Developing SIMASTI to disseminate information of season prediction and prepare for adaptation strategies in agriculture to climate change

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Abstract. Even though climate change has a multisectoral impact on the agricultural country Indonesia, farming sector experiences the most significant adversity. The concomitant climate uncertainty potentially harms in particular traditional farmers. Current technology is now able to predict weather and climate conditions, and as such, it is useful for farmers as an input to their decision-making process in farmland management. This paper explains the design of a mobile application created by researchers to present information on seasonal weather prediction that fits adaptation measures in the agricultural sector to climate variability. The product can help to enhance the adaptation capacity of communities to erratic climate, particularly farmers and the Office of Agriculture in Temanggung District. Also, the application is expected to provide recommendations for both parties to be able to reduce crop failure and subsequent loss due to climate variability and increase the resilience of farmers to climate change impact, especially the persistent increase and decrease in rainfall each in the rainy and dry season.

1. Introduction

Increased human activities have led to the release of high concentrations of Greenhouse Gases (GHGs) to the atmosphere that contributes to climate change [1–4]. Climate change has a multisectoral impact on Indonesia as an agricultural country, with significant ramifications in the agricultural sector[5]. It manifests in climate variability, that is, a change in rainfall depth and intensity, shifting onset and cessation of the rainy season, and increasing frequency of floods and drought [1,6–9]. Also, it substantially alters growing seasons, cropping patterns, and types of crops and raises the risk of crop failure due to floods and droughts. Moreover, climate change triggers a statistically wider deviation from normal conditions and creates more uncertainty in future climate conditions [10,11].

The agricultural sector highly depends on the climate, which currently shows uncertainty and potentially harms traditional farmers[12,13]. In the context of climate uncertainty, traditional approaches like the pranoto-mongo system, or the Javanese farmer’s calendar, are deemed less effective[14,15]. On the other hand, technology advances in weather satellites and geospatial modeling currently play a crucial role in weather and climate predictions[3]. Nevertheless, farmers still find information related to these estimates very difficult to understand and access.
Farmers can make use of weather and climate prediction system as an input to the decision-making process in their farmland management[16]. As such, information related to climate prediction is fundamental. For instance, if the prediction indicates that the next rainy season starts late, then farmers can decide to postpone planting. On the contrary, if it estimates a potential for excessive rain near the harvest season, then they have to prepare for increased risk of failure in certain crop species, such as tobacco and shallots.

Temanggung District is located in Central Java. Due to its varied topography, this region has diverse climatic conditions, including rainfall and temperature as the most influencing factors to crop growth[12,17]. Tobacco, coffee, chili, onions, and several types of vegetables are among the agricultural commodities widely grown in the district [18]. Tobacco and shallot are typically susceptible to climatic changes. Tobacco requires low rainfall, i.e., only 100 mm/month, and dry condition during the harvest [19]. Rainfall in harvest time leads to failed tobacco curing process and generate a considerable amount of losses for farmers [20]. Therefore, climate information is of great value for farmers to determine the appropriate adaptation measures for their agricultural land.

The increasing climate variability has a significant impact on agriculture in Temanggung District. On the other hand, many researchers worldwide have publicized their studies on climate variability [21–23], yet the findings have not been widely applied by the community as mitigation and adaptation efforts. An example of the research products is a mobile application that presents weather forecasts for the next planting season, called SIMASTI (abbreviation in Indonesian: Sistem Informasi Musim untuk Adaptasi Pertanian/Seasonal information system for agricultural adaptation). This paper highlights the technical background and method of developing SIMASTI and the products of this application.

2. SIMASTI Development Methods
The development of SIMASTI application involved several stages of research, as explained below. These stages are 1) identification of agricultural problems due to climate change in Temanggung, 2) development of season prediction design, and 3) incorporation of the prediction system into the mobile application and dissemination. At the first stage, field observations and expert consultation with the Office of Agriculture for Temanggung Regency were carried out. These procedures aimed to identify some of the potential climate change impacts, such as delay in cropping season, drought, and excessive rainfall. At the second and third stage, any identified problems were considered in the application design and disseminated to the farmers.

In stimulating weather conditions in detail, the design of the prediction system centered on the Weather Research and Forecasting (WRF) model [24–26]. The developed weather forecasting consisted of two systems, namely short-term prediction system (6 days ahead) and long-term prediction system (6 months ahead). The inputs to the WRF model are listed in Table 1.

Table 1. The data used in the WRF simulations.

| Data | Sources | Functions |
|------|---------|-----------|
| Global Forecast System (GFS) - National Centers for Environmental Prediction | https://nomads.ncdc.noaa.gov/data/gfs4 | Simulation of 6-day weather forecasts |
| Climate Forecast System (CFS) FLXF product - National Centers for Environmental Prediction | https://nomads.ncdc.noaa.gov/mo/data/cfsv2_forecast_6-hourly_9mon_flxf/ | Simulation of 6-month weather forecasts |
| Climate Forecast System (CFS) PGBF product - National Centers for Environmental Prediction | https://nomads.ncdc.noaa.gov/mo/data/cfsv2_forecast_6-hourly_9mon_pgbf/ | Simulation of 6-month weather forecasts |

The Weather Research and Forecasting (WRF) is a non-hydrostatic model developed by the National Center for Atmospheric Research (NCAR), the National Centers for Environmental Prediction (NCEP), and several other institutions in the United States [24,25,27]. The input data of the
WRF simulations were synoptic climate parameters as shown in Table 1. This research used the WRF ARW 4.0.3, which is operable in the Ubuntu 16 operating system. The simulation created a single nesting configuration with a 1-km grid size (horizontal resolution) and 28 vertical levels [25]. The simulated area was Central Java and focused on Temanggung Regency and its surroundings. The specified time interval of the output was 1 hour for each data input with a 6-hour interval.

In this study, the WRF simulation results concentrated on rainfall, temperature, humidity, solar radiation, and wind speed and direction. These data were combined to provide a basis for calculating crop water needs, which were based on crop type and reference crop evapotranspiration [28]. Then, the consumptive use of each crop was computed by the Blaney-Criddle method [28]. The analyzed crop type and assumed coefficient of crop evapotranspiration are presented in Table 2.

### Table 2. The types and coefficients of crops for water requirement analysis.

| Crop Types | Initial Stage | Crop Development Stage | Mid-season stage | Late season stage |
|------------|---------------|------------------------|-----------------|------------------|
| Tobacco    | 0.35          | 0.75                   | 1.1             | 0.90             |
| Cabbage    | 0.45          | 0.75                   | 1.05            | 0.90             |
| Carrot     | 0.45          | 0.75                   | 1.05            | 0.90             |
| Potato     | 0.45          | 0.75                   | 1.15            | 0.85             |
| Tomato     | 0.45          | 0.75                   | 1.15            | 0.85             |
| Paddy      | 1.10          | 1.10                   | 1.30            | 1.00             |

The above analysis was carried out continuously on the server. Afterward, the output was presented in tables and graphs and imported into the Android application using the Android Studio v.3.4.2 software. The result of the process was an operable application on the Android platform.

3. Results and Discussion

3.1. Agricultural problems due to climatic conditions in the study area

Some areas in Temanggung Regency have different characteristics, from low-lying lands to mountains with steep slopes (Figure 1). Tobacco is one of the main commodities of the district, in addition to paddy, coffee, chili, tomatoes, and potatoes, while tobacco is mostly cultivated in hilly topography, rice dominates the farmland in the low-lying areas. Based on the interview results, rice production is generally higher in quantity when compared with tobacco. However, from a financial perspective, the latter is much more lucrative than the former.
The varied topography determines the length of the growing season in mountains and low-lying lands, especially that of tobacco (Figure 1). The tobacco planted on dry farmland in low-lying land, e.g., in the Candiroto area, needed three to four months to completely mature. Meanwhile, the growing season of the tobacco cultivated in mountainous areas could last up to six months. The initial stage of tobacco growth varied between March and May, and the harvest time was in late August to early September.

In the last five years until 2019, there has been an increase in weather variations in the local farmland. During the interviews, farmers perceived climates in the past as more predictable than the current ones. The beginning of the growing season is decided traditionally using the Javanese farmer’s calendar called pranoto-mongo (lit., determination of season), which is currently considered to have reduced accuracy. Combined with climate change-induced water shortage, this calendar yields poor-quality tobacco. For tobacco, low rainfall at early rainy season will bring about small plants and leaves. Meanwhile, excessive rains close to the harvest time will make these plants rot quickly and have a low selling price.

During the expert consultation, they consider that the farmers need climate and weather information. At this time, they expected the Meteorological, Climatological, and Geophysical Agency (BMKG) to provide weather and climate information, especially one that could notify wet drought events (in 2010 and 2016) in advance. In this condition, the harvested tobacco did not dry properly, and the selling price dropped. Most farmers suggested it as the main problem in today’s tobacco planting because it inevitably led to much less profit.

The tobacco plantation in the study area uses the intercropping system. With this system, farmers can combine tobacco with other crops. Nevertheless, this practice is not without a problem because these crops are subject to certain pests and diseases that can harm tobacco. The interviews also found
that some types of pests and plant diseases had increased in frequency, which is attributable to changes in air humidity. Farmers also felt the impact of erratic precipitation on crop yields. For instance, they claimed that when the fertilizers were just applied, high rainfall did not allow the added nutrients to seep into the soil and be absorbed by tobacco; instead, it carried them away.

3.2 Weather and season monitoring efforts

In an attempt to monitor the weather and climate in Temanggung District, two Automatic Weather Stations (AWS) have been installed at the Agricultural Extension Office for Kledung Sub-district (“kecamatan” in Indonesian) and the Agricultural Extension Center for Temanggung Sub-district. The selection of the two sub-districts was based on their different physical conditions, i.e., Kledung is a mountainous area, while Temanggung is in low-lying land. Tobacco is the most cultivated commodity in both sub-districts. These AWS are expected to provide detailed information on the weather and season characteristics in the region and, at the same time, validate and improve the accuracy of the developed prediction system. The AWS installation works collaborate with the local Agricultural Extension Office to facilitate supervision and data collection. The collaboration includes installing AWS at the office in Kledung Sub-district (Figure 2).

Figure 2. The Installation of the Automatic Weather Station at the Agricultural Extension Office in Kledung Sub-district.

Figure 3 shows the first weather recording by AWS from June 18 to July 11, 2019, in Kledung Sub-district. The AWS measured several parameters, namely, temperature, humidity, rainfall, solar radiation, air pressure, and wind direction and speed. Figure 3 presents the recording of the most influencing climatic factors in agriculture, including temperature, humidity, rainfall, and solar radiation.

As seen in Figure 3-top, the temperature fluctuated between 20-30°C every day from June 18 to July 11, 2019. There was a temperature rise in early July, indicating the potential for increased rate of evapotranspiration and, by extension, drought. The dry season was marked by high temperature, but there was light rain with an intensity of less than 1 mm/day in mid-July. As for the air humidity, its daily fluctuation was not significant, meaning that in short-term the condition of the dry season did not experience much change. It is in line with the recorded solar radiation, which varied less significantly and, thereby, indicated bright days with sufficient sunlight for crop growth.
3.3 The development of SIMASTI application for weather and season forecasting

With a more extended period of observation, the above AWS recording can validate and improve the accuracy of the developed prediction system. For comparison, Figure 4 presents the results of weather simulation by the WRF model in May-October 2019 which then shown in the SIMASTI app. Based on Figure 4-top left, the lowest temperature occurred in July-August 2019. When compared with the AWS records, the WRF simulation in the SIMASTI app also showed a temperature rise in early July. However, it predicted that the temperature decreased in the middle of the month.

Figure 3. The results of weather monitoring from June 19 to July 11, 2019. From top: temperature, rainfall, air humidity, and solar radiation.

Figure 4. Example of the weather simulation results for the growing season from May to October 2019 in the SIMASTI app. Clockwise from top left: temperature, rainfall, air humidity, and solar radiation.
The rainfall simulation (Figure 4-top right) showed that July and August were the two months with the lowest rainfall. In July, there were several light rain events with an intensity of lower than 10 mm/day, whereas in August, there would be little to no rain. The prediction also said that the rainfall began to increase in September, starting with low-intensity rainfall at the beginning of the month.

Based on the humidity simulation (Figure 4-bottom left), there would not be any significant increase from July to October. An implication includes less frequent rainfall until late October. This condition affirms the estimated rainfall, i.e., rather low rainfall intensity in October.

The simulation of solar radiation showed an increasing trend until the end of October 2019. Similar to the AWS record, it showed a rising trend in mid-July. The solar radiation was predicted to continue to rise until the end of October, indicating bright sunny days.

The simulation results in Figure 4 were then also sent as an information in the SIMASTI app (Figure 5). This way, farmers can directly see the weather simulations for six months ahead from an Android-based mobile device or phone. They can use these forecasts as input before deciding their land management activities in the future. For instance, if the prediction shows a low rainfall at the beginning of the growing season, then farmers can choose to plant earlier as an attempt to adapt to the upcoming weather. The same case applies if SIMASTI estimates a high rainfall near the harvest time.

Figure 5. The developed SIMASTI app and an example of its display.

Aside from the results of weather simulations, this application is further designed to provide information about crop water needs, including the dissemination through training and brochures. Crop water needs can be estimated from rainfall and temperature. Based on this information, any conditions of excess or lack of water become computable. Figure 6 shows an example in May-October that show the water needs of tobacco (right) for each growth stage (left) using the amount of rainfall as the input (middle). At the initial stage (early May 2019), the rainfall reached 30 mm/day, and the crop water requirement was less than 1 mm/day. It demonstrates that the rainfall can meet the crop water needs at the beginning of the growing season. At the mid-season, the rainfall dropped to approximately 1.4 mm/day and was lower than the crop water need, i.e., 2.4 mm/day. This condition signifies a potential
water shortage in the middle of the growing season. Meanwhile, light rainfall with intensity of less than 10 mm/day was predicted to occur at the end of the season until the harvest time. All of this information can warn farmers of future adversities and help them to develop strategies should rain occur at the end of the growing season.

Figure 6. An example of crop water requirement simulation for tobacco plant in SIMASTI app, with a growing season starting in early May 2019.

4. Conclusion
Over the past few decades, technological advances in weather and climate forecasting have increased rapidly. Nevertheless, there is not much analysis at a detailed scale, and the prediction results are not significantly implemented for public use [25,26]. In other words, there is still a gap between weather and climate experts and the wider community, resulting in weak attempts to mitigate and adapt to climate change, especially in agriculture [6]. Although farmers have come to recognize and experience climate change impacts, such as shifting seasons, more frequent drought events in dry seasons, excessive rainfall in rainy seasons, and temperature rise, there have been minimal efforts to address them [5].

Currently, there are many efforts in agricultural application based on weather and climate forecasting technology, such as in United States, European, and African Countries [12,29,30]. In Indonesia, the development SIMASTI application seeks to simulate seasons in detail and disseminate the analysis results to the public. This research has successfully produced a derivative of the simulation results, namely estimates of crop water needs. Comparison between the AWS records and SIMASTI simulations shows acceptable results. However, for the application users, which in this case are farmers, are advised to not entirely trust the simulation results because so far, the validation only involves short-term comparison. Therefore, long-term observation and research become necessary as an effort to measure the accuracy of the generated simulations. Data obtained from long-term weather observations are also crucial to improve the performance of the prediction system and, finally, produce a model with high precision.

Aside from long-term observations, the question of which mitigation and adaptation measures are appropriate for agricultural practices remains unanswered. There are some alternative solutions carried out in other regions, namely groundwater utilization or water extraction from underground rivers in
karst areas. However, these strategies are less suitable for Temanggung because of its mountainous terrain and deep groundwater. Rainwater harvesting also does not meet agricultural water needs in this district. Therefore, future research is expected to contribute to the development of functional mitigation and adaptation strategies to overcome the impacts mentioned above.

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