p-ISSN : 2685-9106
e-ISSN : 2686-0384

Optimization Study of Cropping Pattern in the Klakah Irrigation Area, Lumajang Regency, Using Linear Programming

Author Notification
20 September 2023
Final Revised
30 October 2023
Published
09 November 2023

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To cite this document:
Sejati, W., & Akbar, T. T. (2023). Optimization Study of Cropping Pattern in the Klakah Irrigation Area, Lumajang Regency, Using Linear Programming. ADI Journal on Recent Innovation, 5(2), 136–145.
DOI : https://doi.org/10.34306/ajri.v5i2.999

Abstract

The utilization of water resources encompasses activities related to providing water for human needs, one of which is irrigation water supply. In this research, optimization techniques are employed to optimize the availability of irrigation water in order to achieve maximum agricultural production and profit, as well as more effective and efficient irrigation utilization. The optimization technique used in this crop pattern optimization study employs linear programming through the use of the POM QM application. This study plans for 3 alternatives involving 2 different crops, namely corn and peanuts. Alternative 1 implements the cropping pattern for MT I in November, alternative 2 for MT I in November II, and alternative 3 for MT I in December I. Among the planned alternatives, the cropping pattern that yields maximum profit is alternative 3, which results in a rice cultivation area of 634.15 hectares for MT I, 15.22 hectares for MT II, 3.1 hectares for corn, and 7.5 hectares for peanuts. The achieved profit in one year is Rp 11,553,320,000 for the cropping pattern with corn and Rp 11,566,000,000 for the cropping pattern with peanuts.

***Keywords**: Irrigation, Linear Programming, Cropping Pattern*

1. Introduction

Agriculture, as a foundational sector in economic development, assumes a pivotal role in providing sustenance, energy, and livelihoods for rural populations. Nevertheless, in the village of Lumajang, particularly within the Klakah sub-district, recurrent challenges linked to the degradation and instability of irrigation channels necessitate the continual rehabilitation of the irrigation network[1]. The Klakah sub-district predominantly relies on local rainfall as its primary water source, and achieving a harmonious water balance is paramount[2]. This demands a meticulous assessment of water availability and the actual water requisites within the Klakah irrigation area[3], [4]. Furthermore, the region has witnessed substantial damage to its irrigation infrastructure, mandating a comprehensive analysis of water requirements and damage assessment[5]. To forget how to dig the earth and to tend the soil is to forget ourselves[6]. This research is dedicated to preserving the very essence of agriculture by addressing these pressing issues[7].

The study specifically scrutinizes irrigation water requirements, with a dedicated focus on surface irrigation systems within the Klakah area[8]. Surface irrigation systems, dependent on gravity-driven flow sourced from proximate water bodies such as rivers or reservoirs, hold substantial promise for sustainable and efficient irrigation[9], [10]. Hence, this research is primed to conduct a rigorous analysis and optimization of the irrigation cropping pattern in Klakah, Lumajang Regency, meticulously adhering to the principles of linear programming[11]. The ultimate aspiration is to maximize agricultural production, enhance economic profitability, and optimize water resource allocation, all while ensuring the longevity of the irrigation infrastructure[12].

In conclusion, this research promises to make substantial contributions to bolstering the sustainability and productivity of agriculture in the Lumajang region, land and soil and water and creatures all are bound into a single fabric of Creation[13], bound by the profound and intricate relationships.

2. Literature review

2.1 Hydrologi Analysis

Hydrological analysis begins by determining the nearest rain station to the research location and obtaining maximum daily rainfall data[14]. Water availability refers to the estimated amount of water that is expected to be continuously present at a specific location (dam/other water structures) in a river, in terms of quantity[15]. In water allocation management, rainfall contributes to reducing the irrigation water requirements, which is known as effective rainfall[16]. Subsequently, probability is determined using the Weibull method.

$$P = \frac{m}{n+1} x \ 100\ \%$$

Where :
P : Probabilitas
m : Order number data
n : Amount

Effective rainfall for rice is 70% of the monthly median rainfall that is exceeded 80% of the time within that period. For effective rainfall for other crops, it is determined based on the monthly period (fulfilled 50%) in relation to the ET table.

2.2 Water Requirement Analysis

Irrigation water requirements depend on factors such as the amount of water needed for soil preparation and saturation, consumptive use value (growth period requirements), percolation, effective rainfall inundation, and the extent of water loss during distribution (irrigation efficiency)[17], [18]. For crops other than rice, it still depends on the availability of rainwater storage, which is influenced by the crop type and root depth.

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1. **Land Preparation**

The amount of water required for soil preparation depends on soil saturation, duration of soil processing, evaporation, and percolation[19]. The formula for calculating water requirements for land preparation is as follows:

$$PL = M .\ ek + \frac{ek}{ek-1}$$

$$K = M .\ (\frac{T}{S})$$

$$Eo = 1{,}1\ x\ ETo$$

$$M = Eo\ x\ P$$

Lp : Unit of water requirement for soil preparation, (mm/day).
M : Maximum requirement, Evaporation + Percolation (Eo + P), (mm/day).
T : Duration of soil processing time, from the first irrigation to planting (days).
S : Total water requirement for soil saturation and water layer stabilization (mm).
E : Natural logarithm constant ≈ 2.71.

2. **Evapotranspiration**

Evapotranspiration is the combined occurrence of Evaporation and Transpiration, where both mutually influence and are closely related to each other[20]. The analysis of evapotranspiration aims to understand the water evaporating from the soil and plants, which will later significantly determine the amount of water needed for irrigation[20]. Evapotranspiration (Eto) is calculated using the Modified Penman method[21].

3. **Consumptive Use**

To calculate the value of consumptive use, the Penman method is employed with the NEDECO/PROSIDA and FAO approaches[22]. The value of evapotranspiration is multiplied by the crop coefficient in use.

$$ETc = Kc\ x\ ETo$$

Where:
ETc = Consumptive Use (mm/day)
ETo = Evapotranspiration (mm/day)
Kc = Crop Coefficient

4. **Percolation**

Percolation refers to the loss of water within a paddy field, either downward or sideways[23]. The extent of percolation is influenced by soil characteristics, particularly the physical properties of the soil such as texture and structure[24].

5. **Cropping Pattern**

To meet the water requirements for plants, determining the cropping pattern is an essential consideration[25]. The table below provides an example of cropping patterns that can be used.

Table 1. Cropping Pattern

Water Availability for Irrigation Network	Cropping Patterns in One Year
Adequate water available	Rice – Rice – Rice
Sufficient water available	Rice – Rice – Other Crops
Regions prone to water scarcity	Rice – Other Crops – Other Crops

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2.3 Debit Andalan FJ MOCK

In principle, the Mock method considers the calculation of water volume entering, leaving, and stored in the soil[26]. Water entering comes from rainfall. Outflow includes infiltration, percolation, and dominantly results from evapotranspiration. The calculation of evapotranspiration employs the Penman method[27]. Meanwhile, soil storage pertains to the water volume retained in the soil pores, up to the point of soil saturation. For the reliable discharge analysis, the F.J. Mock method is used.

The equation utilized is: **Q =** $(\boldsymbol{Dro} + \boldsymbol{Bf})\,\boldsymbol{A}$

Where:
Q : Reliable discharge (m3/dt)
Dro : Direct runoff (m3/det/km2)
A : Catchment area (km2)
Bf : Base flow (m3/det/km2)
Dro : Ws – I
Ws : water surplus
Vn : Storage Volume
R : Precipitation
Et : Evapotranspiration

2.4 Optimization Using Linear Programming

Fundamentally, linear programming consists of three essential components, namely:

1. Decision variables are the variables to be determined and provide values towards the objective to be achieved.
2. Objective Function is a function that needs to be maximized or minimized and reflects the goal intended to be achieved.
3. The Constraint Function is a function that becomes an obstacle to maximizing or minimizing the objective function.

3. Result and

The problem encountered when processing data is that the rainfall data needs to be further processed into semi-monthly annual rainfall data in order to determine effective rainfall for rice and crops. The data processing phase involves the transformation of raw rainfall data into semi-monthly annual rainfall data, which is crucial for determining effective rainfall for rice and crops. To tackle this challenge, a systematic methodology is employed, including the categorization of rainfall into semi-monthly periods and annual summaries. This meticulous data processing is vital for accurate irrigation and cropping decisions.

Furthermore, the research utilizes optimization techniques, particularly linear programming through the POM QM application. These techniques are integral to achieving maximum agricultural production and profitability while ensuring efficient irrigation resource utilization, as highlighted in the abstract. The methodology's practical implementation is pivotal for comprehending the research's findings. This enhanced depth in analysis and methodology enriches the research's overall value.

3.1 Results Hydrological Analysis

The results of the hydrological analysis were obtained by collecting daily rainfall data for 10 years at the research location, which was then processed into semi-monthly annual rainfall data.

Table 1. Rainfall Data

Year	Rainfall
2010	3862

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2011	3184
2012	1241
2013	3009
2014	2917
2015	2526
2016	3690
2017	3261
2018	2925

(Source : calculation 2023)

Tabel 2. Semi-Monthly Rainfall Probability at 50% and 80%

NO	P (%)	Year	Rainfall (mm/jam)
1	10	2017	153
2	20	2018	152
3	30	2010	142
4	40	2013	137
5	50	2015	125
6	60	2011	117
7	70	2014	115
8	80	2016	99
9	90	2012	75

After determining the effective rainfall, you can analyze the irrigation water needs of 3 alternatives with different secondary crops, namely corn and long beans. The results of irrigation water requirements obtained for each alternative are shown in table 3.

3.2 Cropping Pattern Optimization

The results of the hydrological analysis were obtained by collecting daily rainfall data for 10 years at the research location, which was then processed into semi-monthly annual rainfall data

Tabel 3. Irrigation Water Needs for Each Alternative

	Rice	Corn	Peanut
Production Yield	30 Million	16.5 Million	12 Million
Production Costs	12.5 Million	8 Million	6.75 Million
Profitability	17.75 Million	8.5 Million	5.25 Million

3.3 Irrigation Optimization

Mathematical Model Mathematical model in analysis this optimization is:

- The decision variables are land area and harvest profits
- The objective function is to maximize the distribution of land area for crops that can produce harvest profits.
- The constraint function is your debit and the area of the irrigation area.

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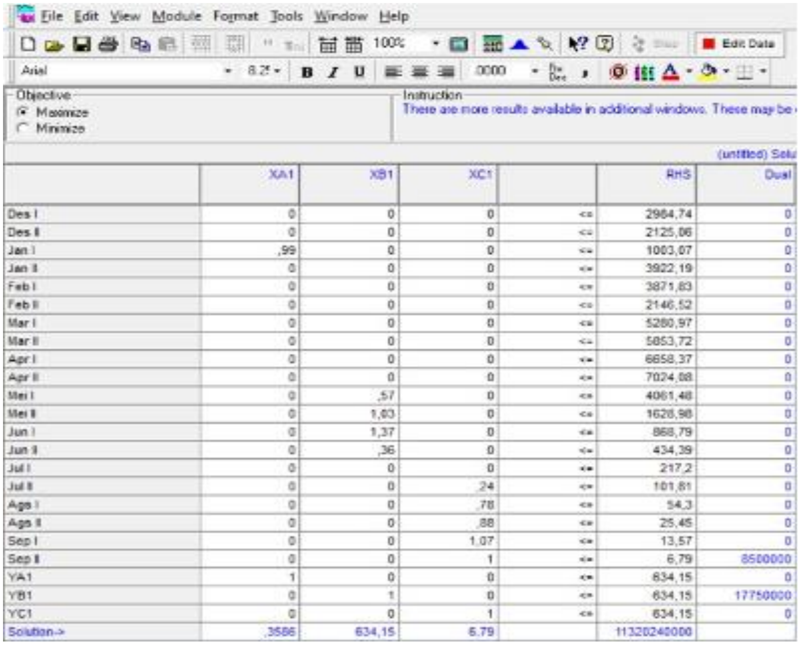
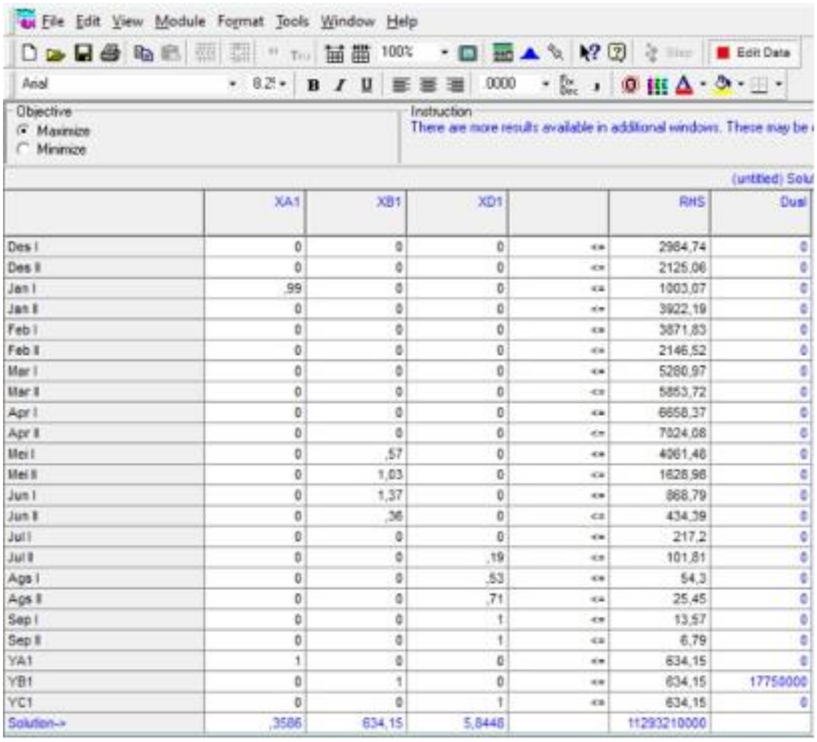
3.4 Optimization Result Analysis

The equations for linear programming for all alternative planting patterns have been iterated using the POM-QM for Windows 3 auxiliary program. The results that will be obtained are profit and maximum land area.


Objective
Maximize
Minimize
Instruction
There are more results available in additional windows. These may be
(untitled) Solu

	XA1	XB1	XC1		RHS	Dual
Des I	0	0	0	<=	2984,74	0
Des II	0	0	0	<=	2125,06	0
Jan I	,99	0	0	<=	1003,07	0
Jan II	0	0	0	<=	3922,19	0
Feb I	0	0	0	<=	3871,83	0
Feb II	0	0	0	<=	2146,52	0
Mar I	0	0	0	<=	5280,97	0
Mar II	0	0	0	<=	5853,72	0
Apr I	0	0	0	<=	6658,37	0
Apr II	0	0	0	<=	7024,08	0
Mei I	0	,57	0	<=	4061,48	0
Mei II	0	1,03	0	<=	1628,98	0
Jun I	0	1,37	0	<=	868,79	0
Jun II	0	,36	0	<=	434,39	0
Jul I	0	0	0	<=	217,2	0
Jul II	0	0	,24	<=	101,81	0
Ags I	0	0	,78	<=	54,3	0
Ags II	0	0	,88	<=	25,45	0
Sep I	0	0	1,07	<=	13,57	0
Sep II	0	0	1	<=	6,79	8500000
YA1	1	0	0	<=	634,15	0
YB1	0	1	0	<=	634,15	17750000
YC1	0	0	1	<=	634,15	0
Solution->	,3586	634,15	6,79		11320240000	

Figure 1. Advantages of the Alt 1 Corn Planting Pattern
(Source: Windows 3 POM-QM Input)


Objective
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	XA1	XB1	XD1		RHS	Dual
Des I	0	0	0	<=	2984,74	0
Des II	0	0	0	<=	2125,06	0
Jan I	,99	0	0	<=	1003,07	0
Jan II	0	0	0	<=	3922,19	0
Feb I	0	0	0	<=	3871,83	0
Feb II	0	0	0	<=	2146,52	0
Mar I	0	0	0	<=	5280,97	0
Mar II	0	0	0	<=	5853,72	0
Apr I	0	0	0	<=	6658,37	0
Apr II	0	0	0	<=	7024,08	0
Mei I	0	,57	0	<=	4061,48	0
Mei II	0	1,03	0	<=	1628,98	0
Jun I	0	1,37	0	<=	868,79	0
Jun II	0	,36	0	<=	434,39	0
Jul I	0	0	0	<=	217,2	0
Jul II	0	0	,19	<=	101,81	0
Ags I	0	0	,53	<=	54,3	0
Ags II	0	0	,71	<=	25,45	0
Sep I	0	0	1	<=	13,57	0
Sep II	0	0	1	<=	6,79	0
YA1	1	0	0	<=	634,15	0
YB1	0	1	0	<=	634,15	17750000
YC1	0	0	1	<=	634,15	0
Solution->	,3586	634,15	5,8448		11293210000	

Figure 2. Advantages of Alt 1 Planting Pattern for Peanuts
(Source: Windows 3 POM-QM Input)

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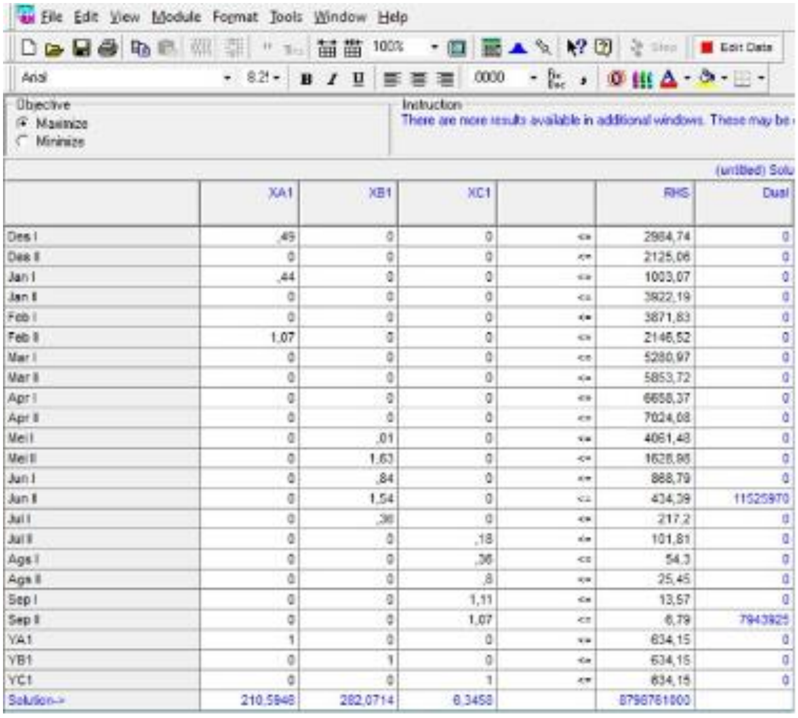
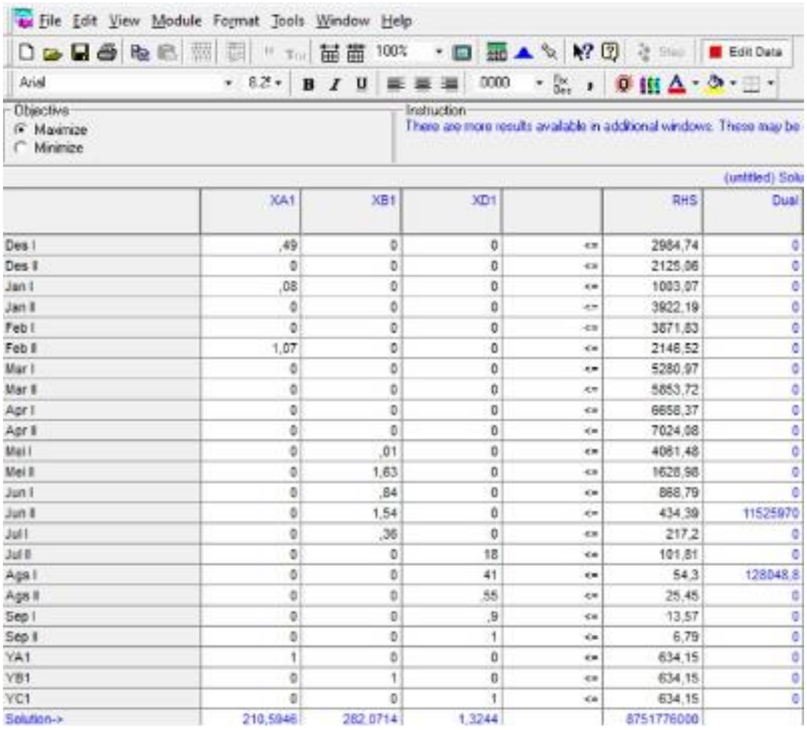
e-ISSN : 2686-0384



	XA1	XB1	XC1		RHS	Dual
Des I	,49	0	0	<=	2984,74	0
Des II	0	0	0	<=	2125,06	0
Jan I	,44	0	0	<=	1003,07	0
Jan II	0	0	0	<=	3922,19	0
Feb I	0	0	0	<=	3871,83	0
Feb II	1,07	0	0	<=	2146,52	0
Mar I	0	0	0	<=	5280,97	0
Mar II	0	0	0	<=	5853,72	0
Apr I	0	0	0	<=	6658,37	0
Apr II	0	0	0	<=	7024,08	0
Mei I	0	,01	0	<=	4061,48	0
Mei II	0	1,63	0	<=	1628,98	0
Jun I	0	,84	0	<=	868,79	0
Jun II	0	1,54	0	<=	434,39	11525970
Jul I	0	,36	0	<=	217,2	0
Jul II	0	0	,18	<=	101,81	0
Ags I	0	0	,36	<=	54,3	0
Ags II	0	0	,8	<=	25,45	0
Sep I	0	0	1,11	<=	13,57	0
Sep II	0	0	1,07	<=	6,79	7943925
YA1	1	0	0	<=	634,15	0
YB1	0	1	0	<=	634,15	0
YC1	0	0	1	<=	634,15	0
Solution->	210,5946	282,0714	6,3458		8796761000	

Figure 3. Advantages of the Alt 2 Corn Planting Pattern
(Source: Windows 3 POM-QM Input)



	XA1	XB1	XD1		RHS	Dual
Des I	,49	0	0	<=	2984,74	0
Des II	0	0	0	<=	2125,06	0
Jan I	,08	0	0	<=	1003,07	0
Jan II	0	0	0	<=	3922,19	0
Feb I	0	0	0	<=	3871,83	0
Feb II	1,07	0	0	<=	2146,52	0
Mar I	0	0	0	<=	5280,97	0
Mar II	0	0	0	<=	5853,72	0
Apr I	0	0	0	<=	6658,37	0
Apr II	0	0	0	<=	7024,08	0
Mei I	0	,01	0	<=	4061,48	0
Mei II	0	1,63	0	<=	1628,98	0
Jun I	0	,84	0	<=	868,79	0
Jun II	0	1,54	0	<=	434,39	11525970
Jul I	0	,36	0	<=	217,2	0
Jul II	0	0	18	<=	101,81	0
Ags I	0	0	41	<=	54,3	128048,8
Ags II	0	0	,55	<=	25,45	0
Sep I	0	0	,9	<=	13,57	0
Sep II	0	0	1	<=	6,79	0
YA1	1	0	0	<=	634,15	0
YB1	0	1	0	<=	634,15	0
YC1	0	0	1	<=	634,15	0
Solution->	210,5946	282,0714	1,3244		8751776000	

Figure 4. Advantages of the Alt 2 Planting Pattern for Peanuts
(Source: Windows 3 POM-QM Input)

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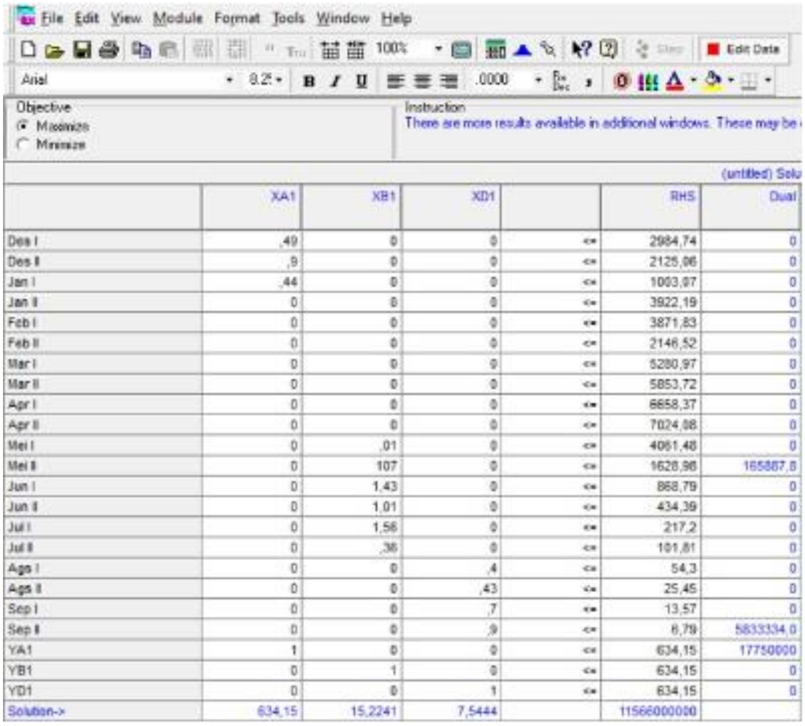
e-ISSN : 2686-0384



	XA1	XB1	XD1		RHS	Dual
Des I	,49	0	0	<=	2984,74	0
Des II	,9	0	0	<=	2125,06	0
Jan I	,44	0	0	<=	1003,07	0
Jan II	0	0	0	<=	3922,19	0
Feb I	0	0	0	<=	3871,83	0
Feb II	0	0	0	<=	2146,52	0
Mar I	0	0	0	<=	5280,97	0
Mar II	0	0	0	<=	5853,72	0
Apr I	0	0	0	<=	6658,37	0
Apr II	0	0	0	<=	7024,08	0
Mei I	0	,01	0	<=	4061,48	0
Mei II	0	107	0	<=	1628,98	165887,8
Jun I	0	1,43	0	<=	868,79	0
Jun II	0	1,01	0	<=	434,39	0
Jul I	0	1,56	0	<=	217,2	0
Jul II	0	,36	0	<=	101,81	0
Ags I	0	0	,4	<=	54,3	0
Ags II	0	0	,43	<=	25,45	0
Sep I	0	0	,7	<=	13,57	0
Sep II	0	0	,9	<=	6,79	5833334,0
YA1	1	0	0	<=	634,15	17750000
YB1	0	1	0	<=	634,15	0
YD1	0	0	1	<=	634,15	0
Solution->	634,15	15,2241	7,5444		11566000000	

Figure 5. Advantages of the Alt 3 Corn Planting Pattern
(Source: Windows POM-QM Input)

The following is a comparison table between the benefits and the maximum irrigation water requirement for each alternative cropping pattern.

Table 4. Comparison of Irrigation Water Needs and Benefits of Each Alternative Cropping Pattern

Results of Optimizing	Profit	Irrigation Water Needs
Alternative	**Rp**	**lt/dt/ha**
1 Corn secondary	11.320.240.000	2,37
1 Peanut Secondary Crops	11.293.210.000	2,37
2 Corn secondary crops	8.797.761.000	1,85
2 Secondary crops Peanuts	8.751.776.000	1,85
3 Corn secondary crops	11.553.320.000	1,56
3 Secondary crops Peanuts	11.566.000.000	1,56

In the table above it can be seen that alternative 3 has the maximum profit for the cropping pattern with corn secondary crops of IDR 11,553,320,000 and for peanut secondary crops IDR 11,566,000,000 compared to other alternatives and the maximum irrigation water requirement is 1.56 l/sec/ Ha.

4. Conclusion

The research findings present a comprehensive analysis of irrigation water requirements and cropping patterns within the Klakah irrigation area. Among the alternatives considered, Alternative 3, with its relatively lower irrigation water demand, emerges as the most efficient choice, leading to cost savings in canal infrastructure. Furthermore, the selection of planting patterns designates Alternative 2 as the optimal configuration, involving a substantial expanse of MT I and MT II rice cultivation, alongside secondary crops. This configuration results in a significant annual profit of IDR 30,340,570,000. In summary, the research findings provide insights that can inform judicious decision-making in irrigation management, offering resource efficiency and economic benefits to the agricultural sector in the Klakah irrigation area.

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