Improving the climate variability adaptive capacity of rain-fed farmers in Pabuaran Subdistrict, Sukabumi Regency using environmentally friendly innovation

Aris Pramudia[1*], Abriani Fensionita[2], Mahmud[3], Muzirwan[4], Novi Muhani[5], Retno Pujihastuti[6], Maria Ulfa[7], and Arfiah[8]

{aris029@brin.go.id[1], abriani.ditlin@gmail.com[2], mahm001@brin.go.id[3], muzi001@brin.go.id[4], novimuhani@gmail.com[5], enochubby.rp@gmail.com[6], mariaulfa0891@gmail.com[7], arfiaha@rocketmail.com[8]}

Research Center for Climate and Atmosphere, National Research and Innovation Agency, Jl. Sangkuriang, Dago, Kecamatan Coblong, Kota Bandung Jawa Barat 40135[1,3,4]

Directorate of Food Crops Protection, Director General of Food Crops, Indonesia Ministry of Agriculture, Jl. AUP no.3 Pasar Minggu, Kota Jakarta Selatan 12520[2,5,6,7,8]

Innovation Center for Tropical Science, Jl. Komp. Bogor Raya Permai No.24, RT.05/RW.11, Curug, Kecamatan Bogor Barat, Kota Bogor 16113[1]

*Corresponding Author

Abstract. Pabuaran Subdistrict, Sukabumi Regency has 3.594 Ha of rainfed paddy fields, with a 5.78 Tons/Ha productivity. The rainy season starts in October, and the dry season is in June. The El Nino event impacts delaying the rainy season to November and accelerating the dry season to May. Using pumps to uptake and supply river water can only increase crop productivity to 6.3 Tons/Ha and maintain a cropping index of up to 200% due to the increasing production costs of using fossil fuels. Through assistance provided by researchers, and pest observers, farmers then built waterwheels to uptake river water and distribute it to the paddy field. Thus, farmers can increase the cropping index by up to 300%, increase productivity by up to 6.8 tons/ha, apply environmentally friendly innovation, reduce production costs by up to 3.28 million Rupiahs.ha^{-1}.season^{-1}, or increase profits by up to 106.8%.yr^{-1} compared to using the pump.

Keywords: Farmer's climate variability adaptation, rainfed paddy fields, clean innovation, production cost reduction, profits increasing.

1 Introduction

According to the BMKG's seasonal forecast zoning, Pabuaran Subdistrict, Sukabumi Regency is included in zone 180 or Jabar_08 Zone which has an annual rainfall of 2,684 mm/yr with 6

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wet months and 3 dry months [1], [2]. In this sub-district, there are 3,594 hectares of rainfed rice fields which can only be planted once a year, and 814 simply irrigated rice fields which can be planted twice a year. Rice productivity in the Pabuaran sub-district is 5.78 tons/ha [3]. In Cibadak village there are rain-fed rice fields covering an area of 370.6 Ha and simple irrigated rice fields covering an area of 125.7 Ha. The problems encountered by local farmers in cultivating rice in rain-fed paddy fields are cultivation techniques that are highly dependent on rainfall conditions and limited accessibility to water sources to sufficient crop water requirements [4]. This means that rice can only be planted in paddy fields once a year. Ironically, there are rivers surrounding the rain-fed paddy fields whose water flows all year round. However, there exists a water gap between the river water level and the surface of the field. This is because the river is located lower than the paddy fields. Due to this elevation difference, farmers are unable to access the river water for crop irrigation purposes **(Figure 1)**.

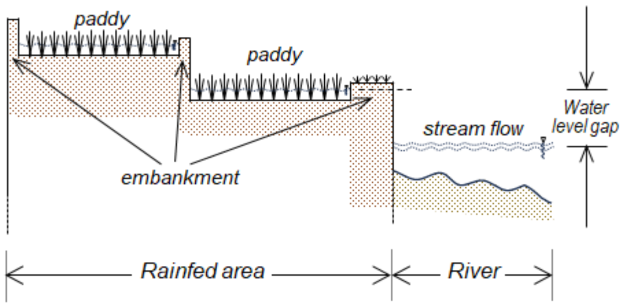

Fig. 1. The gap of water level, the problem of farmers‘ rainfed area in Cibadak Village Pabuaran Subdistrict, Sukabumi Regency.

To fulfill the crop water requirements using river water that is lower than their paddy fields, farmers pump up river water and distribute it to the land using fossil fuel-powered pumps. However, this has several negative consequences. Firstly, it increases production costs because farmers have to buy fossil fuels. Secondly, the fuel spill contaminates parts of the land. Due to the rise in production costs, farmers are less inclined to plant three times a year. Through the assistance of pest observers, extension workers, and researchers, local innovations are encouraged to replace the use of river water for land irrigation, such as implementing a water wheel.

There are three main types of gravity water wheels: overshot, breastshot, and undershot wheels. The overshot water wheel is the wheel with the water entering from the top or upstream side, the breastshot water wheel is the wheel with the water entering from the middle, and the undershot water wheel is the wheel with the water entering from the base or bottom stream side [5], [6]. The undershot wheels are the best choice installed in the river streamflow.

The use of water wheels is an effort to apply environmentally friendly technology to move water from rivers to land. Environmentally friendly technology is a technology that is created to make human life easier but does not cause damage or hurt the surrounding environment [7]. Among the principles of environmentally friendly technology related to the design of waterwheels, include: Refine, which means using environmentally friendly materials and using a process that is safer than previous technology; Reduce, which means reducing the amount of waste by optimizing the use of materials; and Retrieve Energy, which means energy savings in a production process.

The aim of the paper is to describe how farmers fulfill the crop water requirements by using either fossil fuel-powered pumps or water wheels to extract water from the river. The paper also intends to compare the efficacy of both methods to aid the adoption of climate-resilient farming practices with the help of pest observers, extension workers, and researchers.

2 Methodology

The study was conducted in the Pabuaran Subdistrict, Sukabumi Regency. This sub-district has a food crop farming area which is generally rain-fed and dry land. The study location is located approximately 57 km south of Sukabumi City **(Figure 2)**. The cropping calendar at the study location is limited by the condition of the land which is rain-fed land that only depends on rainfall patterns, as well as due to the gap between river water levels which are lower than agricultural land. To sufficiently the crop water requirement, farmers then use pumps to uptake water from the river to the land. This effort increases production costs and farmers do not use it all the time. Through assistance provided by Pest Observers, Extension Workers, and Researchers, a water wheel was then built which was used to uptake water from the river to the land. Making and using waterwheels by farmers not only reduces operational costs but also innovates in the application of environmentally friendly technology through the use of natural energy, saving on the use of fossil fuels and reducing the potential for environmental pollution that often occurs when using fossil fuels.

The scope of activities includes data collection and rainfall analysis to learn the characteristics of rainfall at the study location, analysis of the rainfall variability related to El Nino and La-Nina events, analysis of cropping calendar under existing conditions compared to the conditions for implementing environmentally friendly technological innovations as efforts to anticipate the impact of climate change, and comparative analysis of food crop farming in existing conditions, through the use of fossil fuel-powered pumps, and the use of water wheels.

Fig. 2. The location of the study, Cibadak Village at Pabuaran Subdistrict, Sukabumi Regency.

2.1 Rainfall data compilation and analysis

The rainfall data used is ten daily rainfall data obtained from BMKG during the 2016-2022 period. Pabuaran Subdistrict rainfall data is the result of analysis of satellite data based on seasonal forecast zones corrected with surface observation data. Then, the zone-based data rainfall data was converted to sub-district based as carried out by the Balitbangtan Integrated Cropping Calendar Team [8], [9].

2.2 Water and crop pattern management through the application of clean technology

The water wheel is an undershot water wheel that utilizes a river water stream at the bottom of the wheel. The diameter of the wheel is around 6 meters. On the outside of the wheel, 40 blades are installed with a size of around 50 x 40 cm2. The position of the mill is located approximately 1-2 meters from the river bank, not too far from the river bank to avoid being hit by strong streamflow which could damage the wheel **(Figure 3)**. Attached to the blade is a bamboo tube that will dredge the river water lift it to the top of the wheel, and then enter a channel that will drain it into a water reservoir in the paddy field by gravitally. The operation of the wheel only uses energy from river streamflow and does not use fossil fuels so it does not pollute the environment. Sufficient irrigation water through water wheel applications makes it easier for farmers to prepare land that is not prone to drought and can carry out planting seasons 3 times a year.

Fig. 3. Designing the waterwheels by farmers at Cibadak Village Pabuaran Subdistrict, Sukabumi Regency.

2.3 Farming analysis in crop management

To reveal the added value of waterwheel use, a farming analysis of water management, productional costs, harvest sales, and profits obtained by farmers was carried out. The analysis was carried out in existing conditions where farmers only depend on the water availability of rainfall, farmers who sufficiently their crop water requirements using fossil fuel-powered pumps, and farmers who sufficiently their crop water requirements using water wheels.

3 Results and Discussion

3.1 Rainfall conditions, cropping seasons, and their variability due to climate change

Pabuaran District has a monsoon rainfall pattern, meaning it has a seasonal pattern where there is a significant difference in the amount of rainfall between the wet season and the dry season. Normal annual rainfall is around 2,468 mm/year, with an average number of consecutive wet months at an intensity >200 mm/month of 6 months, and an average number of consecutive dry months at an intensity <100 mm/month of 3 months [10] **(Figure 4)**.

Rainfall observation data for 7 years (2016-2022) illustrates that under normal conditions the start of the rainy season occurs in September III, while the start of the dry season occurs in June II. Thus there is a planting season period of approximately 27 decades. During this period, food crops can be planted twice a year, where the first and second planting seasons can each be planted for 12 decades.

In La-Nina conditions, the start of the rainy season occurs earlier in September I, while the start of the dry season is later in July I or July III, even under certain conditions there is no dry season. Thus there is a growing season period of approximately 33 decades or more. During this period, food crops can be planted 2-3 times a year, each planting for 12 decades each season.

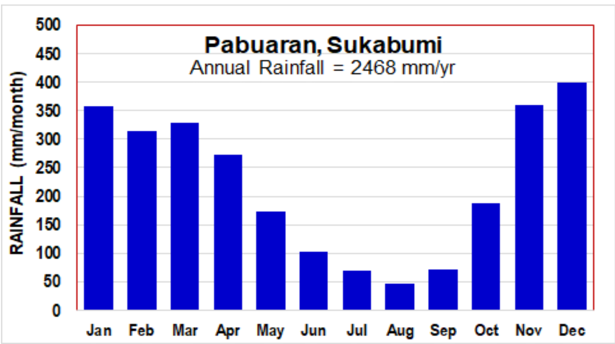

Fig. 4. The monthly rainfall pattern at Pabuaran Subdistrict Sukabumi Regency.

Table 1. Impact of the climate anomaly on the start of Wet and Dry Season and the length of the growing periods (decades) at Pabuaran Subdistrict Sukabumi Regency.

ENSO Events	Start of Wet Season	Start of Dry Season	LGP (decades)
El-Nino	November III	May III	19
La-Nina	September I	July I, July III, or No Dry Season	33 or more
Normal	September III	June II	27

Note: LGP = The length of the growing period

Under El-Nino conditions, the start of the rainy season occurs later in November III, while the start of the dry season occurs earlier in May III. Thus there is a planting season period of approximately 19 decades. During this period, food crops can be planted once, or they can be forced to be planted twice a year with the risk of agricultural failure in the second planting season **(Table 1)**.

3.2 Utilization of water wheels in water management and cropping patterns

The components and installation of the water wheel include (1) the wheel body in the form of two bamboo parallel circles with a diameter of about 6 meters and a distance between the circles of about 50 cm, (2) rectangular blades of woven bamboo measuring 40 cm x 60 cm, installed in between two ring circles, (3) 'lodong' or tube, placed at the ring circle, (4) pillar supporting the mill, also assembled from bamboo, (5) intake pipe, made from serially connected bamboo, (6) water reservoir in rice fields, (7) distribution pipes from the water reservoir to the land. The water is collected and distributed as follows: (1) The blade at the end of the outer circle of the waterwheel will receive kinetic energy from the water streamflow so that the waterwheel rotates in the direction of the river flow. The blade is designed to be slightly curved to absorb the kinetic energy of the river flow, (2) the blade at the bottom of the wheel when it sinks below the water surface will scoop up the water and lift it to the top of the wheel, (3) at the top of the wheel the blade will spill the water that was scooped up into the intake pipe, (4) through the intake pipe, river water is channeled to the water reservoir on the field, (5) the water collected in the water reservoir is then distributed through the distribution pipe by gravity **(Figure 5)**.

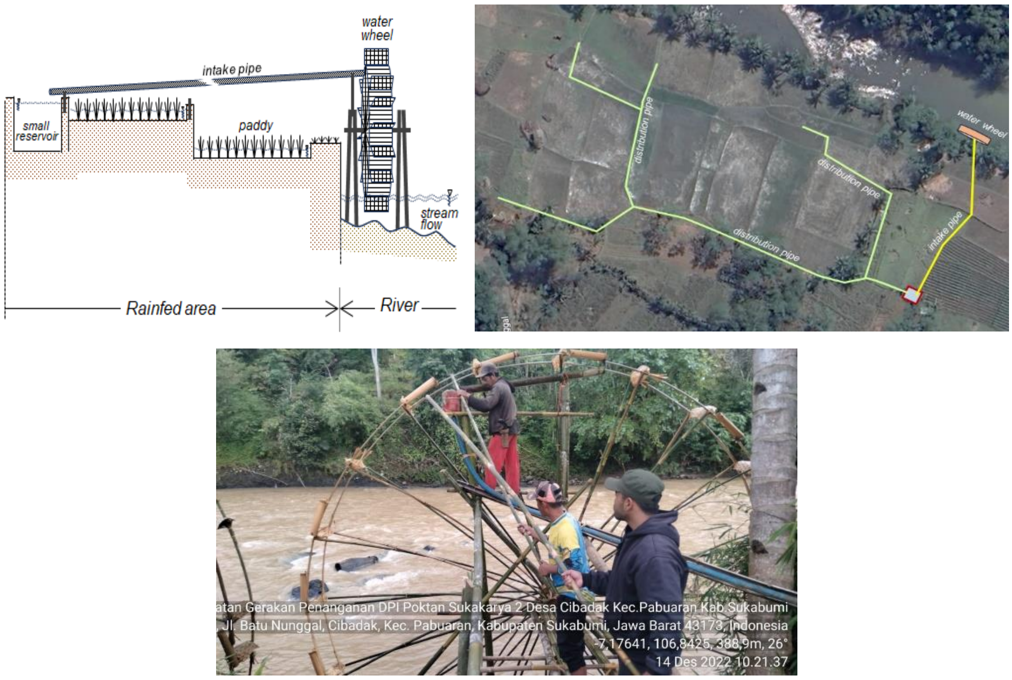

Fig. 5. The scheme of water wheels' position on the river bank, and design of water management from the water wheel to the paddy field.

In the dry season, the river water decreases and recedes. To ensure that there is still river flow under the waterwheel, the river bed is deepened and designed to form a channel that carries water under the waterwheel so that the waterwheel can continue to rotate and channel water to the land. During the rainy season, the river water flows quite fast, so it can potentially damage several parts of the wheel, especially the blades, wheel axles, and wheel spokes. Generally, waterwheels have a lifespan of 2 seasons, even up to 2 years, however, during their use, some of the parts can also wear out and break due to hot weather. Therefore, the main maintenance of a waterwheel is to repair or replace the blade components, wheel spokes, or support pole construction if they are damaged due to river currents or worn out due to weather. However, the biggest operational cost of using a waterwheel is the cost of making it.

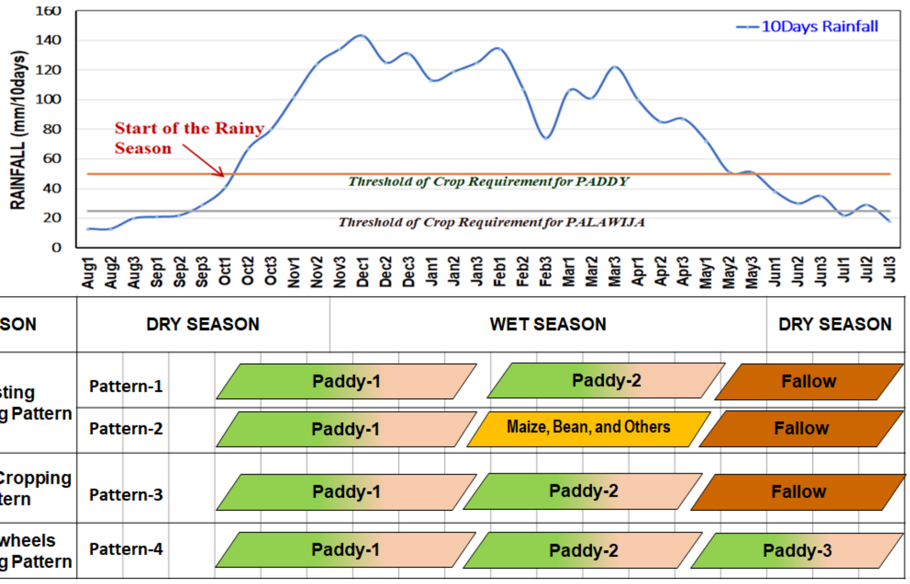

Fig. 6. Comparison of the existing cropping pattern with the planting pattern if the irrigation water supply uses a pump, and the planting pattern if the irrigation water supply uses a water wheel.

At the study location, in rain-fed paddy fields that depend only on rainfall for water, farmers can only plant 1-2 times a year. There is a risk of agricultural failure in the second planting season. Farmers then try to sufficient their water requirements using fossil fuel-powered pumps. Farmers can increase the planting season but with the consequence of increasing operational costs for providing fuel. Therefore, farmers are only able to carry out planting seasons up to two times. The next alternative is that farmers try to apply the use of water wheels to provide water to meet the needs of plants and the cultivation process. The use of a water wheel is very practical because it only uses renewable energy in the form of the kinetic power of river streamflow. The existence of a water wheel allows farmers to supply water to the field as long as it is needed and as long as there is still river water flowing. Therefore, by using this water wheel, farmers can plant 3 times a year without any additional operational costs **(Figure 6)**. Although there might not be a direct correlation between rainfall and the use of waterwheels in the study location, however, the increasing operational costs have reduced farmers' interest in using fossil fuel-powered pumps. As a result, farmers are considering waterwheels as an alternative to supply their water requirements for the second and third planting in rainfed paddy fields.

3.3 Comparative farming analysis

Table 2 presents a comparison of rice farming under different conditions, including conventional methods, the use of fossil fuel-powered pumps, and the use of water wheels. To compare the three water management techniques, several assumptions are made, such as the projected cost requirements for the same area and the same use of fertilizers, pesticides and labor in cultivation management. In conventional farming, there are no budget requirements for water management. However, in farming using fossil fuel-powered pumps, there are initial costs for purchasing the pump, as well as purchasing fuel to use the pump. In farming using waterwheels, initial costs are incurred for purchasing materials for making the waterwheel. It is assumed that the making of the wheel is carried out through mutual cooperation, so there is no cost for labor to make the wheel.

In conventional farming, the planting index is typically 1-2 times per year, with an average value of 1.5. However, when farmers use fossil fuel-powered pumps for irrigation, they can actually plant up to 3 times per year. The downside is that the additional cost of purchasing fuel reduces farmers' interest in planting during the third season. As a result, the planting index for farming using pumps is 2. On the other hand, farmers prefer using water wheels for irrigation, which allows them to plant during both the second and third planting seasons. Therefore, the planting index for farming using a water wheel is 3..

In conventional farming, the total production cost is IDR 14,850,000.yr^{-1}. With an average productivity of 5.78 Ton.ha^{-1}, the total income of farmers is IDR 43,350,000.yr^{-1}. So farmers get a profit of IDR 28,500,000.yr^{-1}. By using a fossil fuel-powered pump, farmers can plant crops twice a year, with a total production cost of IDR 25,410,000.yr^{-1}. With an average productivity of 6.30 Ton.ha^{-1}, the total income of farmers is IDR 63,000,000.yr^{-1}. So farmers get a profit of IDR 37,590,000.yr^{-1} or almost 32% higher than conventional farming. By using a water wheel, farmers can plant 3 times a year, with a total production cost of IDR 24,275,000.yr^{-1}. With an average productivity of 6.80 Ton.ha^{-1}, the total income of farmers is IDR 102,000,000.yr^{-1}. So farmers get a profit of IDR 77,725,000.yr^{-1} or around 173% higher than conventional farming or 107% higher than farming using fossil fuel pumps.

At the study location, the use of water wheels provides not only economic benefits but also environmental ones. Compared to using fossil fuel-powered pumps, waterwheels offer a sustainable way of utilizing renewable energy. This is because the kinetic energy that drives the wheel is readily available as long as the river flows, and it also provides a solution for irrigation by overcoming the difference in height between the water level and agricultural land. Additionally, the environmental impact of using waterwheels is minimal since it does not generate any waste that can pollute the surroundings, unlike fossil fuel-powered pumps. Using fossil fuels on agricultural land can potentially contaminane the soil, water, and plants, and disrupt plant growth, resulting in stunted growth, burnt plants, and reduced productivity [11], [12].

Table 2. The analysis of farming costs using waterwheels and fossil fuel-powered pumps compared to conventional.

No.	Parameter	Conventional Farming	Farming with fossil fuel-powered pumps	Farming with a water wheel
1.	Cropping Index (season)	1-2	2	3
Production Cost				
1.	Seed	325,000	325,000	325,000
2.	Fertilizer: (500 kg Petroganic, 300 kg Phonska, 200 kg Urea)	1,540,000	1,540,000	1,540,000
3.	Pesticide	500,000	500,000	500,000
4.	Water management:			
	- Rainfed	0	-	-
	- Pumps	-	4,500,000	-
	- Fuel 60 ℓ	-	780,000	-
	- Water wheel	-	-	2,000,000
5.	Labor (Soil preparation, planting, weeding, fertilization, spraying, harvesting)	5,060,000	5,060,000	5,060,000
6.	Total cost			
	Rp.season^{-1}	7,425,000	12,705,000	9,425,000
	Rp.yr^{-1} (‡)	14,850,000	25,410,000	24,275,000
Productivity				
1.	Weight (Tons.ha^{-1})	5.78	6.30	6.80
2.	IDR (Rp.ha^{-1}.yr^{-1})†	43,350,000	63,000,000	102,000,000
Profit:				
1.	Rp.ha^{-1}.yr^{-1}	28,500,000	37,590,000	77,725,000
2.	% of conventional	100,0	131,9	272,7
3.	% of pumps	75,8	100,0	206,8

† assumed that the mean of the selling price of grain is IDR 5,000/kg.

‡ no costs for making waterwheels in the second and third planting seasons.

Waterwheels have been used for generations to lift water from river sources, based on local wisdom. However, due to the remote location and lack of resources, the technology didn't develop much. Recently, farmers have once again embraced the use of waterwheels due to their positive benefits. There are currently around 30 waterwheels in the study location and their surroundings are being used for similar purposes. In the future, assistance from related stakeholders is required to develop better waterwheel construction technology that is capable of withstanding heavy flow and hot weather while remaining sustainable.

4 Conclusion

A major problem in the rainfed paddy area of Pabuaran Subdistrict, Sukabumi Regency, is the high dependency on rainfall and lack of access to water sources due to the gap between the water level in rice fields and the river. To address this, Pest Observers, Extension Workers, and Researchers have assisted by introducing an undershot water wheel. This environmentally friendly technology refines, reduces, and retrieves energy and allows farmers to bring water from the river to their fields as required, resulting in up to three cropping seasons per year. By using the undershot water wheel, farmers can lower their production costs per season, earn higher incomes of up to IDR 102,000,000 per year, and achieve a profit that is 173% higher than conventional farming or 107% higher than farming that uses fossil fuel-powered pumps. Furthermore, the use of water wheels has a positive impact on the environment and plant health. However, there is a need for continued assistance and support from related stakeholders to enhance the quality and sustainability of the water wheel in the study area.

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