Evaluating Alternate Wetting and Drying as a Drought-Responsive Land and Water Intervention for Paddy Cultivation in Sri Lanka: An Economic Analysis Using the APSIM Model

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1. Abstract

Agriculture in Sri Lanka faces increasing challenges from climate change, particularly in the form of rising temperatures, erratic rainfall, and prolonged dry spells that threaten both crop productivity and farmer livelihoods. These challenges underscore the need for evidence-based interventions that enhance climate resilience and resource efficiency. Climate-Smart Agriculture (CSA) offers a framework for achieving this balance by promoting technologies that sustain productivity while reducing vulnerability to climate extremes. Among such interventions, Alternate Wetting and Drying (AWD) has emerged as a promising water management technique with the potential to reduce irrigation demand, enhance water-use efficiency, and improve profitability, making it a strong candidate for drought-responsive agricultural policy support.

This study evaluates the agronomic and economic impacts of AWD technology under changing climatic conditions using a combination of time-series climate modeling, crop simulation, and economic analysis. The analysis was designed to quantify how changes in rainfall and temperature, combined with adaptive land and water management interventions, affect paddy yields and profitability across different agro-ecological zones in Sri Lanka. Future climate projections for the period 2026–2030 were generated using an Autoregressive Integrated Moving Average (ARIMA) model trained and validated with daily temperature and rainfall data from 1993 to 2023. The projected climatic variables were then used as inputs to the APSIM (Agricultural Production Systems Simulator) model to simulate paddy yield responses under both baseline and AWD intervention scenarios. The simulation results revealed significant spatial variation in yield responses to climate change. Without any CSA interventions, APSIM projections indicated yield increases ranging from 26% to 29% in the Intermediate Zone mid country, and Intermediate Zone up country in Sri Lanka, suggesting a positive climate-induced yield response in these regions. Moderate yield gains of 4.5% to 15% were observed in the Intermediate Zone low country and Dry Zone moderate-yielding areas, reflecting a partial benefit from future climate conditions. However, not all areas benefited. In low-yielding Dry Zone regions, yields declined slightly by 6.5%, while in high-yielding Dry Zone areas, the reduction was more pronounced at 21.2%. These findings highlight the need for targeted drought-responsive land and water management policies tailored to zone-specific vulnerabilities.

To assess the economic feasibility of AWD under both current and projected climate conditions, a cost benefit analysis was conducted for the Intermediate Zone low country, where water stress during the dry season is increasingly evident. The analysis covered the period 2020–2030, comparing the profitability of

conventional irrigation with that of AWD managed cultivation. Under projected climate change conditions, the Net Present Value (NPV) of paddy production increased from LKR 80,806 to LKR 114,421 per hectare per year with AWD implementation. In scenarios without climate change, NPV similarly rose from LKR 78,489 to LKR 115,080 per hectare per year, confirming that AWD enhances profitability even under normal climatic conditions. The findings clearly demonstrate that AWD adoption delivers multiple benefits; agronomic, environmental, and economic. From an agronomic perspective, AWD improves water-use efficiency by reducing irrigation requirements without compromising yield potential. Environmentally, it contributes to groundwater conservation and mitigation of methane emissions associated with continuous flooding. Economically, it offers higher returns on investment, making it an attractive business case for smallholder farmers and a cost-effective intervention for policymakers aiming to promote sustainable water management in drought-prone areas. From a policy and business standpoint, these results build a strong case for integrating AWD into national drought adaptation and land use policies. Economic evidence supports its inclusion in incentive-based schemes, such as water-saving subsidies, climate-smart farming credit programs, and irrigation scheduling advisories. At the institutional level, demonstration projects and capacity-building initiatives could encourage broader adoption, particularly in regions projected to face yield declines under future climates.

In conclusion, this study establishes AWD as a financially viable and environmentally sound drought-responsive intervention for Sri Lanka's paddy sector. By combining economic modeling, climate simulation, and policy-oriented analysis, it provides robust evidence to guide land and water management decisions in the face of increasing climate variability. Promoting AWD within the CSA framework would not only strengthen drought resilience but also contribute to sustainable agricultural transformation, improved farmer incomes, and efficient use of the country's limited water resources.

2. Background

Rice is the primary food crop in the developing world and serves as the staple diet for nearly half of the global population (Li *et al*., 2024; CHEN *et al*., 2017; Shrestha *et al*., 2022). Approximately 900 million of the world's poor rely on rice either as a source of income or as a key part of their diet (Mishra *et al*., 2022). On average, rice makes up about 50% of food expenditures and 20% of overall household spending for low-income households. Rice is cultivated on around 155 million hectares worldwide and supplying between 35% to 59% of the daily energy intake for approximately 3 billion people across Asia (Pandey *et al*., 2010; Meng *et al*., 2005). Rice demand is projected to rise by 25% by the year 2030 (Poutanen *et al*., 2022; Naik *et al*., 2022; IRRI 2019). Rice has traditionally been an essential crop in Asia, it has also been a dietary staple in parts of Africa and Latin America for many years, with its significance continuing to increase in these regions (Pandey *et al*., 2010). While rice farming holds regional significance in some developed nations, it is far more critical in low- and lower-middle-income countries, where it represents 19% of total harvested crop area. In contrast, it accounts for only 2% in upper-middle- and high-income countries. During the early 2000s, an estimated 144 million rice-farming households existed globally, with the vast majority located in developing nations (Dawe, Pandey and Nelson, 2010).

Climate change presents various dimensions, such as shifts in long-term temperature and rainfall patterns, along with increased inter-annual variability and a higher frequency of extreme weather events. These evolving conditions are already impacting agriculture, but substantial uncertainties remain regarding how agricultural systems will be directly or indirectly affected and what the consequences will be for rural livelihoods (IPCC 2007). Climate change adds pressure to already strained agricultural systems facing rising food demand, with uncertain regional impacts on productivity (Pampana *et al*., 2022). As both a greenhouse gas source and potential carbon sink, agriculture also plays a key role in climate change mitigation (Wassmann *et al*., 2009; Lou *et al*., 2024). Rice production systems are particularly susceptible to drought compared to many other cropping systems (O'Toole., 2004). As climate change intensifies irregular rainfall patterns and increases the frequency of extreme weather events, crops face greater risk (Eswaran *et al*., 2024). However, the impact of drought on rice yield is more strongly influenced by the timing and distribution of rainfall rather than the total seasonal rainfall amount. Addressing the complex nature of drought stress now requires a comprehensive strategy that combines plant breeding, physiological analysis of drought resistance traits, molecular genetics, and improved agronomic practices. At the opposite extreme, flooding poses another significant threat under changing climatic conditions. Prolonged submergence of rice plants can result in widespread crop failure. This issue now affects an estimated 10–15 million hectares in South and Southeast Asia, leading to considerable yield losses (Bates *et al*.,2008; Mackill *et al*., 2012). Additionally, climate change exacerbates salinity issues, especially in arid and semi-arid areas, where high temperatures increase plant transpiration and salt accumulation. Rising sea levels will further intensify salinity problems in coastal and delta regions, making rice cultivation increasingly challenging in these vulnerable areas (Dasgupta *et al*., 2015).

CSA offers a promising solution to mitigate the impact of climate change (Mohapatra *et al*., 2025). CSA is a strategic framework designed to address climate-related risks in agriculture by integrating three key pillars: sustainably increasing agricultural productivity (productivity), strengthening resilience to climate change(resilience), and reducing greenhouse gas emissions (mitigation) (Walsh et al., 2024). CSA practices cannot be universally applied as the same set of practices, but it is an approach that involves different elements that are embedded in different regions and are concerned towards to meet local needs (CIAT., 2014). CSA encompasses a range of technologies, policies, institutions, and investments. It involves on-farm practices like composting, mulching, intercropping, enhanced animal feeding, the use of tolerant crop varieties, and climate-risk insurance. Additionally, it extends beyond the farm, incorporating initiatives such as carbon financing, developing efficient markets, and improving weather forecasting. CSA focuses not only on addressing these challenges but also on the processes required to resolve them effectively (Notenbaert *et al*, 2017).

Climate-smart rice varieties represent a recent advancement in rice cultivation aimed at enhancing resilience to climate change (Das *et al*., 2024). These specially bred varieties are designed to withstand environmental stresses such as drought, extreme heat, and flooding, ensuring stable productivity under changing climatic conditions (Rosenstock *et al.,* 2016; Thornton *et al*., 2010). More water is needed to cultivate paddy rice than any other crop, and almost 40% of the irrigation water utilized worldwide is used for rice farming (FAO 2014). Water management practices such as AWD & System of Rice Intensification (SRI) can help to overcome water scarcity (Joshua *et al*., 2023; Al Mamun *et al*., 2023). Direct-Seeded Rice (DSR), promoted by IRRI, is a more sustainable and climate-resilient alternative to manual transplanting, requiring less labor, water, and time to mature. Despite its advantages, limited mechanization and guidance have hindered its effectiveness. Studies show DSR can reduce production costs by US$9–125 per hectare and lower methane emissions (IRRI 2021).

Among available CSA interventions within Sri Lankan context AWD has emerged as a promising water-saving, economically viable, and eco-friendly alternative to Continuous Flooding (CF). AWD can reduce water use by 25–70%, lower and decrease heavy metal accumulation in rice grains while maintaining or even enhancing paddy yields (10−20%). Mild-AWD has also been shown to improve grain quality by reducing chalkiness, increasing head rice recovery, and boosting micronutrient concentrations. Figure 1 shows the distribution (%) of water management practices such as AWD , CF, and Rainfed across different farming systems. Eastern irrigated farming relies heavily on flooding (around 70%), while smallholder mixed farming predominantly uses AWD (nearly 60%). In contrast, Northern mixed cropping and Southeastern rainfed paddy systems show a higher proportion of rainfed practices (World Bank 2025).

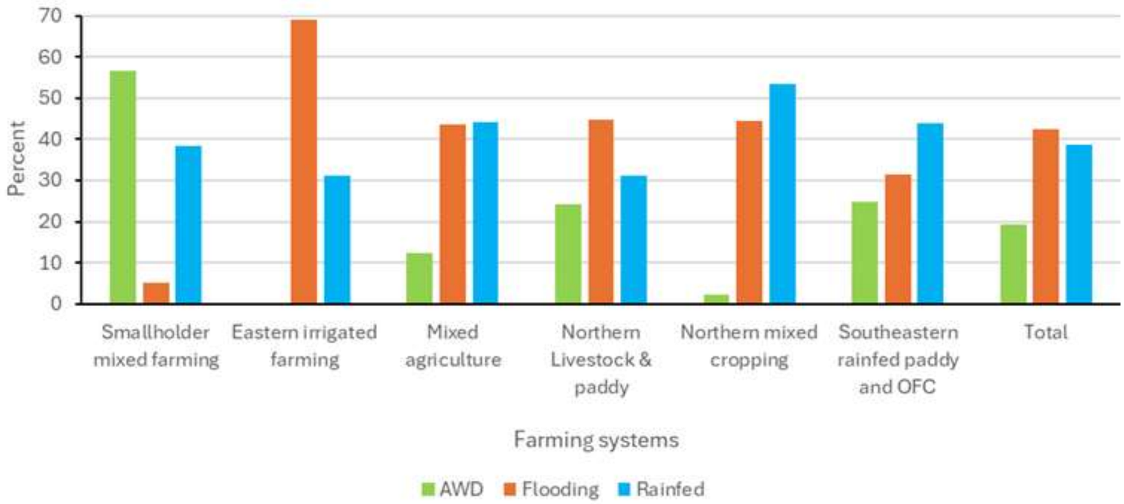

Figure 1: Adoption of water management practices across farming systems

Source – World Bank 2025: Constraints to Adoption of CSA in the dry zone(forthcoming)

Agricultural simulation models serve as valuable tools in supporting farmer decision-making (Hochman *et al*., 2009), guiding crop breeding programs (Cooper *et al*., 2009), and public policies (Bezlepkina *et al*., 2010), all aimed at tackling global issues such as food security and climate change adaptation and mitigation. The APSIM is such simulation model which is a flexible, modular modeling framework created by the Agricultural Production Systems Research Unit in Australia. It is designed to simulate biophysical processes within farming systems, especially in situations where understanding the economic and environmental impacts of management practices under climate variability is important (Keating *et al*., 2003). APSIM consists of a suite of interconnected models designed to simulate biophysical processes involving soil, crops, trees, pastures, and livestock. It is widely utilized by researchers to evaluate on-farm management practices, strategies for adapting to climate variability and change, mixed pasture-livestock systems, resource competition in agroforestry, nutrient leaching under diverse conditions, gene trait expression, and a variety of other applications (Holzworth *et al*., 2014). These models are categorized into plant, soil, animal, and climate models, all of which operate using a similar underlying structure (Keating *et al*., 2003). Plant models simulate key physiological processes such as phenological development; growth of plant organs including leaves, stems, roots, and grains; water and nutrient uptake; carbon assimilation; biomass and nitrogen partitioning among plant parts; and responses to abiotic stresses. Soil models represent essential processes within the soil profile, including water infiltration and movement, evaporation, runoff, drainage, temperature changes, nutrient cycling, and decomposition of soil organic matter. Additionally, APSIM includes modules for simulating livestock, such as cattle and sheep and their interactions with crops and soils within agricultural systems (Holzworth *et al*., 2014).

The APSIM modelling framework consists of several key components, 1. biophysical modules that simulate natural biological and physical processes in agricultural systems, 2. management modules that define user-specified management rules to represent different farming scenarios and guide the simulation,3. data input and output modules that manage information exchange with the simulation, 4.Simulation engine that coordinates the simulation by handling communication among the independent modules and, 5. a user interface to make it accessible to a broad range of users (Keating *et al*., 2003; Holzworth *et al*., 2014). APSIM requires daily input data on rainfall, maximum and minimum temperature, and solar radiation. In addition, it needs measurable soil physical parameters for different soil layers, including bulk density, saturated water content, field capacity, and wilting point (Ritchie, 1972). Essential soil chemical properties such as soil pH, organic carbon content, and initial levels of mineral nitrogen must also be provided. Some parameters, such as those related to soil organic matter (SOM) mineralization, soil carbon cycling, crop phenology, and soil water dynamics, cannot be directly measured also required. Once accurately parameterized, the model demonstrated strong performance in simulating a variety of cropping systems. The Root Mean Square Errors (RMSEs) were typically lower than the standard deviations observed in experimental data, indicating reliable model accuracy. Notably, the model showed particular effectiveness in simulating multi-crop sequences (Gaydon *et al*., 2017).APSIM-Oryza is a rice growth simulation model that has seen growing use in research due to its integration with the widely recognized and trusted APSIM platform and Oryza2000 model (Gaydon *et al*., 2012a; Holzworth *et al*., 2014; Amarasingha *et al*., 2015; Gaydon *et al*., 2017; Radanielson *et al*., 2018). APSIM-Oryza enhances the basic APSIM framework by providing rice-specific functionality, making it suitable for simulating diverse rice-growth under water limited and N-limited conditions (Liu et al., 2019). The Agricultural Production Systems Simulator (APSIM), particularly its APSIM-Oryza module, has been effectively applied in Sri Lanka to simulate rice production under diverse agro-climatic zones and water management practices. A validated APSIM-Oryza model is available for Sri Lanka, having been parameterized and tested for short-, medium-, and long-duration rice varieties such as Bg 300, Bg 359, Bg 403, and Bg 379-2.

Validation was conducted using secondary data and field observations from multiple locations, including MahaIlluppallama (Dry Zone), Batalagoda (Intermediate Zone), and Bombuwela (Wet Zone). The model showed strong performance in simulating yield and phenological stages, with coefficients of determination (R^2) ranging from 0.77 to 0.99, low coefficients of variation, and RMSE values indicating high accuracy (R. Amarasingha *et al*., 2014; R. Amarasingha *et al*., 2015; Fernando *et al*., 2015). The model has also been used to evaluate water management strategies, comparing purely rainfed systems with those using supplementary AWD method. Planting rice with the onset of rainfall reduced irrigation needs by 8% in years with early rainfall, whereas delayed onset reduced rainfall availability and increased irrigation dependency. Supplementary irrigation consistently resulted in higher crop yields and water productivity while rainfed conditions led to significantly lower crop yields and water productivity (R. Amarasingha *et al*., 2015).Despite these advantages, the widespread adoption of AWD remains limited, possibly due to the complex interactions between agricultural and socioeconomic factors and the lack of institutional support (Ishfaq *et al*., 2020). Many studies focus on climate change and paddy farming primarily focus on assessing its impact on productivity rather than exploring effective mitigation strategies. While some research suggests potential solutions, these recommendations often lack consideration of region-specific cultivation factors, making them less applicable to diverse agro-climatic conditions. The absence of tailored interventions limits farmers' ability to adapt to climate variability effectively. Additionally, the economic feasibility of CSA practices remains underexplored, particularly regarding the costs associated with their adoption. Implementing CSA interventions remains challenging without a comprehensive understanding of both their agronomic and economic dimensions. This study aims to assess the economic impacts of implementing AWD on paddy production in Sri Lanka by integrating climate projections with APSIM based yield modeling and cost-benefit analysis across different agro-climatic zones and adoption scenarios.

3. Actions taken

Actions and Decisions

Climate impact on rice studies using APSIM remains limited, especially in terms of analyzing near-future, year-by-year climate variability. Most existing research relies on long-term climate projections obtained from global climate change portals which typically offer data for distant time horizons like 2040 or 2100 (Amarasingha *et al*., 2018; Esham & Garforth, 2013). These projections are useful for long-term policy planning but are not well suited for short- to medium-term decision-making at the farm level. Decisions taken in this study were guided by the need to generate actionable insights on the short-term impacts of climate variability on rice production in Sri Lanka. While these long-term projections are valuable for strategic planning and policy formulation, they are less suitable for short- to medium-term decision-making at the farm level, where immediate, actionable insights are necessary for guiding cultivation practices, irrigation management, and resource allocation. Recognizing this gap, the research team made a series of deliberate decisions to ensure that the study addressed both the agronomic and economic realities of paddy cultivation under near-future climate variability. Therefore, this research provides a novel contribution by integrating near-future climate analysis into APSIM simulations to support more timely and locally relevant agricultural planning. Under the supervision of Prof. Jeevika Weerahewa, and with guidance from co-supervisors Dr. Sumali Dissanayake (Department of Agricultural Economics) and Dr. Nuwan De Silva (Department of Crop Science), I defined the main and specific objectives of the study. The main objective is - to evaluate AWD as a drought-responsive land and water management intervention for paddy cultivation in Sri Lanka by integrating biophysical simulation using the APSIM model with economic analysis. This main objective was subsequently refined into the following three specific objectives. This main objective was subsequently broken down into three specific objectives as below, (i) to analyze current and future paddy yields under a business-as-usual (BAU) scenario, (ii) to analyze current and future paddy yields with AWD, and (iii) investigate associated costs and benefits.

A key decision during the planning phase was the selection of the temporal horizon for climate impact assessment. Unlike studies that rely on long-term climate projections, this research focused on the near-future period of 2026 to 2030, for which year-specific climate projections were not readily available from global climate portals. This focus was guided by the recognition that farm-level decision-making requires timely, actionable, and regionally relevant information on anticipated climatic conditions. Consequently, the research team opted to use the ARIMA model, a well-established time-series forecasting technique capable of capturing trends, seasonality, and variability in historical data (Shumway & Stoffer, 2017; Dimri *et al*., 2020). ARIMA was applied to 30 years of historical daily climate data (1993–2023), including maximum temperature (Tmax), minimum temperature (Tmin), and rainfall (RF), which are critical determinants of rice growth, development, and yield formation. The ARIMA model was used to generate monthly climate forecasts for each of the years from 2026 to 2030. However, since the APSIM crop simulation model operates on a daily time step, it was necessary to downscale the monthly forecasts to daily values. This was achieved by applying the proportional percentage change in the monthly forecast relative to a baseline year, 2023, to each corresponding daily observation

$$\text{Climate change (\%) for each year} = \frac{(\text{Future Year annual average T/RF - 2023 annual average T/RF})}{\text{2023 annual average T/RF}} \times 100$$

……………… Equation (1)

Daily weather data for future years (2026-2030) = 2023 daily T/RF * Climate change (%) for each year

……………… Equation (2)

Equations 1&2 illustrate how daily weather data were downscaled from ARIMA monthly predictions. Once the daily datasets for the years 2026 to 2030 were generated, they were formatted into APSIM-compatible .met files. These files included standard weather inputs such as radiation, temperature, and rainfall, ensuring that the future weather data could be seamlessly integrated into the simulation model. The APSIM model was then run using these predicted datasets to simulate rice crop performance under future climatic conditions. This allowed for an evaluation of the sensitivity of rice yield to predicted changes in temperature and rainfall patterns. This methodological approach offers a robust and data-driven framework for applying future climate predictions to crop simulation models.

While the methodological decisions focused heavily on generating accurate climate data, decisions regarding the selection of study regions were equally critical to ensure that the findings would be representative of Sri Lanka's diverse rice-growing environments. Rice is cultivated across multiple agro-climatic zones, each exhibiting unique patterns of rainfall, irrigation infrastructure, soil types, and yield potential. To capture this diversity, the research team initially considered nine broad agro-climatic zones as potential study areas. However, given the high variability in yield and production practices observed within the Dry Zone(DZ), it was further subdivided into three sub-regions: low-yielding (DL1), moderate-yielding (DL2), and high-yielding (DL3). This subdivision was informed by historical yield data (Kadupitiya *et al*., 2022). The varietal selection Bg-359 is also based on literature (Kadupitiya *et al*., 2022). So considered regions are DZ (DL1, DL2 &DL3), Intermediate Zone low, mid & up country (IML, IMU&IMU) and,Wet Zone low,mid & up country (WL, WM&WU). Another important decision involved the integration of CSA interventions into the study framework. Among the wide range of CSA practices available, the research prioritized interventions that were both proven to enhance productivity and feasible for adoption at the farm level. The selection was informed by a combination of literature review, and consultation with local agricultural experts. Particular attention was given to AWD as a water saving irrigation method, which has been shown to reduce water use, enhance yield stability, and mitigate greenhouse gas emissions. While other CSA strategies, such as optimized fertilizer application and SRI were reviewed, AWD was prioritized for its dual agronomic and environmental benefits and its compatibility with Sri Lanka's irrigation infrastructure.

The process of defining objectives and selecting interventions also incorporated economic considerations from the outset. Cost-benefit analysis (CBA) was integrated as a core component of the study to ensure that the economic feasibility of CSA interventions could be assessed in parallel with their agronomic impact. The research team decided to use actual field-level fertilizer and management practices, rather than relying solely on standard Department of Agriculture recommendations, to reflect real-world conditions and improve the relevance of economic assessments. This decision ensured that the resulting CBA would provide practical guidance for farmers and policymakers regarding the financial viability and risk associated with adopting AWD practices under near-future climatic conditions.

The cost evaluation of implementing the AWD method and standard cultivation in the Kurunegala district involved assessing various costs listed as associate with labor, machinery, and materials used. Labor cost accounts for the expenses related to general land preparation, first, second, and third plough with 4 wheel tractor, plastering bunds, leveling and broadcasting, fertilizer application, weed control with weedicides, pest and disease control, water management, harvesting and processing with the combined harvester, additional drying and transport produce to stores. Machinery cost is basically for ploughing and harvesting. Material costs mainly include the seed, fertilizer, pesticides, and weedicide costs. The Cost of Cultivation book of the Department of Agriculture was the major resource for obtaining the values of cost components. Labor wages were obtained from farmers. Cost change in the management practices for AWD, water management cost was reduced by 30% as reviewed in the literature (CGIAR, 2014). Material cost for the AWD was obtained from Hayleys agriculture website. This analysis used actual field-level fertilizer practices as reported by farmers which was obtained from Cost of Cultivation book. This improves the real-world applicability and relevance of the findings.

Table 1: Labor requirement associated with the standard cultivation and with AWD method

Farm operation		Labour requirement	
		Standard	CSA
Variable cost	Unit	Quantity	Quantity
Labor Cost			
Land preparation	Md/Ac	1.61	1.61
1st , 2nd &3rd plough with 4 wt	Md/Ac	0.53	0.53
Plastering bunds	Md/Ac	7.07	7.07
Broadcasting	Md/Ac	4.27	4.27
Fertilizer application	Md/Ac	1.6	1.6
Weed control with weedicides	Md/Ac	1	1
Pest and disease control	Md/Ac	1.34	1.34
Water management	Md/Ac	1.53	1.02
Harvesting (machinery)	Md/Ac	1.43	1.43
Additional drying	Md/Ac	2.95	2.95
transport produce to stores	Md/Ac	0.66	0.66

Source – Author's own work

Table 1 illustrates the labour requirement associated with standard cultivation and the AWD method. In the AWD method, the water management cost was adjusted per the recommendations. All the other practices remained the same as standard cultivation.

Table 2: Material requirements for standard cultivation and AWD method

Standard	AWD
Seeds	Seeds
Pesticides	Pesticides
Weedicides	Weedicides
Fertilizer	Fertilizer
Urea	Urea
TSP	TSP
MOP	MOP
	Installation materials

Source – Author's own work

Table 2 illustrates the material requirements related to standard cultivation and AWD. In the AWD method, the additional cost in material cost was only installation material, 7-8 tubes/ha if the land is flat (DOA).

The steps of CBA,

1. Total of cultivation (LKR/ha) = $\text{Labor cost} + \text{Material cost} + \text{Machinery cost}$ ……………… Equation (3)
2. Unit cost / kg = $\frac{\text{Cost of cultivation (LKR/ha)}}{\text{Yield (kg/ha)}}$ ……………… Equation (4)
3. Cost of cultivation each year = Yield * Unit cost ……………… Equation (5)
4. Income = Yield (kg/ha) * Price (LKR/kg) ……………… Equation (6)
5. Cost-benefit analysis

   Discount rate = 10%

   Discounting Cost / Benefit = $\left(\frac{1}{1+0.1}\right)^{n}$ * Cost of Cultivation / Income (benefit) ……………. Equation (7)

   n = Year
6. BCR = $\frac{\text{PVB}}{\text{PVC}}$ ……………. Equation (8)

Equations from 3 to 8 describe the basic steps involved in calculating cost and benefits associated with Conventional cultivation and the AWD method. Table 3 presents a CBA comparing rice production under two scenarios: conventional farming practices without CSA interventions, and a scenario with CSA(AWD) practices implemented. For each scenario, economic indicators are provided including revenue from paddy, cost of cultivation, the present value of benefits (PVB), the present value of costs (PVC), net present value (NPV), and benefit-cost ratio (BCR).

Table 3: Cost-benefit analysis for standard cultivation and AWD method

Parameters		**Unit**
Revenue from paddy	BAU; No CSA	LKR/ha
Cost of cultivation	BAU; No CSA	LKR/ha
PVB	BAU; No CSA	LKR/ha
PVC	BAU; No CSA	LKR/ha
NPV = PVB - PVC	BAU; No CSA	LKR/ha
BCR		
Revenue from paddy	With CSA	LKR/ha
Cost of cultivation	With CSA	LKR/ha
PVB	With CSA	LKR/ha
PVC	With CSA	LKR/ha
NPV = PVB - PVC	With CSA	LKR/ha
BCR		

Source – Author's own work

PVC – Present value of costs PVB – Present value of benefits

NPV - Net Present Value BCR – Benefit Cost Ratio

This analysis was conducted across multiple periods under four distinct scenarios

1. Yield in without climate change and without CSA
2. Yield in without climate change and with CSA
3. Yield with climate change and without CSA
4. Yield with climate change and with CSA

CBA analysis was done for the periods

1. 2020 – 2030
2. 2025 - 2030

With the above 4 scenario analysis Effect of climate change and the effect of CSA intervention were assessed. CBA was conducted over the period from 2020 to 2030 and 2025 to 2030, using actual fertilizer recommendations followed by farmers in the field, rather than the DOA recommendations.

Finally, the prioritization of methods and interventions was guided by the principle of maximizing both scientific rigor and practical relevance. Year-by-year climate projections using ARIMA allowed for accurate APSIM simulations, while the careful selection of representative regions ensured that results reflected the spatial variability of rice production across Sri Lanka. The integration assessing the effects of AWD and associated CBA enabled a holistic assessment of both agronomic and economic outcomes, fulfilling the study's overarching objective of providing actionable insights for sustainable rice production under near-future climate variability. By integrating climate projections, crop simulation, and economic analysis, the research provides a comprehensive framework for understanding and enhancing the resilience of paddy production systems under near-future climate variability, while also offering guidance on the economic viability of AWD intervention.

Data sources

Simulation of rice yield with the APSIM-Oryza model requires several key inputs, including daily weather data, soil properties, crop phenology, and management practices. In this study, daily weather data comprising maximum and minimum temperatures, rainfall, and sunshine duration were obtained from the NASA POWER database. Soil profile characteristics were sourced from Mapa et al. (2010). The rice variety used in this study was Bg 359, a widely cultivated short-duration variety in Sri Lanka. Crop phenological parameters for Bg 359 was adopted from Amarasingha *et al*. (2014). These included the development rate in the juvenile phase (DVRJ), the development rate in the photoperiod-sensitive phase (DVRI), the development rate during the panicle development phase (DVRP), and the development rate in the reproductive phase (DVRR), all expressed in degree-days per day (°C day^{-1}). These parameters were essential for accurately simulating crop growth stages and thermal time accumulation within the APSIM framework. Crop management practices including planting dates, and fertilizer application were incorporated according to the recommendations of the Department of Agriculture, Sri Lanka. Irrigation practices were modeled according to traditional CF methods, while AWD irrigation schedules were developed based on values and timings reported in published literature. For the cost-benefit analysis, however, actual fertilizer usage and costs were derived from the Department of Agriculture's Cost of Cultivation reports, to reflect real-world farmer practices more accurately.

4. Outcomes

The results obtained through the APSIM-based simulation, climate forecasting, and CBA together reveal a detailed picture of the continuing challenges, implementation issues, and potential pathways toward sustainable and climate-resilient rice cultivation in Sri Lanka. Despite clear evidence of the agronomic and economic benefits of CSA interventions particularly AWD, several systemic, institutional, and technical barriers still constrain the widespread realization of these gains. Understanding the extent of these persistent problems, the degree of their influence, and the outcomes that could be expected if they were effectively addressed provides valuable insights for agricultural development policy, extension reform, and future research in Sri Lanka's paddy sector.

The introduction of the AWD technology as a drought responsive land and water management intervention produced significant agronomic, environmental, and economic outcomes across the study regions. The combined use of ARIMA-based climate projections and APSIM model simulations provided a robust analytical basis for evaluating AWD's potential to improve productivity and profitability under both existing and future climatic conditions.The APSIM simulations under future climate scenarios (2026–2030) demonstrated regionally differentiated yield responses. In the absence of any CSA interventions, yield increases ranging from 26% to 38% were projected in the Wet Zone low country, Intermediate Zone mid country, and Intermediate Zone up country. These areas appear to benefit from projected moderate increases in rainfall and temperature, resulting in enhanced soil moisture retention and improved photosynthetic activity. Conversely, several Dry Zone and Wet Zone highland regions showed yield reductions, with the most substantial declines, up to 40%, occurring in the Wet Zone mid and up country, where higher temperatures and erratic rainfall are expected to intensify water stress and reduce soil fertility.The implementation of AWD in the Intermediate Zone low country significantly improved the economic performance of paddy cultivation. A cost benefit analysis for the period 2020–2030 showed that AWD adoption increased the NPV from LKR 80,806 to LKR 114,421 per ha/yr under climate change conditions. Even in the absence of climate change, NPV rose from LKR 78,489 to LKR 115,080 per ha/yr, confirming that AWD generates robust economic returns independent of climatic uncertainty. These findings indicate that the project successfully achieved its key objectives: improving water-use efficiency, maintaining or enhancing yields, and increasing profitability for farmers.

The underlying reasons for the improved economic performance associated with AWD stems from its capacity to reduce irrigation costs, optimize water use, and maintain soil aeration, which enhances nutrient uptake and root development. Additionally, AWD lowers methane emissions compared to continuous flooding, contributing to environmental sustainability and potential eligibility for carbon-credit programs. The spatial differences in yield outcomes, however, reflect underlying disparities in soil type, irrigation infrastructure, and rainfall variability, factors that must be addressed for wider adoption.

Existing Problems

Despite its demonstrated benefits, AWD implementation faces several challenges. The technology requires careful monitoring of soil moisture levels, which may be difficult for smallholder farmers lacking technical training or access to simple field tools. Institutional coordination between irrigation authorities and local farmers is also limited, constraining large-scale adoption. In regions with poor irrigation control, the intermittent wetting and drying cycles are harder to manage, reducing potential water savings. Furthermore, awareness and trust gaps persist, as some farmers remain reluctant to alter traditional irrigation practices that have provided a sense of security against drought. Major problem concerns resource constraints and limited diffusion of CSA practices. AWD, despite its proven water-saving potential (23–37% reduction in water use) and yield-stabilizing effects, is still practiced by only a small fraction of Sri Lankan paddy farmers. Adoption barriers stem from several sources lack of awareness, insufficient training in water-management techniques, inconsistent access to irrigation scheduling information, and resistance to change among farmers accustomed to continuous flooding. Moreover, the existing irrigation infrastructure is not always compatible with precise water-level management required for AWD. Many minor tank systems in the Dry Zone suffer from poor maintenance, and siltation, which prevent accurate alternation between wet and dry phases. Thus, while AWD is scientifically sound, its large-scale effectiveness is constrained by institutional and infrastructural realities.

The ongoing problem lies in the economic vulnerability of smallholder farmers. Even though the CBA indicates that AWD increases the NPV by LKR 369,768 under climate change and improves the Benefit-Cost Ratio (BCR) from 1.4 to 1.6, these financial benefits accrue gradually. Farmers facing short-term liquidity shortages or credit barriers may be unable to invest in the transition. Subsidies and credit schemes remain inadequately aligned with CSA adoption; existing agricultural loan products rarely recognize the long-term returns from sustainable practices. This economic asymmetry perpetuates low adoption despite clear profitability in the model projections. These barriers suggest that while AWD is technically sound, institutional and behavioral constraints still limit its full potential.

Extent of the Problems

The magnitude of these issues is considerable. Climate vulnerability affects nearly all major rice-growing districts, particularly in Dry Zone. Simulation results for DL3 show a projected 21.2% yield decline under

BAU by 2030. Given that DL3 represents one of the most productive rice belts, such losses could threaten regional food security and national self-sufficiency targets. Meanwhile, infrastructural and institutional gaps further amplify vulnerability rendering AWD implementation difficult without rehabilitation. Economically, the persistence of traditional water-intensive practices means that potential NPV gains of AWD, remain unrealized across thousands of hectares. Socially, uneven access to training and information perpetuates inequality, with progressive farmers and better-connected irrigation schemes more likely to benefit from CSA adoption.

Implementation Issues and Their Current Status

Implementation challenges have historically hindered the scaling of CSA interventions in Sri Lanka. The most critical among these include (i) inadequate extension capacity, (ii) infrastructural limitations in irrigation systems, (iii) the absence of localized monitoring mechanisms.

The extension system, though widespread, remains heavily focused on input distribution rather than adaptive management. AWD requires frequent field-level observation and farmer empowerment to manage irrigation independently, yet extension officers often lack both training and time to provide such tailored support. Moreover, monitoring AWD water levels necessitates simple yet reliable tools such as field water tubes; however, distribution and usage remain limited outside pilot projects. Irrigation infrastructure also presents a structural challenge. While major irrigation schemes in the Dry Zone could technically accommodate AWD, most minor systems cannot regulate water with the precision required. This limitation means that farmers practicing AWD may still experience unplanned flooding from upstream canals or unexpected shortages during the drying phase, undermining the consistency needed for yield improvement.

Impact on policy and institutional development

The economic evidence generated by this study has significant implications for national drought adaptation and agricultural water management policies. The findings provide a quantitative foundation for integrating AWD into Sri Lanka’s CSA strategy, National Adaptation Plan, and Irrigation Policy. The results also support the design of incentive-based schemes, such as subsidies for moisture-monitoring devices or credit facilities that encourage farmers to transition toward water-saving practices. At the institutional level, the study has contributed to capacity building by strengthening local expertise in simulation-based impact assessment using tools such as APSIM, thereby improving decision-making in climate and water policy domains.

Beneficiaries

The primary beneficiaries of AWD adoption are smallholder farmers who face high irrigation costs and frequent drought risks. By reducing water demand and input costs, AWD enhances their profitability and resilience. The broader community also benefits from improved groundwater sustainability and reduced methane emissions. However, potential “losers” may include farmers in areas with unreliable irrigation infrastructure or those dependent on existing water allocation systems that discourage conservation. In such contexts, targeted training and policy support are essential to ensure equitable outcomes.

Sustainability and resource considerations

The sustainability of AWD implementation depends on maintaining access to technical guidance, financial incentives, and institutional support. The relatively low cost of implementation, mainly associated with training and monitoring makes it economically sustainable if integrated into existing extension services. Furthermore, the reduction in water use provides long-term benefits for aquifer recharge and ecosystem stability, reinforcing its environmental sustainability. With continued government backing and community engagement, the changes initiated through AWD adoption are expected to remain effective and expand across water-scarce regions.

Results and Achievement of Objectives

Climate prediction were obtained from ARIMA model in order to get the most accurate prediction for APSIM future yield simulation for the period of 2026 -2030.Table 8 indicates that the ARIMA model effectively captures the monthly temperature variations, showing fluctuations in both Tmax and Tmin throughout the year. Given its ability to reflect temperature changes more accurately, predictions from the ARIMA model were used for further analysis.

Table 4: Climate prediction for IML region with ARIMA and RF model for 2027

ARIMA Model		
Year	Tmax (^oC)	Tmin (^oC)
1/1/2027	27.69	19.58
2/1/2027	29.15	19.79
3/1/2027	31.60	20.91
4/1/2027	32.16	22.97
5/1/2027	30.20	23.69
6/1/2027	29.29	23.41
7/1/2027	29.43	23.03
8/1/2027	29.96	22.85

9/1/2027	30.04	22.71
10/1/2027	29.48	22.29
11/1/2027	28.10	21.42
12/1/2027	27.42	20.63

Source – Author's own work

Annual daily temperature and rainfall variations were analyzed to identify differences and changes between years. Table 5 shows that the annual variations in rainfall, maximum temperature (Tmax), and minimum temperature (Tmin) between consecutive years are minimal. Rainfall fluctuates slightly from 6.02 mm in 2026 to 5.62 mm in 2030, while Tmax and Tmin exhibit very small changes over the years. Given this low interannual variability, instead, selecting specific years as "milestones" helps simplify the analysis while still capturing key trends. The years 2027 and 2030 were chosen as milestone years because they effectively represent the short-term and long-term trends within the forecast period. The year 2027 serves as an early checkpoint to assess changes shortly after the forecast begins, while 2030 marks the end of the projection period, allowing for a comparison of long-term trends. Since the variability is low, selecting multiple intermediate years would provide little additional insight, making 2027 and 2030 optimal reference points for evaluating changes in climate conditions.

Table 5: Annual Rainfall, Tmax, and Tmin analysis of IML region

Year	Daily_Rainfall (mm/day)	Daily_Tmax (°C)	Daily_Tmin (°C)
2026	6.02	29.58	22.13
2027	5.82	29.54	21.94
2028	5.67	29.53	21.95
2029	5.62	29.55	21.97
2030	5.62	29.53	21.97

Source – Author's own work

Identification of long-term climate change impact

To identify the long-term effect of climate change, yields were simulated with APSIM as below and compared with the current (2023) yield. The figure 2 presents a comparison between current (2023) rice yields and projected yields at the end of the climate prediction period (2030). The current yield represents the baseline productivity observed under existing climatic conditions with traditional farming practices. Future yield estimates are derived from simulations incorporating projected climatic variables for 2030 using the APSIM model. The comparison allows us to visualize the potential impact of climate change on paddy productivity.

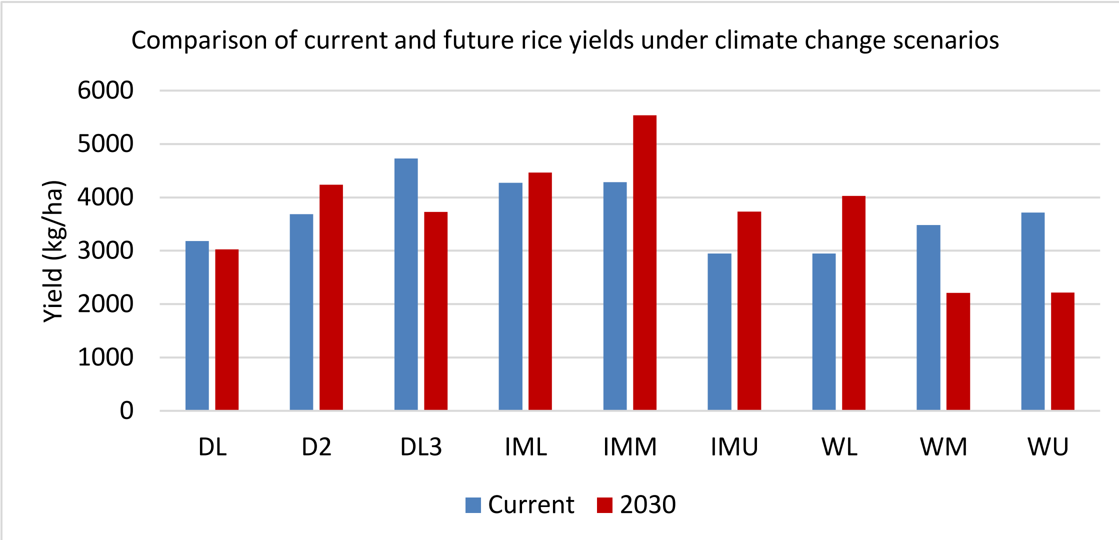

Figure 2: Current (2023) and anticipated future (2030) paddy yields

These projections highlight the significant spatial variability in how climate change and other factors may influence agricultural productivity. In certain regions, such as DL1 and DL3, a decline in paddy yields is expected over the next several years. These areas, which currently maintain stable productivity levels, are projected to experience continuous reductions in yield by 2030. However, in the DL2 region, future yields are expected to be higher than the current levels. Similarly, in the IMZ, predicted future yields are also higher than the current yield. In the Wet Zone, most regions are projected to see a decline in yields compared to the current period, except for WL, where future yields are expected to improve.

This aligns with findings from studies conducted in Sri Lanka, where temperature variations have been shown to have significant non-linear effects on yields, particularly in the dry zone. Moreover, rainfall was found to significantly decrease yields in the dry and wet zones, while having a positive effect in the intermediate zone. Rainfall fluctuations had a particularly detrimental impact on yields in the wet zone, more so than in other regions. Based on the analysis of the compiled annual district-wise panel dataset covering 39 years (1981 to 2019) and encompassing 18 districts, panel regression techniques were applied (Chandrasiri *et al*., 2023). As the climate predictions are based on past climate data, the trends identified in the analysis are expected to reflect similarly in the future, suggesting that the accuracy of these predictions is reasonable and influence of climatic parameters continuously influences particular regions in the same pattern. Given these projections, there is an urgent need to emphasize the importance of region-specific CSA strategies. These strategies are essential for mitigating losses in vulnerable regions and for sustaining or enhancing productivity in areas with growth potential.

Incorporation of AWD method.

In this research, two CSA intervention, AWD were incorporated into APSIM simulations. AWD was selected for its potential to reduce water use and methane emissions while maintaining or increasing the yields. According to the agricultural guidelines issued by the DOA specify that AWD is most suitable for the DZ and IMZ, where water availability and soil characteristics support its successful implementation. In line with these recommendations, AWD was applied in the DZ and IMZ to maximize yield potential while ensuring practical relevance.

Table 6: Irrigation intervals in AWD for a 3.5-month rice variety

Crop Stage	Water Table Threshold	Drying Days (Gap Between Irrigations)
Establishment	Continuous shallow flooding	0 days
Vegetative	10-15 cm below the surface	3-5days
Flowering	Shallow flooding (no AWD)	0 days
Maturity	Stop irrigation	

Source – Author's own work

Table 6 details the irrigation intervals in AWD based on crop growth stages for a 3.5-month rice variety. Typically starting about two weeks after transplanting.

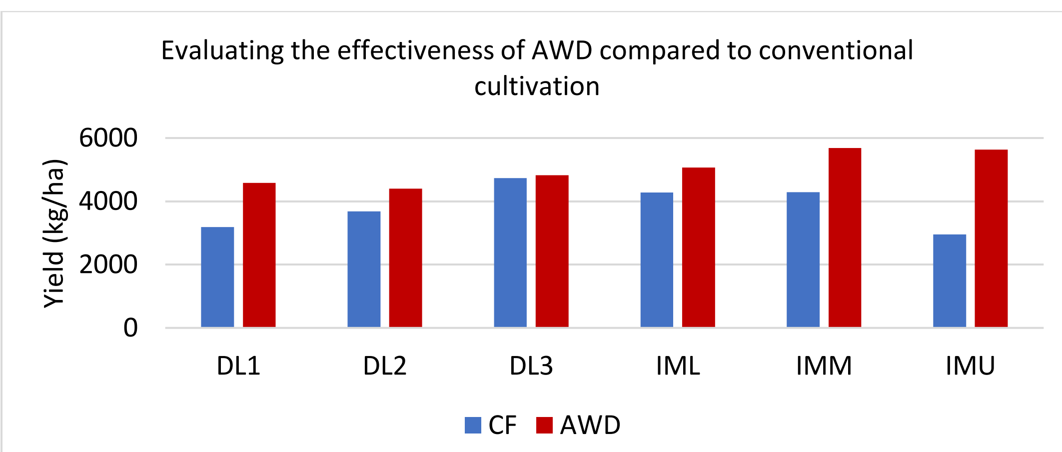

Figure 3: Yield comparison of AWD and conventional cultivation method (CF).

The consistent performance of AWD in enhancing paddy productivity highlights its effectiveness as a water management technique, particularly in regions experiencing water scarcity or variable rainfall. Table 7 indicate several regions, including DL1 and DL3, are projected to experience yield reductions by 2030 without CSA interventions. DL3, one of the highest-yielding regions in Sri Lanka, is also expected to see a 21.2% reduction, indicating the negative impact of climate change on historically productive areas. Conversely, other regions such as D2, IML, IMM and IMU are expected to achieve higher yields in 2030 even without CSA practices. This suggests that some areas may benefit from changing climate conditions or other agronomic factors that favor rice growth despite the absence of CSA. If CSA practices are implemented, five out of six regions are projected to have higher yields than the current levels. The only exception is DL3, where CSA helps reduce the extent of yield loss but does not completely prevent it. Without CSA, DL3's yield would decline by 21.2%, but CSA reduces this loss to 9%, highlighting its role in mitigating climate-related risks. Moreover, DL3 is already under major irrigation practices, so merely changing irrigation techniques like AWD may not be enough to mitigate the effects of climate change. This indicates that additional CSA interventions such as soil fertility enhancement, improved nutrient management, and stress-tolerant rice varieties should be explored to enhance resilience in this region. These are some visible benefits of AWD but rather than this according to Ishfaq *et al*. (2020) AWD irrigation system significantly reduces GHG emissions, and toxic metal accumulation in rice grains while maintaining or improving yields.

Table 7: Yield comparison with identified region-specific CSA in future climate change scenario

Region	Current (kg/ha)	2030 (kg/ha)	2030 with CSA (kg/ha)	Yield_Change(%) Compared to 2023	Yield_Gain(%) Compared to 2023 with CSA
DL1	3184	2976	4310	-6.5%	35.4%
DL2	3687	4237	4588	15.0%	24.5%
DL3	4729	3726	4305	-21.2%	-9.0%
IML	4275	4466	5221	4.5%	22.1%
IMM	4287	5536	5840	29.1%	36.2%
IMU	2950	3731	5134	26.5%	74.0%

Source – Author's own work

The findings indicate that effectiveness of AWD is not uniform across all regions. While AWD boosts yields in most areas, its impact is less pronounced in high-yielding regions like DL3, suggesting that AWD and other general CSA interventions may not work equally well everywhere. This underscores the necessity for localized field trials and adaptive management strategies to identify the most effective CSA interventions for specific agroecological zones. This analysis demonstrates that while CSA can substantially improve yield outcomes and eco-friendly as well, a one-size-fits-all approach may not be effective. Instead, region-specific CSA strategies should be prioritized based on local soil properties, climate conditions, and rice-growing practices. Practical implementation trials are essential to determine the best interventions for climate-vulnerable regions, ensuring sustainable rice production in the face of future climate challenges.

Cost Benefit Analysis.

A cost-benefit analysis was done for the AWD method by considering the IML country and there the yields were obtained from the actual fertilizer use instead of DOA recommendations which may not always reflect real-world practices. By using actual farmer practices for fertilizer application, the analysis reflects more realistic, region-specific conditions and inputs, allowing for a more accurate assessment of the economic impact of fertilizer use on crop yields. By aligning the yield data with the real-world application practices over the designated period, the CBA becomes more relevant and applicable to the conditions that farmers face, offering insights that could inform future CSA-related strategies and policies.

Table 8: Cost-benefit analysis for the period of 2020 - 2030

2020 – 2030 NPV (LKR)			
	without climate change	Climate Change	CC effect
No AWD	863,375.0	888,861.0	-25,486.8
With AWD	1,265,879.0	1,258,629.0	7,250.0
CSA effect	402,505.0	369,768.0	
Annual NPV (LKR)			
	without climate change	Climate Change	CC effect
without AWD	78,489.0	80,806.0	-2,317.0
With AWD	115,080.0	114,421.0	659.0
CSA effect	36,591.0	33,615.0	
BCR			
	without climate change	Climate Change	CC effect
without AWD	1.4	1.4	0.0
With AWD	1.6	1.6	0.0
CSA effect	0.2	0.2	

Source – Author's own work

This cost-benefit analysis of paddy cultivation, covering the period from 2020 to 2030, assesses both yield (kg/ha) and NPV under various scenarios involving the climate change and static climate with the AWD method. To represent conditions without climate change, it was assumed that current climatic patterns would remain stable. In this scenario, yield projections for the years 2026–2030 were based on historical yields recorded in the IML region during the period 2004–2020 with and without AWD, under the assumption that the climate remains unchanged. For the climate change scenario, future yields were simulated using ARIMA predictions with comparing outcomes with and without AWD. This analysis provides insights into the potential economic and agronomic benefits of adopting AWD practices in the face of ongoing climate variability.

The NPV without climate change scenario without AWD was LKR 863,375 whereas, under climate change without AWD, it increased to LKR 888,861 reflecting a gain of LKR 25,487. However, when AWD was implemented, the NPV without climate change was LKR 1,265,879, and under climate change, it was LKR 1,258,629 resulting in a smaller loss of LKR 7250 although there is a slight reduction in NPV under climate change when AWD was implemented a loss of LKR 7,250 compared to the no climate change scenario), AWD still delivers significantly higher economic returns in both scenarios. Specifically, AWD result in an NPV increase of LKR 369,768 under climate change and LKR 402,504 without climate change, compared to their respective without AWD counterparts. This demonstrates that, despite a minor loss due to climate change, AWD substantially enhance overall profitability and provides strong economic resilience across both climatic conditions. Without AWD, BCR is 1.43, while with interventions it increases to 1.60 in both cases. This reflects a consistent improvement of 0.18, indicating that AWD enhance economic efficiency regardless of climate conditions.

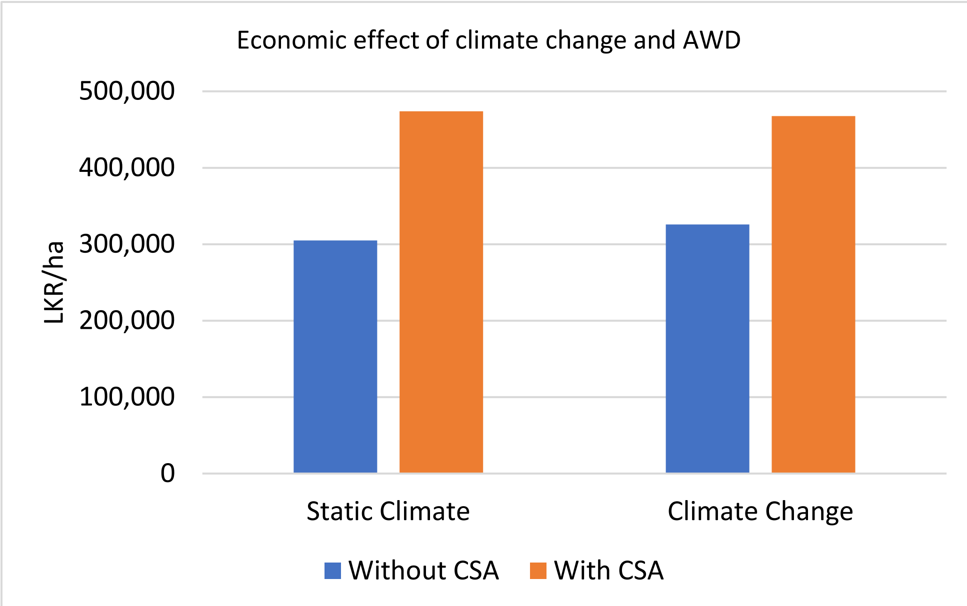

Figure 4: Economic impact of AWD in the climate change scenario and without any climate change scenario.

Figure 4 illustrates the economic effect of climate change and Alternate Wetting and Drying, a CSA intervention, on NPV. CSA results in significantly higher NPV compared to the non-intervention baseline. While climate change slightly reduces the benefit of CSA, the intervention still delivers strong economic gains across both conditions.

Table 9: Cost-benefit analysis for the period of 2025 - 2030

2025 -2030 NPV (LKR)			
	without climate change	Climate Change	CC effect
No CSA	594,162.0	635,208.0	-41,047.0
With CSA	923,305.0	911,629.0	11,676.0
CSA effect	329,144.0	276,421.0	
Annual NPV (LKR)			
	without climate change	Climate Change	CC effect
without AWD	99,027.0	105,868.0	-6,841.0
With AWD	153,884.0	151,938.0	1,946.0
CSA effect	54,857.0	46,070.0	
BCR			
	without climate change	Climate Change	CC effect
without AWD	1.4	1.4	-
With AWD	1.6	1.6	-

CSA effect	0.2	0.2

Source – Author's own work

When CSA practices are implemented, the annual NPV reaches LKR 153,884 LKR without climate change, which is LKR 54,857 higher than the non-CSA scenario, clearly indicating strong economic gains. Under climate change, the CSA effect slightly decreases to LKR 46,070, yet it still maintains a higher economic return compared to the without AWD scenario. This demonstrates that AWD not only improves profitability but also effectively buffers the adverse impacts of climate change, making it an economically viable and resilient strategy for paddy farming. Moreover, the BCR remains consistently higher with AWD at 1.60 in both climate conditions, reinforcing its long-term economic viability.

The comparison shows that the effect of AWD strengthens over time. During 2020–2030, Under AWD annual NPV increased by LKR 36,591 without climate change and LKR 33,615 under climate change. In the later period of 2025–2030, these gains rose to LKR 54,857 and LKR 46,070 respectively, indicating that CSA will deliver higher economic returns in the future, regardless of the climate scenario. While the impact of climate change is not expected to be severe shortly, the consistent economic benefits of AWD suggest their significance regardless of climate conditions. Notably, Chandrasiri *et al*. (2023) observed that historical climatic factors positively influenced agricultural productivity in the Intermediate Zone, a trend expected to persist in the future. This explains the moderate positive gains observed under climate change conditions.

Summary of the findings

The research findings indicate that the projected impact of climate change on paddy yields will not be uniform across the country. The analysis conducted using the APSIM model for the current period, shows significant regional variations in yield responses under the BAU scenario, where AWD is not applied. Without AWD, significant yield losses were observed in certain regions. According to ARIMA predictions, the effects of climate change are expected to vary geographically, with regions such as DL1 and DL3 facing negative impacts, while IML shows a mild positive effect. Other regions such as DL2, IMM and IMU are projected to experience significant positive yield changes due to climate change.

However, the study reveals that the timely adoption of AWD as CSA practice, can significantly mitigate the negative effects of climate change. AWD practice demonstrated their potential to increase paddy yields and improve productivity, even under projected climate change scenarios. These results suggest that the implementation of AWD as CSA intervention can enhance yield resilience and stability across different agro-climatic zones, reducing the adverse impact of climate change on paddy farming. The CBA conducted for IML for the period 2020–2030, which was based on actual farmer practices rather than DOA recommendations, validates the financial viability of CSA. The BCR remained consistent over the years, ranging from 1.43 to 1.6, regardless of AWD implementation. Moreover, the NPV of CSA consistently surpassed that of conventional farming practices, with an incremental increase of 0.18, reinforcing the economic profitability of CSA interventions.

Conclusions

The analysis of current and future paddy yields under BAU revealed the potential risks and limitations posed by changing climatic conditions. AWD was identified as best affordable CSA intervention. simulation of their impacts, it was evident that AWD can enhance or maintain the paddy yields while improving resilience to climate variability. Furthermore, the cost-benefit analysis for AWD in the IML region demonstrated that AWD not only increases NPV and BCR but also ensures higher economic returns under both current and projected climate scenarios. Overall, the study confirms that AWD as CSA intervention is a viable and effective strategy for sustaining and improving paddy productivity in the face of climate change.

5. Lessons Learned

Based on the findings of the research, it is recommended to promote the widespread adoption of AWD practices, particularly in areas vulnerable to climate change. This could be achieved through training programs that educate farmers on effectiveness of AWD. Additionally, government policies should be developed to provide financial and technical support for CSA implementation, including subsidies for CSA technologies and extension services to facilitate the transition from conventional to climate-resilient farming practices. Strengthening research and extension services will be crucial to identify locally suitable CSA practices, while also demonstrating their benefits to farmers. Financial mechanisms such as climate risk insurance or low-interest loans should be introduced to reduce the economic risks associated with CSA adoption. Furthermore, robust monitoring and evaluation systems should be established to assess the impact of CSA practices on paddy yields and farm profitability, allowing for continuous improvement of these strategies. Fostering collaborative partnerships between government, NGOs, and the private sector can help share resources, technologies, and knowledge to support the widespread adoption of CSA.