



Sustainable Development Strategies of Rainfed Paddy Fields in Central Java, Indonesia: A Review

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Abstract

Rainfed paddy fields have a great potential to be developed in Indonesia, especially in Central Java. However, water irrigation management, drought stress, pest and disease infestation and low nutrients that affect paddy yield remain the constraints. Unpredictable climate pattern is also a limiting factor in the cultivation of rainfed paddy fields. This narrative review aims to identify and discuss solutions to problems that exist to increase the yield of rainfed paddy fields with several techniques that support sustainable agriculture. This review paper was prepared by collecting government data and interviews with several farmer group leaders as complementary data. Based on field conditions, farmers in rainfed paddy fields provide fertilization inputs that are not following the fertilizer recommendations. Moreover, field conditions with limited water availability have caused paddy cultivating in several locations only once a year with low yields. Water storage can help farmers meet the need for water, especially during dry and water-stress conditions. The farmers also need to pay attention to the appropriate fertilization doses and the use of additional organic matter derived from cultivation residues, which are expected to increase the availability of nutrients in the soil. The use of short-life and drought-resistant varieties can aid in overcoming the problem of crop failure in the middle phase caused by water scarcity. Finally, we identify and emphasize that rainfed paddy fields generally have a limiting factor for water and nutrients and several technologies are needed to contribute to increasing more sustainable paddy yields.

Keywords: agronomical practices; drought-resistance rice; organic matter; productivity; water management

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INTRODUCTION

Agriculture is one of the essential sectors in Indonesia. It also gives a considerable contribution to Indonesia's economic growth (Statistics Indonesia, 2021). One of the core issues in agricultural commodities is rice. As the staple food of Indonesia, rice consumption in 2020 was 78.52 kg year⁻¹ for the nation per capita (Statistics Indonesia, 2021). Increasing population also

affects food demand, especially national rice consumption per capita. That has become the government's attention to providing food, mainly rice, during the limited productivity of paddy each year.

Statistics Indonesia (2022) reported that Indonesia's paddy harvested area in 2021 was around 10,515,323 ha. It decreased by around 0.013%, compared to the area in 2020, which was 10,657,274. The total harvest area consists of

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wetland paddy fields (93%) and dryland paddy fields (7%) (Agricultural Statistics, 2019) and thus, it requires technology to optimize the use of dryland paddy fields and increase the harvested area. Most dry paddy fields in Central Java Indonesia are categorized as rainfed paddy fields, paddy fields that depend on rainwater as the main irrigation source. Rainfed paddy fields in Indonesia are included in the category of non-irrigated paddy fields. The area of non-irrigated paddy fields is around 46.46% or 3,301,503 ha (Agricultural Statistics, 2019). Rainfed paddy fields are spread across various areas in Central Java, including in Blora, Pati and Rembang Regency.

Cropping systems in the rainfed areas, especially in Blora, Pati and Rembang, commonly take traditional cultivation with a low crop index around 100 (Statistics of Blora Regency, 2019). In Indonesia, there are three crop seasons a year. As a tropical country, Indonesia has two seasons: rainy season (November to June) and dry season (July to October). However, crop patterns on rainfed paddy fields depend on the dry and rainy seasons each year. In the rainfed areas, paddy plants are cultivated on the rainy season until early in the dry season, typically from November to July. They are planted once to twice a year, namely in the first and second crop seasons. The last crop is grown with beans or maize from August to October. However, the farmers on the rainfed paddy fields often decide to fallow their fields at the end of the dry season and this depends on the availability of rainwater (Setiawan et al., 2016; Apriyana et al., 2017).

Water scarcity is a dominant problem in the rainfed paddy fields and this increases the risk of drought stress (Alou et al., 2018). The amount of rainfall determines the yield on the rainfed paddy fields (Mathanraj and Kaleel, 2016). The availability of water determines plant growth. Plants deactivate functional cells as a form of defense against the drought. Moreover, water stress causes decreasing leaf (Purbajayanti et al., 2020). On other hand, rainfed paddy fields have several drought adaptations, such as root volume, leaf water-loss percentage and leaf rolling (Ding et al., 2013). Water scarcity also impacts soil nutrients. Nutrient availability is one of the limiting factors in rainfed paddy fields. Drought possibly affects microbial and enzyme activities, the most important components

in biogeochemical processes. Reduced water availability can exacerbate and limit soil nutrient such as phosphorus deposition effects by increasing its immobility in the soil (Olatunji et al., 2018). Nutrient availability also affects paddy yield. Mboyerwa et al. (2021) reported that nutrient levels especially N influence the grain yield.

Purbajayanti et al. (2020) reported that water stress reduces the rate of soil nutrient diffusion toward the nutrient uptake by roots. Increasing soil temperature also relates to the decrease of soil moisture. It affects soil microbial activities and soil nutrient processes. Microbial activities on soil are commonly controlled by soil moisture and soil temperature (Borowik and Wyszowska, 2016) as the microbial actions on soil help decomposition process and affect soil organic matter content (SOM) (Yuan et al., 2013). Other than that, increasing soil temperature will increase carbon dioxide emission (CO_2). Another nutrient, Nitrogen (N), generally NO_3^- form, is also released in the soil system and therefore, it cannot be absorbed by plants properly. Disruption of the system can affect nutrient availability and enzymatic activities, which are essential for biomass and grain yield (Chatzistathis and Therios, 2013).

Unpredictable rainfall, drought stress, flooding and erosion as the impacts of climate change cause planning for rainfed paddy fields erratic and certainly affect the yield (Gitz et al., 2016), whereas Liliane and Charles (2020) mentioned that climate is an abiotic factor supporting the growth and yield of the crop. Another problem of rainfed paddy fields in Blora, Pati and Rembang is the fertilizer application dose. Based on the interviews, the farmers usually use fertilizer inputs that are not in accordance with the dose (shown in Table 1). Chandini et al. (2019) reported that overuse of synthetic fertilizer without recommendation can cause nutrient imbalance, increasing bulk density, soil degradation and destruction of soil structure. Moreover, the overuse of synthetic fertilizers in the long term can cause environmental problem, such as water pollution, water eutrophication and soil pollution such as increasing soil acidity and increasing greenhouse gases especially N_2O emission.

However, there is development potential for the rainfed paddy fields in Blora, Pati and Rembang. Rainfed paddy fields make up

almost 65.61% of the overall paddy fields in the Blora Regency and around 71.69% of the total paddy fields in Rembang (Table 2). To maximize potential and raise productivity, rainfed paddy fields, which predominate in Blora and Rembang, require additional attention. To achieve a high yield and sustainable agricultural farming, however, reform initiatives must also take the environment into account (Ray and Chakraborty, 2021). This paper aims to identify the constraints and discuss the solutions to face the problems and increase the yield of rainfed paddy fields with several techniques that support sustainable agriculture.

MATERIALS AND METHOD

Several comprehensive sources such as government data (Statistics and Agricultural Data of Blora, Pati and Rembang), peer-reviewed publications and other supporting data were collected to complete this review article. Furthermore, field surveys were carried out by doing an in-depth interview with the nine farmer group leaders in Blora, Pati and Rembang. Each farmer group leader is the representative of 25 to 50 farmers. However, there is one leader of farmer group, namely Sido Rukun Pati with around 100 farmer members. The farmer groups in Blora include Dadi Mulya, which is located in Prantaan, Bogorejo, Blora ($6^{\circ}56'19.2984''$ S to

$6^{\circ}58'0.984''$ S and $111^{\circ}29'7.872''$ E to $111^{\circ}30'36.864''$ E); Trisno Bongso, which is located in Klopoduwur, Banjarejo, Blora ($7^{\circ}0'20.34''$ S to $7^{\circ}3'24.084''$ S and $111^{\circ}23'41.676''$ E to $111^{\circ}25'19.092''$ E); and Mitra Tani, which is located in Prantaan, Bogorejo, Blora ($6^{\circ}56'19.2984''$ S to $6^{\circ}58'0.984''$ S and $111^{\circ}29'7.872''$ E to $111^{\circ}30'36.864''$ E). The farmer groups in Pati are Mukti Rahayu, which is situated in Kebonturi, Jaken, Pati ($6^{\circ}44'55.2372''$ S to $6^{\circ}46'8.112''$ S and $111^{\circ}10'37.1532''$ E to $111^{\circ}11'53.8728''$ E); Sido Rukun, which is situated in Sukopuluhan, Pucakwangi, Pati ($6^{\circ}47'54.3336''$ S to $6^{\circ}49'22.8036''$ S and $111^{\circ}9'36.8136''$ E to $111^{\circ}11'33.5832''$ E); and Sengkut Tani in Batangan, Pati ($6^{\circ}43'59.016''$ S to $6^{\circ}44'55.9428''$ S and $111^{\circ}9'46.7928''$ E to $111^{\circ}10'47.1468''$ E). The farmer groups in Rembang consist of Gotong Royong 1 and Gotong Royong 2, which are located on Kaliori, Rembang ($6^{\circ}44'39.8364''$ S to $6^{\circ}45'16.5996''$ S and $111^{\circ}14'1.554''$ E to $111^{\circ}15'25.686''$ E); and Tani Rahayu 3, which is situated in Sumber, Rembang ($6^{\circ}46'56.4276''$ S to $6^{\circ}48'25.92''$ S and $111^{\circ}15'3.5856''$ E to $111^{\circ}17'3.0408''$ E). Interviews were conducted from November to December 2021. The results of this interview were used to complete the review. The locations of Blora, Pati and Rembang are presented in Figure 1.

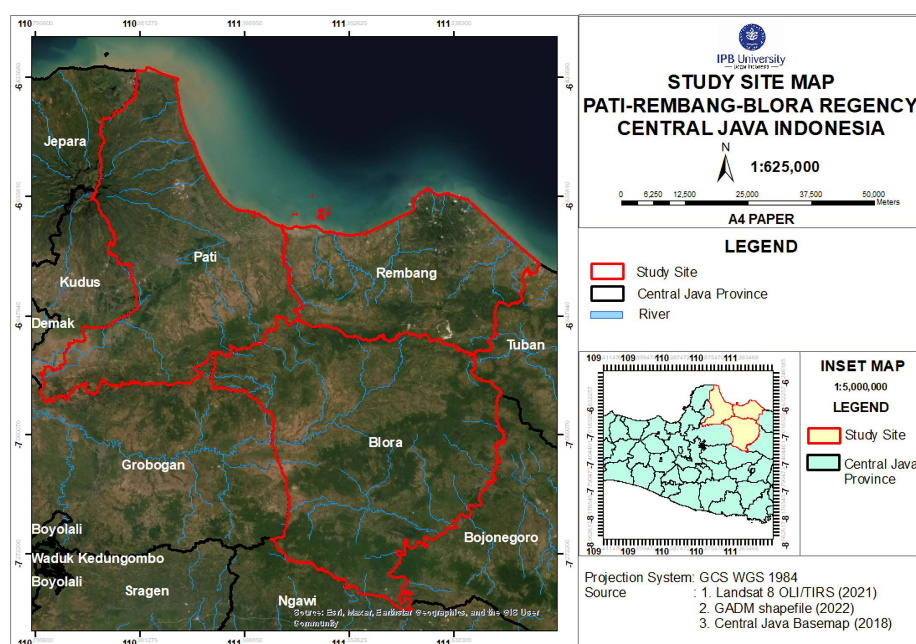


Figure 1. Study site map

RESULTS AND DISCUSSION

Challenge faced by rainfed paddy

Water and drought stress

Rainfall in Blora, Pati and Rembang is not much different. Figure 2, 3 and 4 present

rainfall data for Blora, Pati and Rembang in 2021. The highest rainfall in the three regencies is in January, with an average rainfall of 12.1 inches or around 307.34 mm month⁻¹. The lowest rainfall is in August, with an average of 0.9 inches or around 22.86 mm month⁻¹.

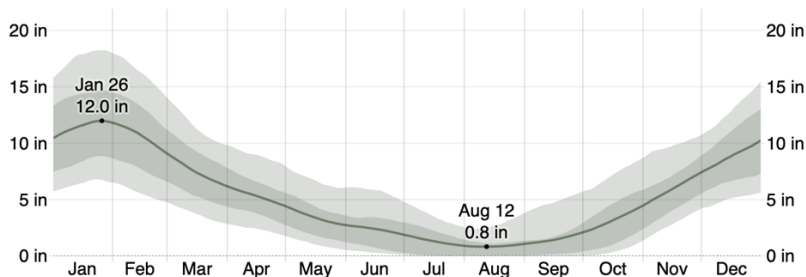


Figure 2. Average monthly rainfall in Blora in 2021 (source: waterspark.com)

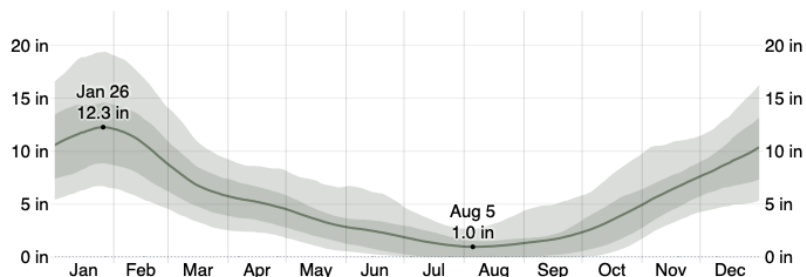


Figure 3. Average monthly rainfall in Pati in 2021 (source: waterspark.com)

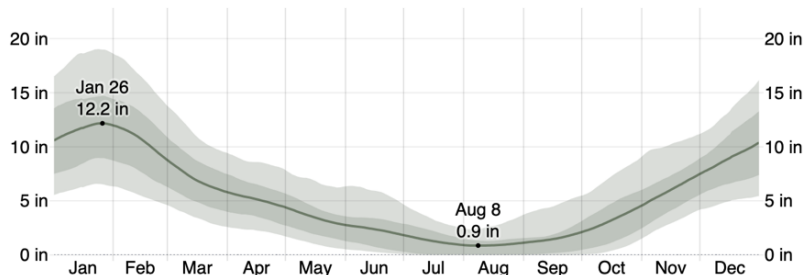


Figure 4. Average monthly rainfall in Rembang in 2021 (source: waterspark.com)

The El Nino-Southern Oscillation (ENSO) climate pattern strongly influences rainfall in Indonesia, especially in Java. Indonesia's Meteorological Climatological and Geophysical Agency (BMKG) stated that ENSO is an increasing sea surface temperature above normal conditions in the central Pacific Ocean. In average condition, the tropical western Pacific Ocean is warmer than the eastern Pacific Ocean. As a result, equatorial winds are moving westward, helping the convection over the west Pacific Ocean and settling over the east Pacific

Ocean. ENSO climate patterns can restrain the wet season and have negative impacts such as drought due to reduced rainfall, especially from June to August. This, certainly, can threaten agricultural fields, particularly paddy and probably cause crop failure. The rainfall affects the availability of water, mostly in unfavorable climatic conditions. Thus, water scarcity is a significant problem in the rainfed paddy fields. Late or low rainfall during the rainy season might cause planting and fertilization delays since plowing and applying fertilizer need water.

Soil characteristics

Generally, rainfed paddy fields in Blora, Pati and Rembang are spread around the northern Kendeng Mountains and thus have nearly identical soil type. The data from Department of Agriculture of Pati (2021) recorded that the dominant soil types are grumusol (vertisols), inceptisols and alfisols. Kasno et al. (2016) reported that soil in Jakenan, Pati, has a clay texture and is slightly acidic (pH 5.4). The soil has low levels of organic C, total N, P and K nutrients, as well as Ca and Mg cations. The cation exchange capacity (CEC) is low and as a consequence, the organic C, N, P and K nutrients and soil CEC are the limiting factors for paddy growth in Pati.

Ritung and Suryani (2013) reported that Kunduran, Blora, has a variety of soil types such as entisols, inceptisols, mollisols, vertisols and alfisols. The soil's pH ranges from slightly acidic to alkaline, its CEC is moderate to high, the P₂O₅ content is moderate to very high, the K₂O is generally low and the total N is very low. Kadarwati (2016) noted that the soil types in Rembang are entisols, inceptisols, vertisols and alfisols. The characteristics of the soil types are very low to low total N and total C, very low to very high available P, very low to high available K, low to high organic matter, very acidic to slightly alkaline pH and moderate to very high CEC. The level of soil fertility varies from low to moderate with the main constraints including N content, pH, available P, organic C and available K.

Virmani et al. (1982) described vertisol as a soil that contains a clay-size particle around 30% or more in all layers or horizons and can crack at least 1 cm, around 0.4 inches, wide extending downward from the land surface. The high content of clay fraction combined with the dominance of smectite minerals is one of the causes of vertisol's properties difficult to process in wet and dry conditions.

Prasetyo (2009) reported that vertisols in Indonesia mostly contain > 60% of the clay fraction. Organic matter content is generally low, ranging from 0.06 to 4.46%, decreasing with soil depth. Prasetyo (2007) also observed that the clay mineral smectite is probably contained in paddy soils. Smectite mineral is a 2:1 mineral type that can affect the paddy soil's physical and chemical properties. The essential properties of smectite include having a negative charge,

which makes this mineral very reactive in its environment. Soils containing smectite clay mineral have high clay fraction (33 to 92%) and are neutral to alkaline soil reaction with soil pH of 6.5 to 8.0. The availability of micronutrients (Fe, Cu, Zn and Mn) is commonly low due to low soil acidity. Organic matter content is low to moderate, while potential K content, bases (Ca and Mg) and CEC are generally high. Vertisols have the potential to develop, since they contain high plant nutrient content, but they are not well suited to cultivation without careful management due to their high clay content (Prasetyo, 2007).

Fertilizing dose

Fertilization is one of the essential inputs in paddy cultivation. Fertilization is also a critical factor determining nutrient uptake, plant growth and yield. In order to increase the effectiveness of nutrient usage and nutrient loss, it is necessary to monitor the fertilization dose (Yousaf et al., 2017).

Table 1 presents the fertilizers used by farmers in paddy cultivation by in-depth interviews in each farmers group. Based on interviews, the farmers in the Blora cultivate paddy once or twice a year, while the farmers in Pati and Rembang cultivate paddy twice a year. The frequency depends on the availability of water, especially rainwater, as previously mentioned. Farmers with rainfed paddy fields mainly provide a various dose of organic matter as input for fertilization. They typically use synthetic fertilizers since adding organic matter needs more than synthetic fertilizer. Paddy straws are rarely used as an addition to soil organic matter but mainly used as livestock feeds. Additionally, there is an opportunity to add straw and other harvested biomass, like that from corn, to the organic matter.

Table 1 shows that farmers in each area provide different fertilizer doses. The dominant fertilizers given include Urea, NPK, ZA and KCl. The Ministry of Agriculture regulates the site-specific nutrient management. Husnain et al. (2020) reported that the fertilizer dose requirement in Pati Regency is 150 to 250 kg ha⁻¹ of NPK and 150 to 250 kg ha⁻¹ of Urea. The fertilizer need in Blora Regency is 200 to 350 kg ha⁻¹ of NPK, 100 kg ha⁻¹ of ZA and 50 to 100 kg ha⁻¹ of NPK. Meanwhile, it was recently suggested on Sumber Sub-district,

that the need for fertilizer application in Rembang Regency is 200 to 350 kg ha⁻¹ of NPK, 50 to 125 kg ha⁻¹ of Urea and 100 kg ha⁻¹ of ZA. Based on the recommendation, farmers in Pati and Rembang give fertilizers that are higher than the recommended dose, whereas farmers in the rainfed lowland areas of Rembang provide inputs that are less than the recommended

dose. Fertilizer application based on region-specific needs gives various advantages, such as providing plant nutrient intake according to needs, reducing nutrient loss and lowering the adverse effects of the environment, especially water and soil, from excessive use of fertilizers in the long term (Shambhavi et al., 2017).

Table 1. Average fertilizer consumption in each regency based on the in-depth interviews

Regency	Frequency of cultivating paddy	Fertilizer dose used				
		Organic matter (t ha ⁻¹)	Urea (kg ha ⁻¹)	NPK (kg ha ⁻¹)	ZA (kg ha ⁻¹)	KCl (kg ha ⁻¹)
Blora	Once - twice a year	0 - 0.20	250 - 400	0 - 200	150 - 200	-
Pati	Twice a year	0 - 3.00	200 - 250	± 250	-	0 - 50
Rembang	Twice a year	0 - 0.48	-	160 - 200	0 - 40	-

Low paddy yield

Yield is a significant concern in paddy cultivation activities. Table 2 presents the average paddy productivity in the last five years in Blora, Pati and Rembang, which is less than 5 t ha⁻¹, with no significant increases in yield occurring on a regular basis. It is undesirable considering that rainfed paddy fields almost entirely dominate the paddy fields in the Blora and Rembang area. As a result, various aspects become impediments and management becomes less optimal. This has an effect on paddy yield. The main issue in paddy cultivation in lowland paddy fields is a lack of water. The main causes

of irregular fertilization times are limited water sources and unpredictable rainfall and this can be one of the reasons for low yields.

Interviews with farmers noted that farmers did not follow fertilizer recommendations. They apply fertilizers in low or high doses. However, it was also reported by the Department of Agriculture of Blora, Pati and Rembang that the amount of fertilizers did not affect the yields. Yield productivity in Blora was around 4.50 t-ha⁻¹ in 2020, which was higher than those in the other two regencies. On the other hand, the yield productivity in Rembang was the lowest, with about 2.90 t ha⁻¹.

Table 2. The rainfed fields area, total paddy area and productivity in Blora, Pati and Rembang Regency in the last five years

Regency	The rainfed field area (ha)	Total paddy area (ha)	Average productivity in 5 years (t ha ⁻¹)				
			2016	2017	2018	2019	2020
Blora	30,573	46,593	4.02	4.59	4.70	4.37	4.50
Pati	21,025	56,641	4.13	3.90	3.61	2.55	3.23
Rembang	20,803	29,015	3.26	3.48	4.04	3.20	2.90

Source: Department of Agriculture of Blora, Pati and Rembang Regencies (2021) (Unpublished)

Many factors cause low yields in rainfed paddy fields in Blora, Pati and Rembang, such as limited water sources, unpredictable rainfall, poor soil nutrients, and poor crop and land management. In general, the farmers in the three areas apply traditional agricultural cultivation activities. The Statistics of Blora Regency (2019) identified that 21.27% of the total paddy field area (9.855 ha) of rainfed paddy fields were cultivated once and 41.94%

of the total paddy field area (19.426 ha) were cultivated twice in a year. Farmers can increase paddy yields per ha or paddy productivity by using the dominant cultivating frequency of two times. Furthermore, rainfed paddy fields account for 65.62% paddy fields in Blora. On the other hand, rainfed paddy fields in the Rembang account for 71.69% of paddy fields. Therefore, it has a high potential for increasing paddy yields.

Strategies towards sustainable land management and paddy yields

Water management practices

Water availability is one of the main problems in the rainfed paddy fields. Since the rainfed paddy fields depend on rainwater, farmers cannot control the water level and the availability of water on the fields. Moreover, unpredictable rainfall pattern in this current situation causes a serious problem for the rainfed paddy fields and in extreme cases, this can contribute to drought. Aryal et al. (2022) reported that drought is one of the biggest constraints to rainfed production. Drought, water scarcity and lack of nutrients (especially N, P and K) are interrelated. Macronutrients, such as K^+ , are particularly mobile and both membrane transport and soil solution highly contribute to distributing K^+ from roots to cells. Water deficit and drought significantly impact K^+ mobility and K^+ uptake due to low soil moisture (Figure 5) (Nieves-Cordones et al., 2019). Aryal (2012) recorded that paddy needs a large quantity of water due to the growing period for various physiological functions. Further, Dianga et al. (2021) described the water requirement of paddy cultivation based on the ecosystem. Upland rainfed crops require 100 mm of rain per month on average. It is also necessary to have at least 200 mm of average monthly rainfall to cultivate rainfed lowland crops.

According to Apriyana et al. (2017), 65% of rainfed paddy fields farmers try find other water sources and 35% of them delay the onset by about a month. Several strategies, such as by adding water irrigation from rainfed ponds and well, can help increase water availability in rainfed paddy fields. Ponds can be used not only as irrigation water sources, but also as water storage facilities. It is critical to examine the morphology of the ponds, including the area, inflow and outflow structure and a pattern that corresponds to the area of paddy field. Dong et al. (2009) suggested that the length-to-width ratio should be around 3:1 and the length of the pond should be greater than 20 m, so that the drainage water can pass and through the pond by plug-flow. The pond effectiveness depends on the size of the area and the needs of the paddy plants. Rao et al. (2017) reported that the pond, which has a total volume of 12,325 m³ of harvested water, can irrigate around 13.30 ha of paddy fields of critical height (about 5 cm) and increase yields from 0.4 to 0.6 t ha⁻¹. Pond can also change cropping patterns and increase the frequency of planting (Apriyana et al., 2017; Rao et al., 2017). In addition to the construction of water storage, it is necessary to build canals as water distribution roads. The structure of water channels also benefits the farmers to store rainwater in the canals (Figure 6). Nadeem et al. (2021) concluded that the existence of canals and irrigation conditions can affect farmers' welfare.

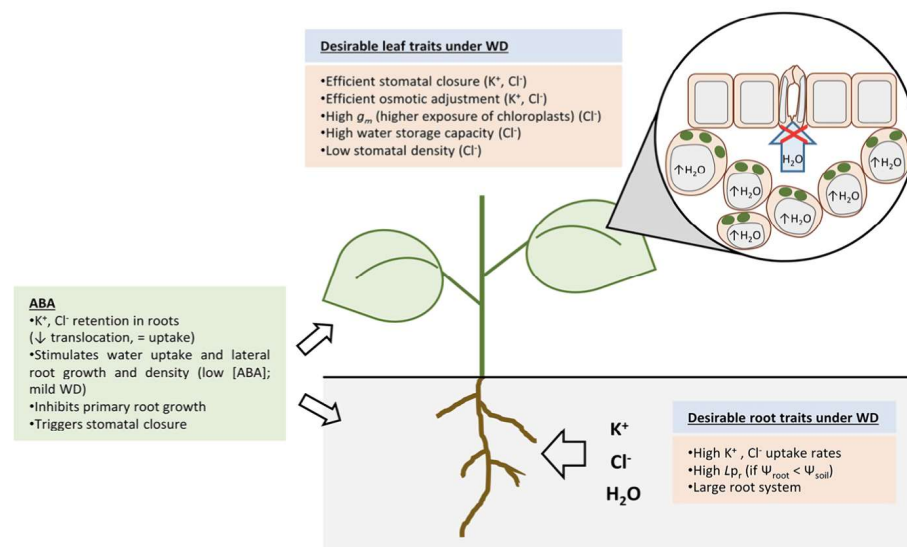


Figure 5. Illustration of the main processes associated to water deficit to K^+ and Cl^- mobility (Nieves-Cordones et al., 2019)

The rainfed pond has also made a significant contribution to climate change adaptation (Rao et al., 2017). Additional water irrigation sources, such as rainfed ponds, can facilitate the farmers to harvest rainwater to avoid the threat of flooding during high rainfall and the danger of drought during the water shortage in the dry season. Mustapha (2012) and Pathak et al. (2013) reported that harvested rainwater for supplementary irrigation on rainfed land can increase the average yield by 40 to 90%.

Well construction and water pumping are two other technologies used in rainfed paddy fields. Aرسال et al. (2020) announced that supplementary water irrigation sources, such as well and water pumps, known as *diesel*, can help farmers cultivate paddy in the dry season. Farmers of rainfed paddy fields typically

delay planting and fertilizing by waiting for the rain in order to reduce the damage and loss caused by drought. Therefore, using a well and water pump helps the farmers avoid relying on rain when planting or fertilizing (Apriyana et al., 2017).

Nevertheless, the cost of drilling wells is high. In one hectare of paddy fields, there are only one to two privately owned wells or even no deep-water wells from several locations. When there is a scarcity of water due to rainfall, farmers usually take water as a source of irrigation at nearby wells owned by other farmers. The costs incurred vary and depend on the distance from the well to the land. These certainly affect the production costs of paddy cultivation. The cost of water hoses and fuel oil can be reduced only if there are drains around the paddy fields.



Figure 6. Water channel as a rainwater reservoir (source: personal author documentation)

Organic and farm waste application

Residues from paddy cultivation, such as straw and rice husk, can be a source of organic matter by composting. Yan et al. (2019) revealed that on their 5-year experiment on compost, the release of C, N, cellulose and hemicellulose occurs during the first and second years after straw incorporation. In addition, P and K are released mainly during the first month, while lignin is released at varying rates throughout the study period.

Pan et al. (2017) reported that rice straw is composed of cellulose, hemicellulose and lignin. Pan et al. (2010) also described that silica, polysaccharides and lignin are reported to form complex rigid structures that inhibit the decomposition of straw lignin. A high lignin content can trigger a lengthy decomposition process that requires the help of microorganisms. Microorganisms

play a prominent role in the decomposition process. The addition of microorganisms is expected to accelerate the process. Jusoh et al. (2013) found that the addition of effective microorganisms (EM) in compost can increase the N, P and K nutrients in the soil, compared to the compost without EM. Sia et al. (2019) reported that the combination of compost and chemical fertilizers can increase the total N, available P in the soil and exchangeable K. In addition, soil pH and soil CEC are increased with the application of straw compost.

Aside from straw, another organic material that can be used is cow dung. Baig and Zia (2006) reported that the addition of organic manures improves soil's physical and chemical properties. Water and nutrient holding capacity and pore space can be improved by adding organic manures. The significant factors are moisture stress at the critical growth phase, poor fertilizer

management practices, severe weed problems in high rainfall areas and poor crop and land management practices adopted in the dry areas, such as rainfed paddy fields.

Haque et al. (2021) explained that using only chemical fertilizers as inputs could not increase paddy yields. Moreover, most fertilization in rainfed paddy fields does not follow the government recommendations and this is estimated to affect fertilization efficiency in the soil. Rashid et al. (2004) noted that imbalanced fertilizer application is considered one of the most critical factors responsible for low fertilizer use efficiency. It may cause a 20 to 50% decrease in efficiency.

Haque et al. (2021) also reported that paddy grain yields are significantly higher (31 to 45%) under organic amendments than chemical fertilizer treatment. Lenin et al. (2021) noticed that applying 2.5 t ha⁻¹ compost without chemicals can reduce yield by 23%. In contrast, using 2.5 t ha⁻¹ of compost combined with synthetic chemical fertilizers can increase yields by 4.7%.

Long-term application of chemical fertilizers, manure and straw can increase the total P concentration at a soil depth of 0 to 20 cm and rise the available P concentration at a soil depth of 0 to 60 cm (Lu et al., 2020). In addition, Guo et al. (2018) described that applying chemical fertilizers in combination with manure in the long term can significantly intensify soil organic carbon stocks. Moreover, the rate of change in soil organic carbon per unit C input varies depending on soil type.

Soil tillage practice

Tillage is a fundamental technical operation in agriculture as its effect on nature, soil environment and plant growth (Sharma et al., 2018). Farmer on the rainfed paddy fields regularly apply minimum tillage practice. Based on the interview, most farmers in rainfed areas carry out tillage as soon as possible after harvesting. Planting is carried out soon after tillage process. However, unsuitable tillage activities can cause soil compaction, reduced soil infiltration and aeration and the potential for soil erosion (Qureshi et al., 2003). Moreover, Rashid et al. (2015) stated that low organic matter and a high proportion of fine silt, sand and sodium in the rainfed areas can cause surface soil crust. Soil compaction

can reduce seed germination, affecting plant growth and yield.

Baig et al. (2013) reported that deep tillage can increase water infiltration. It also increases underground water resources through the rainy season, so deep tillage has incredible potential to conserve soil moisture. Moreover, Eck and Unger (1985) concluded that water content is increased by the deep tillage practice. Schneider et al. (2017) recorded that adding deep tillage can improve nutrient availability and crop yield.

Long-term application of deep tillage is thought to have an effect on soil properties. Baumhardt and Jones (2005) reported that the application of deep tillage for 30 years can affect the physical properties of the soil. Deep tillage improves drainage and the soil density layer does not reform after 30 years. Li et al. (2020) reported that deep vertical rotary tillage can reduce soil bulk density more than the conventional tillage on rainfed dryland in China.

Using short-lived paddy varieties

Using drought-resistant varieties can be preventive action to decrease yield loss during the dry season (Kumar et al., 2014). The yield loss in paddy plants due to drought depends on the growing phase and duration of drought (Zhang et al., 2018). Pandey and Shukla (2015) stated that several plant responses to drought are decreased plant height, biomass, germination index. Drought also affects the level of stomatal conductance, chlorophyll and water potential.

Based on the interview, most farmers in rainfed paddy fields regularly use the same paddy varieties as irrigated paddy; some of which are Inpari 32, Ciherang and Inpari 42. The farmers commonly lack of knowledge about paddy varieties in rainfed paddy fields. These varieties are the most favorite consumer demands. The cultivars have a long life ranging from 110 to 120 days after sowing (DAS) (Ministry of Agriculture, 2022) and this probably causes crop failure at the second planting season, in the dry season. Hence, plant cultivars with a shorten lifespan are required. Cakrabuana Agritan at 104 DAS, Sidenuk at 103 DAS, Inpari 18, Inpari 19, Inpari 20 and Inpari at 93 to 102 DAS are some of the paddy varieties suitable for rainfed paddy fields. Several varieties with superior drought resistance can also be used in the areas. Some of them are

Inpari 38, with an age of 105 DAS, Inpari 39, with a period of 115 DAS and Inpari 41, with an age of 114 DAS (Ministry of Agriculture, 2022). Noviana et al. (2021) reported that Inpari 39, Cakrabuana, Inpago 11, Rindang 1 and Luhur 1 have the potential to experience drought stress during the dry season on rainfed paddy fields with average productivity of 6 to 7 t ha⁻¹. Further, Cakrabuana has the highest grain yield around 7.15 t ha⁻¹ when matured at 85 days after planting.

In addition to short-lived paddy varieties, drought-resistant varieties are necessary to be planted. Research conducted by Salsinha et al. (2020) concluded the potential local varieties that are drought-tolerant in East Nusa Tenggara, such as Seratus Malam Boawae, Padi-Putih Kuantana and Padi-Putih Maumere. This is an opportunity for the exploration of local varieties that have the potential to be developed as drought-resistant varieties. The selection of local drought-tolerant paddy cultivars is critical for the development of drought-tolerant seeds, as well as commercial food production.

CONCLUSIONS

In conclusion, rainfed paddy fields generally have a limiting factor for water and nutrients. Several technologies that can be applied to increase yields in rainfed paddy fields in Indonesia are water management practices by adding water storage and canal, utilization of cultivation residues, such as straw, husks and manure as organic matter input, improvement of the concern about tillage management to reduce soil compactness and add roots grow space, and use of short-lived, drought-resistant and high-yielding varieties as an adaptation to climate change that affects rainfed paddy fields. Further field studies are still required to complete the research.

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