Satellite-Powered Crop Insurance to Protect Rice Farmers from Climate Risk in the Philippines

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Abstract: *Smallholder rice farmers in the Philippines face increasing losses from climate hazards. Conventional indemnity-based crop insurance, while available at no cost to smallholder farmers in the Philippines, suffers from slow claims processing, subjective damage assessments and limited coverage. This study presents the development and simulation of the Area-Based Yield index insurance (ARBY) product, an innovative and scalable crop insurance solution that leverages the Philippine Rice Information System (PRISM). PRISM integrates remote sensing and crop modeling to generate monthly and seasonal estimates of rice area, planting date, and yield estimates, which are used to define homogeneous insurance zones (IZ) and estimate seasonal yields. Using six-year historical baselines (2018-2023), we parameterized the mean and variance of yields per IZ and conducted simulations for the 2023–2024 rice crop seasons in six municipalities in the Philippines. Two coverage options (80% and 90% of historical mean yield) were evaluated to balance affordability and protection. Results show that 80% coverage was cost-effective for moderate-risk areas, while 90% coverage delivered greater protection in high-risk zones, at higher premiums. ARBY demonstrates significant potential to reduce financial losses from climate-induced yield shortfalls, with benefits amplified by farmer education, local government engagement, targeted subsidy schemes and continuous refinement of yield models. This study illustrates how remote sensing–based yield estimation can overcome key limitations of traditional crop insurance and strengthen climate resilience and food security in rice-based systems. By replacing costly and time-consuming farm-level loss adjustment with satellite-derived yields, ARBY addresses core limitations of traditional schemes and can improve the speed, transparency, and scale of financial protection. Through active role of the Philippine Crop Insurance Corporation (PCIC) in co-developing and piloting ARBY, the product has a clear pathway and strong potential to scale nationally.*

Keywords: Area yield index insurance, climate risk, crop insurance, food security, Philippines

Introduction

The Philippines is among the most climate-vulnerable countries globally due to its geographic location and diverse environmental features. The country is regularly exposed to multiple climate hazards, including tropical cyclones, floods, droughts, sea-level rise, and increasing temperatures (ADB, 2021). These hazards are further intensified by large-scale climate phenomena such as the El Niño–Southern Oscillation, which drives variability in rainfall and soil moisture and severely impacts agricultural productivity. Projections also suggest worsening water scarcity by 2040, which will place additional strain on agriculture, still a major livelihood sector in the Philippines. Between 2012 and 2022, total disaster-related damages to properties averaged nearly Php 44 billion (USD 760 million) annually, with agriculture accounting for 60% of the losses (Php 26.4 billion or USD 475 million per year). Rice was consistently among the most affected crops (PSA, 2023; Galang & Briones, 2024).

Historical records show that typhoons, floods, and droughts have consistently caused substantial damage to rice production. For example, the combined effects of tropical cyclones Kristine (Trami) and Leon (Kong-rey) in October 2024 caused approximately Php 6.75 billion (USD 118 million) in damages, affecting more than 168,000 farmers, and resulting in losses of 313,479 metric tons of rice, representing 1.64% of the country's total rice production (NDRRMC, 2024). Likewise, during the 2023–2024 El Niño episode, among the most severe droughts in recent history, agricultural losses reached Php 15.3 billion (USD 268 million), of which rice accounted for nearly 39% (Php 5.93 billion or USD 104 million). Losses in rice production reached 330,717 metric tons, representing 1.73% of the country's total rice production. Rice-producing provinces such as Palawan, Iloilo, Camarines Sur, and Occidental Mindoro (Annex 1) were significantly affected (DA, 2024). These disruptions reduced both harvest areas and yields, and affected national food supply chains and farmer livelihoods. Such climate shocks disrupt crop growth stages, reduce yield potential, and diminish farmer incomes, generating annual economic impacts measured in the millions of dollars. These yield fluctuations are highly sensitive to variable precipitation and soil moisture deficits, while rising temperatures are expected to further increase production risks.

Smallholder rice farmers bear these impacts more acutely. Their reliance on small landholdings, coupled with limited financial and technical resources, constrains their adaptive capacity (Galang & Briones, 2024). In addition to climate hazards, farmers face recurrent problems with pests and disease. Access to formal risk-transfer mechanisms remains limited. While the government provides subsidized indemnity-based crop insurance, program effectiveness is constrained by low coverage ceilings, with full subsidy limited to three hectares per household , prioritized first for farms 1.5 hectares or less (PCIC, 2025), delayed claims processing, and reliance on manual, site-specific loss assessments. These operational limitations undermine the scheme's effectiveness in supporting timely recovery (ADB, 2021).

To address these gaps, the International Rice Research Institute (IRRI) and national government institutions, Philippine Crop Insurance Corporation (PCIC) and Philippine Rice Research Institute (PhilRice), co-developed the Area-Based Yield index (ARBY) insurance product as an alternative risk transfer option for rice farmers. ARBY leverages the Philippine Rice Information System (PRISM), which integrates satellite-based remote sensing, smartphone-based surveys, and crop growth modeling to generate seasonal maps of rice area, start of season (SOS), and yield (Mabalay et al., 2022). The system further applies Synthetic Aperture Radar (SAR) data to derive biophysical parameters (e.g., Leaf Area Index, LAI), which, when combined with weather, soil, and management data, produce accurate rice yield forecasts and estimates (Setiyono et al., 2018). These outputs form the basis for insurance zones, historical benchmarks, and payout triggers.

IRRI, PCIC, and PhilRice piloted ARBY in six municipalities during the 2023–2024 cropping seasons. Results from simulations indicate financial viability, faster claims processing, and expanded coverage against climate-related risks such as flood, drought, and pest outbreaks. Recommendations emphasize the need for robust and timely yield data for calibration, as well as continuous refinement of actuarial models, to ensure sustainability and operational scalability.

Literature Review

Over the past fifteen years, historical records consistently demonstrate that rice production in the Philippines and across Southeast Asia are highly vulnerable to climate hazards such as typhoons, floods, and droughts. Major events, such as Typhoon Haiyan (local name Yolanda) in 2013, inflicted catastrophic losses on both standing rice crops and agricultural infrastructure, with more than 80,000 hectares of rice in the Visayas regions, approximately 2% of the national rice area in 2013 severely affected and national production losses reaching crisis levels (USDA, 2013). In recent years, intensifying El Niño events and erratic rainfall have further compounded these vulnerabilities, leading to significant shortfalls in yield. For instance, the 2023 El Niño event caused notable disruptions in rice-growing regions across Southeast Asia. In the Philippines, palay production declined to 19.09 million MT, representing 4.84% reduction (or 970,000 MT loss) from the previous year's record harvest of 20.06 million MT due to combined effects of El Niño, typhoons and La Niña (PSA 2025b). Concurrently, global rice supply experienced a deficit exceeding 8 million metric tons in 2023, the largest since 2004, resulting in elevated prices and intensified food insecurity throughout the region (CSIS, 2024). In the Philippines, these compounded shocks have led to increased rice imports and contributed to inflation rates as high as 4.1% in late 2023, with 50–70% of inflation attributed to rising food costs (CSIS, 2024; DA, 2024).

Given these vulnerabilities, the region's resilience depends on adopting climate-smart technologies, innovative risk transfer mechanisms, and targeted policy interventions designed to buffer producers against systemic risk (CSIS, 2024; DA, 2024). These recent trends in yield decline, economic losses, and food price instability underscore the imperative for robust agricultural risk management strategies, including the integration of satellite-based insurance schemes (Nguyen et al., 2025).

Recent advances highlight the expanding application of SAR and other satellite-derived indices for area-based yield index insurance in agriculture, with particular concentration in Africa and Asia. A systematic review by Nguyen et al., (2025) demonstrates a rapid increase in studies since 2015, initially focused on the Normalized Difference Vegetation Index (NDVI) and, more recently, leveraging high-resolution SAR data such as Sentinel-1, Cosmo-SkyMed, and ENVISAT ASAR. These methodologies have primarily targeted major cereal crops - rice, wheat, and maize - as well as pasture systems, with much of the research concentrated in Kenya, China, India, and Southeast Asia. Medium-resolution datasets like MODIS (Moderate Resolution Imaging Spectroradiometer) and AVHRR (Advanced Very High-Resolution Radiometer) still dominate the scientific literature, although the adoption of higher resolution SAR (e.g., Sentinel-1) is increasing. Across most studies, time series span an average of 15 years, highlighting the importance of historical data archives. The prevailing approach in index development involves aggregating SAR or spectral indices at the insurance unit scale (e.g., district level), often combined with ground-truth data for calibration and validation. The main methodological frameworks include data assimilation into crop models and application of statistical regression to establish links between satellite indices and reported yields.

Nguyen et al. (2025) synthesized findings from 89 global studies, concluding that satellite-driven vegetation indices, primarily NDVI and Enhanced Vegetation Index (EVI), are consistently more effective in correlating with crop yield losses than traditional weather-based insurance triggers. As a result, basis risk is significantly reduced when insurance units are carefully defined and when satellite data products are both temporally extensive and high in spatial resolution. Similar technical advantages have been reported by Nordmeyer and Musshoff (2025), who observed that the inclusion of remotely sensed vegetation health metrics in index insurance products enhances their adoption by farmers, attributable to the provision of spatially detailed and timely indicators directly linked to crop performance. Farmonaut (2025) further emphasized the operational benefits of satellite-powered crop insurance, including real-time crop health monitoring using spectral indices like NDVI and

SAVI (Soil adjusted Vegetation Index), rapid risk assessment at broad spatial scales, cost efficiency, lower fraud potential, and greater transparency in claims verification. These innovations facilitate the expansion of insurance coverage and expedite objective payouts based on remotely sensed crop health evidence.

Despite these advances, operational challenges persist. These include residual basis risk at both spatial and temporal scales, the need for specialized technical capacity to define and validate indices, and the complexities of applying standardized indices across highly heterogeneous landscapes. Basis risk refers to the possibility that the index used for insurance payouts does not perfectly match the actual losses experienced by individual farmers—for example, a farmer may experience significant yield loss, but the index may not trigger a payout due to spatial averaging or timing mismatches. This mismatch can undermine the intended financial protection and reduce farmer trust in index-based products (Hochrainer-Stigler et al., 2014). Evidence from pilot programs and systematic reviews, however, confirms both the technical feasibility and growing importance of SAR-based and satellite-driven solutions in area yield index insurance for major crops (Nguyen et al., 2025).

Index-based insurance continues to attract attention as a risk management strategy for climate-vulnerable crop producers. A feasibility study by Gregerson (2024) in Battambang, Cambodia, explored the use of rainfall-based indices along with field yield surveys for rice insurance. While the findings indicated potential welfare gains, they also highlighted persistent issues such as basis risk, low rainfall-yield correlation, and limited farmer trust in contracts. The study underscores the necessity of robust contract design, accurate and representative indices, and deep stakeholder engagement for the successful deployment of index-based insurance in smallholder agriculture.

The application of SAR for operational rice crop monitoring and yield estimation has advanced significantly, offering robust methodologies applicable across diverse agroecosystems. For instance, a SAR-based rice mapping study was conducted across 13 locations in six Asian rice-producing countries with varying water management systems, crop establishment practices, and varietal maturity profiles (Nelson et al., 2014). The methodological framework integrated multi-temporal SAR imagery with a rule-based classification approach. Parallel progress has been made in integrating SAR-derived parameters into crop simulation models. Setiyono et al. (2018) tested rice yield estimation system by incorporating SAR-based variable, such as start of season dates and leaf area growth rate, within the ORYZA crop growth model across five Asian countries including the Philippines. The approach enabled mid-season yield forecasting with results closely matching crop-cut data and official statistics, thereby demonstrating significant value for food security monitoring, disaster response, and insurance applications. These studies by Nelson et al. (2014) and Setiyono et al. (2018) further validate the benefits of coupling SAR-derived biophysical indicators with simulation modeling to improve yield prediction and monitor rice production dynamics at scale.

Methodology

a. Study sites

The development and simulation of the ARBY index insurance were conducted in six municipalities in the Philippines: Canaman and Pamplona in Camarines Sur, Ivisan and Sigma in Capiz, and Echague and San Isidro in Isabela (Figure 1). These sites were strategically selected as representative rice-based production areas with high vulnerability to climate-related risks. Camarines Sur and Isabela are among the country's major rice-producing provinces, frequently affected by hazards such as flooding, drought, and saltwater intrusion, particularly in locations along river basins.

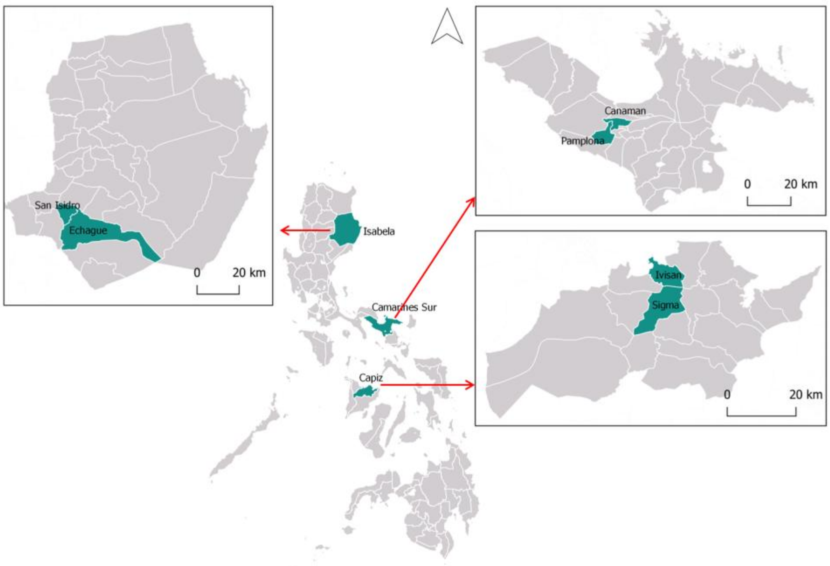

Figure 1. Location of ARBY test sites in the Philippines.

b. ARBY insurance product development workflow

ARBY followed a two-stage workflow, integrating remote sensing–based rice yield estimation into the actuarial insurance design (Figure 2).

The first stage, an external process, leverages multi-temporal SAR data to monitor rice production systems. PRISM generates key spatial products, including rice area maps, start of season (SOS), risk assessments for floods and typhoons, and leaf area index (LAI), derived from SAR data. Rice area mapping using multi-temporal Synthetic Aperture Radar (SAR) involved three main steps: pre-processing, rule-based classification, and accuracy assessment. Pre-processing was performed using an automated MAPscape-RICE® workflow, converting SAR data into terrain-geocoded backscatter ($\sigma 0$) and applying temporal smoothing to correct radiometric anomalies (Nelson et al., 2014; Holecz et al., 2013). Multi-temporal stacks of backscatter values were analyzed with monitoring field data to calibrate algorithm parameters. The rule-based classification algorithm identifies rice fields by detecting low backscatter values during planting, followed by increases corresponding to rice growth stages—patterns validated across several studies (Choudhury & Chakraborty, 2006; Ribbes & Le Toan, 1999; Nelson et al., 2014). The algorithm used all relevant polarizations and assigned a Start of Season (SOS) date based on a reliability coefficient computed from SAR trends, polarization agreement, and local incidence angle (Raviz et al., 2018). Accuracy of the rice maps were 86%-89% initially (Nelson et al., 2014) and reached 92%-96% in 2016-2018 (Mabalay et al., 2022).

Rice yield estimation leveraged the ORYZA crop model which simulates yield based on daily weather, soil, management, and varietal data (Bouman et al., 2001). SAR-derived parameters such as Start of Season (SOS) and Leaf Area Index (LAI) were assimilated into the model via the Rice-YES interface. The overall system enables dynamic integration of multi-temporal SAR information, ensuring the crop model reflects actual growth conditions and calendars (Setiyono et al., 2018). Validation resulted in RMSE of 86% (dry season) and 89% (wet season). This efficient coupling of remote sensing and crop modeling addresses the challenge of spatial scale, supports rapid assessment after climate events, and provides robust tools for agricultural policy and insurance product design, both historical benchmarking and current season assessment. Benchmarking against historical data is a foundational practice in index-based crop insurance, to ensure that payout triggers are grounded in long-term productivity trends rather than one-off anomalies (Ward et al., 2019). Presenting the end-of-season yield as a percentage of the benchmark makes explicit the degree of risk realization due to climatic or agronomic stressors. Published studies highlight that the use of historical yield benchmarks enables objective assessment of damages and supports the transparency required for effective insurance product design (Adelesi et al., 2024).

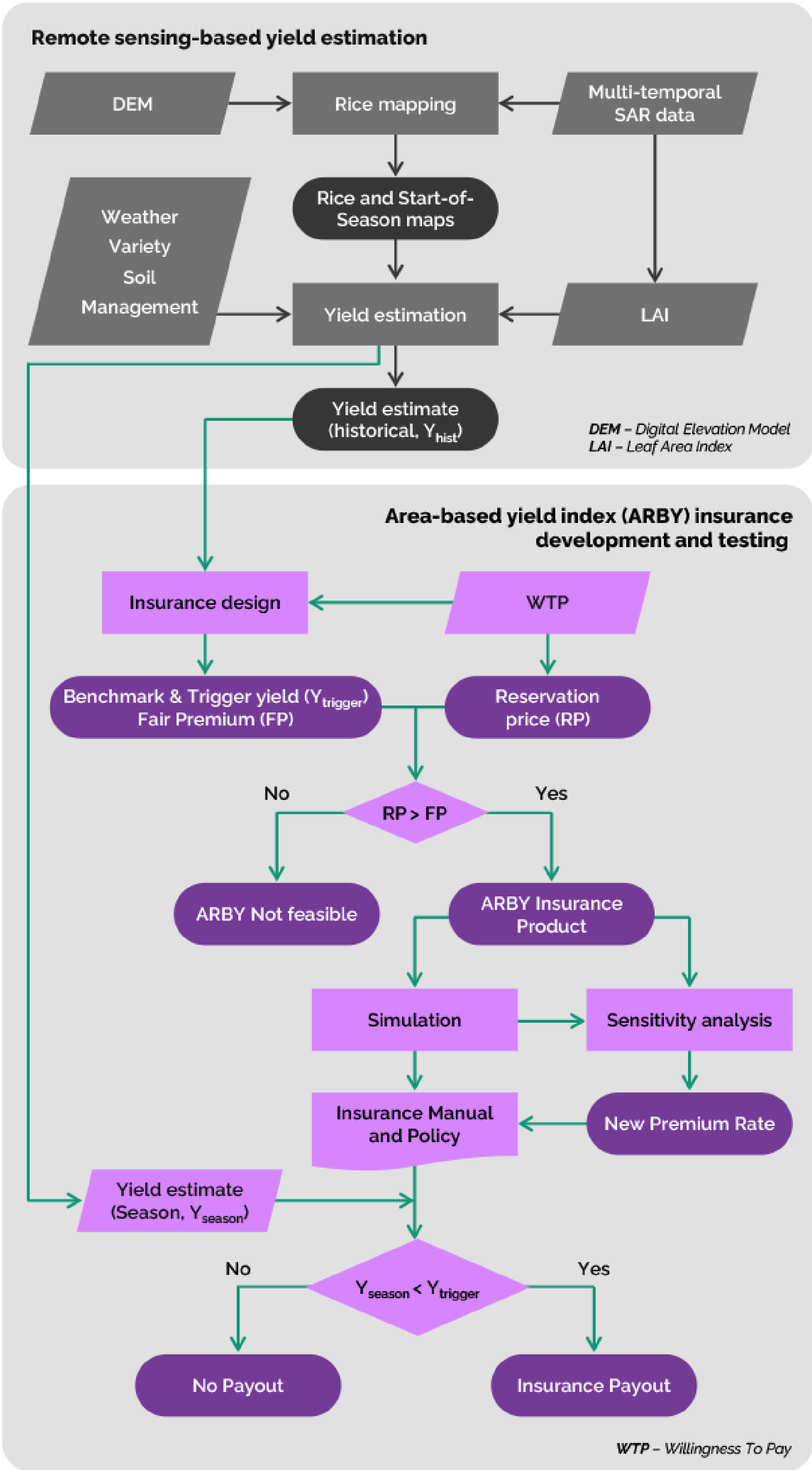

Figure 2. ARBY product development flow. The remote sensing-based yield estimation is from PRISM and Setiyono et al., 2018 and the ARBY development is adapted from Dela Cruz (2023).

A willingness-to-pay (WTP) survey in the six municipalities was conducted to collect empirical data on the maximum price each farmer was willing to pay for ARBY, a value known as the reservation price (RP), which represents the point at which farmers were indifferent between purchasing insurance and remaining uninsured. This reservation price was essential for setting premiums that would be both attractive to farmers and sustainable for insurance providers. The method involved face-to-face interviews, lasting approximately 20–30 minutes, using a structured questionnaire with information on household demographics, rice production, risk perceptions, insurance awareness, and willingness to pay for ARBY. The key question regarding WTP used a descending (reverse) payment ladder approach: interviews began by proposing the maximum amount and then decreased it incrementally by 5% up to 40%. By initiating the process with the highest value, the respondents' WTP was not anchored by lower starting amounts, thereby encouraging consideration of the maximum price they would be willing to pay. If the respondent remained unwilling to pay after the 40% reduction, the exact amount they would consider paying was recorded. The reservation price generated through this survey was used not only to assess product feasibility but was also directly embedded as a core parameter in the final insurance product design and premium-setting process. Thus, WTP survey responses served as key inputs for calibration, ensuring farmer demand aligned with actuarially reasonable premiums.

The subsequent stage used these remote sensing-derived historical yield data to set thresholds such as the benchmark and trigger yields, and to calculate actuarially fair premiums. Insurance zone (IZ) was defined by grouping 400–500 hectares of rice fields with similar cropping systems and climate types, based on Corona classification, to reduce basis risk and moral hazard. Moral hazard occurs when farmers, knowing they are insured, may take less care or assume greater risk than they otherwise would because potential losses would be partly covered by insurance. IZ size reflects a trade-off: overly large zones reduce correlation between individual and area yields; zones that are too small, on the other hand, may increase susceptibility to adverse selection (Dela Cruz, 2023). Yield parameterization used six-year data (2018–2023) from PRISM (Dela Cruz, 2023). The historical mean yield (μ) and standard deviation (σ) were calculated as follows:

$$\mu = \frac{1}{n}\sum_{i=1}^{n} Y_i$$

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n} (Y_i - \mu)^2}$$

where Y_i is rice yield in year i, and n the number of years in the dataset.

Insurance contract thresholds for payouts (triggers) were defined as proportions of the mean yield:

$$\mathrm{Y}_{trigger} = p \times \mu$$

with p set at 80% and 90%. The likelihood of yields falling below each trigger was estimated using the normal cumulative distribution function:

$$P(Y_{season} < \mathrm{Y}_{trigger}) = \Phi\left(\frac{\mathrm{Y}_{trigger} - \mu}{\sigma}\right)$$

where $\Phi(.)$ is the standard normal cumulative distribution function (CDF).

All monetary compensations were standardized to the prevailing farm gate price for rice. Following the product design, simulation and sensitivity analyses were performed to optimize payout rules and finalize contract details for implementation. Following this, policy documents and operational guidelines were prepared. Post-season, area yield assessments (Yseason) for the season were obtained from PRISM, which used the same remote sensing and modeling workflow. If Yseason fell below the predetermined trigger yield, there is payout; otherwise, no payout. This integrated approach coupling remote-sensing-based yield estimates with transparent statistical and actuarial protocols, advance climate risk management and strengthens farmer confidence in the insurance product.

Results and Discussion

a. Farmer profile and reservation price

A total of 648 farmers were interviewed across six municipalities. Average age ranged from 56 to 59 years, 58% were male (Table 1). This information is important for contextualizing insurance uptake and understanding the age and gender composition of target beneficiaries. Across municipalities, there was a noticeable predominance of male respondents. Age ranges were relatively broad, but average ages clustered in the late 50s, reflecting a mature farming population that may have nuanced risk attitudes and insurance preferences.

Table 1. Demographic profile of respondents by site.

Study sites Province/municipality	Number of respondents by gender		Age of respondents	
	Female	Male	Range	Ave
Camarines Sur	107	128	24-82	56
Canaman	30	80	31-82	55
Pamplona	77	48	24-80	57
Capiz	69	109	29-85	58
Ivisan	34	54	35-85	59
Sigma	35	55	29-83	58
Isabela	99	136	28-87	59
Echague	66	95	28-87	58
San Isidro	33	41	29-81	60
Grand total	**275**	**373**	**24-87**	**58**

Table 2 compares actuarially calculated fair premiums and the average WTP by municipality. In most sites, the average WTP was below the fair-premium estimates, indicating underlying demand but highlighting affordability as a barrier. This table illustrates the economic feasibility of index insurance offerings. Where the fair premium exceeded the average WTP, insurance provider may face a challenge in achieving voluntary adoption without subsidies or product redesign. Narrow gaps in some municipalities suggest promising conditions for scaling with targeted adjustments and farmer education.

Table 2. Fair premiums and average reservation prices across study sites.

Study sites Province/municipality	Fair premium, PhP/ha	Ave WTP, PhP/ha (n=648)
Camarines Sur	174.51-734.14	516.14
Canaman		530.00
Pamplona		503.94
Capiz	19.42-187.15	179.84
Ivisan		181.31
Sigma		178.36
Isabela	579.00 1,619.00	1,055.72
Echague		1,045.65
San Isidro		1,077.64

Overall, the findings indicated that the product was feasible to offer because farmers were generally willing to invest in insurance despite the gap between premium rates and their reservation prices. However, any increase in premiums beyond the average willingness to pay could discourage purchase, underscoring the importance of calibrating premium rates to local realities. For insurance providers, establishing a balance between affordable premiums for farmers and financial sustainability is essential for long-term program success. Consideration of targeted subsidy schemes, flexible payment options such as installment-based premiums through cooperatives or digital wallets, or bundling with complementary services like credit packages, input supply programs, or climate advisory services may help bridge affordability gaps, expand reach, and increase perceived value, especially among older farmers.

b. Dry season simulation (2023-2024)

ARBY results for the dry season are presented in Table 3 and Table 4. In Capiz (Ivisan and Sigma), EoS yields fell below the respective triggers, generating payouts of up to PhP 1,950 and PhP 950 per hectare under 80% coverage, dramatically higher for 90% coverage at PhP 8,620 and PhP 7,620 per hectare respectively. No payouts were calculated in Camarines Sur and Isabela, suggesting yields exceeded trigger levels and reinforcing the responsiveness of ARBY to spatial production risk.

In this study, differences between sites, such as higher relative yield performance in Isabela and notable deficits in Capiz, demonstrate the spatial variation in climate risk, reflecting the literature on geographic risk stratification (Nguyen et al., 2025). Coverage triggers are directly linked to the calibration of insurance contracts and reflect the package's risk tolerance; lower thresholds correspond to basic coverage, while higher ones address extreme risk exposures (Shirsath et al., 2019; Sinnarong et al., 2022). Published references on weather index and area-yield insurance routinely underscore the importance of locally informed coverage triggers to minimize basis risk and optimize program effectiveness (Kölle et al., 2021).

Table 3. Study site and yield profile in the dry season.

Study sites Province/municipality	Yield (kg/ha)				
	Historical (2018-2023)	**Benchmark**	**Trigger (80%)**	**Trigger (90%)**	**End-of-season (EoS), DS 2023-24**
Camarines Sur					
Canaman	3,603	3,532	2,826	3,179	3,110
Pamplona	3,485	3,532	2,826	3,179	3,470
Capiz					
Ivisan	2,423	2,672	2,138	2,405	2,060
Sigma	2,913	2,672	2,138	2,405	2,100
Isabela					
Echague	4,368	4,501	3,601	4,051	4,240
San Isidro	4,935	4,501	3,601	4,051	5,750

In Camarines Sur, Pamplona's EoS yield (3,470 kg/ha) nearly reached the benchmark (3,532 kg/ha) and both coverage triggers, indicating negligible risk realization and zero payout. Canaman, however, resulted in a modest shortfall with an EoS yield (3,110 kg/ha) below the 90% trigger (3,179 kg/ha), resulting in a payout under the 90% coverage; its EoS yield, while above the 80% trigger (2,826 kg/ha), did not breach that threshold. In Capiz's Ivisan and Sigma sites, EoS yields (2,060 and 2,100 kg/ha, respectively) fell below both triggers (2,138 and 2,405 kg/ha), triggering payouts under both policies, the highest payout across sites, at Php 8,620/ha in Ivisan for 90% coverage. These results exemplify index insurance's responsiveness to acute yield shortfalls, validating claims that well-calibrated triggers can deliver timely relief in stress-affected zones (Adelesi et al., 2024).

Isabela's Echague and San Isidro sites further attest to area heterogeneity. Although Echague's EoS yield (4,240 kg/ha) was below the benchmark (4,501 kg/ha), but still higher than the 90% trigger (4,051 kg/ha); hence, no payout, suggesting policy calibration in line with yield volatility. San Isidro's EoS yield (5,750 kg/ha) significantly exceeded all triggers and benchmarks, indicative of robust resilience and supporting emerging evidence on site-level yield variance and insurance heterogeneity. Overall, these observations support the importance of locally contextualized triggers and benchmarks to minimize basis risk and optimize insurance efficacy (Nguyen et al., 2025).

Table 4. Insurance coverage results, dry season 2023-2024.

Study sites Province/municipality	**EoS yield as % of Benchmark**	**80% coverage**		**90% coverage**	
		% Loss (Trigger yield)	**Payout/ha (PhP)**	**% Loss (Trigger yield)**	**Payout/ha (PhP)**
Camarines Sur					
Canaman	88	110	-	98	1,720
Pamplona	98	123	-	109	-
Capiz					
Ivisan	77	96	1,950	86	8,620
Sigma	79	98	950	87	7,620
Isabela					
Echague	94	118	-	105	-
San Isidro	128	160	-	142	-

Table 4 presents losses and payout values (at PhP 25/kg of dried palay) disaggregated by coverage level. The data indicate that Capiz consistently required substantial payouts in both Ivisan (PhP 1,950 for 80%, PhP 8,620 for 90%) and Sigma (PhP 950 for 80%, PhP 7,620 for

90%), reflecting persistent vulnerability and the effectiveness of ARBY's payout mechanism in these environments. In contrast, Camarines Sur's Canaman had a payout only under the 90% policy (PhP 1,720/ha), while Pamplona's yield prevented any payout, confirming policy discrimination between moderate and severe risks (Kölle et al., 2021). Isabela, despite variable yield results, did not trigger payouts, underscoring its resilience and aligning with literature on risk stratification and insurance targeting (Nguyen et al., 2025).

Index insurance models such as ARBY rely on objective area yield statistics rather than individual farm loss verification, lowering administrative costs, expediting payouts, and reducing moral hazard (Teh, 2019). However, they are not without basis risk, payouts may not always match actual farm losses precisely, particularly in heterogeneous landscapes or where within-area yield variability is high (Negi & Ramaswami, 2018). While aggregating yield data into insurance zones reduces cost and moral hazard, it can create basis risk where some farmers experience losses without compensation while others receive payouts with minimal damage, undermining trust and adoption, as documented in similar index insurance pilots across Asia and Africa (Ceballos & Kramer, 2019).

Although ARBY leverages high-resolution SAR data and crop models from PRISM to minimize heterogeneity within zones, residual mismatches remain, as seen in Capiz where payouts were triggered but intra-zone variability likely left some farmers under- or over-compensated. Future refinements could include smaller agro-ecologically defined insurance zones, hybrid indices that integrate PRISM yield estimates with rainfall or flood data, and validation against crop-cutting experiments. Explicitly measuring basis risk - for instance through correlations between individual farm- and area–level yields - will be critical to improve transparency, farmer confidence, and long-term sustainability (Teh & Woolnough, 2019; Adelesi et al., 2024).

These results demonstrate that ARBY can selectively and efficiently address varying levels of risk: payouts are triggered in areas where actual yields fall below established benchmarks, while no payment occurs in locations that maintain high production. This approach maximizes both fairness and efficiency, delivering support in times of real need while conserving resources when losses are not severe. The substantial payouts in Capiz highlight how index insurance can mitigate acute livelihood shocks, a benefit widely discussed in policy and scientific publications (Ward et al., 2019).

c. Wet season simulation (2024)

The 2024 wet season results (Tables 5 and 6) further validate ARBY's application. In Canaman, Camarines Sur, the EoS yield fell below both the 80% and 90% trigger thresholds, indicating severe yield shortfall and qualifying for insurance payout, PhP 18,350 (80% coverage) and PhP 28,278 (90% coverage). Under 80% coverage, the rest of the municipalities in Camarines Sur, Capiz, and Isabela, did not receive payouts, indicating yield resilience or limited adverse impact. For 90% coverage, Ivisan, Capiz received a PhP 3,650 payout for 90% coverage despite EoS yields matching the trigger, highlighting the precision of the satellite-informed index calculation.

Table 5. Study site and yield profile in the wet season.

Study sites Province/municipality	**Yield (kg/ha)**				
	Historical (2018-2023)	**Benchmark**	**Trigger (80%)**	**Trigger (90%)**	**End-of-season (EoS), WS 2024**
Camarines Sur					
Canaman	3,965	3,969	3,175	3,572	2,441
Pamplona	3,970	3,969	3,175	3,572	3,806
Capiz					
Ivisan	3,105	3,296	2,637	2,966	3,150
Sigma	3,441	3,296	2,637	2,966	3,640
Isabela					
Echague	3,985	4,196	3,357	3,776	3,610
San Isidro	4,455	4,196	3,357	3,776	4,540

Table 6. Insurance coverage results, wet season 2024.

Study sites Province/municipality	**EoS yield as % of Benchmark**	**80% coverage**		**90% coverage**	
		% Loss (Trigger yield)	**Payout/ha (PhP)**	**% Loss (Trigger yield)**	**Payout/ha (PhP)**
Camarines Sur					
Canaman	62	77	18,350	68	28,278
Pamplona	96	120	-	107	-
Capiz					
Ivisan	96	119	-	96	3,650
Sigma	110	138	-	110	-
Isabela					
Echague	86	108	-	96	4,150
San Isidro	108	135	-	120	-

Literature indicates yield index insurance is most valuable in seasons of abnormal adverse climate, such as excessive rainfall or drought, when reported losses are highly correlated with observed yield declines (Rola et al., 2015; Afshar et al., 2020). Adoption of triggers set to benchmark yields optimizes actuarial fairness while enhancing protection during severe crop failures (Benso et al., 2023; Shikuku et al., 2025). Nevertheless, the use of high-resolution satellite estimates, as in ARBY, is crucial for minimizing basis risk and efficient payout determination.

The results demonstrate striking differences between coverage levels and seasonal performance, with important implications for farmers, insurers, and local government units (LGUs). We tested two primary coverage options, 80% and 90%, each showing distinct financial outcomes that highlight the fundamental trade-offs between premium costs and protection levels. The wet season particularly demonstrated the critical value of higher coverage levels during adverse conditions, with 90% coverage providing substantial financial relief to affected areas despite significantly higher premium costs.

ARBY's dual-trigger system (80% and 90% of historical yield) produces scalable protection for farmers. Higher deductibles (90% triggers) yield larger payouts for more severe yield shortfalls but also require greater thresholds to be crossed. This aligns with best-practice guidance for index contract design, ensuring the greatest value to farmers is delivered during catastrophic events (Negi & Ramaswami, 2018; Teh, 2019).

The results affirm the utility of area-based yield index insurance in stabilizing income, enhancing climate resilience, and incentivizing risk management among smallholders.

Conclusion and Recommendation

The results of this study demonstrate that satellite-powered index-based crop insurance, exemplified by the ARBY product, substantially enhances the climate resilience of smallholder rice farmers in the Philippines. The integration of remote sensing-based yield data into insurance product design enables objective, timely, and scalable protection against climate risk, addressing major limitations of conventional indemnity-based insurance. These innovations not only improve farmers' risk management capabilities but also provide critical insights for scaling similar approaches in other climate-vulnerable agricultural settings as part of growing interest in climate adaptation. Building on this pioneering work and earlier collaborations to develop ARBY, a Memorandum of Agreement was signed by partners including PCIC, PhilRice, PAGASA, CIAT, and IRRI on June 9, 2025, to pilot the solution bundle of ARBY and weather-informed agro-advisory for 1,000 rice farmers in two provinces. This partnership, established as a direct result of the innovations and evidence generated in this study, underscores PCIC's strong interest and institutional capacity for scaling ARBY nationally—enabling rapid, objective, and inclusive risk management for a broader base of Filipino farmers and aligning with national strategies to address disaster-related agricultural losses (Insurance Asia, 2025; IRRI, 2025).

The study recommends expanding ARBY to additional provinces and agro-climatic zones, while continuously refining actuarial models and remote sensing yield estimates to minimize basis risk and optimize payout triggers. Policy makers should create targeted subsidy schemes to address premium affordability gaps. Insurance providers, in collaboration with local governments, should strengthen farmer outreach and education to build trust and product adoption. Robust national partnerships among research institutions, insurers, and government agencies are vital for integrating satellite-powered insurance products into broader climate adaptation programs and for scaling the approach at regional and national levels. In the long term, model refinement and ongoing validation of contract conditions will ensure that index insurance solutions remain responsive to farmers' evolving needs and changing climate risks.

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Annex 1. Map of rice extent in the Philippines, highlighting provinces severely affected by the 2023–2024 El Niño event.