Development and evaluation of four-wheel tractor-attached multi-crop planter for mechanized seeding of maize in the Philippines

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Abstract: The use of a multi-crop planter (MCP) attached to a compact 4-wheel tractor (4WT) is still not yet fully explored in the Philippines because it is not locally available in the market, despite the popularity of 4WT for land preparation in maize areas. A 4WT-attached MCP was developed for row seeding of rice, maize, and mung bean. This study evaluates the MCP adaptive model for maize in a field experiment and on-farm trials at two farmers' fields during dry season. The MCP with seed metering plate having seven 12-mm diameter holes and 3-mm thickness had a seeding rate of 18.9 kg ha^{-1} which is within the targeted design range at 15 – 20 kg ha^{-1}, a field capacity of 0.14 ha h^{-1} and field efficiency of 78% in well-tilled-clay soil in an experiment station trial. In farmer's fields, the MCP delivered seeding rates of 19.6 and 24.9 kg ha^{-1}, which are within and higher than the prescribed design range. In reduced-tilled-loamy soil, the field capacities were 0.24 – 0.26 ha h^{-1} and field efficiencies were 53% – 72%. Grain yields of MCP did not differ with farmer's practice, but the seeding rate was significantly reduced by 35% – 38%. Compared with farmer's practice, labor productivity with MCP increased by 37% – 51%. Economic analysis showed that owning an MCP and providing machine rental services is viable. Investment cost can be recovered after 3.6 years and the benefit-cost ratio at 1.5. This study underscores the potential benefit of using the MCP to improve the utilization of 4WT, increase the efficiency of planting maize in the Philippines, and reduce cost of production,while maintaining grain yield.

Keywords: field efficiency, labor productivity, machine rental service, maize, multi-crop planter, seeding rate

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1 Introduction

After rice, maize is the second most important crop in the Philippines with one-third of Filipino farmers depending on it as source of livelihood (Gerpacio et al., 2004). The average area harvested to maize in the last five years was 2.5 million (Mil) ha with an average production of 7.2 Mil metric tons (PSA, 2018). During dry season, maize is planted after rice, due to limited irrigation water in most rainfed lowland and upland areas. Common methods for seeding maize are manual dibbling and the use of an improvised farmalite (Labios et al., 2002) or a jabber (Dela Cruz and Malanon, 2017) on tilled furrowed field. According to Dela Cruz and Malanon (2017), planting and harvesting are the two most labor-intensive farm operations in maize production where manual labor is still employed in the Philippines. Although there are now existing mechanical seeders being developed for rice and maize, these are usually driven by two-wheel tractors (Bautista et al., 2018).

Despite the popularity of four-wheel tractors (4WT) for land preparation (primary tillage) which is mostly done by machine rental service providers in the Philippines (Dela Cruz and Malanon, 2017), the use of a multi-crop planter (MCP) especially as attachment to a

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compact 4WT (< 50 hp rating) is still not yet fully explored because it is not locally available in the market (Bautista et al., 2018). The advantages of using mechanical row seeders include reduction of labor requirement and further improvement of seedling emergence because seeds are drilled at uniform depth in the field (Bakker et al., 2002; Chauhan, 2012). Mechanical seeders also promote uniform crop establishment during seeding and facilitate efficient weeding between rows (Chauhan, 2012). However, reported constraints of mechanical seeders also include limited seed flow and workability of the soil (Bakker et al., 2002).

The level of mechanization for rice and maize in the Philippines is still low at 2.31 hp ha^{-1} (Dela Cruz and Bobier, 2016). The Philippine Agriculture and Fisheries Modernization Act of 1997 and Agricultural and Fisheries Mechanization Law of 2012 highlighted the country’s need to accelerate agricultural mechanization as a means to increase farm income and modernize agriculture in the Philippines (Dela Cruz and Malanon, 2017). In 2019, the implementation of Rice Competitiveness Enhancement Program by virtue of the Rice Tariffication Law, farm machinery and equipment and other support packages are being provided to farmers’ organizations and cooperatives to help farmers improve their income and serve as safeguard to cushion the sudden effects of paddy farmgate price depression due to trade liberalization in rice (Tobias, 2019). These provisions of farm machinery and equipment will enable farmers to mechanize their farm operations during land preparation, planting, and harvesting for not only rice production, but also other rice-based crops, such as maize. It will also create business opportunity though machine rental services among farmer-members. The machine rental service will allow the owners to fully utilize their tractor to its capacity and attain the economic viability of owning tractors (Paman et al., 2010) and its attachments, such as MCPs.

This study was conducted to adapt a locally developed and fabricated MCP for sowing a rice-based crop, such as maize, to suit local field conditions in the Philippines. The local adaptive model of the MCP was fabricated at the Rice Engineering and Mechanization Division of the Philippine Rice Research Institute (PhilRice) in Nueva Ecija. Specifically, it aims to: 1) evaluate the field performance of the MCP in terms of capacity, efficiency, and seeding rate; 2) evaluate the agronomic performance of maize sown using the MCP and compare it with that of farmers’ local practice; and 3) determine the economic viability of the MCP for machine rental service.

2 Materials and Methods

2.1 Brief description of the planter

The locally designed and fabricated MCP has nine rows with 1.8 m effective width and a field capacity of 0.25 – 0.38 ha h^{-1}. Seed metering plates were designed separately for rice, maize, and mung bean (*Vigna radiata*). For maize, the target seeding rate was 15 – 20 kg ha^{-1}, with planting distance between row and hills at 600 and 200 mm, respectively, and number of seeds at 1 – 2 seed hill^{-1}. Major parts of the planter include the seed hopper, fertilizer hopper, main frame, hitch assembly, furrow opener, and ground wheel (Figure 1). The improved local MCP design is equipped with shoe-type furrow opener with a wider slit, which could create a wider trench or furrow to facilitate the flow of water during irrigation, especially for maize. The planter is rear-mounted by three-point linkage to a compact 4WT (35 hp or 26 kW power rating).

2.2 Laboratory performance test

The planting distance between hills and the number of seeds per hill was determined in a laboratory set-up (Figure 2) using a one-row hopper attached to a conveyor running at 1400 r min^{-1}, which simulates the speed of a tractor at third gear. Four treatment combinations of seed metering plate with different numbers of holes and thickness (mm) were tested in three trials for each treatment: six holes - 5 mm, 10 holes - 5 mm, six holes - 3 mm, and seven holes - 3 mm. The diameter of each hole was 12 mm. The treatment combinations that gave the closest planting distance between hills and number of seeds per hill against the target design parameters of 200 mm spacing and 1 - 2 seed hill^{-1} were used in fabricating additional two seed metering plates for calibration and further evaluation in the field experiments.

No.	Main Parts
1	Seed Hopper
2	Fertilizer Hopper
3	Main Frame
4	Hitch Assembly
5	Furrow Opener
6	Groundwheel

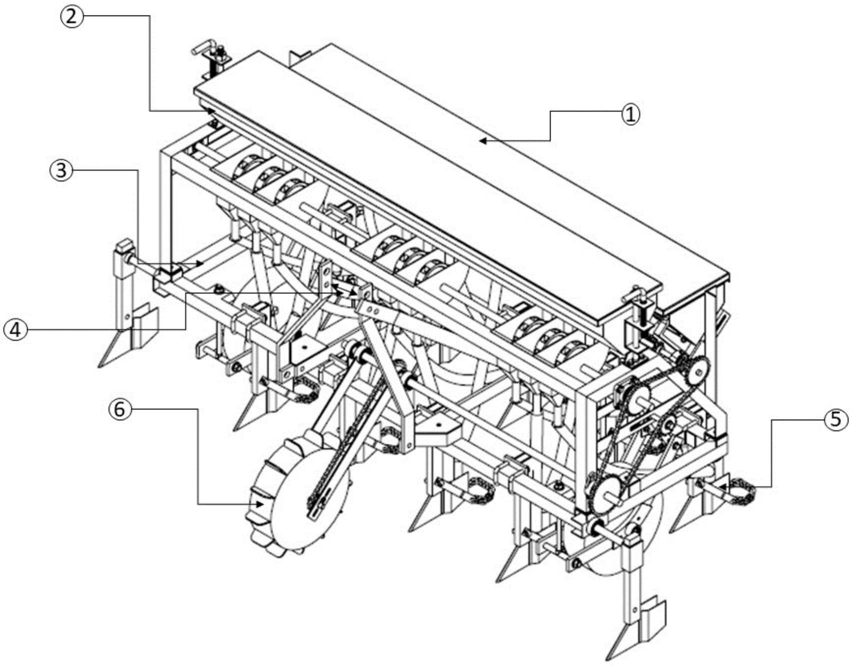

Figure 1 Major parts of the MCP

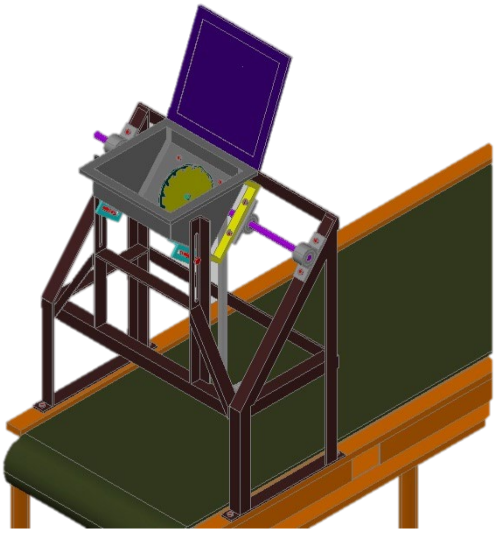

Figure 2 3D view of the one-row hopper for the laboratory testing of seed metering plate

The seed metering plates were calibrated following the procedures of Jat et al. (2013). The seeder was jacked up and the circumference of the driving wheel was measured to determine the distance covered in one revolution of the wheel. The number of revolutions required to plant one hectare was identified by marking a point on the rim of wheel. The wheel was rotated manually and the seeds discharged by each seed plate from the hopper to the seed tube were collected though a fine net bag was placed under the tube. The seeding rate per hectare was determined by adding the weight of the seeds from each bag. If the seeding rate is less than the targeted seeding rate (i.e. 15 - 20 kg ha^{-1}), adjustments in the inclination of the seed hopper were done. Further trial was done to determine the actual seeding rate and the field capacity of the planter in a test run at field condition. Three kilograms of seeds were used to fill three out of nine seed hoppers of the planter. A 20 - meter distance in the field was marked and the tractor with attached planter operated at this distance. The discharged seeds from each delivery tube were collected and weighed for the actual seeding rate. The seeding rate was determined as the ratio of the difference between initial and final weight of seeds used over the field area (Idago et al., 2019). The field capacity was determined as the ratio of the area planted to the total operating run time of the planter (PAES, 2005).

2.3 Field experiment

After the laboratory tests, further evaluation was conducted at controlled field condition. A field experiment was conducted in 2017 DS (January-May) at the experimental farm of PhilRice (15˚39'59 N, 120˚54'1"E) in Muñoz, Nueva Ecija. The soil at PhilRice is Maligaya clay and is classified as fine montmorillonitic, isohyperthermic ustic epiaquerts (Corton et al., 2000). The experiment was laid out in randomized complete block design with four replicates. The treatments were MCP with six - holes seed metering plate (MCP - 6), MCP with seven - holes seed metering plate (MCP - 7) and manual seeding using dibbling method as farmer's practice (FP). The thickness of the seed metering plate was three - mm with holes having 12 - mm diameter each. The size of the experimental area was 3.5 × 30 m per replication with 0.8 m distance in between treatments. Irrigation water in the field was pumped from a shallow tube well near the experimental farm.

Dry cultivation (twice) using a rotary cultivator or rotavator attached to a 4WT was done during land preparation. In manual seeding, a moldboard plow drawn by a carabao (water buffalo) was used to create a furrow opening before sowing the seeds and the furrow was manually covered with soil after sowing. Hybrid maize seeds were sown on January 4, 2017 according to treatments. The field was irrigated one day after sowing to facilitate seed germination, and thereafter, the field was flash irrigated once a week. The total fertilizer rate (i.e. 164 - 49 - 139 kg ha^{-1} NPK) per treatment was based from the nutrient management recommendation of the web-based decision support tool, Maize Crop Manager (IRRI, 2017), applied at seven and 30 days after sowing (DAS). Pre- and post-emergence herbicides were applied to keep the plot weed-free. The maize was harvested at 126 DAS on May 5, 2017.

2.4 On-farm adaptive trials

To further verify the performance of the planter, adaptive trials at farmer's field were conducted at two rainfed sites in northern Philippines: San Vicente, Sta. Maria, Pangasinan and Victoria, Aurora, Isabela during the 2018 dry season (January – May). The provinces of Pangasinan and Isabela are among the largest maize producers in the northern region with maize area at 54 160 and 269 266 ha, respectively (PSA, 2015). The soil texture in Victoria, Isabela is Bago sandy clay loam (BSWM, 1985) and is classified as fine, isohy-perthermic Typic Epi - aqualf, while in Pangasinan, it is San Manuel sandy loam (BSWM, 1985) and is classified as fine loamy, mixed, isohy-perthermic, typic haplus (PhilRice, 2013). In each site, a paired trial of MCP with 7 - holes seed metering plate (MCP - 7) and FP was evaluated in an area ranging from 1296 – 3186 m^2. The area in each site was subdivided and marked for each treatment in thee replications. The MCP - 7 was attached to a 26 - kW 4WT during sowing. The FP in Pangasinan used an improvised manual corn seeding device called farmalite (Labios et al., 2002), while in Isabela, FP was manual dibbling, both in a reduced-tilled and furrowed soil. In both sites, a moldboard plow drawn by a carabao was used to create a furrow opening before manual seeding and the sown seeds in Isabela were covered with soil manually. Hybrid seeds were sown on January 12, 2018 in Isabela and February 15, 2018 in Pangasinan. The choice of maize variety in both trials was according to farmer's preference. In each field, the farmer carried out land preparation and his usual crop management practices in both treatments, and we only established the dry seeding using the MCP. Irrigation water in both sites was pumped from a shallow tube well. The maize was harvested on April 30 (108 DAS) and May 28, 2018 (102 DAS) in Isabela and Pangasinan, respectively.

2.5 Data gathering and measurement

Field performance of the planter was evaluated following the procedures detailed in the Philippine Agricultural Engineering Standard 123 : 2001 (PAES, 2001). The total elapsed time of seeding (T) in each treatment, including the idle time (e.g. turning, refilling of seed hopper, and adjusting the machine), and speed of machine (S) were recorded. The actual seeding rate (SR), field capacity (FC), theoretical field capacity (TFC) and field efficiency (FE) were calculated using Equations 1 - 4 (Idago et al., 2019).

$$SR = W_S/A \tag{1}$$

$$FC = A/T \tag{2}$$

$$TFC = (S * W)/10000 \tag{3}$$

$$FE = FC/TFC \times 100\% \tag{4}$$

Where, SR is in kg ha^{-1}, FC and TFC are in ha h^{-1}, W_S is the weight of the seeds planted in kg, A is the area planted in ha, T is the total operating time of the tractor in h, S is the speed of the tractor in m h^{-1}, and W is the width of the implement in m.

At 9, 15 and 20 DAS, a 1 × 1 m quadrat was randomly selected in each replicate plot to measure the seedling emergence and seed / hill in Nueva Ecija, Pangasinan and Isabela respectively. Seeding depth was also measured from six plants per replicate randomly selected outside the sampling area. To measure the seeding depth, the soil was slowly scraped away from each plant samples until the bottom of the seed was exposed. The seedlings from the soil were gently and carefully removed, taking care to leave the sown seed attached to the plant. The base of the seed to the part of the plant where it has emerged through the soil surface was measured using a ruler. Under the same sampling area, distances between hills and row, and missing hills were measured at 30 DAS at PhilRice, 15 DAS in Pangasinan, and 20 DAS in Isabela. At physiological maturity, two randomly selected sub-plots (4 rows × 5 plants per row) per replicate were selected and plants were harvested. Cobs were removed from the plant, and the grains were shelled out and weighed. The moisture content of the grains was measured using a digital moisture meter (GMK 303 RS, Korea). The grains were sun dried for three days and the final grain yield was calculated based on the adjusted 15.5% moisture content.

2.6 Unit production cost and labor productivity

The number of hours and human-labor to perform land preparation, seeding, fertilizer, pesticide and herbicide application, irrigation, harvesting, hauling and shelling were recorded in all sites. Labor use was determined by multiplying the number of persons by the number of hours spent per activity, and this was divided by eight hours to construct a laborer-day (Moya et al., 2016). The total cost of production was determined by summing up all the variable costs of inputs used (i.e. seeds, fertilizers, herbicides, pesticides, fuel, labor). The cost of each item was estimated by multiplying the quantity by its prevailing price in the area. The unit production cost was calculated as the ratio of the total production cost and the grain yield, expressed in USD kg^{-1}. Labor productivity, which is the efficiency of the direct use of field human power, was determined as the ratio of the grain yield to the total laborer-days.

2.7 Benefit-cost analysis of machine rental service

To determine the economic viability of owning an MCP, a proof of concept for the benefit-cost analysis was done using prevailing rate in Pangasinan to determine the total cost and total benefits derived from owning the machine and machine rental service. In the analysis, we excluded the cost of the compact 4WT assuming that it is already existing and provided free by the government for the farmer's association. Total Seeding (TS) cost was obtained by adding the fixed costs (depreciation, interest on investment, and insurance) and variable costs (fuel, labor, lubrication, repair and maintenance) following the procedures outlined by FAO (1992). The depreciation cost was computed in a straight-line method with 10% salvage value and machine's life span of five years. The interest, insurance, and repair and maintenance were assumed as 12%, 3% and 10% of the total investment cost, respectively. An overhead charge (O_C) for supervision and establishment and interest on working capital was calculated as the 20% of the TS (Singh and Mehta, 2015). The rate for machine rental (MR) in USD ha^{-1} was determined by using Equation 5 and we assumed a 20% for the profit over new cost.

$$MR = [(T_S + O_C) * 1.20]/FC \tag{5}$$

Where T_s and O_c are in USD hr^{-1}. The gross income (USD yr^{-1}) was estimated by multiplying MR with the machine utilization per year. While the net income was computed as the difference between the gross income and T_S. Payback period, break-even point, and benefit-cost ratio (FAO, 1992) were determined to evaluate the feasibility of investing in the machine for rental service.

2.8 Statistical analysis

Data were analyzed using an open software Statistical Tool for Agricultural Research (IRRI, 2014), which is implemented in the R statistical package. The data from the laboratory test was analyzed using one-way analysis of variance (ANOVA) and the Least Significant Difference (LSD) test for comparison of treatment means. Data from the field experiment were analyzed in randomized complete block design, except for the performance indicators of the planter, such as the TFC and FE wherein independent t-test was used to determine significant differences between seed metering plates of the planter. Similarly, independent t-test was also used to analyze data from the farmers' field trials. When the grain yields of the treatments within sites had no significant effects detected, the yields in each sites were treated as replicate to compare significance of the treatments using independent t-test.

3 Results and Discussion

3.1 Performance of MCP

The number of holes and thickness of the seed metering plate significantly influenced the planting distance between hills and number of seeds per hill (F (3, 8) = 19.15. $p < 0.05$).

Table 1 Effects of different number of holes and thickness of the seed metering plate on the distance between rows and hills of maize in a laboratory test

Treatments	Distance between hill, mm	No. seed per hill
6 holes - 5 mm	348.0 a	1 b
10 holes - 5mm	234.7 b	1 b
6 holes - 3mm	246.9 b	2 a
7 holes - 3mm	220.3 b	2 a

In a column, different letters indicate significant difference at 5% probability

Treatment with six holes-5 mm thickness significantly produced the farthest distance (348 mm) between hills, with one seed hill^{-1} among treatments. While there were no significant differences among other treatments, using the seven holes-3 mm thick plate resulted in a planting distance between hills of 220.3 mm (Table 1) with two seeds hill^{-1}, which was relatively closest to the desired distance (200 mm). Similarly, the average seeding rate during calibration was 27.3 kg ha^{-1}. During test run in the field, the seeding rate decreased to 22.1 kg ha^{-1} (Table A1), which is 11% higher than the maximum target seed rate (i.e. 15 - 20 kg ha^{-1}). The field capacity was 0.38 ha h^{-1} at 1400 r min^{-1} and tractor speed of 1.93 km h^{-1}. Jat et al. (2013) reported that actual seeding rates in the field could differ from the design-specified rate due to drag and slippage of the drive wheel, which depend on soil moisture, surface roughness, presence of crop residue, and levelness of the field.

At PhilRice (Nueva Ecija), the seeding rate of MCP-7 holes (18.9 kg ha^{-1}) did not significantly differ from that of MCP-6 holes (15.7 kg ha^{-1}), and both were within the desired range for maize. The FP obtained a significantly higher seeding rate (F (2, 4) = 24.61, P < 0.01) at 30.6 kg ha^{-1} relative to both MCP settings. Similarly, the FCs of MCP-6 and MCP-7 holes did not also differ at 0.13 and 0.14 ha h^{-1}, respectively but both were significantly higher than that of FP at 0.02 ha h^{-1} (Table 2). In this study, the seeding rate of the MCP was lower than the reported seeding rate for maize using a multi-purpose seeder drawn by a two-wheel tractor (Bautista et al., 2018). The difference could be attributed to the number of holes, diameter and size of the seed metering plate used. Another plausible reason is that the seed metering plate of MCP was designed and developed specific for maize only, while the multigrain seed drill of Bautista et al. (2018) was tested for several crops such as for rice, maize, and mung bean. The calculated TFC was 0.18 ha h^{-1} at tractor speed of 1.0 km h^{-1} in both MCP settings. Field efficiencies of MCP-6 and MCP-7 did not vary significantly and ranged from 72% – 78% (Table 2). The FEs were above the standard minimum efficiency (i.e. 55%) of a tractor-driven seeder with fertilizer applicator in the Philippines (PAES, 2001), and were within or even higher than the prescribed range of 65% – 75% for row crop planters (Kepner et al., 1987).

At farmer's fields, the MCP-7 holes-3 mm seed plate was used to further verify the performance of the planter in loamy soils (i.e. sandy loam and sandy-clay-loam). The seeding rate of MCP-7 in Pangasinan was 19.6 kg ha^{-1} and in Isabela, 24.9 kg ha^{-1}. As expected from manual seeding, the FP seeding rates were higher at 30.3 kg ha^{-1} in Pangasinan and 31.4 kg ha^{-1} in Isabela compared with MCP-7. The FCs were 0.29 ha h^{-1} in Pangasinan and 0.26 ha h^{-1} in Isabela. The TFC in

Pangasinan was 0.55 ha h^{-1} at tractor speed of 3.06 km h^{-1} and 0.36 ha h^{-1} in Isabela at a speed of 1.98 km h^{-1}. According to Cortez et al. (2020), the forward speed of a tractor seeder is directly related to the ability of the seeder to work in the field. Field efficiency of the machine was 53% in Pangasinan and 72% in Isabela (Table 2). Comparing these with the FE in Nueva Ecija, the FE at farmer's field decreased by 8% – 26% because of either the soil condition or quality of land preparation on the seedbed. Excessive amount of crop residues on the soil could block the furrow openers (Aikins et al., 2019) which may reduce the field efficiency of the planter. For example, in Nueva Ecija, higher FE was obtained because the seedbed was well-prepared with well-pulverized soil and less biomass residue, which were favorable for the driving wheel to operate continuously during sowing. Any time delays during field operation due to cleaning of plugged machine or making adjustments of machine parts affect the field efficiency of any machine (Hanna, 2016). At farmers' fields, the presence of stubbles from previous crop and larger soil clods, especially in Pangasinan, resulted in frequent stoppages to de-clog and adjust the machine, hence, the low FE. According to Bakker et al. (2002) compact seed drills have limited residue-handling capability. Better performance of our MCP in terms of efficiency was achieved with at least two passes of rotary tillage and with less biomass residue from previous crop.

Table 2 Field performance test on seeding rate, field capacity, theoretical field capacity and field efficiency for maize seeding in the Philippines, 2017–2018 dry season

Treatments	Seeding rate, kg ha^{-1}	Field Capacity, ha h^{-1}	Theoretical Field Capacity, ha h^{-1}	Field Efficiency%
PhilRice (*Nueva Ecija*)				
MCP-6	15.7 b	0.13 a	0.18	72
MCP-7	18.9 b	0.14 a	0.18	78
FP	30.6 a	0.02 b	-	-
p-value	0.006*	0.000***	0.343^{ns}	0.138^{ns}
		Farmer's Fields		
Pangasinan				
FP	30.3	0.02	-	-
MCP-7	19.6	0.29	0.55	53
Difference	10.7***	-0.27**	-	-
Isabela				
FP	31.4	0.04	-	-
MCP-7	24.9	0.27	0.36	72
Difference	6.5***	-0.23*	-	-

Different letters in a column indicate significant differences. $*p < 0.05$, $**p < 0.01$, $***p < 0.001$, ns-not significant.

3.2 Agronomic performance: field experiment and on-farm

There were no significant differences in seeding depth, number of seedlings emerged per m^2, distance between rows and hills, number of seeds per hill and missing hills among treatments in Nueva Ecija (Table 3). The number of seedlings that emerged was 7 – 8 per m^2 with one seed per hill, distance between hill varied from 273 – 354 mm, and distance between rows, 614 – 628 mm. FP gave the farthest distance between hills and widest row spacing among treatments. Missing hills recorded in both MCP seed plate settings were one per m^2. The seeding depth ranged from 48 – 53 mm in all treatments; However, the MCP depths were higher by 6% – 13% compared to FP. The seeding depths of FP and MCP-7 holes were within the range of recommended seeding depth for maize (i.e. 38 – 51 mm) for proper root system development (Elmore et al., 2014). According to Bautista et al. (2018), variations in seeding depth in MCP are dependent on the conditions of seedbed preparations. Surface residue produced non-uniform seeding depth which can contribute to reduced seed emergence rate and yield (Mock and Erbach, 1977).

At farmer's fields, results of tests comparing MCP-7 with two different methods of FP in each site showed that there were significant differences ($p < 0.05$) observed in the seeding depth, distances between rows, number of seeds per hill, and missing hill per m^2 (Table 3). In Pangasinan, the distance between rows with MCP was significantly ($t(10) = -2.91$, $p < 0.05$) higher by 23% than that with FP, while in Isabela, the MCP row distance was significantly (t (10) = 2.59, $p < 0.05$) lower by 16% than FP. Similarly, the distance between hills with MCP in Pangasinan was higher by 33% and lower by 7% in Isabela compared with FP. In both sites, the actual distances between rows and hills did not meet the targeted design specifications of the planter (i.e. 600 mm row spacing and 200 mm hill spacing). This could be attributed to the drag and slippage of the drive wheel caused by the uneven soil level and numerous stubbles from previous crop on the seedbed. The number of seed hill^{-1} obtained was 1 – 2 at both sites and was within the prescribed amount of seeds of the MCP. However, there was a significantly (t (8) = -5.24, P < 0.001 for Pangasinan and t (8) = -3.08, $p < 0.05$ for Isabela) higher number of missing hills per m^2 in the MCP-7 compared with FP in both sites. In terms of seeding depth, there was no significant difference (t (8) = -0.96, P = 0.36) observed in Pangasinan which ranged from 62 – 68 mm. In Isabela, the seeding depth of MCP was significantly (t (8) = 4.40, P < 0.01) higher by 41% than FP. Comparing the seeding depth between FPs of the two sites, seed placement was deeper in Pangasinan owing to the farmalite used by the farmer. This seeder was manually operated by pushing it into soil to drill the seed. In contrast, the farmer in Isabela just dibbled the seed into the furrows and manually covered it with soil. The number of emerged seedlings per m^2 with MCP-7 was 4 – 6 seedlings at both sites.

Grain yields of MCP-7 and FP in all sites did not differ significantly and ranged from 4258 - 5073 kg ha^{-1} at PhilRice, 11 659 - 13 114 kg ha^{-1} in Pangasinan, and 5810 - 6031 kg ha^{-1} in Isabela (Table 3). The differences in grain yield levels at all sites were due to the differences in variety of maize planted and crop management practices. Moreover, we still found no statistical differences (t (18) = -0.25, P = 0.98) in the average grain yields between MCP-7 and FP across all sites (i.e. treating sites as replicates) (Figure 3). Previous reports also showed that there were no significant differences on the grain yields of rice and maize using multi-crop seeder compared with manual broadcasting or conventional method (Bautista et al., 2018; Ramesh et al., 2014). In spite of insignificant yield differences, MCP-7 was better in terms of lower seeding rate and higher field capacity compared to farmer's local practice, and this could possibly reduce total cost of production.

Table 3 Agronomic performance of maize under different methods of planting in three sites in the Philippines, 2017 – 2018 dry season

Treatments	Seeding depth, mm	Seedling emergence per m^2	Distance between rows, mm	Distance between hills, mm	No. of seeds per hill	Missing hill per m^2	Grain yields, kg ha^{-1}
PhilRice (*Nueva Ecija*)							
MCP-6	53.5	8	614.5	314.4	1	1	4683
MCP-7	50.6	7	615.1	273.3	1	1	4258
FP	48.1	7	628.4	354.3	1	1	5073
p-value	0.781^{ns}	0.849^{ns}	0.734^{ns}	0.215^{ns}	0.421^{ns}	0.421^{ns}	0.437^{ns}
Farmer's Field							
Pangasinan							
FP	62.6	5	442.6	243.9	1	0	13 114
MCP-7	67.9	4	545.5	323.1	2	4	11 659
Difference	-5.3^{ns}	1^{ns}	-102.9*	-80.2*	-1*	-4***	1455.2^{ns}
Isabela							
FP	29.7	5	594.8	341.1	1	0	5810
MCP-7	41.9	6	501.1	318.7	2	3	6031
Difference	-12.2**	-1^{ns}	-93.7*	22.4^{ns}	-1*	-3*	224.3^{ns}

ns- not significant, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

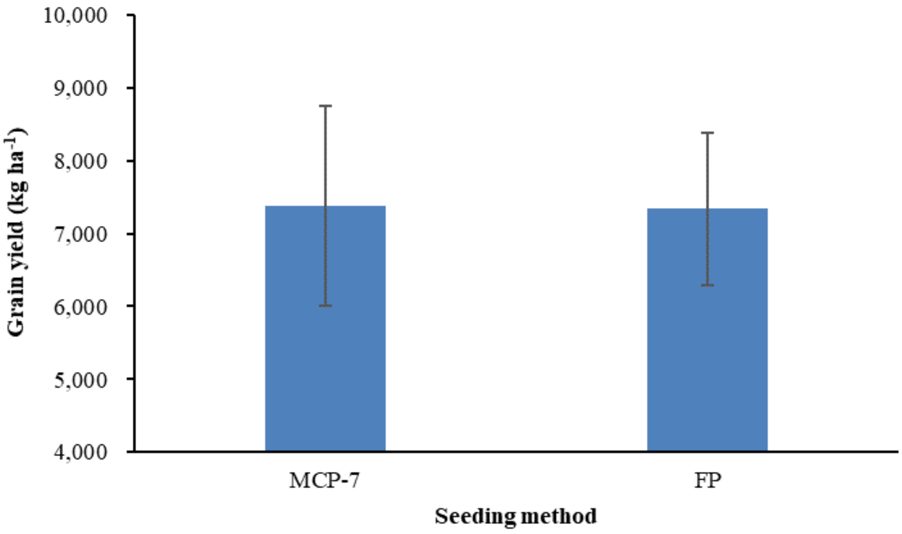

Figure 3 Average grain yields of maize between MCP-7 and FP

Error bars represent the standard errors (n = 10 for each treatment).

3.3 Unit production cost and labor productivity

There were no significant differences (t (4) = 0.87, p = 0.43 for Pangasinan; t (4) = 1.24, p = 0.28 for Isabela) in the unit production cost between MCP and FP within sites (Table 4). However, MCP consistently obtained a lower average unit production cost by 7% - 10% under farmers' fields. Similar trend was obtained at the experimental farm in Nueva Ecija, but the unit production cost was two – three times higher than farmer's fields. This can be attributed to the low level of grain yields in Nueva Ecija and relatively high cost of production. In all sites, the combined costs of high seeding rate, large quantity of human-labor to perform manual seeding, and additional cost for furrowing under FP contributed 42% – 52% of the total cost of production (USD 786 - 1375). When using the MCP with relatively low seeding rate and high field capacity, the combined costs of seeds and imputed cost of planting/furrowing were only 22% – 35% of the total cost of production. In contrast, labor productivity with MCP was significantly higher (t (4) = -4.05, $p < 0.5$ for Pangasinan, t (4) = -3.28, $p < 0.05$ for Isabela) by 37% – 61% than with FP under farmer's fields. The higher grain yields in Pangasinan than in Isabela resulted in higher labor productivities. At the experimental farm in Nueva Ecija, labor productivity was not significantly different among treatments owing to low yields. The heavy clay in Nueva Ecija, which is poorly drained may have caused the lower level of maize yields there, compared with the farmer's fields in Pangasinan and Isabela. Previous reports showed that higher maize yields were obtained in medium coarse textured soil than fine textured soil such as clay (Ziadi et al., 2013). Nevertheless, labor requirement to perform seeding using MCP was reduced significantly by an average of nine laborer-days per ha relative to FP. This is due to the reduced human labor to perform seeding and no additional furrowing was required using the MCP. In general, the immediate economic benefit in using MCP is generated from increased labor productivity especially in a well-drained soil.

Table 4 Unit production cost and labor productivity of MCP and FP in the three sites

Treatments	Unit Production Cost, USD kg^{-1} (PHP kg^{-1})^{a}	Labor Productivity, kg per man-day
Philrice (*Nueva Ecija*)		
MCP-6	0.21 (10.5)	91.8
MCP-7	0.24 (11.9)	83.5
FP	0.30 (15.1)	87.5
p-value	0.148^{ns}	0.7472^{ns}
Farmer's Fields		
Pangasinan		
MCP-7	0.07 (3.7)	240.4
FP	0.08 (4.1)	176.0
p-value	0.446^{ns}	0.045*
Isabela		
MCP-7	0.14 (6.9)	143.4
FP	0.15 (7.5)	95.0
p-value	0.552^{ns}	0.044*

ns- not significant, *$p < 0.05$; ^{a}conversion: 1 USD = 50 PHP

3.4 Benefit-cost on machine rental services

The economic potential of owning a multi crop planter can be shown through machine rental service by an organized farmers' association. Machine rental service can be the practical way to make expensive farm machinery available for use by other farmers without the need for individual farmers to buy such machine, and is potentially useful as an alternative source of livelihood (Paman et al., 2010). Economic analysis of using a MCP with an initial investment cost of USD 3400 showed that the total seeding cost was USD 15.5 per ha (Table 5). To generate income from machine rentals, calculated custom hiring rate was USD 23.30 per ha. This is far less costly than hiring many laborers to do manual seeding in the field. For example, in Pangasinan, the prevailing rate of labor for planting is USD 7 per laborer-day. With a capacity of 0.02 ha h^{-1}, it would approximately require seven laborer-days to completely plant a hectare. At USD 7 per day, the total cost would be USD 49 per ha, which would be twice more expensive than renting a planter (Table A2). Additional labor to perform furrowing before seeding is also an additional cost for manual seeding. From the viewpoint of the owner-investor (e.g. farmers association), investment cost can be recovered in 3.6 years at an annual machine utilization rate of 120 ha. Break-even point is 240 ha, while the benefit-cost ratio is 1.5 (Table 5).

Table 5 Economic analysis of using the multi-crop planter through machine rental service

Parameters	USD	(PHP)*
Investment Cost	3400	(170 000)
Fixed Cost, USD per day		
Depreciation	1.7	(83.8)
Interest on Investment	1.1	(55.9)
Insurance	0.3	(14.0)
Sub-Total	3.1	(153.7)
Variable Costs, USD per day		
Fuel	19.4	(969.0)
Repair and Maintenance	0.9	(46.6)
Labor	7.0	(350.0)
Lubrication	0.7	(35.0)
Sub-Total	28.0	(1400.6)
Total Cost of seeding, USD day^{-1}	31.1	(1,554.3)
Total Cost of seeding, USD year^{-1}	1865.1	(93 256.4)
Capacity, ha day^{-1}	2	
Seeding cost, USD ha^{-1}	15.5	(777.1)
Rental service rate, USD ha^{-1}	23.3	(1165.7)
Machine utilization, ha year^{-1}	120	
Gross Income derived, USD year^{-1}	2797.7	(139 884.7)
Net Income derived, USD year^{-1}	932.6	(46 628.2)
Net benefit derived, USD year^{-1}	7.8	(388.6)
Payback Period, year	3.6	
Break-even point, ha	240	
Benefit-cost ratio	1.5	

*conversion: 1 USD = 50 PHP

4 Conclusion

The MCP was locally developed and adapted primarily to improve labor productivity and field efficiency of crop establishment for maize, rice and mung bean. In this study, the agronomic and field performance of a MCP in sowing maize in two different soil types were evaluated. Field experiment and adaptive trials at farmers' fields showed that the planter had higher field capacity and lower seeding rate compared with FP. The adaptive MCP model also achieved efficiencies above the minimum required field efficiency of a row seeder provided that a two-pass tillage operation is carried out and there is less biomass residue from previous crop on the seedbed. Although grain yields of MCP did not differ from those of FP in all sites, the amount of seed used was significantly reduced and rate of planting was much faster. Economic analysis showed the viability of owning and operating a multi crop planter through machine rental service. The results of this study underscore the potential benefits of using the adaptive model of the MCP to improve the utilization of 4WT, which is limited to land preparation and hauling or transport, increase the efficiency of planting maize in the Philippines, and reduce cost of production while maintaining grain yield. However, the residue handling capacity of the planter under reduced-till soils should be studied and improved further to increase the efficiency.

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References

Aikins, K. A., D. L. Antille, T. A. Jensen, and J. Blackwell. 2019. Performance comparison of residue management units of no-tillage sowing systems: A review. *Engineering in Agriculture, Environment and Food*, 12(2): 181-190.

Bakker, R. R., M. A. Bell, and J. F. Rickman. 2002. Mechanization issues in tillage and crop establishment for dry direct-seeded rice. In *Proc. International Workshop on Direct Seeding in Asian Rice Systems: Strategic Research Issues and Opportunities*, eds. S. Pandey, M. L. Mortimer, T. Wade, P. Tuong, K. Lopez, and B. Hardy, 219-230. Los Baños (Philippines): International Rice Research Institute.

Bautista, E. G., E. C. Gagelonia, J. E. Abon, A. M. Corales, C. S. Bueno, N. P. M. C. Banayo, R. V. Lugto, R. R. Suralta, and Y. Kato. 2018. Development of hand-tractor-mounted seed drill for rice based cropping systems in the Philippines. *Plant Production Science*, 22(1): 54-57.

BSWM. 1985. Soil survey. GIS Data Base. Diliman, Quezon City: DA-Bureau of Soils and Water Management.

Chauhan, B. S. 2012. *Weed management in direct-seeded rice systems*. Los Baños (Philippines): Int. Rice Res. Inst..

Cortez, J. W., M. Anghinoni, and S. N. S. Arcoverde. 2020. Seed metering mechanisms and tractor-seeder forward speed on corn agronomic components. *Engenharia Agrícola*, 40(1): 61-68.

Corton, T. M., J. B. Bajita, F. S. Grospe, R. R. Pamplona, C. A. Asis Jr., R. Wassmann, R. S. Lantin, and L. V. Buendia. 2000. Methane emissions from irrigated and intensively managed rice fields in Central Luzon (Philippines). *Nutrient Cycling in Agroecosystems,* 58: 37–53.

Dela Cruz, S. M., and H. G. Malanon. 2017. State of on-farm maize mechanization in the Philippines. *Agricultural Engineering International: CIGR Journal*, 19(4): 20–28.

Dela Cruz, R. S., and S. B. Bobier. 2016. Farm power available for utilization in Philippine agriculture. *Postharvest and Mechanization Journal*, 2(1): 1–16.

Elmore, R., A. K. Mahdi, and M. Hanna. 2014. Corn Seeding Depth: Back to the Basics. *University of Maryland Extension Agronomy News*, 5(1): 1-3.

FAO. 1992. Cost Control in Forest Harvesting and Road Construction, Paper 99. Rome: FAO Forestry.

Gerpacio, R. V., J. D. Labios, R. V. Labios, and E. I. Diangkinay. 2004. *Maize in the Philippines: Systems, Constraints, and Research Priorities*, 1-37. Mexico, D.F.: CIMMYT. Available at: https://ageconsearch.umn.edu/bitsream/7650/1/mp04ge01.pdf. Accessed 28 February 2020.

Hanna, M. 2016. Estimating the field capacity of farm machines. Available at: https://lib.dr.iastate.edu/cgi/viewcontent.cgi?article=1003&context=pubs_agdm. Accessed 28 October 2020.

Idago, R. G., R. S. M. Dela Cruz, D. Flores, D. R. Miranda, and M. G. Corpuz. 2019. Performance evaluation of multi-row onion seeder. *Agricultural Engineering International: CIGR Journal*, 21(3): 69–75.

IRRI. 2017. Maize Crop Manager. Available at: http://www.knowledgebank.irri.org/decision-tools/crop-manager. Accessed 4 January 2017.

IRRI. 2014. Statistical tool for agricultural research (STAR) v.2.0.1. Available at: http://bbi.irri.org. Accessed 1 January 2018.

Jat, M. L., B. R. Kapil Kamboj, H. S. Kamboj, M. Sidhu, A. Singh,, D. K. Bana, M. K. Bishnoi, Y. S. Gathala, V. Saharawat, A. Kumar, H. S. Kumar, R. K. Jat, P. C. Jat, R. K. Sharma, R. Sharma, T. B. Singh, R. K. Sapkota, R. Malik, Gjupta, and H. S. Jat. 2013. Operational manual for Turbo Happy Seeder- Technology for managing crop residues with environmental stewardship. International Maize and Wheat Improvement Center, Indian Council of Agricultural Research, New Delhi, India. pp.28.

Kepner, R. A., R. Bainer, and E. L. Barger. 1987. *Principles of Farm Machinery*. New Delhi: CBS Publishers and Distributors.

Labios, R. V., L. T. Leonardo, J. D. Labios, C. M. Medinal, E. P. Ocampo, D. M. Miciano, J. Trinidad, and J. O Manalo. 2002.

Conservation Tillage Strategies for Corn Grown in Paddy Fields: Using on-Farm Research for Technology Transfer. In *Proceedings 12th ISCO Conference*, 369-373. Beijing, May 26-31, 2002.

Mock, J. J., and D. C. Erback. 1977. Influence of conservation-tillage environments on growth and productivity of corn. *Agronomy Journal*, 69: 337-340.

Moya, P. F., F. H. Bordey, P. F. Moya, J. C. Beltran, R. G. Manalili, C. C. Launio, A. B. Mataia, A. B?(family name), and A. C Litonjua. 2016. Cost of rice production. In *Competitiveness of Philippines Rice in Asia. Nueva Ecija*, eds. F. H. Bordey, P. F. Moya, J. C Beltran, D. C. Dawe, 79-111., Philippines: Philippine Rice Research Institute and International Rice Research Institute.

PAES-Philippine Agricultural Engineering Standards. 2005. No. 144. Agricultural Machinery-Rice Drum Seeder-Methods of Test, p. B-55. Available at: https://amtec.ceat.uplb.edu.ph/wp-content/uploads/2019/07/paes-144-rice-drum-seeder-test.pdf. Accessed 28 October 2020.

PAES. 2001. PNS/PAES 123. Agricultural Machinery-Seeder-Planter-Methods of Test. Quezon city: Department of Agriculture.

Paman, U., S. Uchida, and S. Inaba. 2010. The economic potential of tractor hire business in Riau province, Indonesia: A case of small tractor use for small rice farm. *Agricultural Engineering International: CIGR Journal*, 12(1): 135-142.

PhilRice-Philippine Rice Research Institute. 2013. Simplified keys to soil series in Pangasinan. Maligaya , Science city of Muñoz, Nueva Ecija, p. 21. Available at: https://www.philrice.gov.ph/wp-content/uploads/2015/08/Simplified-Keys-to-Soil-Series-Pangasinan.pdf. Accessed 2 March 2020.

PSA-Philippine Statistics Authority. 2018. Major Crop Statistics in the Philippines: 2010-2014. Available at: https://psa.gov.ph/sites/default/files/Selected%20Statistics%20on%20Agriculture%202018.pdf. Accessed 5 February 2019.

PSA, 2015. Major Crop Statistics in the Philippines: 2010-2014. Available at: https://psa.gov.ph/sites/default/files/MajorCrops10-14.pdf. Accessed 5 April 2019.

Ramesh , S. S., S. C. Negi, S. Kumar, and S. K. Subehia. 2014. Effect of resource-conserving and planting technique on productivity of maize (*Zea mays*)-wheat (*Triticum aestivum*) cropping system. *Indian Journal of Agronomy*, 59(1): 34-40.

Singh, K. and Mehta, C.R. 2015. Decision support system for estimating operating costs and break-even units of farm machinery. *Ama-Agricultural Mechanization in Asia Africa and Latin America*, *46*(1):35-42.

Tobias, A. M. 2019. The Philippine Rice Tariffication Law: Implications and Issues. Available at: http://ap.fftc.agnet.org/ap_db.php?id=960&print=1. Accessed 2 March 2020.

Ziadi, N., A. N. Cabouris, J. Nyiraneza, and M. C. Nolin. 2013. Across landscape, soil texture controls optimum rate of N fertilizer for maize production. *Field Crops Research*, 148: 78-85.

Nomenclature

4WT	four-wheel tractor
A	area planted, ha
AFMA	Agriculture and Fisheries Modernization Act
AFMech	Agricultural and Fisheries Mechanization
DAS	days after seeding
FC	field capacity, ha h^{-1}
FE	field efficiency, %
hp	horsepower
MCP	multi-crop planter
Mil	million
NPK	nitrogen ,phosphorous, potassium
PhilRice	Philippine Rice Research Institute
PHP	Philippine peso
S	speed of machine, h
SR	seeding rate, kg ha^{-1}
T	total operating time, h
TFC	theoretical field capacity, ha h^{-1}
USD	US dollar
w	width of implement, m
W_s	weight of seeds, kg

APPENDIX

Table A1 Seeding rate of MCP-7 under laboratory and field-run tests in Philrice, Nueva Ecija

Trials	Seed rate, kg ha^{-1}	
	Laboratory	Field-test run
Trial 1	27.0	21.1
Trial 2	27.6	24.8
Trial 3	27.4	20.4
Average	27.3	22.1
p-value	ns	ns

Table A2 Cost estimate on labor requirement of farmer's practice using *farmalite* in sta. Maria Pangasinan, 2018 dry season

Parameters	Unit	Value
Labor Requirement	person-day	1
Prevailing labor-cost	USD/person/day	7
Field capacity	ha/day	0.16
No. of Man required to plant 1 ha	person/ha/day	7
Total labor cost	USD/ha	49