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Optimization of Cropping Patterns on Paddy Plots in Puri Village, Puri District, Mojokerto Regency, East Java Province with Linear Program

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Abstract

The research site is located in one of the hamlets in Puri village, which has an agricultural land area of approximately 25 hectares. Because of its fertile soil conditions, the land is very suitable for agriculture. However, the agricultural productivity in Puri village has decreased due to changing weather conditions. Puri village, Puri district, Mojokerto regency, has a flat landscape. The duration of the dry season is slightly longer, affecting the availability of water and causing a change in the initial cropping period. As a result, the cropping pattern in the village is not appropriate, leading to a decrease in agricultural productivity. To solve these problems, an optimal cropping pattern needs to be planned to increase agricultural productivity in the village. In order to plan the optimal cropping pattern, the first thing that needs to be done is to calculate the availability of existing water. Then, the need for irrigation water should be calculated. Using the two sets of calculation data, the optimal cropping pattern can be planned with linear program. The analysis is revealed that Puri village has an optimal cropping pattern with a Paddy-Corn-Corn cropping model and an initial planting period in December period 2.

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1. Introduction

Puri Village, located in Puri village Mojokerto regency, has a plain landscape. The research site is situated in one of the hamlets in Puri Village, with approximately 25 hectares of agricultural land with fertile soil conditions, making it very suitable for farming. Puri Village, Puri District, Mojokerto Regency, East Java, already has an irrigation network that uses a river weir. Water from the river is dammed and flowed into existing irrigation canals, which are distributed on each paddy plot.

The area's large plain landscape, supported by fertile soil, makes it unfortunate if agricultural productivity in Puri Village decreases. This decline is due to changing weather conditions, particularly the longer duration of the dry season, which affects the availability of water and changes the time of the initial planting period. This is an important factor but often overlooked, which makes the planting pattern incompatible with the village. This research aims to plan an optimal planting pattern that corresponds to the existing water availability to increase agricultural productivity in the area.

To obtain the optimal planting pattern, the Linear Program method is used. This method helps determine the maximum profit value of farming on each type of plant. This information is crucial for farmers to increase agricultural productivity to the maximum, and thus increase their income. Increased income is important for farmers to have a better standard of living.

2. Materials and Methods

2.1 Theoretical Frame Work

This study utilizes planting pattern optimization using a linear program. The linear program method is a modelling activity that turns work activities into mathematical models that can be used to achieve certain goals. In this study, the goal is to find new optimal planting patterns that can increase agricultural productivity. The mathematical modelling can also be used to determine the advantages of agricultural products in the region, making it valuable information for farmers.

2.2 Research Location

The research is conducted in an irrigation area situated in Puri Village, Puri District, Mojokerto Regency. Location surveys are carried out to understand the location's state, which can be analysed to solve existing problems.

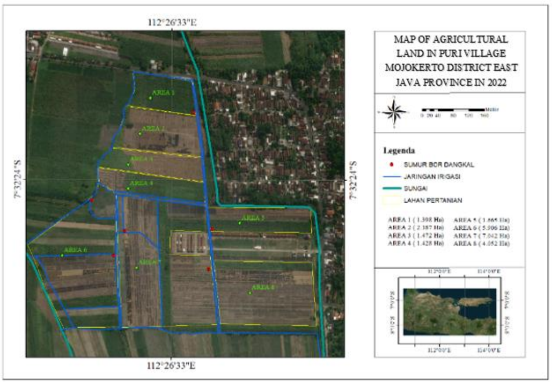

Figure 2. Research Location

2.3 Data

The data used for this study includes primary and secondary data. Primary data is collected directly from the field, including commodity data and photo documentation of field conditions. The commodity data will be used to determine the optimal commodity planting pattern, which will be calculated using the linear program method. On the other hand, secondary data is obtained from other sources, such as rainfall data (2012-2021), climatological data (including temperature, humidity, wind speed, solar radiation), and land outcrop data.

2.4 Analysis Method

This study uses a linear program method. The analysis is consisted of mainstay discharge analysis, irrigation water requirements analysis, and optimization with linear program model.

2.4.1 Mainstay Discharge Analysis

The mainstay discharge refers to the minimum water discharge used for irrigation purposes. The method being used in this research is F.J. Mock. In order to perform the calculation, rainfall data and average evapotranspiration will be required. The data will be calculated according to the F.J. Mock method to produce reliable discharge data. The analysis is consisted of:

1. Average Rainfall

   Data is used from three rain stations, namely STA Pasinan, STA Tampung, and STA Tangunan. The method used to calculate the average rainfall is arithmetic.

   $$R = \frac{R_1 + R_2 + R_3 + \ldots + R_n}{n}$$

   R is average rainfall, R_1 is rainfall data at the station 1, and n is the number of rainfall station.

2. Discharge per Year

   Analysis of discharge per year uses data from the calculation of average rainfall. The discharge from every year is recapitulated. The used method is FJ. Mock method.

2.4.2 Irrigation Water Requirements Analysis

This analysis is determined by many factors, which are plant consumption water requirements, land preparation requirements, percolation, effective rainfall, irrigation efficiency, water requirement for water layer replacement (WLR) and water requirement for rice field. After that, it will be used to find the lowest water requirement based on cropping pattern design. This analysis contains average rainfall analysis, effective rainfall analysis, potential evapotranspiration analysis, and plant water requirements analysis.

Effective rainfall is obtained by sorting rainfall data every month from largest to smallest. The magnitude of probability is obtained from sequence number of sorting sample.

2.4.3 Optimization with Linear Program Model

An optimization model involves preparing a system model that reflects real-world conditions, which can later be transformed into a mathematical model by identifying the main elements. This enables the achievement of a solution that aligns with the goals or objectives of decision-making.

- Alternative Cropping Pattern

  Based on the cropping pattern in Puri Village, an alternative cropping pattern of Paddy - Palawija - Palawija is usually implemented. The start of the cropping period is determined based on rainfall data.

- Water Balance

  The water balance is used to compare the irrigation water requirements with the available discharge, in order to determine whether there is a deficit or surplus of water in the agricultural land.

- Analysis of Farm Business

  The results of farming refer to the net income is derived by farmers from the process of harvesting crops. This revenue is calculated by subtracting the production costs from the production results, in order to obtain the net income.

- Mathematical Model in Optimization
  The model is divided into two functions, which are objective function and constraint function. The function is consisted of maximize based on profit, mainstay discharge and maximum area.
  $Z = P_{p1}.X_{p1} + P_{j1}.X_{j1} + P_{j2}.X_{j2}$
  Z is maximum profit achieved (Rp/Ha), P_{p1} is profit from paddy crops, (Rp/Ha), P_{j1} is profit from corn crops 1 (Rp/H), P_{j2} is profit from corn crops 2 (Rp/Ha), X_{p1} is land area of paddy crops (Ha), X_{j1} is land area of corn crops 1 (Ha), and X_{j2} is land area of corn crops 2 (Ha).
  $V_{p1}.X_{p1} + V_{j1}.X_{j1} + V_{j2}.X_{j2} \leq Q_1$
  V_{p1} is water requirements of rice (lt/s/Ha), V_{j1} is water requirements of corn 1 (lt/s/Ha), V_{j2} is water requirements corn 2 (lt/s/Ha) and Q_1 is available discharge (m^3/s).

3. Result and Discussion

3.1 Mainstay Discharge

The calculation of the mainstay discharge in this analysis begins with preparing annual rainfall data. The data required must include a period of at least the last 10 years. In this analysis, the stations used are Pasinan Station, Tangunan Station, and Tampung Station.

3.1.1. Average Rainfall Analysis

The analysis takes an example for the year of 2012 in January. The station used is consisted of 3 stations, which are STA Pasinan, STA Tangunan, and STA Tampung. Rainfall data and rain days for the year of 2012 in January are used in this analysis.

Average Rainfall :

$$P = \frac{P_{Pasinan}+P_{Tangunan}+P_{Tampung}}{n}$$

$$= \frac{315+257+364}{3}$$

$$= 312 \text{ mm}$$

Average Rain Days :

$$H = \frac{H_{Pasinan}+H_{Tangunan}+H_{Tampung}}{n}$$

$$= \frac{27+13+24}{3}$$

$$= 21,3 \sim 21 \text{ Days}$$

3.1.2. Annual Mainstay Discharge Analysis

From the average rainfall analysis above, it is acquired rainfall data and rain days. Those data is used for annual discharge analysis. Furthermore the analysis is consisted of many calculations, which are water surplus, infiltration, direct run-off etc. Recapitulation of these analysis is shown in Table 1.

Table 1. Recapitulation of Mainstay Discharge

Month	Discharge (m^3/s)									
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Jan	0,016	0,029	0,017	0,013	0,024	0,024	0,016	0,027	0,027	0,021
Feb	0,012	0,019	0,018	0,024	0,036	0,037	0,039	0,021	0,034	0,021
Mar	0,011	0,019	0,013	0,017	0,017	0,028	0,018	0,017	0,009	0,006
Apr	0,006	0,021	0,010	0,017	0,006	0,02	0,009	0,013	0,02	0,007
May	0,007	0,016	0,004	0,003	0,008	0,001	0,001	0,000	0,003	0,001
Jun	0,002	0,013	0,001	0,000	0,009	0,000	0,001	0,000	0,000	0,009
Jul	0,000	0,006	0,002	0,000	0,005	0,002	0,000	0,001	0,000	0,000
Aug	0,000	0,000	0,000	0,000	0,002	0,000	0,000	0,000	0,000	0,000
Sep	0,000	0,000	0,000	0,000	0,002	0,000	0,001	0,000	0,000	0,004
Okt	0,000	0,000	0,000	0,000	0,016	0,003	0,000	0,000	0,004	0,006
Nov	0,011	0,008	0,003	0,002	0,012	0,02	0,011	0,002	0,007	0,007
Des	0,026	0,026	0,012	0,011	0,019	0,022	0,019	0,018	0,014	0,015
Average	0,008	0,013	0,007	0,007	0,013	0,013	0,010	0,008	0,010	0,008
Max	0,026	0,029	0,018	0,024	0,036	0,037	0,039	0,027	0,034	0,021

After calculating the mainstay discharge, 80% probability of water source discharge is found at the sorted discharge. The mainstay discharge is sorted from largest to smallest. Every discharge has probability. 80% probability of water source discharge is shown on Table 3.

Table 2. Recapitulation of Average Discharge

No	Year	Average Discarge
1	2012	0,008
2	2013	0,013
3	2014	0,007
4	2015	0,007
5	2016	0,013
6	2017	0,013
7	2018	0,010
8	2019	0,008
9	2020	0,010
10	2021	0,008

Table 3. 80% of Probability Discharge

No	$\frac{m}{n+1}$	Year	Average Discarge
1	0,09	2013	0,013
2	0,18	2017	0,013
3	0,27	2016	0,013
4	0,36	2020	0,010
5	0,45	2018	0,010
6	0,55	2019	0,008
7	0,64	2021	0,008
8	0,73	2012	0,008
Q_{80} (80% of Probability)			
9	0,82	2015	0,007
10	0,91	2014	0,007

3.2 Water Requirements

The analysis of water requirements is determined by several factors, including plant consumptive water needs, land preparation water needs, percolation, water needs for replacing water layers (WLR), effective rainfall, irrigation efficiency, and water needs in rice fields. This analysis is then used to determine the minimum water requirements based on the planting pattern plan.

3.2.1. Rainfall Analysis

The rainfall data is obtained from three rain stations located closest to the study site, namely the Pasinan Rain Station, the Tangunan Rain Station, and the Tampung Rain Station. Then, the average rainfall data is obtained using the arithmetic mean method. The result of analysis is presented in Table 4.

Table 4. The Result of Average Rainfall

Year	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Okt	Nov	Des
2012	312	218	218	120	130	44	0	0	0	0	204	493
2013	557	333	365	390	309	239	108	0	0	0	150	493
2014	321	314	246	192	78	21	37	6	0	0	53	229
2015	241	420	319	307	64	0	0	0	0	0	36	204
2016	470	652	335	106	158	174	89	35	39	306	226	364
2017	461	646	539	366	15	5	32	0	4	55	368	414
2018	312	673	355	173	19	13	0	0	24	0	200	356
2019	516	371	318	246	2	0	14	0	0	0	45	344
2020	529	614	167	381	52	3	7	0	0	73	128	262
2021	413	358	112	121	23	159	0	1	68	112	124	287
Average	**413**	**460**	**297**	**240**	**85**	**66**	**29**	**4**	**14**	**55**	**153**	**345**

3.2.2. Effective Rainfall Analysis

The effective amount of rainfall is predicted to be 70%, with a monthly rainfall probability of 80%. Effective rainfall is calculated by sorting the monthly rainfall data from largest to smallest and obtaining the probability magnitude from the sequence number of the sample that has been sorted from largest to smallest. The calculation of effective rainfall is shown in Table 5.

Table 5. Effective Rainfall Results

No	P	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Okt	Nov	Des
1	9%	557	673	539	390	309	239	108	35	68	306	368	493
2	18%	529	652	365	381	158	174	89	6	39	112	226	493
3	27%	516	646	355	366	130	159	37	1	24	73	204	414
4	36%	470	614	335	307	78	44	32	0	4	55	200	364
5	45%	461	420	319	246	64	21	14	0	0	0	150	356
6	55%	413	371	318	192	52	13	7	0	0	0	128	344
7	64%	321	358	246	173	23	5	0	0	0	0	124	287
8	73%	312	333	218	121	19	3	0	0	0	0	53	262
9	82%	312	314	167	120	15	0	0	0	0	0	45	229
10	91%	241	218	112	106	2	0	0	0	0	0	36	204
R-50		437	396	319	219	58	17	11	0	0	0	139	350
R-80		312	318	177	120	16	1	0	0	0	0	47	236
R_{ef} Corn		7,28	6,59	5,31	3,65	0,97	0,28	0,17	0,00	0,00	0,00	2,31	5,83
R_{ef} Paddy		7,28	7,41	4,14	2,80	0,37	0,02	0,00	0,00	0,00	0,00	1,09	5,50

3.2.3. Potential Evapotranspiration

In this study, potential evapotranspiration is analysed using the FAO Modified Penman method. Analysis is carried out for every months. The result of evapotranspiration is presented in Table 6.

Table 6. Potential Evapotranspiration Results

Month	Evapotranspiration (mm/day)	
	Eto*	Eto
Jan	3,01	3,31
Feb	2,91	3,20
Mar	2,94	3,24
Apr	3,22	2,90
May	3,77	3,39
Jun	3,80	3,42
Jul	4,32	3,89
Aug	4,99	4,99
Sep	4,93	5,43
Okt	4,45	4,89
Nov	3,44	3,78
Des	3,28	3,61

3.2.4. Plant Water Requirements

The analysis of plant water requirements will result in obtaining an NFR value, which will be used to calculate the planned discharge required to meet the water requirements of the plants. The NFR value used for calculating the planned discharge is the largest value observed during period 2 in November. The step for plant water requirements calculation is carried out by this following:

1. Determine the average of plant coefficient
   Plant coefficient is consisted of K1 and K2.
   $K_{average} = \frac{K1+K2}{2} = \frac{0,93}{0,8} = 0,865$
2. Calculate water requirement for plants
   $W = K_{average} \times Eto$
   $= 0,865 \times 3,78$
   $= 3,270$ mm/day
3. Determine the value of M with P = 2
   $M = (1,1 \times Eto) + P$
   $= (1,1 \times 3,78) + 2$
   $= 8,316$ mm/day
4. Calculate the value of K
   $K = M \times \frac{T}{S} = 8,316 \times \frac{30}{250} = 0,997$
5. Thereafter, IR or water requirements for PL is calculated
6. $IR = \frac{(M \times \exp(K))}{(\exp(K))-1}$
   $= \frac{(8,316 \times \exp(0,997))}{(\exp(0,997))-1}$
   $= 10,714$ mm/day
7. Determine land preparation ratio according by land segments
   $Ratio = \frac{1}{\text{Land Segments}}$
   $= \frac{1}{3}$
   $= 0,333$
8. Then, calculate water requirements for PL with ratio
   Water Requirments $= Ratio \times IR$
   $= 0,333 \times 10,714$
   $= 3,571$ mm/day
9. Calculate the value of water layer replacement (WLR) and the average for 3 land segments
   $WLR = \frac{50}{n}$
   $= \frac{50}{15}$
   $= 3,333$
10. Determine plant area ratio
    Plant area ratio $= 1 - \text{preparation ratio}$
    $= 1 - 0,333$
    $= 0,667$
11. Thereupon, water requirements for RL plant is calculated
    Water $= \text{Plant Ratio} \times (Etc + P + WLR)$
    $= 0,667 \times (3,270 + 2 + 0)$
    $= 3,513$

12. Calculate rainfall effective for paddy

$R_{eff} = \frac{0,07 \times Ra}{n}$

$= \frac{0,07 \times 47}{30}$

$= 1,09$

13. Calculate irrigation water requirements (NFR)

NFR = (Water Requirements for PL + Water Requirements for RL + R_{eff}) × 0,1157

= (3,571 + 3,513 +1,09) × 0,1157

= 0,946 mm/s/h

14. Determine irrigation efficiency

Efficiency = Primary Efficiency × Secondary Efficiency × Tertiary Efficiency

= 80% × 75% × 65%

= 0,364

15. After determining the efficienc, irrigation water requirements in the intake (DR)

$DR = \frac{NFR}{Efficiency}$

$= \frac{0,946}{0,364}$

= 2,598 mm/s/h

3.3 Optimization of Cropping Patterns with Linear Programs

3.3.1. Alternative Cropping Patterns

Based on the cropping pattern in Puri village, usually cropping patterns of Rice – Palawija - Palawija is used as an alternative cropping pattern. Cropping patterns will be optimized by using 4 alternative options, which begin with the cropping period in November Period 1, November Period 2, December Period 1, and December Period 2. The beginning of cropping period is selected based on rainfall data. Water requirements is calculated for alternative cropping patterns, which are recapitulated in Table 8.

Table 7. Alternative Cropping Patterns

PTT	Paddy	Palawija 1	Palawija 2
X1	Nov-01	Mar-01	Jun-02
X2	Nov-02	Mar-02	Jul-01
X3	Des 1	Apr-01	Jul-02
X4	Des 2	Apr-02	Aug-01

Table 8. Recapitulation of Water Requirements for Alternative Cropping Pattern.

Season	Month	NFR (lt/s/ha)			
		X1	X2	X3	X4
Rainy	Nov	0,8780	0,6888	0,6149	0,4468
	Des	1,5153	1,1951	0,8592	0,6757
	Jan	1,7480	1,6873	1,4721	1,1564
	Feb	1,4464	1,6106	1,7321	1,6699
Dry 1	Mar	0,9948	1,1191	1,4501	1,6156
	Apr	0,9473	0,9687	0,9791	1,1031
	May	0,6466	0,8958	0,9969	1,0057
	Jun	0,2971	0,3884	0,6493	0,8993
Dry 2	Jul	0,5447	0,4363	0,3039	0,4023
	Aug	0,8160	0,7464	0,6278	0,4869
	Sep	0,3916	0,7167	0,8675	0,7910
	Okt	0,6828	0,4790	0,3757	0,6685

3.3.2. Optimization Model

Optimization model is made as equations using linear equations or linear programming. To make the model, the steps are as follows:

1. Define the optimization model
2. Determine the limit price on modelling
3. Prepare the optimization model
4. Process the opitimization
5. Analyse of the optimization model to get the results.

Analysis is carried out in 2 models, which are analysis of farm business results in Table 9 and analysis of mathematical model.

Table 9. Analysis of Farm Business Results

No	Description	Paddy	Corn
1	Product Pricing (Rp/Ton)	Rp4.500.000	Rp3.400.000
2	Productivity (Ton/Ha)	5,8	6,4
3	Production Results (Rp/Ha)	Rp26.100.000	Rp21.760.000
4	Production Costs (Rp/Ha)	Rp13.559.300	Rp10.197.140
5	Profitability (Rp/Ha)	Rp12.540.700	Rp11.562.860

Based on the objectives and limitations, the equations of optimization model is divided into 2 functions. Those functions are objective and constraint function. Objective function will maximize the profit according used land area, meanwhile constraint function will maximize from the available discharge.

- Objective Function

  $Z = P_{p1}.X_{p1} + P_{j1}.X_{j1} + P_{j2}.X_{j2}$

  $Z = 12540700X_{p1} + 11562860X_{j1} + 11562860X_{j2}$
- Constraint Function

  $Q_1 \geq V_{p1}.X_{p1} + V_{j1}.X_{j1} + V_{j2}.X_{j2}$

  PTT1

  $0,086 \geq 0,0056X_{p1} + 0,0029X_{j1} + 0,0024X_{j2}$

  PTT2

  $0,086 \geq 0,0052X_{p1} + 0,0034X_{j1} + 0,0024X_{j2}$

  PTT3

  $0,086 \geq 0,0047X_{p1} + 0,0041X_{j1} + 0,0022X_{j2}$

  PTT4

  $0,086 \geq 0,0039X_{p1} + 0,0046X_{j1} + 0,0023X_{j2}$

  $X_{p1} + X_{j1} + X_{j2} \leq 25,15$ Ha

  $X_{p1}, X_{j1}, X_{j2} \geq 0$

The result of analysis is recapitulated in Table 10. After optimization using linear programming, it can be concluded that Planting Pattern 4 (PTT 4) is an alternative to the paddy-palawija-palawija cropping pattern with the cropping period beginning in December period 2. PTT 4 has the maximum profit of Rp.

297,126,400 per year with a cropping area of 25,15 ha.

Table 10. The Results of Optimization Model

Mainstay Discharge	Growing Season	Cropping Pattern			
		PTT 1		PTT 2	
		Ha	Rp	Ha	Rp
80% of	I	8,013	Rp100.482.359	9,157	Rp114.836.444
Probability	II	0,000	Rp0	0,000	Rp0
Discharge	III	17,138	Rp174.753.411	15,993	Rp163.081.956
Profit		25,150	Rp275.235.800	25,150	Rp277.918.400
		PTT 1		PTT 2	
80% of	I	12,268	Rp153.849.308	17,353	Rp217.621.275
Probability	II	0,000	Rp0	0,000	Rp0
Discharge	III	12,882	Rp131.359.592	7,797	Rp79.505.125
Profit		25,150	Rp285.208.900	25,150	Rp297.126.400

4. Conclusion

Based on the results of calculations and evaluations, conclusions have been obtained that are expected to meet the purposes and objectives of this study. The conclusions obtained include: Firstly, the analysis carried out in the irrigation area of Puri village revealed a mainstay discharge of 0.00713 m3/second.

Secondly, based on the results of the analysis carried out, the optimal water needs (NFR) were obtained, namely 0.0003039 m3/second on the PTT 3 alternative.Thirdly, based on the optimization analysis of planting patterns, it was obtained at the beginning of the planting period in December period 2 with the rice planting pattern paddy – palawija – palawija which has a maximum profit of Rp. 297,126,400 per year.

5. Acknowledgment

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6. Author's Note

Everything written in this article is original because it sums up my studies with Faradlillah Saves. And this article is free of plagiarism.

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