SEASONAL WEATHER PREDICTION-BASED DECISION-SUPPORT SYSTEMS FOR INCREASING RICE PRODUCTION IN RAINFED AREAS

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ABSTRACT

Rainfed rice areas contributes less to global rice supply than irrigated one due to its low productivity. However, it is considered as a great potential to the global food security due to its area. Rainfed-rice production relies entirely on rainfall for water supply to support rice growth, which requires substantial amount of water throughout the cropping period. However, rainfall patterns are uncertain considering start and end of the rainy season and total amount and seasonal distribution of rainfall, all of which are crucial factors determining rice productivity. Farmers cultivating rainfed rice usually apply their empirical knowledge to determine when to sow the rice crop, based on certain events/amounts of rainfall occurring at the beginning of the rainy season. However, predicting the sowing date in this manner does not consistently result in greater productivity. Study in Lao-People's Democratic Republic (Lao PDR, Laos) and Indonesia showed that farmers cultivating rainfed rice did not aim to achieve the highest yield but to obtain stable subsistence-level production because of their insufficient capacity to anticipate forthcoming weather events. To make rainfed rice areas more productive in stable manner than before, it is imperative to improve the local capacity to cope with the uncertainties and make an appropriate decision for better practice and productivities; an element of weather forecasting could play a crucial role in improving the capacity of farmers cultivating rainfed rice to consistently achieve higher yields per unit land area. In this study, a weather–rice–nutrient integrated decision-support system (WeRise) was developed through a collaborative research project by the International Rice Research Institute (IRRI) and Japan International Research Center for Agricultural Sciences (JIRCAS) or IRRI-Japan project funded by the Ministry of Agriculture, Forestry and Fisheries of Japan.

WeRise is driven by a seasonal weather prediction-based crop-growth model to optimize the practice of farmers cultivating rainfed rice in terms of sowing date, varietal selection, and fertilizer application, which entails greater efficiency in resource use for higher and more stable rice production in rainfed ecosystems.

Keywords: Unfavorable environment, Southeast Asia, drought, SINTEX-F, WeRise

INTRODUCTION

Rice is an important staple crop for approximately 3.5 billion people in the world but increasing demand from a burgeoning population implies that the production of milled rice should be increased by 120 million tons by 2035. Although globally rice is mainly produced in irrigated-rice ecosystems, enhancing rice production in rainfed areas is becoming crucial for global food security in the present and the future due to very limited availability of physical and economic resources in these areas, with the problems exacerbated by climate change and economic development in developing countries. Although the grain yield in rainfed-rice areas is less than half that in irrigated-rice areas, improvements to achieve greater yields are particularly important; however, it is difficult to consistently increase yield in rainfed-rice areas because of extreme and uncertain events such as drought and flood, driven by fluctuating water supply through current rainfall.

As a consequence, it is imperative to exploit weather forecasts to mitigate constraints in rainfed-rice production. In rainfed-rice farming, the crucial information is not only the total amount of rainfall but also temporal variation in rainfall distribution, including the start and end of the rainy season, so the application of seasonal weather forecasts is indispensable to provide relevant information to farmers cultivating rainfed rice. It is also important to optimize production using weather forecasting, so that the application of a crop-growth model is crucial to identify optimal timings within given phases of the forthcoming rainy season. Furthermore, the integration of the weather forecast into a crop-growth model enables farmers to select a suitable variety, avoid abiotic stress during critical crop stages, and improve the efficiency of resource use during rice production to help farmers cultivating rainfed rice to strategically produce rice. A weather forecast-based decision-support system is the key to transform rainfed-rice areas into more productive and stable rice-producing areas to supply the growing demand for rice in the world.

CURRENT SITUATION IN RAINFED-RICE AREAS

The yield from rainfed-rice farming is lower than that of irrigated rice, and its contribution to the global rice supply is less than 20%. However, its production area is about 40% of the rice cultivation area in Asia and about 70% in Africa, meaning that there is potential to contribute significantly to the global food security should certain improvements be met. It is imperative to strengthen and accelerate research and technological development in rainfed-rice cultivation to achieve the necessary improvements.

In Southeast Asia, which is recognized as a center of rice production and consumption, a survey was conducted to characterize the current rice production in the rainfed cropping area and to identify problems/constraints. The water supply required for the rice growth in these areas depends entirely on rainfall, particularly at critical stages of crop development such as seedling, panicle initiation and flowering stages. According to the results of a field survey, it was found that the sowing date among farmers cultivating rainfed rice varied, with different sowing dates resulting in different grain yields (Fig. 1). For example, the sowing date selected by the majority of farmers in Lao PDR resulted in the lowest yield of all the sowing dates investigated, while the majority of farmers in Indonesia obtained similar grain yields to crops sown one month before their own sowing dates. These case studies indicate that farmers' decision making with respect to sowing date was aiming not at achieving the highest yields but at obtaining at least subsistence-level production, despite the uncertainties which arise during crop growth and development. Furthermore, these findings indicate that farmers cultivating rainfed rice have no way of anticipating any weather events that occur after sowing and that this limitation hampers farmers cultivating rainfed rice from optimizing practices such as sowing and fertilizer application dates. To transform the rainfed-rice areas into more productive areas for rice cultivation, it is imperative to improve the local capacity to respond to weather variation during the cropping season, such as an application of weather forecasting to play a crucial role in improving the production capacity of farmers cultivating rainfed rice. Furthermore, the use of weather prediction is imperative to enable farmers to minimize production costs (labor, materials, machine rental, etc.) as well as to use appropriate technologies, such as improved rice varieties, to respond appropriately to risks in the forthcoming season.

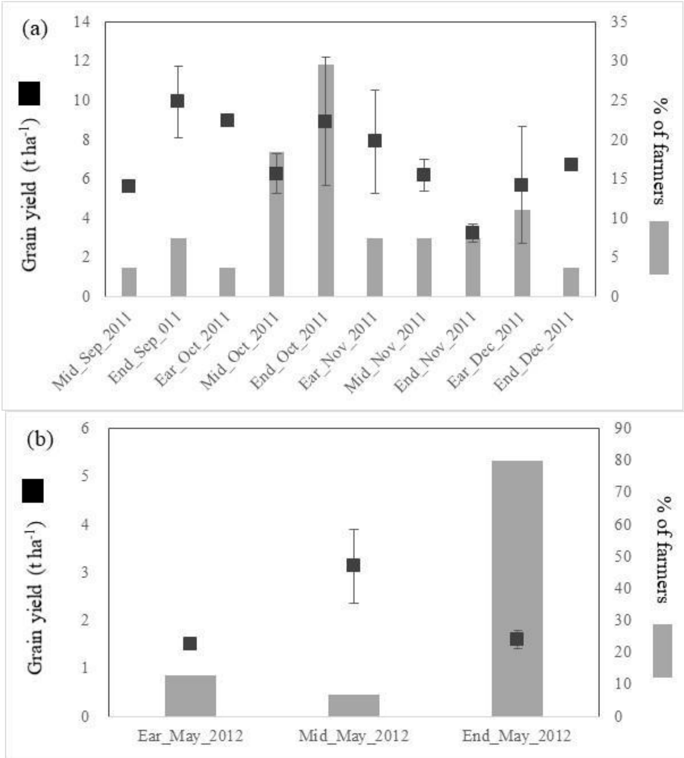

Fig 1. The effect of sowing period on grain yield for farmers cultivating rainfed rice in (a) Central Java, Indonesia, and (b) Savannakhet, Lao PDR. Black square with error bar denotes mean grain yield ± standard deviation, whereas bar shows percentage of farmers who sown at corresponding periods.

APPLICATION OF SEASONAL WEATHER PREDICTIONS TO RAINFED-RICE FARMING

It is crucial for farmers cultivating rainfed rice to know the start and end of each rainy season, as well as the seasonal rainfall distribution, which is determined by the development of the Asian monsoon. Traditionally, rice farmers have used their empirical knowledge to anticipate the weather during the forthcoming season, a strategy which is outdated given the climate change context. Therefore, seasonal weather predictions can play a crucial role in improving the year-on-year stability of crop yield in rainfed rice. The agricultural application of seasonal weather predictions has been mainly studied in Europe, and in Africa for some upland crops such as maize, wheat, and millet, but there has been no study on rice, particularly rainfed rice (Hayashi *et al*. 2018). Therefore, the applicability of seasonal weather predictions was evaluated in Southeast Asia, where most of the countries of this region produce and consume substantial amounts of rice.

The Asian monsoon is the main trigger for initiating rainy season in Southeast Asia and is correlated with the El Niño Southern Oscillation (ENSO). The ability to predict the ENSO is crucial for rainfed areas and the Scale Interaction Experiment–Frontier Research Center for Global Change (SINTEX-F), a relatively high-resolution ocean–atmosphere-coupled general circulation model to simulate ENSO in the tropical Pacific, was used for this study (Luo *et al.* 2008). SINTEX-F is a model at a global scale and it cannot be directly used in a site-specific manner. The cumulative distribution function downscaling model (CDFDM) was employed in order for the SINTEX-F to be applied to rainfed-rice production. CDFDM is an inexpensive downscaling method to apply various daily variables, including daily mean of maximum, and minimum temperatures, precipitation, solar radiation, relative humidity, and wind speed (Iizumi *et al.* 2011), which are the determining parameters for rice growth. Outputs from CDFDM ($CDFDM_{cor}$) were compared with predictions from SINTEX-F to evaluate the applicability of the seasonal weather predictions in Indonesia as an example. Results obtained showed that a discrepancy between observed historical weather data and SINTEX-F was corrected after application of CDFDM through the mean error that showed the closeness of $CDFDM_{cor}$ to observed weather data (Table 1). This indicates that using CDFDM can enable seasonal weather predictions to be used for site-specific rainfed-rice areas. In rainfed-rice areas, sowing date is also a crucial factor in determining crop productivity. According to a field survey, farmers wait for certain rainfall events to occur prior to starting sowing and in Central Java the event was cumulative rainfall amount of 139 mm, which took 108 days to occur. The $CDFDM_{cor}$ showed no significant difference between the observed number of days to reach the cumulative rainfall and the designated number of days for the cumulative rainfall amount, As a consequence, the applicability of CDFDM was considered to be adequate to support farmers cultivating rainfed rice to identify the optimum sowing date.

Table 1. Mean error needed to identify a discrepancy between SINTEX-F or $CDFDM_{cor}$ against observed historical weather data for rainfall (RF), maximum air temperature (Tmx), minimum air temperature (Tmin), and wind speed (WS)

	Mean error (ME)			
	RF	Tmx	Tmin	WS
OBS vs. SINTEX-F	1.13	−3.08	3.55	2.90
OBS vs. CDFDMcor	−1.00	0.04	−0.74	0.13

WeRise DEVELOPMENT

The adoption and diffusion of appropriate technology is imperative to improve the productivity from rainfed-rice areas (Marinao *et al.* 2010). However, farmers cultivating rainfed rice have limited access to new and relevant technologies. For example, farmers cultivating rainfed rice in Central Java use only a small number of varieties, and these were originally selected for high performance under irrigated-rice cultivation systems. This is because of an existing rice-seed marketing system that deals only with varieties that are popular with the farmers and the consumers. It is necessary to have intervention from local/national government in terms of developing varieties suitable for rainfed areas, a strategy that would entail direct and indirect costs, while it would also take time (breeding, trialing, registration, and seed multiplication) to breed such varieties available for farmers of rainfed rice. Instead, it may be better and more appropriate to research ways to use existing varieties more efficiently under rainfed conditions, to achieve greater productivity. The application of seasonal weather prediction is considered to be one of the most suitable interventions to use so that any variety can be grown more efficiently by farmers cultivating rainfed rice.

In rainfed areas, it is imperative to predict not only the start and end dates of the rainy season and the total rainfall during the season, but also the pattern of rainfall distribution during cropping period, to identify potential risks caused by extreme events which could result in a substantial yield loss. Currently, farmers of rainfed rice have no way of predicting undesirable weather extremes in the following season and have limited capacity to avoid or escape risks to their crops through their empirical knowledge. Therefore, it is crucial to develop a tool to help with decision making by farmers cultivating rainfed rice. In this context, the application of seasonal weather predictions to a crop-growth model was tested for its relevance under existing constraints (Hayashi *et al.* 2018). ORYZA, an eco-physiological rice crop-growth model (Bouman *et al.* 2001) was used with seasonal weather forecasts to simulate grain yield according to crop growth in rainfed-rice production in Indonesia. The $CDFDM_{cor}$ was used as the weather inputs for ORYZA, and a grain-yield simulation was carried out as a function of sowing date to obtain predictions of grain yield and hence an optimum sowing date. The field test was conducted during two cropping seasons with two improved rice varieties in Central Java province in Indonesia to evaluate the accuracy of the predictions through this method.

The variety ‘Ciherang’ was released in 2000 for use in irrigated-rice areas and it is still one of the most popular varieties throughout Indonesia, although there are other, more recent varieties Available (Table 2). “Attainable grain yield” for improved varieties is known to be lower than “potential grain yield” (Table 2) as stresses, such as drought, occur during crop growth and development. Farmers cultivating rainfed rice aim to increase yield through adopting new technologies and knowledge. However, a survey showed that farmers mostly rely on empirical information and traditional knowledge to deal with uncertainties with respect to the local weather, which can therefore be considered to be one of the main yield constraints in rainfed-rice areas. Grain yield varies according to sowing date as shown in Fig 2, showing the yields of ‘IR64’ (from four sowing dates) and ‘Ciherang’ (nine sowing dates), both varieties popular in Indonesia. This shows that an optimum sowing date is crucial to achieve higher grain yields in rainfed-rice production. The optimum sowing date also enables farmers cultivating rainfed rice to avoid water stress in their crops during critical crop stages such as panicle initiation and flowering. ORYZA simulation of grain yield as a function of sowing date obtained a reasonably adequate model fit through normalized root mean square (RMSEn) of 13.4% for IR64 and 16.4% for Ciherang, and this showed that the model performance of ORYZA is adequate for simulating grain yield under conditions of rainfed-rice production.

Table 2. Attainable and potential yields of several improved Indonesian improved rice varieties (BB PADI, 2015)

Name of variety	Year of release	Days to maturity	Attainable grain yield (t ha^{-1})	Potential grain yield (t ha^{-1})
Ciherang	2000	116–125	5–7	-
Mekonga	2004	116–125	-	6.0
Inpari 6	2008	118	6.8	8.6
Inpari 10	2009	112	4.8	7.0
Inpari 19	2011	104	6.7	9.5
Inpari 21	2012	120	6.4	8.2
Inpari 27	2012	125	5.7	7.6
Inpari 30	2012	111	7.2	9.6
Inpari 31	2013	119	6.0	8.5
Inpari 32	2013	120	6.3	8.4
Inpari 33	2013	107	6.6	9.8

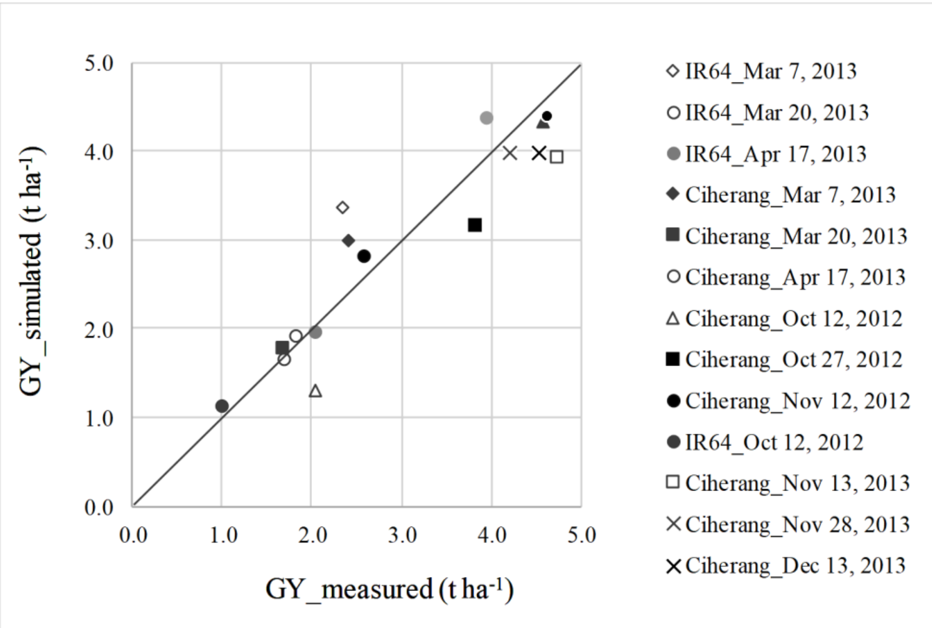

Fig. 2. Grain-yield simulation using ORYZA at different sowing dates (modified from Hayashi *et al.* 2018).

Based on the results obtained, a field test was conducted to evaluate the predictability of grain yield on the basis of seasonal weather prediction-based ORYZA simulation in rainfed-rice areas. The results showed that farmers using weather predictions obtained grain yields significantly higher than did the farmers who did not use weather predictions (Fig. 3). During the test, there was a downpour that triggered farmers to start sowing earlier than the predicted sowing date, resulting in low yield due mainly to a drought spell which lasted for one month immediately after the downpour, stressing the young seedlings at an early stage. This resulted in poor rice growth and incurred substantial yield reductions. On the other hand, sowing date that was selected on the basis of ORYZA simulation resulted in higher yields, which were significantly higher than those achieved by farmers who lacked information from the ORYZA simulation. Some farmers without the support of the ORYZA simulation selected sowing dates that coincided with those from the ORYZA simulation, but their yields were also significantly lower than those of simulated one. This could be due to farmers' practice of fertilizer application being carried out during the early crop stage, which could trigger nutrient deficiencies toward the reproductive stage when rice nutrient demand is greatest to produce more panicles and grains. These actual cases imply that farmers cultivating rainfed rice need to deal with multi risks for better grain yield, and an optimum timing for sowing and fertilizer application play crucial role for this purpose. Seasonal weather prediction-based ORYZA simulation is not only to help farmers cultivating rainfed rice determining an optimum sowing timing but also to apply fertilizer appropriately according to the crop growth stages and surface-water condition in the field. Rice plant can absorb nutrient through applied fertilizer if there is adequate surface water or a downpour is avoided after fertilizer application. Similar results were obtained for the two varieties over the two growing seasons, confirming the applicability of weather prediction to optimize rainfed-rice production. Accordingly, the weather–rice–nutrient integrated decision-support system (WeRise) has been proposed to achieve greater rice production in rainfed-rice areas.

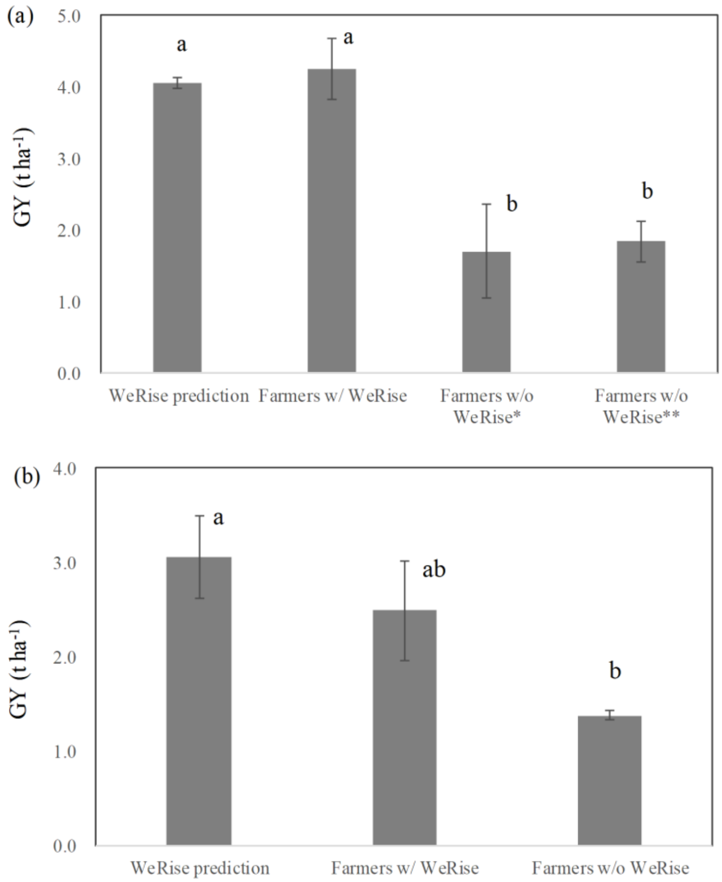

Fig. 3. On-farm testing of grain-yield predictions through seasonal weather prediction-based ORYZA for (a) early rainy season and (b) late rainy season (modified from Hayashi *et al.* 2018). * Farmers without ("w/o") WeRise who sowed earlier than farmers with ("w/") WeRise, ** Farmers without WeRise who sowed at almost the same date as farmers with WeRise.

WeRise'S APPROACH AND TECHNOLOGY ADOPTION PATHWAY

WeRise is designed as a web application to facilitate end-users' decision making (Hayashi and Llorca 2016). WeRise can accommodate a maximum of four varieties at the same time, and users can compare the grain yield as a function of sowing dates to choose better or more suitable varieties (Fig. 4). WeRise can also deliver information on the optimum timing for fertilizer application, i.e., the dates and the number of splits of fertilizer applications. WeRise is also language sensitive and has different modes of information delivery to the end-users. In addition to English as a default language, other languages such as Indonesian, Lao, and Filipino are also available to accommodate interface with local users in different countries. Agricultural extension workers (AEWs) can access WeRise for necessary information and they can print out the information obtained in order to deliver the information to the end-users in their jurisdiction where farmers have limited or no infrastructure of internet access.

For the support of farmers cultivating rainfed rice through a research for development (R4D), WeRise should be a user-friendly tool that end-users (primarily farmers of rainfed rice) can use for their benefit in a sustainable manner. Setting milestones toward social implementation is imperative through developing a user-friendly interface, by encouraging stakeholders' involvement at an early stage of technology development, and by designing a technology dissemination pathway through focus group discussion and/or stakeholders' meetings.

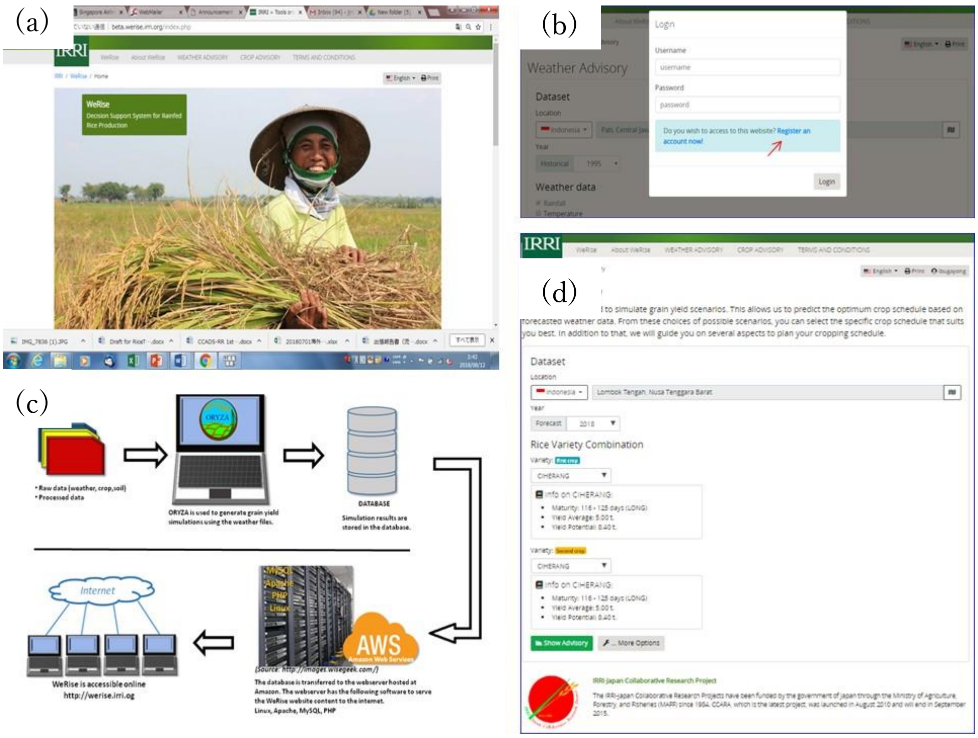

Fig. 4. WeRise online tool and maintenance system: (a) website of WeRise interface, (b) registration page for users to gain access to WeRise, (c) data storage system in WeRise, and (d) structure and information required from users (modified from Hayashi and Llorca 2016).

Key stakeholders, such as local researchers and AEWs, play crucial roles in technology adoption for WeRise. Furthermore, information, communication, and educational materials need to be prepared for capacity- building by local AEWs through “training of trainers.” On the other hand, utilizing an existing national system of technology dissemination is also strategically important for the research project in order to accelerate the process of technology adoption.

In addition to enhance existing capacity and utilizing local system for technology adoption, maintenance of the technology is also crucial for the sustainability of the technology. A low-cost data storage service is one of the keys for sustainable operation by designated stakeholders because it charges a minimal cost for data storage and accommodates access for a large number of end-users. Utilizing weather forecasts through the national meteorological agency in the target country would also assure sustainable operation of WeRise because regular updates could be carried out without incurring high costs.

CONCLUSION

Grain yield achieved through traditional farmers’ practices in rainfed areas remained low due to difficulties in anticipating weather patterns before and after sowing, with optimum sowing dates being identified as one of the major challenges facing growers of rainfed rice. The current study demonstrated the applicability of seasonal weather prediction in rainfed-rice production through integration with a crop-growth model to identify an appropriate sowing date, while WeRise was designed as a web application to facilitate end-users’ decision making. For the support of farmers cultivating rainfed rice through R4D, WeRise should be a user-friendly tool that farmers cultivating rainfed rice can use for their benefit in a sustainable manner. Working with local stakeholders is also crucial not only for R4D, but also for the widespread adoption of the technology, so that designing a technology transfer dissemination pathway in a collaborative manner with local stakeholders is imperative for moving toward a social implementation of WeRise in the target country and beyond.

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