission of Greenhouse Gases (GHG) during operations. A study conducted by Bautista and Saito in 2015 showed that irrigated areas emitted 1.3 kg CH_4/d-ha and rainfed areas emitted 0.35 kg CH_4/d-ha when rice straw is not incorporated in soil while when rice straw is incorporated in soil, the emissions increased to 2.08 CH_4/d-ha for irrigated areas and 0.51 CH_4/d-ha for rainfed areas. A mitigation practice presented in the study is through mechanization. Land preparation done with the help of animals had more GHG emissions than with the help of tractors. According to the study, animals emit GHG even when not in use while tractors only emit GHG when in use. Land preparation also takes less time when using tractors and so the emission from the soil is also lessened. Mechanization is then seen as a way of mitigating GHG emissions.

The design process was followed for the development of the machine**.** The process involves six steps which are iterative in nature. The initial step is identification of need which is done to make sure that the machine to be developed is a necessity to a certain user. The second step is the definition of the problem where the item to be designed is specified. The third process is synthesis where the initial ideas for the machine are developed. The fourth step is analysis and optimization where the design is subjected to the constraints and redesigned if not suitable. The fifth step is evaluation where the prototype is developed and measured against the initial specifications. If all the steps are satisfied, then the machine is presented through documentations such as engineering drawings and reports.

OBJECTIVES OF THE STUDY

The main objective of the study was to develop a rice checkrow seeder for rice production systems. Specifically, it aimed to:

1. design the checkrow seeder;
2. fabricate the checkrow seeder; and
3. evaluate the seeder under laboratory and field conditions.

MATERIALS AND METHODS

Design and Fabrication

The design criteria included functionality, safety, manufacturability, transportability, cost, and maintenance. The machine needs to function based on the intended purpose which is to meter the seeds and plant at the proper spacing. It should pose little or no harm to the user by considering its ergonomic configuration. The machine was designed to be manufactured using locally available materials which makes it easier for mass production at low costs. The total weight of the machine whether in use or not was considered. When not in use, it should be easily transported even without any aide from other machines. This is important because not all farms were close to the residence of the farmers. The users were briefed with the proper repair and maintenance procedures to prevent issues during operations.

The design specifications of the machine are shown in **Table 1.** The fabrication was done in Alaminos City, Pangasinan.

Table 1. Specifications of the seeder.

ITEMS	DIMENSIONS/ SPECIFICATIONS
A1 Dimensions and weight of the seeder	
A1.1 Overall length, mm	1360
A1.2 Overall width, mm	880
A1.3 Overall height, mm	855
A1.4 Weight (hoppers empty), kg	31.97
A2 Number of rows and row spacing, mm	4 x 200 mm
A3 Nominal working width, mm	800
A4 Hill distance, mm (if applicable)	200
A5 Seeds and their condition for which equipment is suitable	Dry
A6 Number of fertilizer openings and fertilizers for which the equipment is suitable	n/a
A7 Suitable field conditions	Dry
A8 Traveling	

Table 1. Specifications of the seeder ***...continuation***

ITEMS	DIMENSIONS/ SPECIFICATIONS
A8.1 Source of power	Manual
A8.2 Recommended traveling speed of equipment, kph	2
A9 Metering Mechanism	
A9.1 Type and method of changing delivery rate	n/a
A9.1.1 Seed	n/a
A9.1.2 Fertilizer	n/a
A9.2 Source of power of metering mechanism	groundwheel
A9.4 Transmission mechanism and speed ratio of metering shaft to input shaft (ground wheel or PTO shaft)	1:1
A10 Hill-dropping mechanism	Delivery tube
A11 Hopper	
A11.1 Number	1
A11.2 Capacity, kg	20
A11.3 Material	
A11.3.1 Seed	GI sheet
A11.3.2 Fertilizer	n/a
A12 Clutch for metering mechanism	
A12.1 Type	Dog clutch
A12.2 Location	Axle
A13 Furrow or hole opener	
A13.2 Material	Flat Bar
A14 Seed covering device	
A14.2 Material	Mooring Chain
A16 Ground wheel	
A16.1 Diameter, mm	400
A16.2 Material	Flat Bar, RoundBar
A18 Marking device (detail of marking)	Ground wheel as marking device
A21 Recommended traveling speed, kph	2
A22 Working capacity, ha/h (given by the manufacturer)	0.149

The materials for fabrication were sourced from the study area. This makes the machine to be easily fabricated by local manufacturers. The bill of quantities is shown in **Table 2.** The total material cost was PhP 5,872.02 and the labor cost was PhP 5,000.00. The total amount for the project was estimated to PhP 10,872.02.

Testing and Evaluation

The methods of test for the checkrow seeder was based on PAES 123 (AMTEC, 2001). Before actual tests, the machine was initially tested for proof of concept. In this test, it was made sure that the machine can perform a seeding operation and adjusted accordingly. This minimized the modifications during the actual tests.

The machine was optimized through laboratory testing before the actual field testing. Using response surface methodology, a two-factor, three-level factorial was done. The independent variables were the metering device hole diameter and hopper capacity. The response variables for the test were the number of seeds per drop, percent (%) missed hills, and percent (%) damaged seeds.

Each metering device used in the laboratory testing was drilled with different hole sizes. The first metering device was drilled with 5-mm holes. The second one was drilled with 7-mm holes. The third one was drilled with 9 -mm holes. The hopper was filled at 20% (4 kg), 60% (12 kg), and 100% (20 kg) capacity. A two-factor, three-level full factorial with three repetitions was done which resulted in a total of 27 trials as shown in **Table 3.**

Table 2. Bill of quantities with fabrication cost.

ITEM	DETAILS	COST (PHP)
Material Cost		
Engineering Plastic	d100mm x 150 mm	1,338.58
Galvanized Iron Sheet	Gauge 18, 1219.2 mm x 2438.4 mm	722.50
Welding Rod	Ordinary Welding rod, E6013, D=2.5mm, 4kg	480.00
Galvanized Iron Pipe	Schedule 40, d25 mm x 1640 mm	436.24
Flat Bar	38.1 mm x 6 mm x 6000 mm	404.00
Square Tube	25 mm x 25 mm x 6000 mm	325.00
Mooring Chain	R8 mm x 24 mm x 28 mm x 55 pcs	320.00
Bearing	#6306 (30 mm x 72 mm x 19 mm)	280.00
Galvanized Iron Pipe	Schedule 40, d32 mm x 672 mm	236.99
Cutting Disc	D105mm x 8 pcs	200.00
Rebar	d8 mm x 6000 mm	175.00
Paint	Black paint, 1 Liter	170.00
Line	Bike Brake Line x 2 pcs	150.00
Paint primer	Paint Primer, Red Oxide, 1 Liter	102.96
Lock Ring	No. 16, 21-38 mm x 6 pcs	90.00
Paint Thinner	2 bottles	80.00
Hinge	Steel 38.1 mm x 38.1 mm x 4 pcs	50.00
Spring	d4 mm x 4 mm x 2 pcs	50.00
Paint Brush	50mm	49.75
Hexagonal Nut and Bolt	m8 x 1.25 x 76.2 mm x 8 pcs	40.00
Hexagonal Nut and Bolt	m6 x 1.0 x 25.4 mm x 8 pcs	40.00
PVC Pipe	d12.7 mm x 1000 mm	40.00
Hexagonal Nut and Bolt	m8 x 1.25 x 50.8 mm x 12 pcs	36.00
Garden Hose	d19.05mm x 1000 mm	35.00
Blind Rivet	d4 x 12 mm x 40 pcs	20.00
	Subtotal	**5,872.02**
Fabrication Cost	10 man-days labor (PHP 500/ day)	**5,000.00**
	TOTAL COST	**10,872.02**

Table 3.Settings for the optimization of the checkrow seeder.

A: HOLE DIAMETER, MM	B: HOPPER CAPACITY, %
5	20
5	20
5	20
5	60
5	60
5	60
5	100
5	100
5	100
7	20
7	20
7	20
7	60
7	60
7	60
7	100
7	100
7	100
9	20
9	20
9	20
9	60
9	60
9	60
9	100
9	100
9	100

The test was done by filling the hopper at 20% capacity and using the 5-mm holed metering device. The seeder was dragged until four (4) revolutions of the ground wheel was achieved. The number of missed hills were then counted, and the discharged seeds were collected. The total number of discharged seeds were counted and divided into the total number of unmissed hills. The process was repeated using the other combination of settings with three (3) trials for each run. The results were processed and inputted into the Design expert ® 11 software. The data generated were analyzed using Analysis of Variance (ANOVA). The optimum settings were then obtained, and confirmation runs were done.

Using the obtained optimum settings of the machine, field testing was conducted and operated by female and male farmers on a prepared area. This is to further verify the functionality and safety features of the machine in actual field condition. Each operator tested on a 16 m by 32 m or a 512-square meter field per trial. The items listed in **Table 4** were measured.

Table 4. Items measured and measuring tools used in field testing.

ITEM	TOOL/S OR METHOD USED
Depth of seeding	Vernier Caliper
Distance within and between rows	Measuring tape
Rate of missing hill	Manual inspection
Actual traveling speed	Timer and measuring tape
Actual operating time	Timer
Time spent for turning at headland	Timer
Time spent for machine trouble	Timer
Working capacity (ha/h)	$Capacity = \frac{Area\ covered\ (ha)}{Total\ time\ (h)}$

The wheel slippage was computed using Equation 1. Based on the field testing results, the wheel slip of the machine by the male operator was 5.7 % while the female had 5.9 %. Wheel slippage is due to the operation in the prepared field.

Equation 1

$$Wheel\ Slip,\ \% = \frac{N_1 - N_0}{N_1}\ x\ 100$$

where:

N_1 is the sum of revolutions of the wheels for a given distance with slip, rpm, and
N_2 is the sum of the revolutions of the wheels for the same distance without slip.

Equation 2

$$Theoretical\ Field\ Capacity,\ \frac{ha}{h} = \frac{Speed\ x\ effective\ width\ of\ machine}{10}$$

Using Equations 2 and 3, the theoretical and actual field capacities were computed.

Equation 3

$$Actual\ Field\ Capacity, \frac{ha}{h} = \frac{area\ planted\ (ha)}{total\ time\ of\ operation\ (h)}$$

where:
speed is in kph and
effective width of the machine is in m.

RESULTS AND DISCUSSION

Design and Fabrication

The isometric view of the checkrow seeder is shown in **Figure 1** and while the fabricated seeder is shown in **Figure 2**. The major components of the seeder include the frame assembly, hopper assembly, handle assembly, ground wheel assembly, metering device, furrow opener and closer, and clutch assembly.

The types of materials used for the seeder are minimized to lessen the costs and reduce excess resources. Each material was used for different parts such as the gauge 18 galvanized iron sheet which was used for the hopper and its cover. The frames of the hopper cover and the skid were made of 8-mm rebars. The frame of the hopper was made of the 38.1 mm flat bar cut lengthwise. This prevents the opening of the hopper from being misaligned and allows for the installation of the hopper cover. The cover was connected to the hopper frame using four (4) hinges. The hinges are welded to the hopper frame while connected to the cover using nuts and bolts which makes it removable for maintenance purposes. A supporting link was added to prevent the cover from closing while filling or emptying the hopper.

The frame was made of square tubing (25 mm x 25 mm), flat bars (38.1 mm x 6 mm), and rebars (d8 mm). The major components of the frame are made of square tubes since these are light and easy to manipulate. The parts of the seeder that are supported by the frame such as

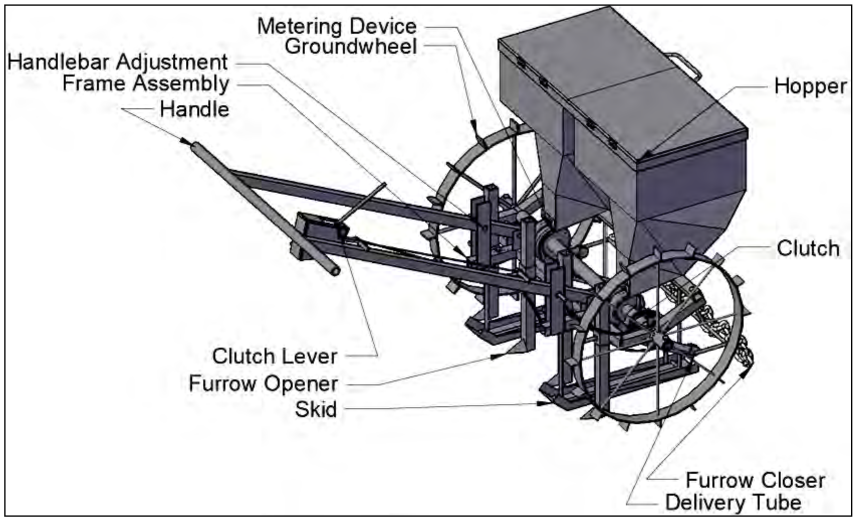

Figure 1. Isometric view of the checkrow seeder using AutoCAD® 2015.

Figure 2. Fabricated checkrow seeder in Alaminos City, Pangasinan.

the delivery tube and furrow closer are made of rebars. Rebars are also easy to work on especially for bending and welding purposes. The supporting components for the furrow opener and handle assembly are made of flat bars that are easy for drilling purposes.

The handle is made of the 25-mm diameter GI pipe connected to the frame through two supporting square tubes. The clutch lever is positioned next to the right-side handle for easier access. The handle has a span of 760 mm and has adjustable height based on the preference of the operator.

The spikes and rim of the ground wheel assembly are made of the 38.1-mm flat bar. The wheels were assembled by initially cutting the 38.1 mm flat bar into a length of 1600 mm which served as the wheel rim. The flat bar was then struck slowly until it had a circular form. A 32-mm diameter GI pipe was then cut to a length of 64 mm which served as the wheel hub. The spokes were made of 8-mm diameter rebars which were welded to the hub. By having equal spoke length, the rim retained its circular form. The wheel is fixed to the axle by drilling holes on the wheel hub and axle and secured using a hexagonal nut and bolt.

The metering device is made of a 110-mm diameter engineering plastic cut into a thickness of 12.75 mm. It was then drilled at the middle until it fits on the 32-mm diameter pipe. The pipe is part of the clutch assembly which rotates only when the clutch is engaged. An 8-mm hole is made adjacent to the middle hole to accommodate the rebar which served as the key. This allows the metering device to rotate with the pipe. Lock rings were used to fix the rebar to the pipe and prevent the metering devices from moving along the pipe.

The delivery tube is made of two types of materials. The first one is made of a Polyvinyl chloride (PVC) pipe which enclosed the metering device. The pipe was heated and bent until it encloses half of the metering device. The inner bent portion is then cut so that the metering device occupies half of the pipe. The top portion of the bent pipe was reheated so that it can be fixed to the hopper. A rectangular GI sheet served as a clamp with the help of nuts and bolts. The lower portion of the delivery tube is made of flexible hose which is fixed using GI pipes connected to the support on the frame. The Gi pipes were cut and pried open to accommodate the hoses without compressing them. Between the hopper and delivery tube is a canvas which prevents excess seeds from the metering device during seeding. Since the metering device and hopper should have clearance, the canvas also prevents the seeds to fall from the hopper.

The furrow opener is made of flat bars which form a pyramidal shape. It is welded to the square tube that is adjustable based on the preference of the farmer on planting depth. The square tube was chosen to support the furrow opener because it will not rotate during operation unlike the available circular pipes. The furrow closer is made of a mooring chain. Each furrow closer has 13 links and the two ends are welded to the furrow closer support. The welded links have a ground clearance of 100 mm to prevent the buildup of soil clods and organic matter during operation.

The clutch assembly starts from the handle to the axle (**Figure 3**). The clutch lever was made of rebar and has flat bar guides where the clutch is engaged. There are two (2) clutch lines which are connected to the lever and the clutch. The clutch has springs which allows it to engage with the metering device pipe. It is disengaged when the lever is pulled back and rested to the other cut. This allows the seeder to stop the seeding operation which is important when doing maintenance or transporting into other fields. The design of the GI pipes look like saw blades which prevents reverse rotation of the metering device. This means that even when the operator goes in the opposite direction, damage to the metering device and seeds in the hopper is prevented.

Figure 3. Clutch lever (left) engaged clutch (middle), and disengaged clutch (right) of the seeder.

Testing and Evaluation

The checkrow seeder was tested based on PAES 123 (AMTEC, 2001). Before the machine was fully completed, proofs of concept tests were done to ensure that the machine was working as intended. Initial tests showed that the seeder can meter and deliver the seeds. After adding the hopper, the machine was tested under laboratory conditions. The variations during the tests include the hopper capacity and hole of the metering device. The obtained data includes the total number of seeds per run, number of missed hills, and number of damaged seeds. Upon installing the desired metering device and putting the proper amount of seeds in the hopper, the seeder was tested by pulling it until the ground wheels achieved four (4) revolutions. It was not tested on a calibration stand because the number of missed hills needed to be counted. In a calibration stand, only the total weight or total number of seeds and total number of damaged seeds can be obtained and so the seeder was tested such that the number of missed hills is counted. **Figure 4** (left image) shows an example of a missed hill during the test. At 20-centimeter intervals, the hill has no dropped seeds for approximately 40 cm which indicates a missed hill. **Figure 4** (right image) shows the damaged seeds during a single test. Damaged

Figure 13. Missed hill (left) and damaged seeds (right).

seeds are those that were peeled and broken seeds which are no longer viable for planting. It is important to note the damaged seeds since it affects the germination rate and therefore total plant population.

Table 5. Processed data used for determining the optimum settings.

A: HOLE DIAMETER (MM)	B: HOPPER CAPACITY (%)	RESPONSE 1 SEED/DROP	RESPONSE 2 DAMAGED SEEDS (%)	RESPONSE 3 MISSED HILLS (%)
5	20	2.06	8.11	40.00
5	20	1.44	0.00	40.00
5	20	1.58	0.00	36.67
5	60	2.90	1.72	33.33
5	60	3.67	3.90	30.00
5	60	2.58	4.08	36.67
5	100	4.28	5.19	40.00
5	100	4.23	2.15	26.67
5	100	3.86	1.18	26.67
7	20	4.09	2.13	23.33
7	20	4.76	2.52	16.67
7	20	4.00	1.04	20.00
7	60	4.96	0.78	13.33
7	60	4.67	3.17	10.00
7	60	5.04	1.42	6.67
7	100	5.71	1.88	6.67
7	100	4.71	1.52	6.67
7	100	4.46	0.00	6.67
9	20	3.83	3.26	20.00
9	20	4.15	3.70	13.33
9	20	4.48	0.89	16.67
9	60	4.39	2.44	6.67
9	60	5.14	3.47	6.67
9	60	5.00	2.07	3.33
9	100	5.71	1.88	6.67
9	100	6.31	1.64	3.33
9	100	5.52	0.63	3.33

Legend: Highest Value - [blue] Lowest Value - [orange]

The summary of data is shown in **Table 5**. The process data was used in Design Expert ® 11 for analysis and optimization.

Analysis of each Response

The effects of the independent variables to each dependent variable were analyzed individually. The fit summary tables show the appropriate model for each response. The tables showing the Analysis of Variance (ANOVA) of each chosen model are used to confirm the significance of each model. This also shows which factors contribute to the predictive equation. The fit statistics show the descriptive statistics for each model. The coefficient for each coded factor is shown in the tables where the proofs of multicollinearity are specified.

The suggested models and their corresponding equations for each response are shown in **Table 6**. Both the first (seeds/drop) and third (missed hills) responses have quadratic models while the second response (damaged seeds) was suggested to have a mean model.

The three-dimensional (3D) surface graph of the effects of hopper capacity and diameter of the hole of the metering device on the responses are shown in **Figures 5 to 7**. The highest recorded response was 6.31 seeds per drop which is at the 9-mm hole diameter with 100 % hopper capacity. The lowest was 1.44 seeds per drop recorded at 5-mm hole diameter with 20% hopper capacity. This means that the seeds per drop increases as the hole diameter and hopper capacity increases. The weight of the seeds affects the number of seeds that are caught in the metering device. Heavier capacity puts more force at the bottom end of the hopper where the metering device is located. The hole of the metering device also affects the number of seeds per drop since holes with wider diameter can accommodate more seeds. Then, the bigger the hole diameter and the higher the hopper capacity, the greater the number of seeds per drop.

The percent (%) damaged seeds have a mean model as affected by the hole of the metering device and hopper capacity. A mean model indicates that the resulting parameter is only

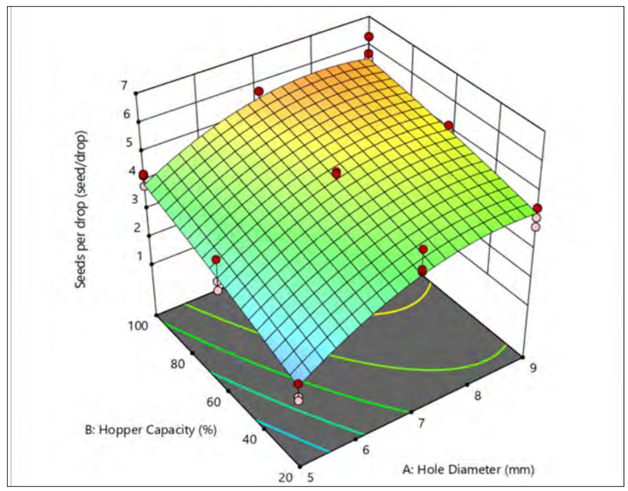

Figure 5. Three-dimensional (3D) surface graph of the effect of metering device hole diameter and hopper capacity on seeds per drop.

Table 6. Suggested models and predictive equations for the seeder test.

	MODEL	EQUATION	
Response 1 Seed/drop	Quadratic	= -10.3832 + 3.29504*A + 0.042391*B – 0.002307*AB – 0.1899*A² - 0.000052*B²	Equation 4
Response 2 Damaged Seeds (%)	Mean	= + 2.2503	Equation 5
Response 3 Missed Hills (%)	Quadratic	= + 180.4167 – 38.6111*A – 0.2917*B – 0.01389*AB + 2.3611*A² + 0.002083B²	Equation 6

Note: A is the diameter of the hole of the metering device and B is the hopper capacity.

affected by a constant number. In the damaged seeds, it is assumed that at any combination of settings, there is an average of 2.25% damaged seeds if the test is repeated in an infinite number of times. This can also be seen in **Figure 6** where the surface graph is flat along the independent variables.

In **Figure 7**, the percent (%) missed hills are affected by hopper capacity and hole of the metering device parabolically. The highest missed hill was 40% which was observed at 5-mm hole diameter and 20% hopper capacity. Smaller holes have a lower chance of getting seeds from the hopper which is why there are many missed hills at 5-mm hole diameter. The hopper capacity also has an inverse effect on the missed hills. Lesser hopper capacity resulted in more missed hills. This is due to the weight of the seeds that are pressing on the metering device. The seeds at the bottom of the hopper where the metering device is found are subjected to greater force. The seeds are then forced to escape from the hopper through the bottom opening and pushed into the hole of the metering device. Therefore, the larger the hole diameter and the greater the hopper capacity, the lower the missed hills during operation.

Optimization and Confirmation

For the optimization of the settings, the hole diameter was set to be in the range of 1 mm to 10 mm. The hopper capacity was targeted to be as close to 100% as much as possible. The seeds per drop was initially set to achieve the range of 2 to 3 seeds per drop. However, no solutions were obtained even when the conditions of the other variables were changed. Hence, it was set to have a range of 1 to 4 seeds per drop. The damaged seeds were set to have a minimum amount with a range of 0 to 10%. The missed hills were also minimized where the range was set from 0 to 40 %.

The results of the optimization are shown in **Table 7** where 13 solutions were generated. Based on the table, the hole diameters ranged from 5.29 mm to 10 mm while the hopper capacity ranged from 21.57 % to 88.28%. The number of seeds per drop and damaged seeds were consistent at 4 seeds and 2.25% respectively. The missed hills ranged from 18.84 % to 26.17%. The desirability of each solution ranged from 0.24 to 0.61. Desirability is an important parameter since it shows the probability of the solution. A higher desirability is desired since it makes sure that the chosen solution will more likely produce the same result if done repeatedly.

Solution 9 was chosen since it has the highest desirability among the solutions that has less than 20% missed hills. It has a hole diameter of 6 mm and a hopper capacity of 60% where the resulting responses are 4 seeds per drop, 2.25%

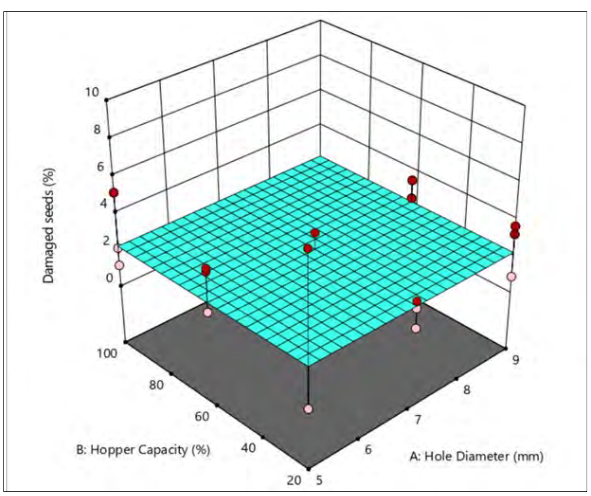

Figure 6. 3D surface graph of the effect of metering device hole diameter and hopper capacity on damaged seeds.

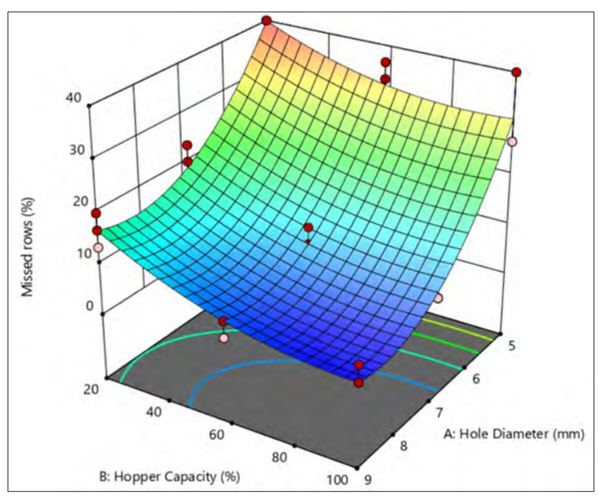

Figure 7. 3D surface graph of the effect of metering device hole diameter and hopper capacity on missed hills.

Table 7. List of solutions for the optimization process.

SOLUTION	HOLE DIAMETER (mm)	HOPPER CAPACITY (%)	SEED PER DROP	DAMAGED SEEDS (%)	MISSED HILLS (%)	DESIRABILITY
1	5.5	75.32	4	2.25	22.77	0.61
2	5.5	75.62	4	2.25	22.84	0.61
3	5.5	74.96	4	2.25	22.69	0.61
4	5.5	75.88	4	2.25	22.90	0.61
5	5.5	76.64	4	2.25	23.08	0.61
6	5.75	67.92	4	2.25	21.17	0.60
7	5.25	86.96	4	2.25	25.79	0.60
8	5.25	88.28	4	2.25	26.17	0.59
9	6.00	59.93	4	2.25	19.73	0.59
10	6.00	54.89	4	2.25	18.98	0.58
11	6.00	53.85	4	2.25	18.84	0.57
12	10.00	23.08	4	2.25	21.59	0.28
13	10.00	21.57	4	2.25	21.71	0.24

damaged seeds, and 19.73% missed hills. Lesser missed hills mean that more space of the farm is utilized. This increases the utilization rate of the farm and therefore increases the highest possible yield. The hole diameter has a desirability of 1 while the hopper capacity is about 0.5. The seeds per drop have a desirability of 1 while the damaged seeds and missed hills have 0.5 and 0.6, respectively. The combined desirability of the chosen optimum solution is 0.59 which means that the chosen optimum conditions for the designed checkrow planter for crop establishment are met 59% of the time. This also indicates that there is still room for design improvement of the machine. The hopper capacity could be adjusted to about 60 % of the original designed capacity of 20kg based on NADA for easier maneuverability of the machine during planting operation. This would also lessen the cost of materials intended for the hopper component.

Using Solution 9 where the hole diameter is 6 mm and the hopper capacity is at 60%, the seeder was tested for confirmation. Results of the test are shown in **Table 8** while the comparison with the results of the predictive equation is shown in **Table 9**. The average seeds per drop was 3.45 seeds while the damaged seeds and missed hills are 3.14% and 13.33%, respectively.

Table 8. Results of confirmation run using the optimum solution.

TRIAL	SEEDS PER DROP	DAMAGED SEEDS (%)	MISSED HILLS (%)
1	4.00	5.77	13.33
2	3.59	2.06	10.00
3	3.52	1.14	16.67
4	3.12	2.56	16.67
5	3.04	3.66	10.00
Average	3.45	3.04	13.33

Based on **Table 9**, the obtained values were within the 99% confidence interval when the predictive equations are used. This means that there is 99% confidence that the predictive equations can determine the seeds per drop,

Table 9. Confirmation run and predicted values using the optimum solution.

RESPONSE	PREDICTED	STD DEV	N	SE PRED	99% PI LOW	DATA MEAN	99% PI HIGH
Seeds per drop	4.08	0.50	5	0.30	3.24	**3.45**	4.92
Damaged seeds (%)	2.25	1.77	5	0.86	-0.14	**3.04**	4.64
Missed hills (%)	18.75	3.46	5	2.06	12.92	**13.33**	24.58

damaged seeds, and missed hills if the diameter of the hole of the metering device and the hopper capacity (%) were given.

Calibration

The seeder was calibrated based on PAES 123 (AMTEC, 2001). **Figure 8** shows the seeding rate with respect to the hopper capacity. The seeder was tested at 1/8, ½, and full hopper capacity. Based on the test results, higher hopper capacity resulted in a higher seeding rate. However, the seeding rates are low compared to the standard of 60 kg/ha done in manual broadcasting methods. The recommended seeding rates for paddy is 40 kg/ha for transplanting and 60 kg/ha for direct seeding (Department of Agriculture, 2019). The obtained seeding rate using the checkrow seeder is lower since the amount of dropped seeds are limited.

The seed spacing was also tested during the calibration test. The diameter of the wheel including the spikes is 549.3 mm which leads to a total circumference of 1725.68 mm. This results in an approximate seed spacing of 215.71 mm or 21.571 cm. The spacing was longer because the test was done on a concrete flooring. The spikes of the ground wheels could not penetrate the concrete, so it was added to the total diameter for spacing computations. The test results for the seed spacing are shown in **Table 10**. The records were randomly obtained during each test.

Based on Table 10, the calibration test does not have much difference with respect to seed

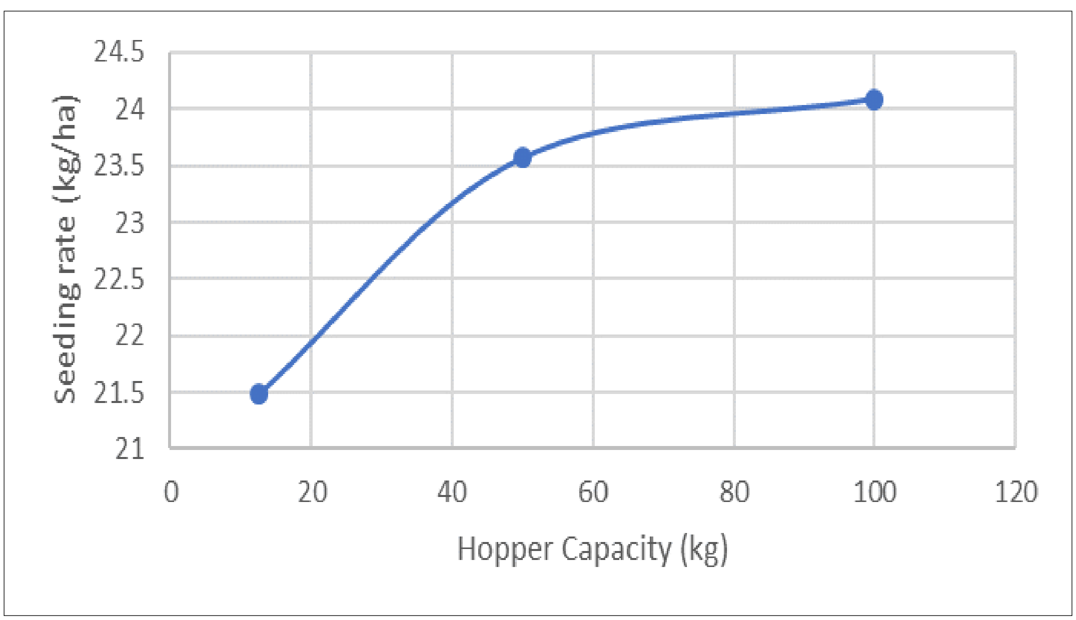

Figure 8. Checkrow seeder graph for the effect of hopper capacity on seeding rate at 6mm metering device hole.

spacing. The spacing of the seeder ranged from 20.67 cm to 21.33 cm with a mean of 20.93 cm. In comparison to the theoretical spacing of 21.57 cm, the mean has a 2.99 % error which is acceptable.

$$Percent\ Error\ ,\ \%\ error\ = \left| \frac{mean\ value - theoretical\ value}{theoretical\ value} \right| x\ 100$$

$$Percent\ Error\ ,\ \%\ error\ = \left| \frac{20.93-21.57}{21.57} \right| x\ 100$$

$$Percent\ Error\ ,\ \%\ error\ = 2.99\ \%$$

Table 10. Seed spacing for each setting during the calibration tests.

CAPACITY	TRIAL	SPACING (CM) 1	2	3	AVE
"1/8	1	21.00	21.00	21.00	21.00
	2	20.50	21.00	21.00	20.83
	3	21.00	20.75	21.00	20.92
"1/2	1	21.50	21.00	21.50	21.33
	2	21.00	21.00	20.00	20.67
	3	21.00	21.00	21.00	21.00
Full	1	20.50	20.75	21.00	20.75
	2	21.00	21.00	21.00	21.00
	3	20.75	20.75	21.00	20.83
					20.93

Field Testing

The checkrow seeder was tested on a prepared field located in Alaminos City, Pangasinan. Before operation, the seeder was tested for issues, and it was discovered that the supporting components for the delivery tube and furrow closer were too close to the ground causing the buildup of soil clods and debris. The built-up materials blocked the exit of seeds. The structure was then repositioned as shown in **Figure 9**.

The seeder was then tested on the field using the optimum laboratory settings. The field-testing operations are shown in **Figure 10.**

Based on the field tests of the female operator, the checkrow seeder has an average of 3.28 seeds per drop and 10 mm seeding depth with 16.67% skipped hills and 16.03% exposed seeds. The male operator has an average of 3.23 seeds per drop and 14.06 mm seeding depth with 20% skipped hills and 26.92 % exposed seeds. The seeding depth of the checkrow seeder varies depending on how low the operator holds the handlebar. During the field tests, the male operator was observed to press the handlebar lower than the female operator. According to the female operator, the seeder was heavy and pulling is more difficult if the furrow opener gets a deeper cut.

Figure 9. Before (left) and after (right) repositioning the supporting structure of the delivery tube and furrow closer.

Figure 10. Field testing operations of female (left) and male (right) operators.

The seed spacing was also measured where the female operator resulted in an average hill spacing of 19.76 cm and row spacing of 20 cm. The male operator has an average of 19.80 cm and row spacing of 20 cm. The hill spacing measured during the field tests are lower than in the laboratory tests because the spikes of the ground wheels were buried since the soil is well pulverized. The row spacing is constant because it is not affected by the present factors.

The average total time spent by the female operator during the operation was 2040.54 seconds or 0.57 hours while the male operator spent 1235.58 seconds or 0.34 hours.

The theoretical field capacity of each operator assuming a constant speed of 2 kph and considering the machine with 0.8 m effective width is 0.160 ha/h. The actual field capacity of the female operator was 0.090 ha/h while the male operator had 0.149 ha/h. Although both operators used the same machine, the female operator commented that the machine was heavy and was difficult to pull especially while turning in the headlands. The time spent by the female operator in turning averaged to 23.60 seconds while the male operator only averaged to 11.12 seconds. The field efficiency of each operator was computed using Equation 8.

Equation 8

$$Field\ Efficiency, \% = \frac{Actual\ Field\ Efficiency\ (ha/h)}{Theoretical\ Field\ Efficiency\ (ha/h)}$$

The computed field efficiency for the female operator was 56.25% while for the male operator was 93.13 %. The male operator has almost twice the field efficiency than the female operator as also observed in their actual field efficiencies. The percent difference (Equation 9) of the female operator from the male operator is 39.6 % which is significant. This implies that the male operator is more efficient than the female operator when using the fabricated checkrow seeder.

Equation 9

$$Percent\ Difference\ ,\ \%\ Difference\ = \left| \frac{FE_{female} - FE_{male}}{FE_{male}} \right| x\ 100$$

$$Percent\ Difference\ ,\ \%\ Difference\ = \left| \frac{56.25 - 93.13}{93.13} \right| x\ 100$$

$$Percent\ Difference\ ,\%\ Difference = 39.6\%$$

CONCLUSION

Based on the study, it can be concluded that the development of a checkrow seeder for rice production systems is possible in Alaminos City, Pangasinan. The checkrow seeder was designed and fabricated using locally available materials. It was tested by male and female operators where it was discovered that the male operator has a better performance based on the field efficiencies when using the seeder.

The generated equations in the optimization process are concluded to predict the responses when the metering device hole and hopper capacity are provided. The generated calibration curve can be used for determining the theoretical plant population when using the fabricated seeder. Field testing showed that the developed seeder is fit for male operators as proven by the computed field efficiency.

The presence of field banks is one of the reasons why mechanization is challenging in the study area.

RECOMMENDATIONS

To improve its performance, some recommendations are generated. In terms of design, it is recommended to use different designs of holes for the metering device for better accuracy. Changing the metering device may reduce the missed hills and damaged seeds of the seeder. With regards to fabrication, it is recommended to use lighter materials to accommodate all possible users and easier usage in lowland applications. The ground wheels can also be designed to rotate on separate axles for easier turning. In terms of cost, value engineering on the different machine elements is recommended to make the machine more profitable. The use of mechanical power to prime the checkrow planter can also be explored. In terms of the end user, it is recommended for the seeder to be operated by male operators for higher efficiency.

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