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Optimizing Irrigation Water Distribution to Maximize Agricultural Profits Using a Deterministic Dynamic Model in the Ameroro Irrigation District, Konawe Regency

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Abstract: Limited irrigation water availability constrains irrigation management and reduces agricultural profitability. This study aims to maximize agricultural profit by optimizing irrigation water distribution using a deterministic dynamic programming model in the Ameroro Irrigation Area, Konawe Regency, Indonesia. The model was structured with planting seasons as stages, irrigation water availability as the state variable, and water allocation as the decision variable. The objective function maximized total profit based on cultivated land area under a rice–rice–secondary crops cropping pattern across a total irrigated area of 2,100 ha. Model constraints included dependable discharge, seasonal water availability, crop water requirements, and land area limitations. In the existing condition, agricultural profit reached IDR 37.4 billion in planting season I, IDR 37.4 billion in planting season II, and IDR 8.6 billion in planting season III, totaling IDR 83.4 billion annually. After optimization, profits increased to IDR 42.03 billion, IDR 44.07 billion, and IDR 12.90 billion, respectively, resulting in a total annual profit of IDR 99.00 billion. The results indicate that deterministic dynamic programming improves water allocation efficiency and increases agricultural profit without additional water resources, supporting sustainable irrigation management.

Keywords: Agricultural benefits; Deterministic dynamic program; Irrigation optimization; Irrigation water distribution; RStudio

Introduction

Water is a strategic resource in supporting sustainable development and national food security. In Indonesia, the agricultural sector accounts for more than 70% of total water use, so the sustainability of food production is highly dependent on the efficiency of irrigation systems (Babba et al., 2021). Increased water demand due to population growth, agricultural expansion, and climate variability has increased pressure on water availability (Kurniasari et al., 2021). The spatial and temporal imbalance in water distribution causes deficits in the dry season and surpluses in the rainy season, which has an impact on reduced productivity and potential conflicts b between water users (X. Zhang et al., 2021). Therefore, efficient and adaptive irrigation management is key to maintaining the stability of agricultural production. The Ameroro Irrigation Area (DI) in Konawe Regency faces an imbalance between water availability and demand sourced from the Ameroro Dam. Under the Q80 discharge condition, the average water availability is around 2.10 m^3/sec, which is lower than the irrigation demand of 2.8 m^3/sec, resulting in a deficit of 0.7–1.0 m^3/sec. As a result, the functional area irrigated is only around 1,700 ha out of a potential area of 2,100 ha. Conversely, under Q20 conditions, there is a surplus discharge of up to 5.20 m^3/sec that has not been optimally utilized due to limitations in the distribution system. Conventional water distribution management

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has not been able to systematically adjust water allocation to seasonal discharge variations.

Various studies show that optimization models are effective in improving irrigation efficiency. Nalurita et al. (2017) reported an increase in distribution efficiency from 86.52% to 97.27% through a stochastic dynamic program. Babba et al. (2021) found an increase in rice production from 3.90 tons/ha to 4.29 tons/ha using a deterministic approach. Palupi et al. (2024) showed an increase in profits of up to 64.39% in three growing seasons through deterministic dynamic optimization. Internationally, Linker (2021) emphasized that the multistage optimization approach can improve the efficiency and resilience of risk-based irrigation systems.

However, most previous studies have focused on the Java region and have not developed a multiseasonal deterministic dynamic model based on actual data on reliable discharge and crop water requirements in the Ameroro irrigation district. In addition, they have not fully integrated optimal planting area, seasonal discharge allocation, and economic benefits into a single recursive model framework. Therefore, this study offers novelty through the development of a multistage Deterministic Dynamic Program model based on local data that integrates reliable discharge limits, crop water requirements, and functional area to produce optimal water distribution patterns per planting season.

This study aims to optimize irrigation water distribution in DI Ameroro using the Deterministic Dynamic Program to determine efficient water allocation patterns between planting seasons, increase functional planting area, and maximize sustainable agricultural profits.

Method

This study was conducted in the Ameroro Irrigation Area (DI Ameroro), Konawe Regency, Southeast Sulawesi Province, which covers a potential irrigation area of 2,100 hectares.

This study uses secondary data from BWS Sulawesi IV Kendari and the Konawe District Agriculture Office, as applied in studies on the optimization of irrigation water distribution based on dynamic programs (Nuf'a et al., 2016; Shafiya et al., 2023). The data used included daily rainfall for the period 2015–2024 from the Abuki, Lambuya, and Mowewe stations, climatological data, Ameroro Irrigation Area intake discharge data, as well as the 2024/2025 RTTG, irrigation network schemes, and crop yield data.

Data processing includes calculating reliable and effective rainfall using the Basic Month Method, analyzing reliable discharge Q80, and processing climatological data for calculating evaporation and crop water requirements using the Van de Goor–Ziljstra and Modified Penman methods (Limantara, 2018). Next, a water balance is compiled as the basis for evaluating irrigation water availability and requirements. The final stage involves optimizing irrigation water allocation using a deterministic dynamic program with step-by-step decision making between planting seasons (Babba et al., 2021; Linker, 2021).

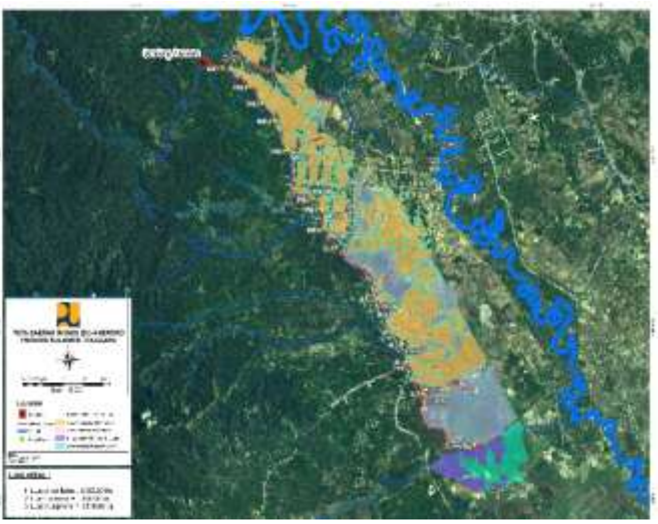


Figure 1. Study location

The objective function of this model is to maximize total profits over three growing seasons, which is expressed as follows:

$$\sum f^* = F^*_{\{MTI\}} + F^*_{\{MTII\}} + F^*_{\{MTIII\}} \quad (1)$$

Explanation:

Σf : Total profit
$F_{MTI}*$: Profit on First Planting Season
$F_{MTII}*$: Profit on Second Planting Season
$F_{MTIII}*$: Profits in the Third Planting Season

Forward recursive equation for each growing season:

$$F^*(S_i) = \max_{d_i}[R_i + F^*(S_{i-1})] \quad (2)$$

Explanation:

$F^*(S_i)$: The goal to be achieved in terms of total profit from allocating water to each stage/building during one planting season (in rupiah)
R_i : benefits from allocating water to buildings (in rupiah units)
$F^*(S_{i-1})$: total profit from allocation to previous stages/buildings (in rupiah units)

Deterministic dynamic programming is a mathem atical programming technique used to allocate resources to multiple targets with the aim of optimizing profits. This approach breaks down the problem into several sequential and interconnected stages (multistage), where each stage contains specific decision variables (C. Zhang et al., 2023).

In an irrigation network system, the stages of a dynamic program are represented as sequentially arranged irrigation structures, such as distribution structures, tapping structures, and tapping structures, which are interdependent in water distribution. A deterministic dynamic program has the characteristic that the conditions at the next stage are completely determined by the decisions at the previous stage, making it suitable for use in the analysis and optimization of irrigation networks (Limantara et al., 2020).

The model formulation is expressed in the form of an objective function and a recursive equation. Equation (1) states that the optimal total profit is obtained from the accumulation of optimal profits in each planting season, while Equation (2) is a forward recursive equation to determine the optimal profit at each stage by maximizing the profit of the current stage and the profit from the previous stage based on the water volume allocation decision. This approach allows for the determination of optimal water allocation at each stage of the irrigation network on an ongoing basis (Zhang et al., 2023).

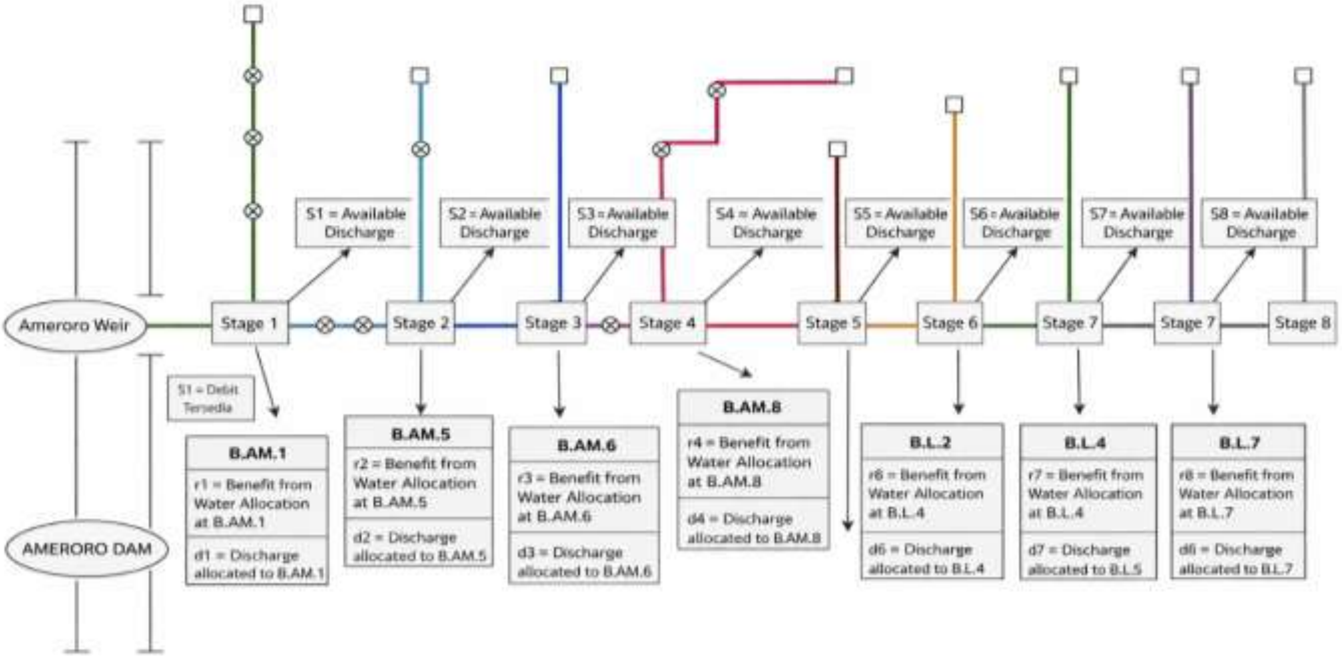


Figure 2. Optimization stage

The figure shows a schematic of the deterministic dynamic program modeling of the Ameroro Irrigation Area irrigation network (X. Zhang et al., 2021). The system begins with the Ameroro Dam as the water source, then is divided into several stages representing the main irrigation structures in the network. Each stage describes the decision-making process for allocating available water discharge (Si) to the associated irrigation structures, taking into account the interrelationships between the structures sequentially from upstream to downstream (Lake et al., 2025; Li et al., 2025; Shu et al., 2025; Yang et al., 2024).

At each stage, there is a decision variable in the form of water discharge allocated (di) to irrigation structures, such as the main distribution structure (B.AM.1), distribution and tapping structures (B.AM.5, B.AM.6, B.AM.8), as well as tapping structures and other tertiary channels (B.L.2, B.L.4, B.L.5, and B.L.7). Each water allocation decision produces a profit (ri) recorded as a stage return, while the remaining discharge becomes a condition or status for the next stage in the irrigation network system (Hoesein et al., 2010; Nalurita et al., 2017).

Through this scheme, the optimization process is carried out gradually using recursive principles, whereby water allocation decisions at one stage affect water availability and profits at the next stage. Thus, the deterministic dynamic programming model is able to describe the cause-and-effect relationship between irrigation structures and support the determination of optimal water allocation strategies to maximize total profits in a single growing season. This approach allows for systematic evaluation of state–decision–return through forward recursion and backtracking to ensure that global solutions remain consistent with system constraints (Gebrewold et al., 2023; Palupi et al., 2023).

Result and Discussion

Irrigation Water Requirements

Irrigation water requirements are influenced by the cropping pattern applied (Taheri et al., 2024). In the Ameroro Irrigation Area, the cropping pattern refers to the Groundwater Supply (RTTG) for the 2024–2025 period, namely rice–rice–secondary crops and sugarcane. The results of the water balance analysis, based on the comparison between water demand and availability, indicate a water deficit in several growing seasons (Li et al., 2025; F. Zhang et al., 2023). Water requirements calculations were carried out comprehensively, assuming uniform planting times. Therefore, the water requirements for each irrigation structure were assumed to be the same and were subsequently used in the construction phase analysis (Yang et al., 2024).

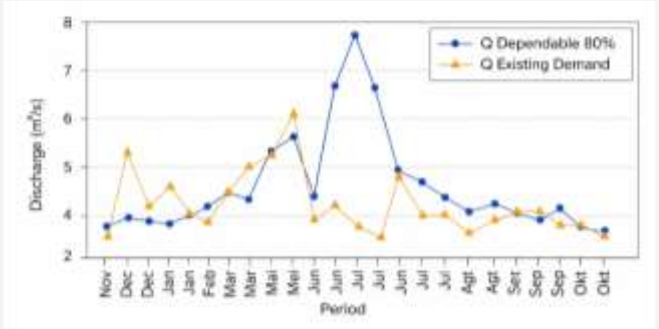
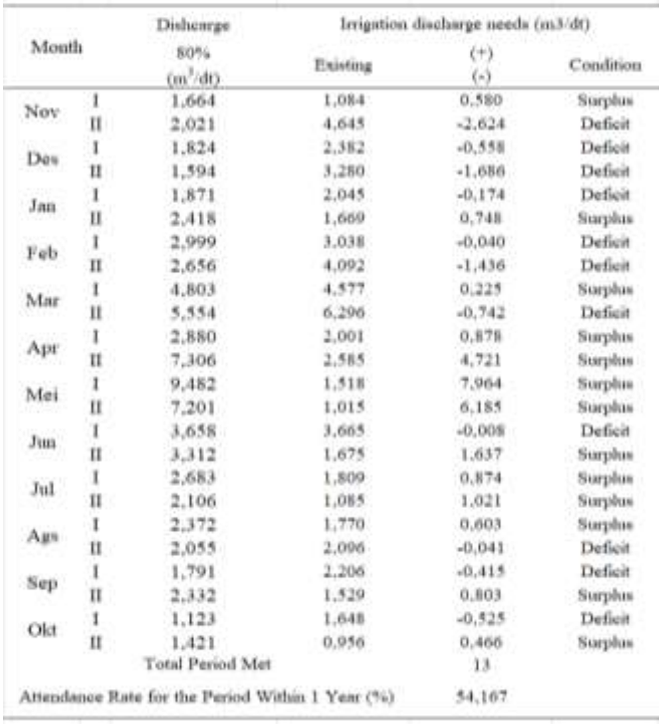


Figure 3. Water balance before optimization

Based on the water balance graph and the water balance table before optimization, it can be seen that the relationship between the 80% mainstay discharge and the existing irrigation water needs has not been balanced throughout the year. Of the total 24 semi-monthly periods, only 13 periods (54.17%) were in a fulfilled condition, while the other 11 periods experienced a deficit. The deficit condition mainly occurred in the period of November II (deficit −2,624 m³/s), December I and II (respectively −0.558 m³/s and −1,686 m³/s), February II (−1,436 m³/s), and April II to May I which showed high fluctuations in water needs and availability.

A significant water deficit was also observed in March II, where water demand reached 6,296 m³/s while the mainstay discharge was only 5,554 m³/s, resulting in a shortfall of -0.742 m³/s. Conversely, the largest surplus occurred in May I, with a difference of +7,964 m³/s, when the mainstay discharge increased significantly to 9,482 m³/s while water demand was relatively low, at 1,518 m³/s. This indicates that water availability is temporally uneven and does not always coincide with peak demand periods.



Month		Discharge 80% (m³/dt)	Irrigation discharge needs (m3/dt)		
			Existing	(+) (-)	Condition
Nov	I	1,664	1,084	0,580	Surplus
	II	2,021	4,645	-2,624	Deficit
Des	I	1,824	2,382	-0,558	Deficit
	II	1,594	3,280	-1,686	Deficit
Jan	I	1,871	2,045	-0,174	Deficit
	II	2,418	1,669	0,748	Surplus
Feb	I	2,999	3,038	-0,040	Deficit
	II	2,656	4,092	-1,436	Deficit
Mar	I	4,803	4,577	0,225	Surplus
	II	5,554	6,296	-0,742	Deficit
Apr	I	2,880	2,001	0,878	Surplus
	II	7,306	2,585	4,721	Surplus
Mei	I	9,482	1,518	7,964	Surplus
	II	7,201	1,015	6,185	Surplus
Jun	I	3,658	3,665	-0,008	Deficit
	II	3,312	1,675	1,637	Surplus
Jul	I	2,683	1,809	0,874	Surplus
	II	2,106	1,085	1,021	Surplus
Ags	I	2,372	1,770	0,603	Surplus
	II	2,055	2,096	-0,041	Deficit
Sep	I	1,791	2,206	-0,415	Deficit
	II	2,332	1,529	0,803	Surplus
Okt	I	1,123	1,648	-0,525	Deficit
	II	1,421	0,956	0,466	Surplus
		Total Period Met		13	
Attendance Rate for the Period Within 1 Year (%)				54,167	

Figure 4. Water balance before optimization

This situation confirms that the existing irrigation system is unable to ensure sustainable water supply throughout the growing season, particularly during the initial planting and land preparation phases. This mismatch between water availability and irrigation needs underscores the need for water distribution optimization to utilize available water flow more efficiently during critical periods.

Available Water Volume

In the deterministic dynamic method, the average discharge value for each growing season is used as input. This discharge is then converted to water volume units, for example, 1 unit = 2,000,000 m³, depending on the required calculation accuracy. The goal is to simplify water allocation calculations. The calculation results show that the available unit volume in Planting Seasons II and III is generally greater due to higher discharge or the addition of additional water supplies such as pumps. In the model, the state variable (Sn) is the number of available unit volumes used to optimize the profitability of the cropping pattern.

Table 1. Available Water Volume at Each Planting Season

Planting Season	Available Water Volume Unit
I	9
II	22
III	8

Required Water Volume

The volume of water required is calculated from the total irrigation water requirement in the Ameroro Irrigation Area. This value is then used to determine the area of land that can be planted and the profit for each planting season. Calculations are performed for each irrigation structure studied, such as tapping structures and distribution structures, by calculating the water requirement for a 15-day period during one planting season.

In this study, water requirements are calculated comprehensively because the planting period for all areas is assumed to be the same, thus ensuring a uniform volume requirement for each structure. The results of these calculations are then used to determine the maximum area of land that can be irrigated and the maximum profit based on water availability during each planting season.

Table 2. Water Volume Requirements for Each Planting Season

Planting Season	Required Water Volume (m^3/ha)
I	8,232.19
II	14,344.34
III	16,968.56

Benefits Based on Water Supply

Irrigation water profitability is calculated based on the economic value of the harvest per hectare obtained by farmers each planting season. This value is determined by multiplying the crop yield by its selling price, then relating it to the volume of air required to irrigate the land in each drained structure (Allen, 2022; Doorenbos et al., 1975). Each structure has different water requirements and service capacities, so the efficiency of profit per unit volume of air also varies. However, when the minimum air supply required to irrigate the land is met, the total profit from the structure is maximized according to the characteristics of the crop and the growing season. Thus, water efficiency serves as the basis for determining the optimal allocation to maximize the benefits of irrigation.

Within the dynamic program modeling framework as shown in the figure, each irrigation structure—both the distribution structure (B.AM.1, B.AM.5, B.AM.6, B.AM.8) and the tapping structure (B.L.2, B.L.4, B.L.5, B.L.7)—has a role as a water distribution decision point. The distribution structure functions to divide the discharge from the main channel into several branches, while the tapping structure channels water directly to tertiary plots or specific service areas. This difference in function causes variations in water needs and marginal benefits at each decision stage (Balitbang SDA, 2013).

Profit calculations in dynamic programming are performed step-by-step through a forward recursive process (Li et al., 2025), starting from the upstream structure and proceeding downstream. At each stage, profit is determined based on the allocated water volume and the irrigable land area. Water availability limits during the growing season determine the unit volume used in the calculations. Tables 4, 5, and 6 below present the maximum profit at each stage, which forms the basis of the recursive process to obtain the optimal total profit from the initial stage to the final stage of the irrigation network.

Furthermore, each water allocation decision at a given stage will affect the conditions of the subsequent stage; therefore, an evaluation of various decision alternatives is necessary to obtain the combination that provides the maximum overall benefit. This process ensures that the interdependence among stages remains optimal.

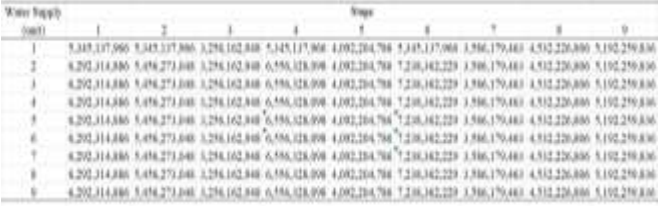


Figure 5. Benefits based on water supply in planting season I

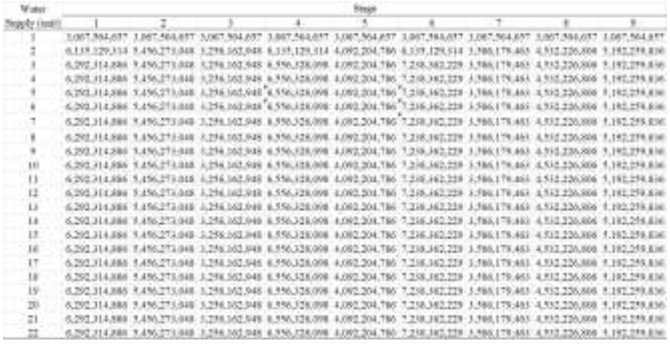


Figure 6. Benefits based on water supply in planting season II

Figure 7. Benefits based on water supply in planting season III

Figures 5, 6, and 7 present the results of profit calculations at each stage and per unit of water volume for Planting Seasons I, II, and III. Each table shows how profits increase with increasing water volume allocation, with varying numbers of stages and units in each planting season depending on variations in water availability. These results form the basis for a forward recursive process in the dynamic program to determine the combination of water allocations that yields maximum total profit.

The next step is to calculate the profit through a backward recursion process, which involves tracing decisions from the most recent stage to the earliest. This procedure can determine the optimal combination of water allocations and the number of units of water delivered to each irrigation structure based on the decision variables at each stage (Aprilia et al., 2022; Palupi et al., 2023).

Optimization Using Dynamic Deterministic Program

Water distribution optimization using Deterministic Dynamic Programming (DDP) resulted in significant increases in profits and irrigated land area in the Ameroro Irrigation Area. The optimization process was carried out through forward recursion, which evaluates all combinations of water allocations at each stage to obtain the best objective function value, and backward tracing, which retraces the optimal decision path from the final stage to the initial one (Bellman, 1957). This tracing results in a different optimal water supply path for each growing season, reflecting DDP's adaptive strategy in responding to variations in water availability and marginal economic value.

In MT I, water allocation was relatively stable (5–5.5 m^3) and the optimal path (1–2–3–4–5–6–7–8–9) showed an even distribution due to sufficient water supply and homogeneous crop needs. In contrast, MT II produced greater allocation variation, including a peak of 7.24 m^3 at location 6, with a non-linear optimal path (1–3–5–8–10–13–15–19–22). This path indicates that the model selectively channeled water to points with the highest marginal productivity, resulting in the highest profit achieved in this season (Rp 44.077 billion). In MT III, water limitations resulted in lower allocations (0–3.23 m^3) and the optimal path (1–2–3–5–6–7–7–8–8) reflected a conservative strategy that maintained supply at points that were still economically profitable.

The consistency between the graph and the optimal path is reinforced by the table results: total profit increased from IDR 83.49 billion to IDR 99.03 billion, while the total irrigated area increased by 866.06 ha after optimization. This indicates that the selection of water supply paths by DDP is not merely a mathematical result, but rather a representation of a distribution strategy that is able to maximize the economic value of each unit of water—in line with the theory of plant response to water and the principle of irrigation efficiency (Doorenbos & Kassam, 1979; Yeh, 1985; Mays, 2011). Thus, DDP optimization has proven effective in increasing the productivity and resilience of the irrigation system under seasonal variations (Li et al., 2025; F. Zhang et al., 2023; X. Zhang et al., 2021).

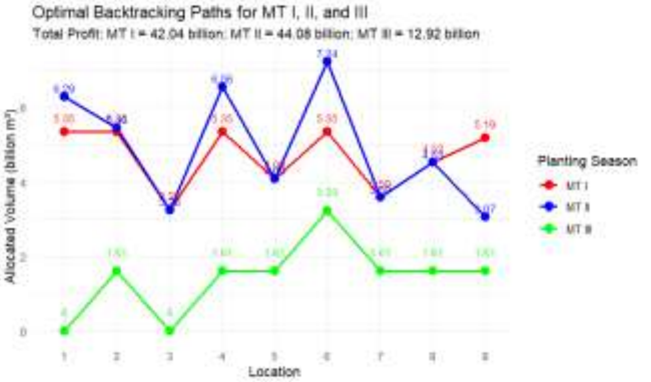
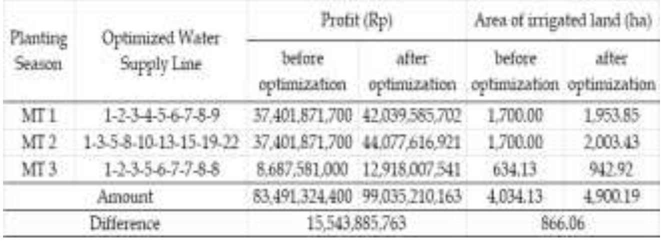
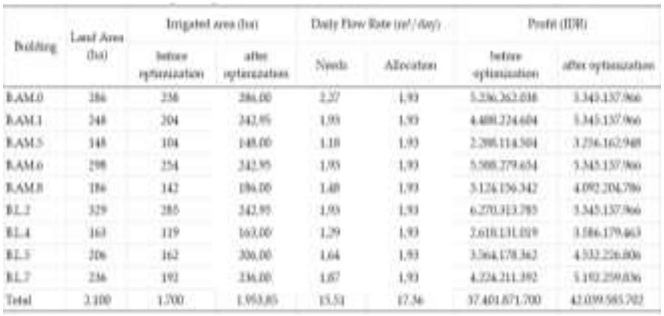


Figure 8. Optimization process using forward recursive and backward tracking methods in RStudio



Planting Season	Optimized Water Supply Line	Profit (Rp)		Area of irrigated land (ha)	
		before optimization	after optimization	before optimization	after optimization
MT 1	1-2-3-4-5-6-7-8-9	37,401,871,700	42,039,585,702	1,700.00	1,953.85
MT 2	1-3-5-8-10-13-15-19-22	37,401,871,700	44,077,616,921	1,700.00	2,003.43
MT 3	1-2-3-5-6-7-7-8-8	8,687,581,000	12,918,007,541	634.13	942.92
Amount		83,491,324,400	99,035,210,163	4,034.13	4,900.19
Difference		15,543,885,763		866.06	

Figure 9. Optimization results using dynamic deterministic program



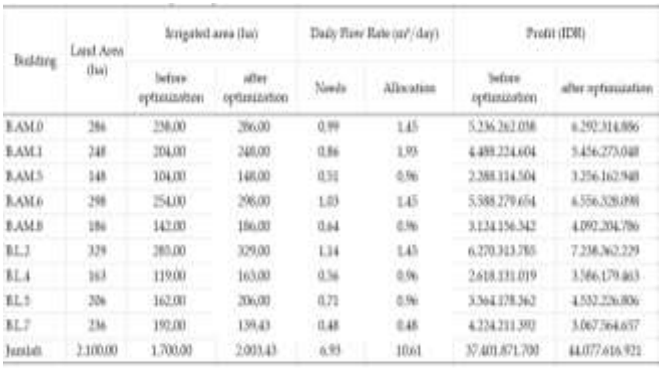
Building	Land Area (ha)	Irrigated area (ha)		Daily Flow Rate (m³/day)		Profit (IDR)	
		before optimization	after optimization	Needs	Allocation	before optimization	after optimization
B.AM.0	286	238	286.00	2.37	1.93	5.236.362.038	5.343.137.966
B.AM.1	248	204	242.95	1.93	1.93	4.408.224.604	5.345.137.966
B.AM.5	148	104	148.00	1.18	1.93	2.298.114.504	3.256.162.948
B.AM.6	298	254	242.95	1.95	1.93	5.508.279.654	5.345.137.966
B.AM.8	186	142	186.00	1.48	1.93	3.124.156.342	4.092.204.786
B.L.2	329	285	242.95	1.93	1.93	6.270.313.785	5.345.137.966
B.L.4	163	119	163.00	1.29	1.93	2.618.131.019	3.586.179.463
B.L.5	206	162	206.00	1.64	1.93	3.564.178.362	4.532.226.806
B.L.7	236	193	236.00	1.87	1.93	4.224.211.392	5.192.259.836
Total	2.100	1.700	1.953.85	15.51	17.36	37.401.871.700	42.039.585.702

Figure 10. Water distribution patterns in the first planting season

Figure 10 shows the improvement in irrigation water distribution performance after optimization using deterministic Dynamic Programming (DDP). This optimization increased the irrigated area from 1,700 ha to 1,953.85 ha, an increase of 253.85 ha, because the model successfully allocated water to tertiary buildings with the best demand-to-profit ratio (Nalurita et al., 2017; Nuf'a et al., 2016). From a hydraulic perspective, the total demand flow of 15.51 m^3/s was met with an optimal allocation of 17.36 m^3/s, indicating that the DDP algorithm prioritizes allocations that provide the highest marginal economic value (Babba et al., 2021).

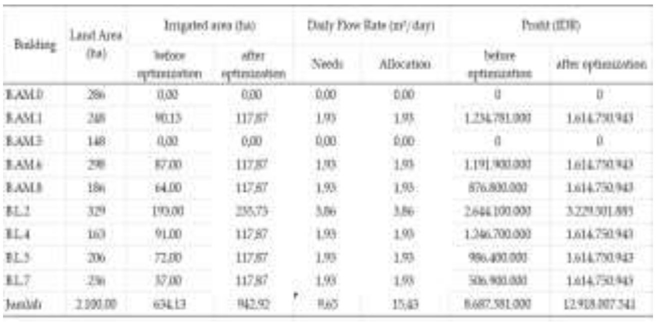
The impact was clearly seen in the increase in total profits from IDR 37.40 billion to IDR 42.04 billion, an increase of approximately 12.4%, in line with research findings that suggest optimization can increase agricultural productivity by 10–20% (Shafiya et al., 2023).

The optimization process was carried out using a combination of forward and backward tracking, which yielded the most efficient water distribution paths for each tertiary structure (Linker, 2021b; C. Zhang et al., 2023). These results indicate that DDP optimization is effective in improving water use efficiency and agricultural benefits. Furthermore, this method is capable of systematically identifying the optimal decision sequence across stages, allowing water distribution to be adjusted according to actual availability and demand conditions in the field.



Building	Land Area (ha)	Irrigated area (ha)		Daily Flow Rate (m³/day)		Profit (IDR)	
		before optimization	after optimization	Needs	Allocation	before optimization	after optimization
BAM.0	286	238,00	286,00	0,99	1,45	5.236.262.038	6.292.314.886
BAM.1	248	204,00	248,00	0,86	1,93	4.489.224.604	5.456.273.048
BAM.5	148	104,00	148,00	0,51	0,96	2.388.114.504	3.256.162.948
BAM.6	298	254,00	298,00	1,03	1,45	5.588.279.654	6.556.328.098
BAM.8	186	142,00	186,00	0,64	0,96	3.124.156.342	4.092.204.786
BL.2	329	285,00	329,00	1,14	1,45	6.270.313.785	7.238.362.229
BL.4	163	119,00	163,00	0,56	0,96	2.618.131.019	3.586.179.463
BL.5	206	162,00	206,00	0,71	0,96	3.564.178.362	4.532.226.806
BL.7	236	192,00	139,43	0,48	0,48	4.224.211.392	3.067.564.657
Jumlah	2.100,00	1.700,00	2.003,43	6,93	10,61	37.401.871.700	44.077.616.921

Figure 11. Water distribution patterns in the second planting season



Building	Land Area (ha)	Irrigated area (ha)		Daily Flow Rate (m³/day)		Profit (IDR)	
		before optimization	after optimization	Needs	Allocation	before optimization	after optimization
BAM.0	286	0,00	0,00	0,00	0,00	0	0
BAM.1	248	90,13	117,87	1,93	1,93	1.234.781.000	1.614.750.943
BAM.3	148	0,00	0,00	0,00	0,00	0	0
BAM.6	298	87,00	117,87	1,93	1,93	1.191.900.000	1.614.750.943
BAM.8	186	64,00	117,87	1,93	1,93	876.800.000	1.614.750.943
BL.2	329	193,00	235,73	3,86	3,86	2.644.100.000	3.229.501.885
BL.4	163	91,00	117,87	1,93	1,93	1.246.700.000	1.614.750.943
BL.5	206	72,00	117,87	1,93	1,93	986.400.000	1.614.750.943
BL.7	236	37,00	117,87	1,93	1,93	506.900.000	1.614.750.943
Jumlah	2.100,00	634,13	942,92	9,65	15,43	8.687.581.000	12.918.007.541

Figure 12. Water distribution patterns in the third planting season

The results of the irrigation water allocation analysis presented in Figure 11 indicate that water distribution optimization significantly increased land allocation efficiency and profits. After optimization, the area of irrigated land was adjusted so that previously underserved units now received more optimal water allocations, resulting in an increase in total profits from IDR 37.4 billion to IDR 44.1 billion (Figure 11). This demonstrates that tailoring irrigation water management to crop needs can increase the economic productivity of irrigation areas, in line with the principle of efficient water resource allocation in agriculture (C. Zhang et al., 2023; F. Zhang et al., 2023).

Furthermore, Figure 12 reinforces this finding by showing that blocks that were previously unallocated water were incorporated into the system with more proportional allocations after optimization, resulting in consistent increases in profits for each unit. The optimized water balance presented in the third figure shows that the monthly irrigation needs generated by the optimization model were largely met by the available 80% of the mainstay discharge, with only one period experiencing a small deficit, and the proportion of periods met reached 95.833%. This condition indicates that optimizing irrigation water distribution can maintain a balance between water availability and crop needs throughout the year, in accordance with the concept of hydrological balance in irrigation systems (Li et al., 2025; X. Zhang et al., 2021).

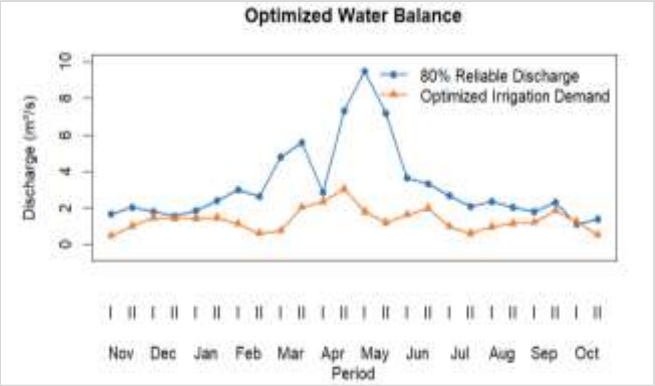
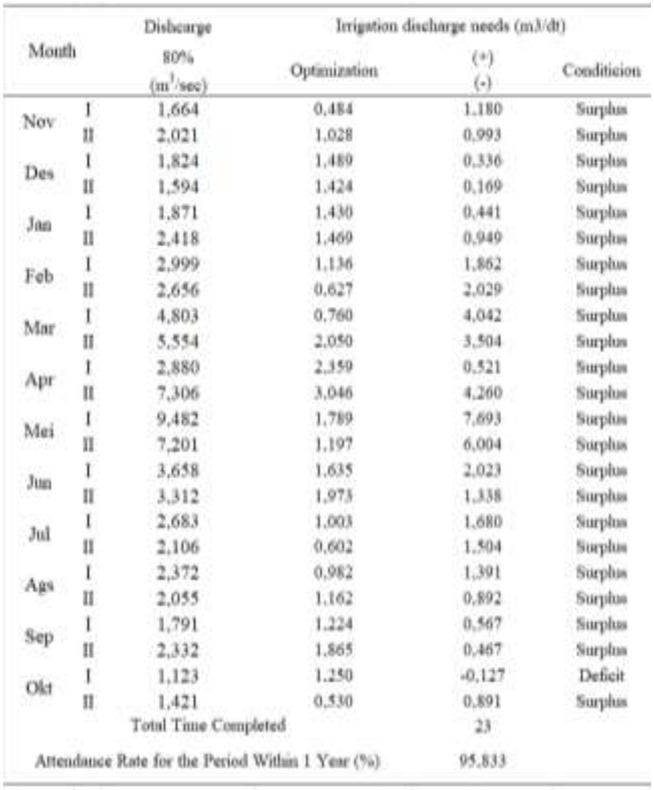


Figure 13. Water balance after optimization



Month		Dishcarge 80% (m³/sec)	Irrigation discharge needs (m3/dt)		
			Optimization	(+) (-)	Conditicion
Nov	I	1,664	0,484	1,180	Surplus
	II	2,021	1,028	0,993	Surplus
Des	I	1,824	1,489	0,336	Surplus
	II	1,594	1,424	0,169	Surplus
Jan	I	1,871	1,430	0,441	Surplus
	II	2,418	1,469	0,949	Surplus
Feb	I	2,999	1,136	1,862	Surplus
	II	2,656	0,627	2,029	Surplus
Mar	I	4,803	0,760	4,042	Surplus
	II	5,554	2,050	3,504	Surplus
Apr	I	2,880	2,359	0,521	Surplus
	II	7,306	3,046	4,260	Surplus
Mei	I	9,482	1,789	7,693	Surplus
	II	7,201	1,197	6,004	Surplus
Jun	I	3,658	1,635	2,023	Surplus
	II	3,312	1,973	1,338	Surplus
Jul	I	2,683	1,003	1,680	Surplus
	II	2,106	0,602	1,504	Surplus
Ags	I	2,372	0,982	1,391	Surplus
	II	2,055	1,162	0,892	Surplus
Sep	I	1,791	1,224	0,567	Surplus
	II	2,332	1,865	0,467	Surplus
Okt	I	1,123	1,250	-0,127	Deficit
	II	1,421	0,530	0,891	Surplus
		Total Time Completed		23	
Attendance Rate for the Period Within 1 Year (%)				95,833	

Figure 14. Water Balance after Optimization

The optimized water balance graph (fourth figure) visually demonstrates that the Q Andalan is generally

80% above the Q irrigation demand, indicating that the irrigation system is able to follow the seasonal pattern of crop water needs and demonstrating the model's effectiveness in aligning discharge fluctuations with irrigation needs. This finding is consistent with the literature stating that optimizing irrigation water distribution can improve farmer welfare through higher productivity without compromising water resource sustainability (Palupi et al., 2023; Shafiya et al., 2023; Yang et al., 2024).

Despite optimization efforts, water deficits still occur at certain times due to a decrease in the main flow rate when crop water demand is relatively high, particularly at the end of the dry season or during the transition period. The conservative use of 80% of the main flow rate also limits water supply to maintain system reliability, so small deficits may still occur.

This indicates that water allocation optimization operates within existing hydrological constraints and cannot fully eliminate the temporal imbalance between water availability and irrigation demand, as described in the concept of sustainable water resource management (S. Zhang et al., 2023).

After optimization, Figure 13 shows that the pattern of water deficits tends to decrease and the distribution becomes more even across periods. This is supported by figure 14, which shows a reduction in the magnitude of deficits during several periods, although water shortages still occur at certain times due to limitations in available supply.

Conclusion

Based on existing conditions with planting patterns according to the Global Cropping Plan (RTTG) for the 2024–2025 period, the maximum irrigation water requirement in the Ameroro Irrigation Area reaches 6,296 m^3/s with an average requirement of 2,444 m^3/s, which in some periods of the planting season causes a water deficit. The application of water distribution optimization using a deterministic dynamic program produces an optimal water supply path in each planting season that represents the sequence of irrigation structures with the most efficient water distribution priority according to the available discharge and plant needs. The optimal path obtained in each planting season is able to direct water allocation in stages so that water distribution is more controlled, even, and produces maximum profits, which in Planting Seasons I, II and III reached Rp. 42,039,585,702, Rp. 44,007,616,921 and Rp. 12,918,007,54 1, respectively. Overall, optimization resulted in an increase in profits of up to 12.40%–48.70%, indicating that optimal path selection plays a significant role in maximizing the utilization of water and land resources. The water balance after optimization showed an increase in the number of growing season periods that could be met compared to existing conditions, although there were still deficits in certain periods, especially at the beginning of the growing season due to the high water demand for nurseries and land preparation. These findings confirm that path-based optimization with a deterministic dynamic program is effective in improving irrigation system performance and farmer profits, but is still affected by hydrological limitations and temporal variations in crop water needs, so that the optimization results can be used as a basis for making decisions for more efficient and sustainable irrigation water management.

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Author Contributions

The authors are responsible for formulating the research concept, collecting and analyzing data, and preparing the manuscript, emphasizing technical intuition in understanding the relationship between water availability, irrigation needs, and agricultural profits. Prof. Dr. Ir. Lily Montarcih Limantara, M.Sc. and Ir. Anggara Wiyono Wit Saputra, S.T., M.Tech., Ph.D., IPM., ASEAN Eng. played a role in providing scientific direction, strengthening methodological intuition, validating the analysis results, and reviewing and refining the manuscript to ensure it complies with academic standards. All authors have read and approved the final version of this article.

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Conflicts of Interest

The author declares that there is no conflict of interest, either financial or non-financial, in conducting the research and writing this article.

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