



Original article

Mobile human powered raking equipment (MHPRE) for spreading and mixing paddy in sun drying

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ABSTRACT

The drying of paddy after harvest is commonly done on concrete pavement by spreading and mixing using the traditional manual raking tool to prepare it prior to storing and milling. During the drying process, when paddy is not uniformly mixed at the desired layer depth, grain quality is reduced especially if drying is delayed, incomplete or ineffective. For these reasons, a Mobile Human Powered Raking Equipment (MHPRE) was developed to uniformly spread and mix the paddy for sun drying in a shorter time. The study was carried out through the development of a two-wheeled detachable and mountable paddy rake type spreader and mixer using a Polypropylene Random Copolymer (PPR) pipe, the development of a four-wheeled human powered vehicle that pulls the paddy rake spreader and mixer and the evaluation of the performance of the MHPRE compared to the traditional manual paddy spreading and mixing. The two-wheeled innovative detachable and mountable PPR raking tool with adjustable paddy leveling plate was found to be effective in spreading and mixing paddy uniformly at the desired layer depth of 4 cm with respect to time, cost and quality. The MHPRE was found to be stable, durable, safe to operate and effective in spreading and mixing uniformly on concrete drying pavement with a lesser period of time. Furthermore, savings of 52.38% was attained in an 8-hour sun drying of paddy using the MHPRE compared to the traditional manual paddy spreading and mixing on concrete pavement. Results suggest that the MHPRE is now ready for deployment in the agricultural community in the country.

KEYWORDS: *grain quality, human powered, paddy, performance, sun drying*

1 INTRODUCTION

The traditional drying method in reducing the moisture content of paddy is through sun drying. This is done by manually spreading and mixing the paddy under the heat of the sun on a concrete pavement or mats using

a raking wooden tool. The solar radiation that heats up the paddy, together with the ambient air, and the heat of the pavement increases the evaporation rate of moisture from the grains. In the postharvest processing of paddy, drying is the most critical step to preserve product quality and reduce losses [1]. The final moisture content of paddy should not exceed 14 % moisture content for a maximum storage period of eight months [2].

In tropical countries, sun drying is the most common drying method compared to mechanical drying because the former does not only require lesser investment but also it is an environmentally friendly method [3,4]. Sun drying is a labor-intensive process since to come up with better quality dried grains, it needs every thirty minutes interval to spread and mix the paddy on the drying pavement. [1]. Aside from the cost of drying the paddy, the uneven depth usually occurs when spreading and mixing are done manually with the use of a wooden-made rake spreader. Through this process, the temperature is difficult to control which could result in overheating the paddy. Too much heat causes cracked grains leading to low milling quality.

Proper sun drying through spreading the paddy in thin layers of ideally 2.0-4.0 cm and turning and mixing the paddy every thirty minutes [1] can produce high-quality grain. If the layers are too thick, the moisture gradient is formed with dry grains on the top and wet grains at the bottom. The paddy usually re-absorbs moisture after mixing. Meanwhile, if the layer is too thin, the paddy heats up so quickly that head grain recovery is not good.

An exhaustive literature review was conducted to ensure that there is the novelty of the developed mobile human powered raking equipment for spreading and mixing paddy in sun drying. A related system was found relating to a rake of hand brown type having resilient metal tines which is metal for raking leaves and the like [5]. Another related system has sought to provide a rake which has all of the advantages of both steel tine rakes and bamboo rakes, without the advantages thereof [6]. Moreover, the invention which relates generally to rakes commonly used by homeowners, gardeners, landscapers, yard maintenance and various other individuals and more specifically it relates to a multi-functional hand rake with

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clog-free heavy-duty spring tines was an innovative rake [7]. Furthermore, a rake is described, having wheels mounted rotatably thereto which enable the rake to be moved easily from place to place without lifting the rake from the ground. When the rake is pulled towards the user, the comb is locked such that its teeth are in the conventional operative position closer to the designed raking equipment [8].

Though numerous articles can be found in the extant literature about rakes, there was minimum contribution specific to spreading and mixing paddy in sun drying and the concept of pulling the rake by a mobile human powered utility vehicle is not well established in the patent databases. However, there was no invention specific to the usage of Polypropylene Random Copolymer (PPR) pipe material as the raking tool to be attached in coupled bicycles intended for uniformly spreading and mixing paddy in sun drying.

Thus, a Mobile Human Powered Raking Equipment [MHPRE] was developed in this study. This MHPRE will solve the demand of more laborers in sun drying and uniformly spread and mix the paddy to the desired depth level accurately in a short period improving the quality of dried paddy before storage and milling process. Hence, this study has the following objectives: (i) to develop a two-wheel detachable, mountable paddy rake type spreader and mixer using Polypropylene Random Copolymer (PPR) pipe material, (ii) to develop a four-wheel human powered vehicle that pulls the paddy rake spreader and mixer, (iii) to determine the percent savings in utilizing the MHRPE than using the traditional manual raking mode, and (iv) to evaluate the performance of the MHPRE as paddy spreader and mixer.

2 MATERIALS AND METHODS

In this section, the development of a Mobile Human-Powered Raking Equipment (MHPRE) in spreading and mixing the paddy on the concrete pavement dryer uniformly at paddy depth of about 4 centimeters to have better drying quality is presented. The first part is the presentation of the system. The second part is the different assessments to verify the performance of the system compared to the traditional manual raking of paddy.

System Development

Polypropylene Random Copolymer (PPR) Raking frame spreader and mixer

A two-wheeled Polypropylene Random Copolymer (PPR) pipe raking frame is developed using fusion pipe fusion thermal technology to uniformly level the paddy at 4 cm range depth in a 0.64 meter spreading width capacity. The PPR pipes were joined to make a 4 cm

spaced rake for spreading and mixing paddy with adjustable spreader plate fastened in the frame which formed an integral part of the whole rake assembly. As shown in Fig. 1, the two-wheeled PPR rake spreader and mixer was fabricated with provisions to be mountable and detachable for easy operation. The design criteria in making the PPR paddy rake is based on time, cost, and quality as to the spreading and mixing paddy on the concrete drying pavement.



Figure 1. PPR Parking Frame Spreader and Mixer

Mobile Human Powered Raking Equipment (MHPRE)

The design of the MHPRE was based on a 400-kg load capacity which includes at least two passengers and cargo. This mobile four-wheel human-powered vehicle was developed by coupling two identical bicycles in a parallel relationship through a bicycle duo coupling kit as shown in Fig.2. The coupling kit is composed of a first bar, second bar, and steering coupling assemblies which secure two parallel bicycles to each other creating a stable structure for the riders to experience biking safely while spreading and mixing paddy in sun drying.



Figure 2. Coupled Bicycles

The coupled bicycles are two identical 26-inch wheel size mountain bikes. The wheel size of the bicycle is usually measured by millimeters or inches (different

manufacturers use different systems). There are three main factors that go into determining the size of a mountain bike wheel: rim height, rim width, and tire diameter. For the 26 inches, 27.5 inches, or 29 inches, would mean wheels, not tires. This refers to the thickness and rim diameter of the tire as a whole, so if these figures on the tire are not visible, there is a need to physically measure these wheels.

Wheel size is significant not just for changing tires but also when deciding which bike to buy and which cycling style the rider will prefer. For bicycles used in tough terrains, like using it on concrete pavement with paddy, 26 inches size is preferable. In looking for a bike with more power, riders should go for one with short wheels, such as those with 26-inch wheels. Another advantage of working with these bikes is that spare parts are easily available and inexpensive.

In this study, the basis of choosing the type of tire to be used is based on the terrain application. The first number is the tire diameter. The most common options are 26 in., 27.5 in. and 29 in. The second number is the width of the tire. This number is expressed in inches for mountain bike tires and in millimeters for road tires. In this study, the 26 inches was selected because of the application of the vehicle on concrete pavement with paddy to spread and mix with needs more power at slower speed.

In Fig.3, the MHPRE prototype assembly has provisions to attach and pull the innovative PPR raking tool to spread and mix the paddy for a layer depth setting of about 4 cm. Figure 3 shows the prototype assembly of coupled bicycles, a four-wheel human powered utility vehicle with Polypropylene Random Copolymer (PPR) pipe raking tool attached at the rear part of the said vehicle.



Figure 3. MHPRE Prototype Assembly

Since the heart of the bicycle is the frame, referring to the MHPRE in this study, the frame materials used were considered based on the cost, comfort, weight, stiffness, strength and durability. A frame can be made from either carbon fiber, aluminum, titanium, steel or a combination of these materials. In this study, a steel alloy frame was used. It was also subjected to stress analysis

at full load using Solidworks software whether it can withstand the loads.

System Assessment

The following assessments were conducted to evaluate the performance of the mobile human powered raking equipment for spreading and mixing paddy in sun drying.

Stress Analysis of the Bicycle Frame at Full Load

The Solidworks software is used to perform a stress analysis of the bicycle with a rider, coupling elements, raking equipment, and other accessories as loads. The test aims to determine the maximum stress experienced by the bike when subjected to these loads. The analysis indicates the critical areas in the bicycle frame with these loads. The following are the considerations in the simulation:

- Bicycle frame material is Aluminum Alloy 6061-T6
- Rider weighs 100 kg.
- The 10% of the rider's weight (10kg) is acting on the bicycle handle
- The 20% of the rider's weight (20kg) is acting on the bicycle pedal
- The 70% of the rider's weight (70kg) is acting on the bicycle saddle
- The total weight of the attachments (coupling elements and accessories) is 73 kg.
- The 20% of the attachments' total weight (14.6 kg.) is acting on the bicycle headtube
- The 80% of the attachments' total weight (58.4 kg.) is distributed equally on the bicycle's seat tube, and the additional two wheels (19.8 kg is acting on the bicycle's seat tube)
- The total weight of the bicycle frame is acting on its center of gravity

Traditional Manual Raking (TMR) versus Mobile Human Powered Raking Equipment (MHPRE)

In the sun drying of paddy of larger capacity is usually done in an open basketball court. The traditional way of spreading and mixing is done by using a rake made of wood or lumber and pulled by a laborer or laborers. In this set-up, a rake was fabricated using PPR pipes with a total spreading width of 0.65 meter and mixing depth of 4 cm and called it Traditional Manual Raking (TMR) as shown in Fig. 4. This TMR was used to spread and mix the paddy in a basketball size drying area within an 8-hr drying period. Also, an innovative two-wheeled rake of the same size was fabricated with mounting provisions at the center of the lower rear portion of the coupled bicycles. This is now called the Mobile Human Powered Raking Equipment (MHPRE) prototype as shown in Fig. 5.



Figure 4. Traditional Manual Raking



Figure 5. MHPRE Prototype

Determination of Paddy Spreading and Mixing Time between TMR and MHPRE

In this study, it is very important to know the time spent in spreading and mixing the paddy on the drying area within the drying period in order to compare the total drying time between the TMR and the MHPRE. The standard size of a basketball court measures 28 m x 15 m having a total drying area of 16.8 cu.m. Based on the raking width of 0.65 m, in a basketball court drying space there are 43 sections of 28 m x 0.65 m for testing runs of both TMR and MHPRE to determine how long will it take to spread and mix the paddy within the drying period considering that there is a need to spread and mix the paddy every thirty minutes according to IRRI.

Percent Savings in Using MHPRE vs TMR

Since the sun drying of paddy is one of the most labor-intensive processes, the cost of paddy spreading and mixing on a basketball court within the drying period with thirty minutes interval is determined to know the percent savings when using the MHPRE compared to TMR utilizing one worker with given rate per day.

Quality Assessment

The respondents and the research team evaluated the

quality performance of the developed equipment through a series of focused group discussions. As a result, the team adopted the items reflected in ISO 25010 for product quality evaluation. These are functional suitability, performance efficiency, compatibility, usability, reliability, and maintainability. The rating scale as indicated in Table 1 was used in the quality evaluation.

Table 1. The rating scale of the quality assessment

Rating Scale	Level of Quality
2.34-3.00	High level
1.67-2.33	Moderate level
1.00-1.66	Low level

2.2.5.1 Performance evaluation of the MHPRE as paddy spreader and mixer.

The evaluation of the performance of a mobile human powered raking equipment is based on safety, capacity, maneuverability, durability, installation and speed [9]. The MHPRE as paddy spreader and mixer was used and tested to operate in the sun drying of paddy on the basketball court covering an area of 420 square meters within the 6 hrs to 8 hrs drying period. The sample drying section of 28 m x 0.65 m drying area can accommodate 2.45 bags approximately equivalent to 183.75 kgs of paddy to be mixed or turned with a layer depth of 4 cm. A basketball court drying area can accommodate about 7,901.25 kgs equivalent to 105.35 bags at 75 kgs per bag.

3 RESULTS AND DISCUSSIONS

In this section, the data gathered from the different assessments are presented as follow:

Stress Analysis of the Bicycle Frame at Full Load

As shown in Fig. 4, the maximum stress experienced by the bicycle frame is approximately 71.767 MPa. It appears to be yellow. It is below the yield strength of the bicycle frame, which is at 275 MPa. Hence, the frame can withstand the weight of a 100-kg rider and 73-kg attachments when considering a factor of safety below 3.83.

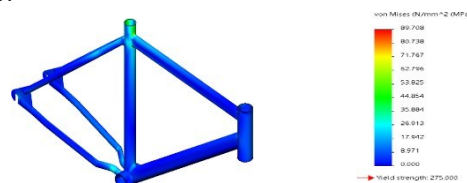


Figure 4. Stress analysis of the bicycle frame at full load

Traditional Manual Raking (TMR) versus Mobile Human Powered Raking Equipment (MHPRE)

Table 1 presents the results of the trial runs in determining the average time in spreading and mixing the

paddy on a basketball court with an experimental testing section measuring 28 m x 0.65 m between the traditional manual raking and the mobile human powered raking equipment with one worker. It was found out that it took a longer period for the worker to spread and mix the paddy in a given drying section with an average time of 26.01 seconds using the TMR. Meanwhile, with the use of the MHPRE, it only took an average time of 8.76 seconds.

Table 1. Time of spreading and mixing paddy through TMR vs, MHPRE

Trial	1	2	3	4	5	6	7	8	9	10	Ave. time sec.
TMR	28.42	28.09	25.21	25.38	20.30	27.6	27.74	28.37	21.38	27.62	26.01
MHPRE	12.02	11.21	10.62	10.13	9.04	6.68	7.22	6.81	7.19	6.69	8.76

As shown in Fig.5, the average time spent in spreading and mixing the paddy in a 28 m x 0.65 m section was 26.01 seconds using the TMR while in MHPRE was only 8.76 seconds. Using the MHPRE, the time spent to spread and mix the paddy in a section of 28 m x 0.65 m is only 33.68 % compared to traditional manual raking.

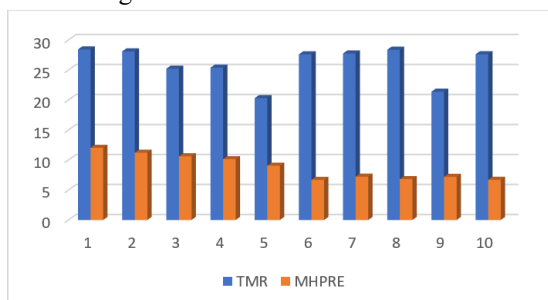


Figure 5. Average Time in Spreading and Mixing

Determination of Paddy Spreading and Mixing Time between TMR and MHPRE

Figure 6 shows the total time spent in hours spreading and mixing paddy for the whole basketball court as the drying area. Using the TMR, it took 6.3 hours for the worker to spread and mix the paddy with 5 seconds delay in pivoting the 43 sections of 28 m x 0.65 m while utilizing the MHPRE, the time spent is only 3.0 hours.

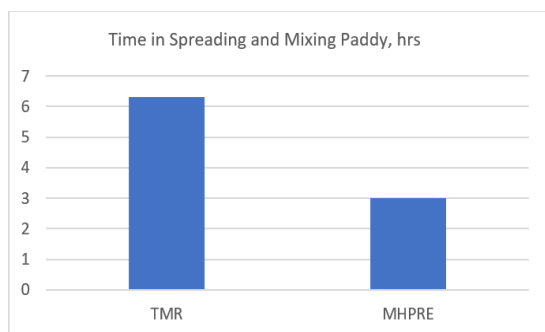


Figure 6. Total Time in Spreading and Mixing Paddy Labor Cost of TMR vs. HHPRE and Percent Savings

Table 2 shows the labor cost and percent savings when spreading and mixing paddy on a basketball court is done by a single worker with a rate of Php 56.25 per hour in drying periods of 6, 7 and 8 hours. Based on the results, for the maximum of 8 hours drying period with 30 minute interval of spreading and mixing paddy, the cost of labor was high at Php 354.38 for the TMR while Php 168.75 labor cost for MHPRE and a variance of Php 185.63. The percent savings of utilizing MHPRE is 52.38 %.

Table 2. Labor Cost and Percent Savings in Drying Using TMR and MHPRE

Labor Cost (one worker)	TMR	MHPRE	Variance	% Savings
6 hrs drying	Php 266.20	Php 127.13	Php 139.07	52.24 %
7 hrs drying	Php 310.28	Php 148.05	Php 162.23	52.35 %
8 hrs drying	Php 354.38	Php 168.75	Php 185.63	52.38 %

Figure 7 shows the percent savings of 52.24 %, 52.35 %, 52.38 % for the drying periods of 6, 7, and 8 hours respectively. The longer the drying period, the higher is the labor cost.

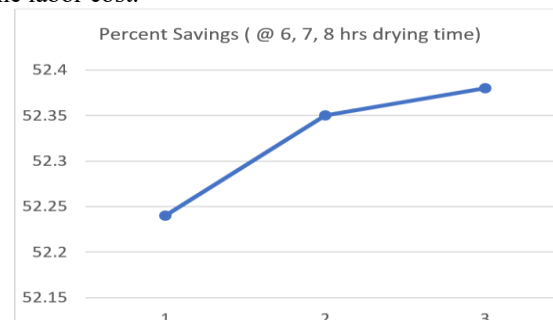


Figure 7. Percent Savings Using MHPRE

Quality Assessment

The team's assessment results of the MHPRE were shown in Table 3. The assessment results suggest that the developed equipment is ready for deployment in the agricultural community. The system features are aligned with the present needs of the mobile human power raking equipment of paddy in sun drying.

Table 3. Quality Assessment Results

Aspect of Quality	Level of Quality
functional suitability	High Level
performance efficiency	High Level
compatibility	High Level
usability	High Level
reliability	High Level
maintainability	High Level

Performance Evaluation of the MHPRE as paddy

spreader and mixer.

This study utilized the basic concepts on engineering mechanics, strength of materials, material testing, machine elements and machine design as bases for the design and testing. In the fabrication aspect, machine shop theory and practice and manufacturing processes were considered to come up with a stable and robust prototype of the vehicle. The evaluation of the performance of a mobile human powered raking equipment is based on safety, capacity, maneuverability, durability, installation and speed [9].

Safety

The safety of the riders or workers of the MHPRE when operating the sun drying of paddy is the first priority. This utility vehicle must be well maintained and in good condition before using it. Table 4 shows the MHPRE braking test results. This was accomplished by a rider who drove the MHPRE at a speed of 5 kph and instructed to step on or apply the brakes upon reaching the breaking reference point and come to a full stop. The braking distance traveled is the distance measured in centimeters from the point of reference up to the full stop position of the front wheels of the MHPRE. The average braking distance was found to be 169 cm or 1.69 m.

Table 4. Breaking Test Results

Trial Runs	Speed kph	Braking distance cm
1	5	146
2	5	156.5
3	5	207.5
4	5	167
5	5	170
Average braking distance		169

Figure 6 shows the MHPRE brake testing area where the rider drove the vehicle at a uniform speed of 5 kilometers per hour in five trial runs and measured the respective distance traveled upon applying the brakes safely up to the full stop position. It was found out that the rider was safe in all trials and the MHPRE was stable and in good condition.



Figure 6. MHPRE Brake Testing

Capacity

The capacity load testing was done by placing loads on the MHPRE from a 50 kg-rider up to 3 riders and additional loads up to 400 kgs as the maximum as shown in Fig. 7 and Fig. 8. It was observed that the MHPRE did not break nor fail during the capacity load testing trial runs. The chain did not break and the MHPRE was stable and the parts were all in place during and after the load testing.



Figure 7. MHPRE with riders



Figure 8. MHPRE with loads

Maneuverability

Testing the maneuverability of the MHPRE is necessary since the nature of operation is to make some turning and pivoting while spreading and mixing paddy on the basketball court size sun dryer. The turning radius testing of the MHPRE was conducted by left turning and right turning directions on a marked pivot point as shown in Fig. 8 and Fig. 9 respectively.



Figure 8. Left Turning Radius



Figure 9. Right Turning Radius

It was found out that the left turning radius as measured was 97.29 cm or 3.2 ft., while the right turning radius was 110.49 cm or 3.6 ft. as shown in Table 5. These turning radius will be the basis then of the path of the MHPRE pivoting on the sun drying area during the spreading and mixing of paddy for optimum operation.

Table 5. Turning Radius Test Results

MHPRE Turning Direction	Turning Radius, cm.	Turning Radius, ft.
Left Turning	97.79	3.2
Right Turning	110.49	3.6

Durability

The durability of the MHPRE is of primary concern for the users. In its durability assessment, tests were conducted at different road terrains in Cebu City, Philippines, as shown in Figs. 10,11, 12, and Fig.13. These terrains were the following: rough and uneven road, flat cemented road with hump, inclined cemented road and sloping concrete pavement.



Figure 10. Rough and Uneven Terrain Testing



Figure 11. Plan Road Hump Testing



Figure 12. Inclined Terrain Testing



Figure 13. Sloping Pavement Testing

Installation

The ease of operation is one of the criteria in the development of the MHPRE. The users of this utility vehicle were trained on how to operate, assemble and disassemble the various components of the MHPRE including the mounting and unmounting of the PPR raking tool at the rear of the coupled bicycles. As shown in Fig. 14, the average assembly time took about 20 minutes and the average disassembly time was about 15 minutes since parts were all designed to be mountable and detachable. The assembly and disassembly time of the coupled bicycles and the PPR raking tool will be reduced when the user is very familiar with the processes and techniques after several trials.



Figure 14. MHPRE Prototype Assembly

Speed

The last criteria in the evaluation of the performance of the MHPRE is the speed. In this study, the MHPRE was tested with a single rider driving the utility vehicle on a 500-meter flat concrete road with humps as the pivoting delay obstacles. The average top speed after five trial runs was found to be 6.61 km per hour, as shown in Table 6. After the testing runs, the MHPRE was in good and stable condition.

Table 6. Top Speed Test Results

Trial Runs	Distance, m	Time, Min.	Velocity, kph
1	500	146	7.14
2	500	156.5	6.0
3	500	207.5	7.5
4	500	167	6.52
5	500	170	5.88
Average Velocity			6.61

The rider was safe with no accidents along the way when sudden stops and braking were applied while maneuvering the humps in a 500-meter concrete road as shown in Fig.15. The MHPRE with two riders as shown in Fig. 16 was tested to run on concrete plain road, sloping terrain or changing direction in a steering maneuver, traveling around the curve, on road humps, braking or accelerating or traveling over rough uneven terrain. The range of speed of the vehicle during the testing was about 5–10 kph within a 3 km distance for 7 round trips in seven days. Preventive maintenance was conducted and post field testing trips maintenance check-up was also done to avoid accidents in future trips. During active riding within the traffic filled 3-km distance in the highway, riders were advised to wear helmets and proper orientation was conducted regarding on how to do the steering when changing direction and apply brakes when slowing down and braking for stopover. Although the application of the MHPRE is on a flat concrete basketball court size drying area, it is still necessary to conduct the above speed testing to see to it that the MHPRE is stable, safe to operate and efficient in spreading and mixing paddy in sun drying.



Figure 15. Speed Testing in a 500 m Road



Figure 16. Speed Testing in a 3 km Road

4 CONCLUSION

The development of the Mobile Human Powered Raking Equipment (MHPRE) for spreading and mixing paddy in sun drying is very important in the agricultural sector particularly in post-harvest activities like sun drying of paddy, storage and milling. The two-wheeled innovative detachable and mountable PPR raking tool with adjustable paddy leveling plate was found to be effective in spreading and mixing paddy uniformly at the desired layer depth of 4 cm with respect to time, cost and quality. The four-wheel MHPRE that pulls the paddy rake spreader and mixer with a rider was found to be stable, durable, safe to operate and effective in spreading and mixing uniformly on concrete drying pavement with lesser period of time. Thus, savings of 52.38% was attained in an 8-hour sun drying of paddy using the MHPRE compared to the traditional manual paddy spreading and mixing on concrete pavement. After a series of assessments, the MHPRE is ready for deployment in the agricultural community in the country.

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