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Evaluation of cropping calendar adherence on an irrigated lowland rice production area using remote sensing-derived aboveground biomass production

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Abstract

Water management and farming operations are inseparable endeavors in effective farming, particularly in irrigated rice schemes. The farmer's response to general protocols, such as the cropping calendar, greatly determines the effectiveness of existing farming protocols. This study was conducted solely to determine farmers' adherence to the proposed calendar, which is important for water and agricultural operations management. This study makes use of the AboveGround Biomass Production (AGBP) estimates derived from the water productivity framework algorithm based on the PySEBAL model. Landsat data and other remote sensing products were assimilated into the model. The model somehow underestimated the AGBP values due to cloud contamination. The AGBP values were valid in terms of AGBP progression, which represents the general phenology of irrigated rice planted over the area. This study found that the AGBP is highest during February and September (when most of the area is between the late vegetative and the harvesting stage), and the low monthly AGBP values during April and May represent the transition period from dry to wet season, where the rice fields are generally harvested, hence the low AGBP values. The results support the conformity of MARIIS Division IV irrigation scheme to the general cropping calendar for the area, which implies that the farmers mainly support management recommendations and protocols.

Key words: aboveground biomass; cropping calendar; farmer’s response; irrigated rice; PySEBAL.

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Introduction

Water is the most crucial factor in lowland rice areas and its effective management relies on proper irrigation scheduling. In irrigated rice areas, the allocation and distribution of water influence major farming activities such as land soaking, land preparation, fertilizer and nutrient management, and harvesting. As a systematic representation of these activities, cropping calendars are devised following the irrigation delivery and the crop cultivar being used. Cropping calendars are an important manifestation of how the prevailing climate influences crop production. Selecting the most suitable cropping calendar promotes higher yield performance (Samejima *et al*., 2020). Timely modification of cropping calendar is also proven to be an effective measure against risks and vulnerability issues under the influence of weather and physical factors (Ferrer *et al*., 2022). Moreover, cropping calendars can include farmer’s knowledge due to their personal experiences in the field (Apriyana *et al*., 2021).

Cropping calendars are also being devised to systematize management-based practices in combatting climate change impacts. Yegbemey *et al*. (2014) recognized how variability in climate particularly in agriculture, could impede sustainable development. Farmer-oriented discussions were employed, and they investigated possible ways to revise and update the current cropping calendar which also tackles socio-economic factors. Crop calendar optimization is also of major importance. The updating of calendars in response to affecting parameters such as weather and change in major land use is always imminent. Cropping calendar adjustment lessens yield loss where significant water requirement reduction is also observed particularly in areas where effective rainfall can be increased strategically by aligning major production stages where consistent water supply is vital (Wang *et al*., 2022). Studies were being conducted where the appropriate cropping calendar is based on the performance of major crops such as rice (Samejima *et al*., 2020). According to Wang *et al*. (2016), rice yields particularly in tropical environments (defined by the radiation use efficiency of the crop) is dependent on temperature and solar radiation making rice production vulnerable due to global warming. Sustainable agriculture in changing climate is attributed to effective management of the cropping calendar (Karandish *et al*., 2016).

The contribution of farmers in the cropping calendar adoption is also highly significant. It is the farmers who determine the applicability of such calendars, which by no means a linear function of informing and doing. According to Yuliarso *et al*. (2020), the farmers’ knowledge of farming innovations such as cropping calendar adjustments is influenced by the level of education that they received and several socio-economic parameters such as experience, communication, knowledge dissemination, training, etc. Successful promulgation of a cropping calendar depends on how the farmers and other stakeholders would work in following it which is also tied to the benefits that farm workers can derive in following such calendar revisions such as the adjustment of planting season and other major farming activities. A cropping calendar, together with crop models, can be applied in estimating regional yield as a function of water availability and other factors that define the windows for transplanting, harvesting, heading, and harvesting (Sawano *et al*., 2008). In Central Java province, cropping calendar analysis was based on land suitability for rice farming, mainly influenced by rainfall which gives provision to secondary crops (Zid *et al*., 2022).

Monitoring of crop growth is among the most important ventures of today. Different crop models represent the seasonal crop progression from planting to harvesting. However, this approach is widely applied for the purpose of determining the response of farmers to cropping calendars. Crop monitoring using remote sensing is highly employed. Crop phenological monitoring has long been applied. Patel and Oza (2014) utilized the moderate resolution imaging spectroradiometer (MODIS) in deriving a net difference vegetation index (NDVI) to generate a cropping calendar based on the interpreted physiological stages of the crops. Other satellite products such as Landsat and Sentinel were also applied to establish NDVI time series in phenological monitoring of agriculture production areas which is considered important in crop management (Boori *et al*., 2019; Choudhary *et al*., 2019). Crop yield prediction is also being carried out using a remote sensing-vegetation index approach that is relevant in obtaining long-term data on crop phenology, which is not feasible for field observations (Ji *et al*., 2021). In Asia, a MODIS-based cropping calendar for rice was devised and compared to RiceAtlas – a census-based report on the important cropping activities that determine rice phenological stages such as transplanting and harvesting. Hence, the use of remote sensing data, particularly from satellites, aids a more systematic formulation of cropping calendars. Similarly, crop phenology is estimated using aboveground biomass estimates (Li *et al*., 2022). Aboveground biomass pertains to the plant-derived organic matter parallel to plant growth and its estimation is important for carbon sequestration studies and crop yield prediction. Remote sensing-derived algorithms are being developed to estimate AboveGround Biomass production (AGBP). The modeling framework also makes use of AGBP for water management and economics, which are among the main concerns of current water resources management projects. AGBP is often synonymously represented by gross primary production. In water productivity framework developed by Mul *et al*. (2020), the AGBP estimation was included in the Python-based surface energy balance algorithm (PySEBAL) model, which estimates both actual evapotranspiration and AGBP to estimate crop water productivity.

While several studies have been conducted which derive cropping calendars using remote sensing data, there are only a few that evaluate the response of farmers across the agricultural landscape that the calendar represents. Monitoring farmers' activities can be tiresome, but with the aid of remote sensing measurements, the cropping calendar promulgation can be monitored solely by looking at the crop condition, which represents crop growth stages. Such a conclusion can be directly derived from spatiotemporal values over the study area. This study employs a simple and systematic approach to investigate the overall adherence of farmers to the proposed cropping calendar over important agricultural rice irrigation scheme in the Philippines. The consideration that farmers in the area have private provisions for shallow tube wells, which makes them capable of deviating from the general cropping calendar was taken into mind in catalyzing this study. Hence, the study aims to determine whether the cropping calendar is being closely followed by the stakeholders, particularly the farmers, and by how much the existing cropping systems offset the ideal one as indicated by the existing calendar. This study makes use of the established water productivity framework to calculate the corresponding crop biomass that determines the overall cropping progression in the area. As a pioneering study in evaluating cropping calendar adherence in the country using the resulting aboveground biomass estimates of a widely employed water productivity framework, based on the PySEBAL model, this study serves as an important overview in identifying areas that deviate from the proposed calendar, if any, and in further optimization or continuous promulgation of the existing calendar.

Materials and Methods

Study area

The study was conducted over the service area of National Irrigation Administration (NIA) Magat River Integrated Irrigation System (MARIIS) Division IV (D4) in Isabela province (Figure 1). MARIIS has 4 divisions and 23.28% of the total service area is under Division IV authority. The area is among the most important rice-producing hotspots in northern Luzon making it the second leading producer of rice. Farmer participation is important to MARIIS Division IV where different programs including livelihood and capacity trainings are being directed toward the farmers.

Satellite data

As mentioned, this study follows the PySEBAL-based water productivity framework, suggested by Mul *et al*. (2020) where the AGBP has been simultaneously solved together with the actual evapotranspiration. In running the model, 30 Landsat scenes for the dry cropping season (DS) from October to February, and 49 Landsat scenes for the wet cropping season (WS), from May to September, of nine years (2015 to 2023) were utilized. Supporting satellite data include meteorological variables, soil hydraulic properties, and DEM data acquired from NASA Global Land Data Assimilation System (GLDAS) (Rodell *et al*., 2004; Beaudoing and Rodell, 2016), HiHydro v2.0 Datasets (Simons *et al*., 2020), and Shuttle Radar Topography Mission (SRTM 30-m resolution DEM respectively. The algorithm for the AGBP is embedded in the PySEBAL-based water productivity code which is the main model of this assessment. However, this study is more particularly focused on the estimated AGBP values which is the main parameter in evaluating cropping calendar adherence. For more detailed information and a description of the PySEBAL model, the reader is referred to Mul *et al*. (2020) and Pareeth (2024).

Land use/land cover data

The land use/land cover (LULC) data was requested and acquired from the Geoportal, an open-source platform managed by the National Mapping and Resource Information Authority (NAMRIA). In order to represent the rice production areas, the annual crop classification was considered from the LULC for 2015 and 2020.

Estimation of aboveground biomass production

Embedded in the PySEBAL algorithm is the provision to calculate the AGBP. The PySEBAL algorithm used in this study was completely discussed by Mul *et al.* 2020). The model algorithm makes use of remote sensing images and iteratively calculates actual evapotranspiration using the estimated latent heat flux, which is taken as the residual of the surface energy balance equation. In the PySEBAL algorithm given by Hessels *et al*. (2017) there is a provision to calculate the aboveground biomass using the vegetation index approach using following the formula:

$$\text{AGBP} = \text{APAR} \times \text{LUE} \times 0.864 \quad \text{(Eq. 1)}$$

where APAR is the absorbed photosynthetically active radiation and LUE is the light use efficiency. The AGBP algorithm in the PySEBAL model makes use of APAR absorbed by the vegetation canopy *i.e.*, APAR which is the product of the photosynthetically active radiation (PAR) – between 400 to 700 nm wavelength, and the fraction of PAR (FPAR) absorbed by green vegetation absorbed by the canopy given by the formula:

$$\text{FPAR} = -0.161 + 1.257\ (\text{NDVI}) \quad \text{(Eq. 2)}$$

where NDVI is net difference vegetation index.

LUE on the other hand is a function of environmental stressors namely, heat stress based on temperature and stomatal activity, vapor stress-based vapor pressure deficit, and moisture stress based on the FPAR, and the maximum LUE, similar to the one used by Jaafar and Mourad (2021) and was further elaborated by Hazimeh and Jaafar (2024). The 0.864 value is the conversion factor from dry matter production to biomass production (de Oliveira Ferreira Silva *et al*., 2018).

Monthly and seasonal gap-filling

Gap-filled monthly maps were created using a spline-based spatial interpolation technique after gaps were temporally filled every four months using local weighted regression (LWR). This technique uses temporal gap-filling to compute outliers and missing data. For every time series observation (pixel) in the map, a polynomial model was built by employing a set of neighboring pixels in the time dimension. Afterwards, the values were calculated by using this model for the relevant time frame. Distance-based weighting resulted in lesser weights being allocated to observations made at later times. All-time series observations were interpolated if there were a sufficient number of non-null observations. Bicubic spline interpolation was subsequently used spatially to reconstruct the remaining gaps caused by insufficient valid observations in the time series that meet LWR conditions. This step was limited to null pixels computed from neighboring valid pixels, ensuring that the observations and temporally interpolated estimates remained unchanged.

Results and Discussion

The seasonal value of AGBP in this study is taken to be the maximum estimated biomass since crop growth is compounding and considering average growth per month significantly underestimates biomass values as the season progresses. According to Wang *et al*. (2016) in a study of rice yield in tropical and subtropical environments, the lower yield value for tropical environments represented by the IRRI experiment area in the Philippines, is associated with lower radiation use efficiency (RUE).

The classic paper of Monteith (1981), cited by Wang *et al*. (2016) states that RUE and intercepted seasonal solar radiation determine crop biomass output. Furthermore, based on the study, the researchers suggested an inverse relationship between RUE and temperature (T) as the reduction of RUE under the tropical environment was due to relatively high temperatures. A significant yield decline was observed when minimum and maximum temperatures exceeded 22 and 20.5°C, respectively. Based on the supplementary temperature data from the ISU Echague Agromet Station, DS has a narrower temperature range at 7.5°C having a minimum

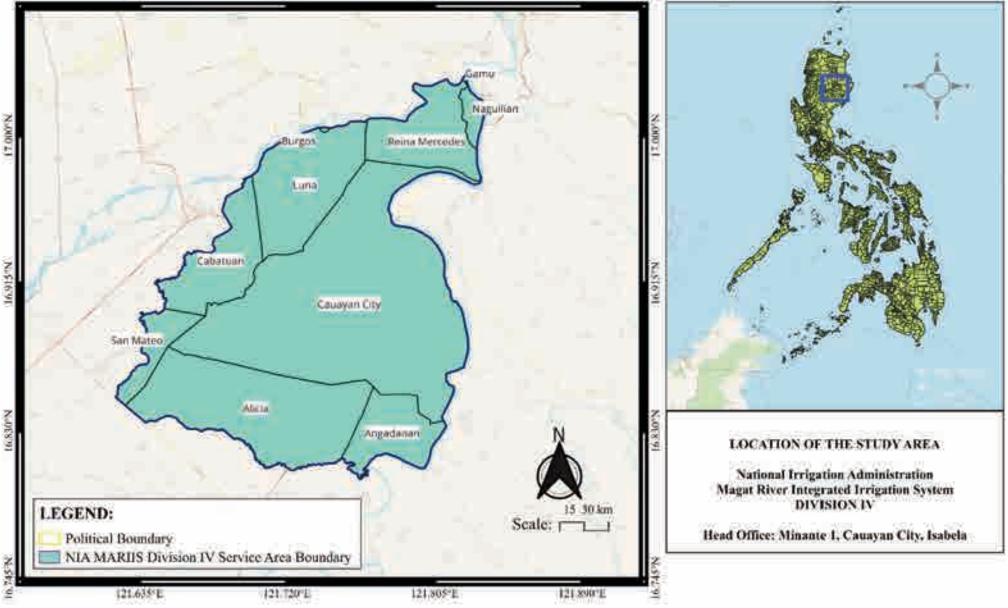


Figure 1. Location of the study area.

and maximum temperature of 21.3°C and 28.8°C, respectively as compared to WS with a minimum and maximum temperature of 23.9°C and 34.0°C. This supports the higher estimated AGBP values during the DS.

The low estimates of AGBP may have risen from the interpolated representative Landsat images. As shown in Figure 2, the highest estimated AGBP-area average is during September for WS and February for DS. However, the representative Landsat data was taken during the second week of August and the first week of September for the WS, while for DS, they were taken during the last week of January and the third week of February. Figure 3 shows the general cropping calendar of the study area for WS 2023 to DS 2024 cropping seasons. The average duration of rice falls within the range of short-duration crops (Figure 4). Given the satellite acquisition date, the representative Landsat image was taken when approximately half of the area was under the mid-vegetative to early reproductive phase for the WS and the late vegetative to mid-reproductive phase for DS. The availability of assimilated Landsat images due to cloud contamination has contributed to underestimate the AGBP values.

The crop stages captured within aforementioned crop phases only include tillering, panicle initiation, and booting stages. The representative image fails to capture the peak growth stage that also covers most of the area. This can be attributed to differences in cropping schedules which cause farmers to deviate from prescribed cropping calendar which may include but is not limited to labor, farming capital, machine availability, etc. The average monthly AGBP plot in Figure 2 extends approximate phenology in the study area which supports promulgation of cropping calendar.

The spatial distribution of the monthly average AGBP is shown in Figure 5. The spatial AGBP values are reflected where the generated monthly spatial maps give a more elaborate depiction of AGBP progression over the area. April and May exhibit lower AGBP values dominated by <3000 AGBP values with higher AGBP values near the western boundary and over mid Luna-Reina Mercedes-Cauayan City area. The low AGBP values can be perceived to represent harvested areas with rice stubbles. Those with high AGBP values represent areas where harvesting is still ongoing or has not yet started except those that are near the boundary of extricated built-up areas where sustained high AGBP values in all

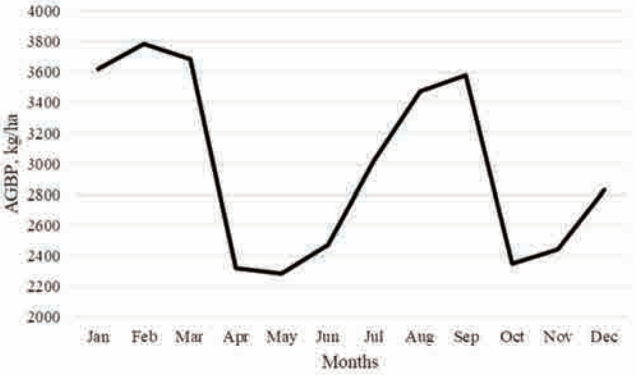


Figure 2. Average monthly AGBP estimates from 2015-2023.

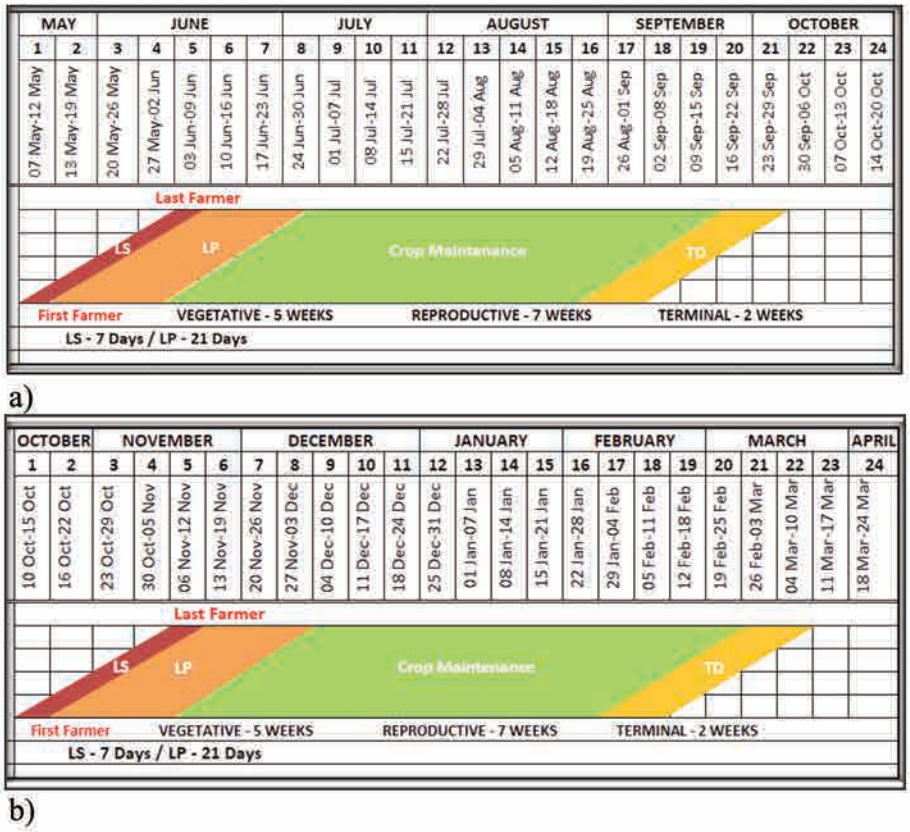


Figure 3. Sample cropping calendar of MARIIS division IV. **a**) Wet season. **b**) Dry season.

months are attributed to unclassified green vegetation such as trees. This limitation on the precise extraction of actual cropped areas using a general LULC map has been previously mentioned.

The DS cropping starts in October and it can be seen that in a span of a month from September, the AGBP values have drastically changed implying that full harvest occurred between the acquisition of the base satellite image for September and October. From October to December there is no visible location on which area has higher growth progression. January and February show the majority of areas having progressed from AGBP values of 4000-5000 kg/ha which eventually measured to have a higher distribution during February. Here, high AGBP values seem to be located on upstream canal areas shown in Figure 4 with corresponding uncertainty since there are patches of relatively lower AGBP values. The higher spatial concentration of AGBP values during February is supported by high monthly average AGBP value for February in Figure 2. Towards March, it can be seen that the AGBP values on the western side of the area are starting to decrease having a higher AGBP value on the eastern portion, particularly over Cauayan City.

The WS cropping officially starts during May up to September (Figure 5 e-i). The May AGBP appears to have lower values over the area compared to March which signifies that most of the area is at land soaking to land preparation phase. In August (Figure 5h) higher AGBP values (up to the 4000-5000 kg/ha) are now visible in the lower western portion of the area particularly over Cabatuan, San Mateo, and Alicia, up to mid-portion of Cauayan City. Figure 5b shows that February is dominated by AGBP values up to 5000-6000 kg/ha. However, parts of the area in Alica, Angadanan, and a large part of Cauayan City have low AGBP values representing harvested portions. The area majority covered by high AGBP values was not observed over the area due to temporal resolution constraints of the Landsat satellites that operate at a return interval of approximately 16 days. Hence, it is possible that the representative images were not acquired during the peak AGBP in the area.

The actual peak AGBP, particularly during the ripening phase in the area was not captured which is exhibited by low expected AGBP values. Nevertheless, average monthly spatial maps show the progression of growth which may be caused by deviating from the cropping calendar as represented by the distribution of AGBP which is not visible in temporal scales (Figure 2). While there are visible areas that do not seem to follow the designated cropping calendar due to cropping constraints, the spatial and temporal distribution of AGBP values strongly agrees with the cropping calendar of area where DS yields higher AGBP in comparison to WS. The spatial distribution of monthly AGBP values for months of March and April shows that western part of the area which is near the main canal was the first to have lower AGBP values and progresses towards the eastern portion. This implies that the areas near the water sources were the first to plant and harvest for the DS. For the WS, mentioned variability of AGBP as presented by the monthly distribution may have been the reason why WS has lower AGBP value than the DS. In accordance with the general cropping calendar of the area (Figure 3), which is the long-existing calendar with minimal deviations from year to year, the average monthly values of maximum AGBP in Figure 2, fall within the specified dates covering the important activities and crop stages on the cropping calendar. Furthermore, the spatial distribution of monthly AGBP values shows how the land cover changes in the area particularly in transitioning from one phase to another which is denoted by the increasing and decreasing AGBP values such as during the harvesting towards the initial land soaking and land preparation phases.

Remote sensing has provided multi-faceted earth systems information, which are vital in effective agricultural development and management. The results of this study show how the overall area follows the cropping calendar trend. Among the satellite products that the PySEBAL model supports, Landsat has the highest spatial resolution which is more suitable for the study area compared to other satellite products like MODIS that has a coarser resolution. However, with the 16-day visiting interval of Landsat, it

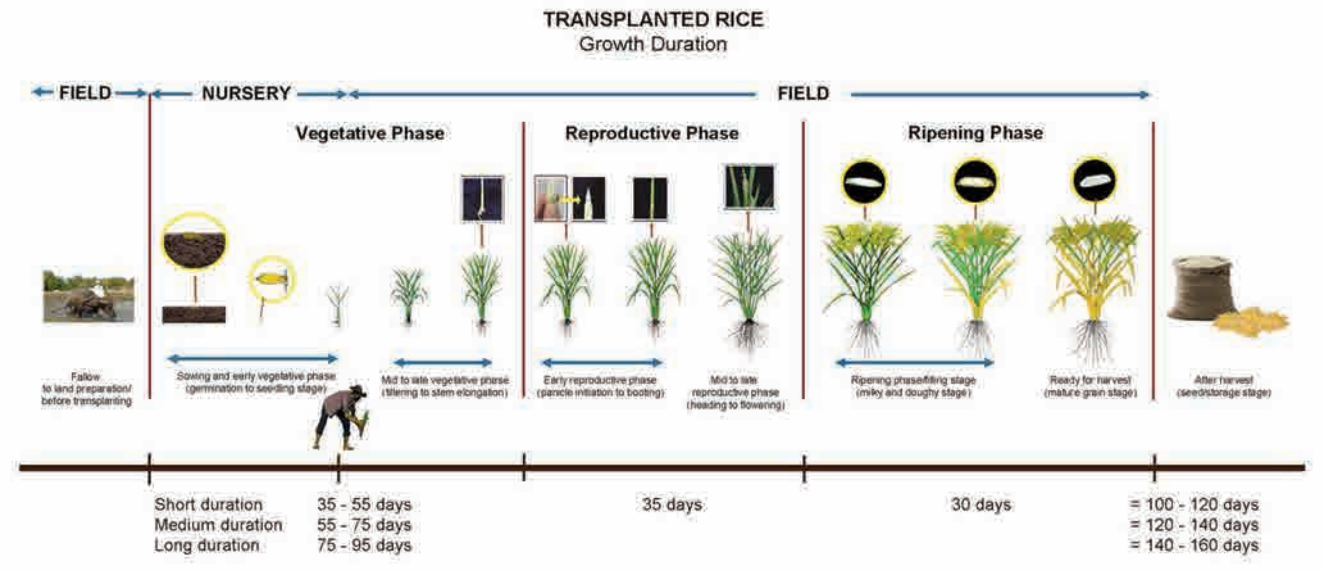


Figure 4. Growth duration of transplanted/flooded rice. Retrieved from: IRRI Rice Knowledge Bank Website (http://www.knowledgebank.irri.org/step-by-step-production/pre-planting/crop-calendar).

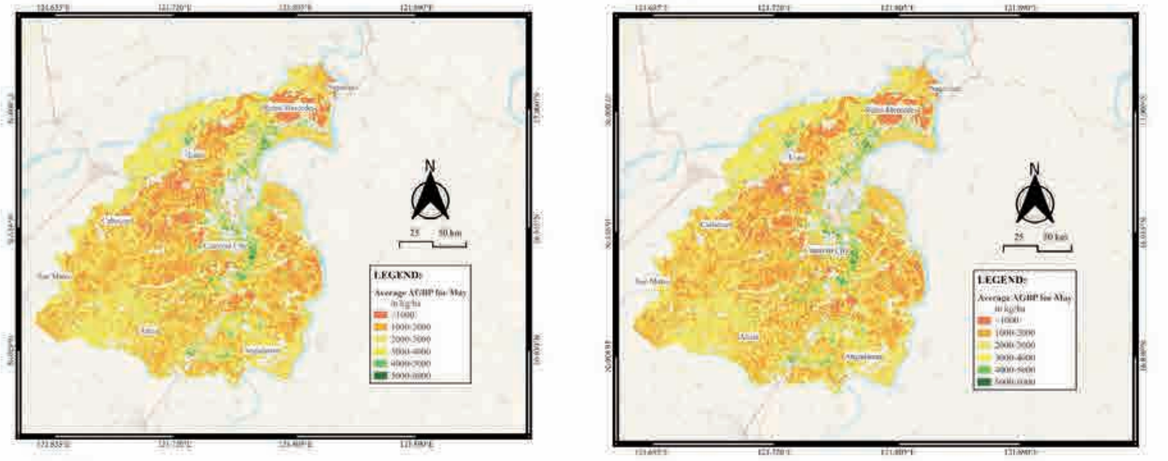
may only capture monthly variation ideally twice a month which is influenced by cloud cover. As previously articulated, this has been the main factor why the AGBP estimates are lower than the expected yield. Nevertheless, estimated temporal AGBP variation is still valid in monitoring the response of area to the designed cropping calendar. Furthermore, this study proved that *in situ* farming operations, though they follow the general cropping calendar, are highly variable on the ground which may be due to limitations in terms of the availability of farming resources particularly water, machinery, manpower, and capital. The presence of private pumping sta-

a) January

b) February

c) March

d) April



e) May

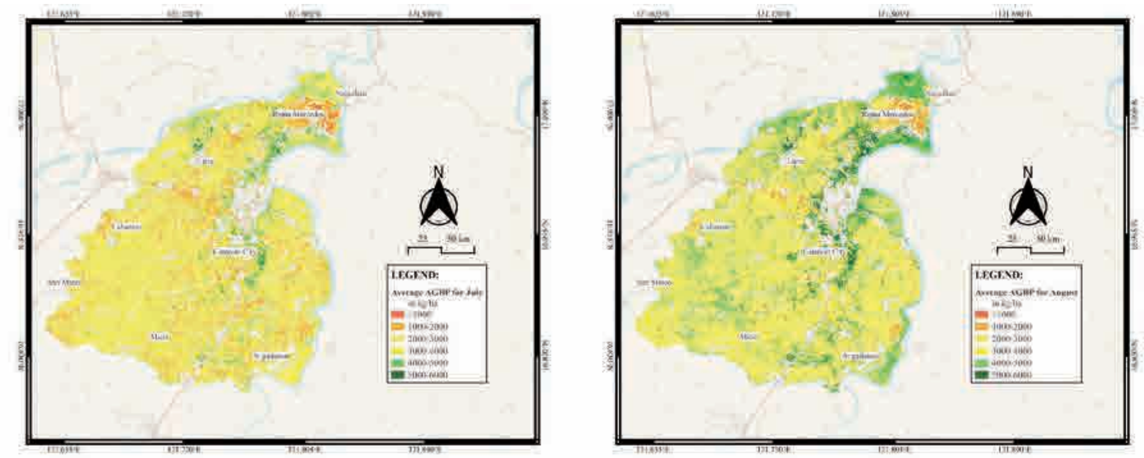
f) June

Figure 5 (a-f). Average monthly ABGP values from 2015-2023.

tions also contributed to the AGBP variability such that some areas even outside their scheduled irrigation water delivery can initially start land preparation while waiting for their water ration.

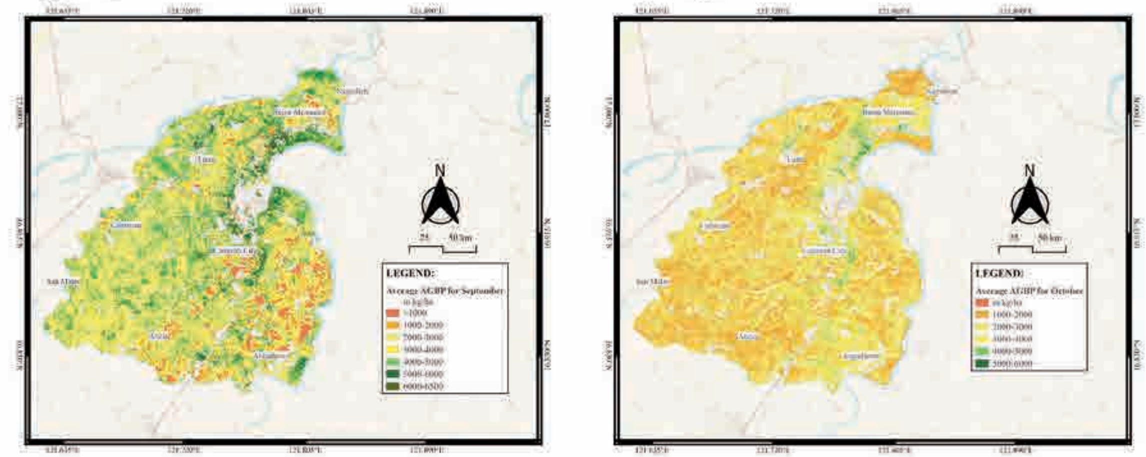
Conclusions

The water productivity framework based on the PySEBAL model has effectively been used in this study to estimate both spa-



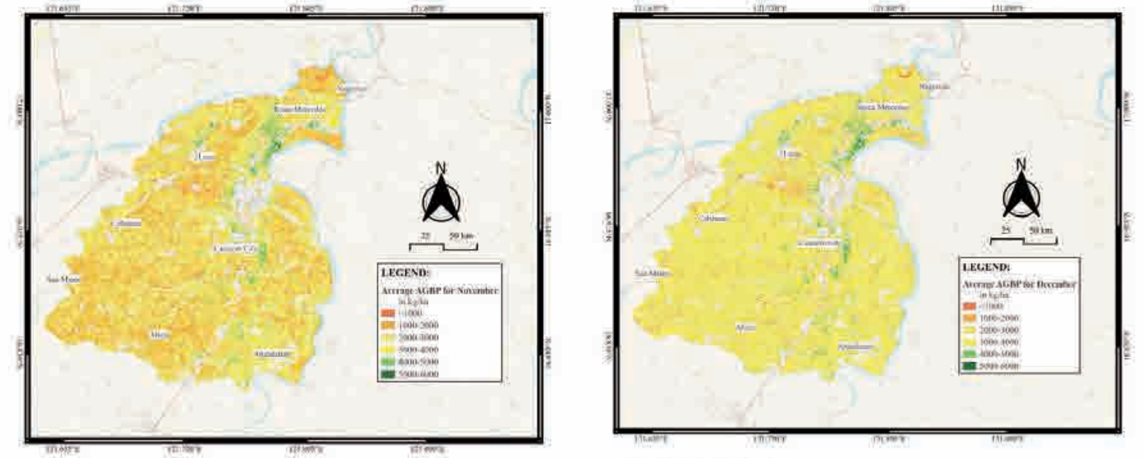
g) July

h) August



i) September

j) October



k) November

l) December

Figure 5 (g-l). Average monthly ABGP values from 2015-2023.

tial and temporal values of AGBP which represents phenological progression of rice in the MARIIS Division IV irrigation scheme. This study serves as the first attempt to use AGBP values of PySEBAL model in evaluating cropping calendar adherence of an irrigated rice scheme in the region. And while the AGBP values were underestimated due to excessive cloud cover in the area (common in tropical settings), the study still captured the growth progression of irrigated rice, which was found to conform to the designed cropping calendar in the area. This implies that the MARIIS Division IV farmers generally follow scheduled activities which are mainly anchored to availability of water. This goes to show that the farmers in the area support management recommendations which are crucial for effective agricultural operations. Moreover, this study captures possible farmers' support if further calendar revisions are promulgated. The result of this study presents an avenue for water managers to evaluate risks brought about by the changing climate. Furthermore, the utilization of the water productivity framework, particularly the PySEBAL model, which incorporates AGBP algorithm, can be adopted by other similar studies as it gives comprehensive estimates of important crop production parameters.

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Conflict of interest: the authors declare no competing interests.

Availability of data and material: the data used to support the findings of this study are available from the corresponding author upon reasonable request.

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