The simulation of cropping pattern to improve the performance of irrigation network in Cau irrigation area.

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Abstract. Cau irrigation area located in Madiun district, East Java Province, irrigates 1.232 Ha of land which covers Cau primary channel irrigation network, Wungu Secondary channel irrigation network, and Grape secondary channel irrigation network. The problems in Cau irrigation area are limited availability of water especially during the dry season (planting season II and III) and non-compliance to cropping patterns. The evaluation of irrigation system performance of Cau irrigation area needs to be done in order to know how far the irrigation system performance is, especially based on planting productivity aspect. The improvement of irrigation network performance through cropping pattern optimization is based on the increase of water necessity fulfillment (k factor), the realization of planting area and rice productivity. The research method of irrigation system performance is by analyzing the secondary data based on the Regulation of Ministry of Public Work and State Minister for Public Housing Number: 12/PRT/M/2015. The analysis of water necessity fulfillment (k factor) uses Public Work Plan Criteria Method. The performance level of planting productivity aspect in existing condition is 87.10%, alternative 1 is 93.90% dan alternative 2 is 96.90%. It means that the performance of the irrigation network from productivity aspect increases 6.80% for alternative 1 and 9.80% for alternative 2.

1. Introduction
The development of an area which is followed by the growth of the population requires the increase of water necessity and food necessity fulfillment. The increase of population along with the increase of land necessity reduces the very limited agriculture area, especially in Java Island. Agriculture is the main user of the world’s water resources. The contribution of irrigated agriculture to food production is important. Therefore, sustainability of irrigated agriculture would demand the efficient management of the available finite water resources under the existing constraints [1]. The indicator of the performance is based on the peasants’ satisfaction of available and reliable irrigation water in order to fulfill irrigation water necessity. Besides, it is needed to have cooperation between government and peasants about the procedures of how to use water well [2]. Water shortage is the main limiting factor for agricultural productivity in many countries and improving water use efficiency in agriculture has been the focus of numerous studies. The usual approach to limit water consumption in agriculture is to apply water quotas and in such a situation farmers should use an irrigation schedule that maximizes the yield [3]. The Government’s budget is insufficient to fund all of the necessity needed every year. The budget includes rehabilitation, operation, maintenance and handling after the natural disaster [4].
Some researches have been done to improve the fulfillment of irrigation water necessity and the production result. The non-linear optimization model for irrigation and cropping pattern optimization are suggested in order to maximize the result in the limitation of available water resources [1]. The uncertain and functional interval methods are introduced in the research about the uncertain water production function of the plant itself and the optimal allocation of water resources in irrigation area. This approach has important value in theoretical and practical for optimal irrigation schedule and has a broad prospect for researchers and the development of related agriculture water management [5]. Other researchers present two mathematical models that consider the physical and chemical site-specific management zones within the parcels. The first model is for the crop planning problem which assesses the chemical and physical management zones to determine the optimal crop pattern for maximizing the farmers’ expected profit. The second model is a real-time irrigation method that takes the solution t the crop planning problem as an input [6]. A random-fuzzy-variable is developed for crop area optimization in response to such complexities in more efficient and sustainable ways. The developed model is helpful for managers in gaining insight into the trade-offs between the system benefit and the constraint violation risk [7].

The benefits of irrigation modernization include increased water efficiency and productivity, improved operation and management of irrigation systems and working conditions of farmers, but increased energy demands and investment amount[8]. Many studies in recent years have focused on developing methodologies to quantify water and energy efficiency with improved irrigation systems. Lecina et al. (2010) analyzed modernization in the Alto Aragón irrigable area. They highlighted some advantages and disadvantages of migrating from the surface to sprinkler irrigation systems and quantified water savings and some of the associated economic and social impacts [9]. Abadía et al. (2010) developed a comparative analysis of energy efficiency in more than 30 collective irrigation networks in Murcia and Castilla-La Mancha, proposing some measures to improve energy efficiency and the main problems with these infrastructures [10]. Rodríguez Díaz et al. (2012) analyzed some modernized areas in Andalucía that migrated from surface irrigation systems to sprinkler and drip irrigation systems, highlighting some strengths and weaknesses of this modernization[11].

The regulation of Ministry of Public Work and State minister for Public Housing Number 12/PRT/M/2015 explains irrigation as an effort to provide, regulate and drain irrigation water in order to support some kinds of farming including surface irrigation, swamp irrigation, underground irrigation, pump irrigation and embankment irrigation. Irrigation Network is the channel, building and complementary building which is one unity needed to provide, divide, give, use and drain irrigation water [12]. Cau irrigation area in Madiun district, East Java province irrigates 1.232 Ha of land covering Cau Primary channel irrigation network, Wungu secondary channel irrigation network and Grape secondary channel irrigation network. The problems in Cau irrigation area are the limited water availability especially during dry season (planting season II and III) and the cropping pattern in the dry season is not obeyed. The evaluation of irrigation system performance in Cau irrigation area needs to be done to see how far the performance of irrigation system is so that it can be improved. The evaluation of the performance of irrigation system is to know the condition of an irrigation system including physical infrastructure aspect, planting productivity aspect, supporting means aspect, personnel organization aspect, documentation aspect, and the institutional condition aspect. The improvement of irrigation network performance through physical infrastructure aspect has great value but is very dependent on the budget provision. Because of that, this study is sought to improve the performance of irrigation network through planting productivity aspect which covers three things such as irrigation water necessity fulfillment (“k” factor), the realization of planting area, and rice productivity. The simulation of some cropping pattern alternatives is needed to get the best “k” factor value (=1).
2. 2. The Necessity of Water Explanation
The analysis of water necessity fulfillment (k factor) refers to Public Work Plan Criteria (KP-01). It used secondary data including rainfall data, climatology data (temperature, air humidity, wind velocity and sunlight), water availability data (debit), data of plant condition report and rice production data. The stages done in the cropping pattern simulation are: counting water necessity in the rice field, counting plant water necessity, counting water availability in the intake, and the cropping pattern simulation.

2.1. Water Necessity in the Rice Field
The amount of water needed by plant in a paddy field terrace is represented in this equation:

\[ NFR = Etc + P + WLR - Re \]  

with:
- \( NFR \) = water necessity in the farm (mm/day),
- \( Etc \) = plant water necessity (mm/day),
- \( WLR \) = water layer replacement (mm/day),
- \( P \) = percolation (mm/day),
- \( Re \) = effective rainfall

2.2. Plant Water Necessity
Plant water necessity is the amount of water needed to replace the losing water as the result of vaporization. The amount of water plant necessity (consumptive use) is counted based on this formula:

\[ ETc = Kc \cdot ETo \]  

with:
- \( ETc \) = plant evapotranspiration (mm/day),
- \( ETo \) = plant reference evapotranspiration (mm/day),
- \( Kc \) = plant coefficient.

Water necessity during land preparation is counted based on the formula V.D Goor-Zijlstra as follow:

\[ IR = \frac{M}{e^{S-1}} \]  

\[ M = Eo + P \]  

\[ K = M \cdot T/S \]  

with:
- \( IR \) = irrigation water necessity (mm/day),
- \( M \) = water necessity to replace the losing as the result of evaporation and percolation in the rice field which has been saturated,
- \( Eo \) = open water evaporation is taken 1.1 Eto during land preparation period (mm/day),
- \( P \) = percolation (mm/day),
- \( T \) = the duration of land preparation,
- \( S \) = the water needed for saturation is added by 50 mm.

Irrigation Water Necessity for rice:

\[ IR = \frac{NFR}{e} \]  

dengan:
- \( NFR \) = water necessity for irrigation,
- \( Etc \) = evapotranspiration (mm),
- \( P \) = percolation (mm/day),
- \( Re \) = effective rainfall (mm/day),
- \( WLR \) = water layer replacement (mm),
- \( e \) = overall irrigation efficiency.
2.3. Water Availability
The amount of water availability is counted based on the mainstay debit which is predicted to exist continuously in certain amount and certain period of time. The mainstay debit is minimum debit for the possibility of standard fulfillment which has been determined and can be used for irrigation. The possibility of fulfillment determined 80% means the possibility of river debit is lower than mainstay debit which is 20%. Mainstay debit analysis using statistic possibility method with normal distribution will give a good result if available debit observation data is more than 20 years (Directorate General of Irrigation, 1986). The formula used is:

\[ Q_{80} = \bar{x} - (0.821 \cdot S_d) \]  
\[ \text{dengan:} \]
\[ Q_{80} = \text{mainstay debit with possibility 80\% (m3/sec),} \]
\[ \bar{x} = \text{debit \( \frac{1}{2} \) average monthly,} \]
\[ S_d = \text{standard deviation.} \]

2.4. Effective Rainfall
Effective rain is the amount of rainfall which is used to fulfill plant necessity. One of the ways used to count effective rain is with the R80 method. The calculation of R80 rain by using formula as follow:

\[ R_{80} = \bar{x} + k \cdot S_d \]  
\[ \text{with:} \]
\[ R_{80} = \text{the amount of rainfall in certain reset period,} \]
\[ \bar{x} = \text{monthly rainfall average (mm),} \]
\[ K = \text{frequency factor (-0.842 for 20\% dry)} \]
\[ S_d = \text{standard deviation.} \]

2.5. K Factor
K factor is counted in order to show the stability between the necessity and availability of water. The formula used to count the amount of k factor is as follow:

\[ k = \frac{Q_i}{Q_n} \]  
\[ \text{dengan:} \]
\[ Q_i = \text{available outflow debit.} \]
\[ Q_n = \text{outflow debit needed.} \]

The value of k factor is about 0 up to 1 in which the worst condition is shown by 0 value which means the water necessity is not fulfilled at all and the best condition is shown by k value = 1 which means the water necessity can be wholly sufficed.

3. Result and Discussion
The method used to calculate potential evaporation (Eto) by using modified-Penman method is shown in Table 1. The result of R80 rain calculation with normal distribution approach by using equation formula (8) is shown in Table 2.
Based on the Irrigation Plan Criteria (KP-01) which is issued by Directorate General of Irrigation and Department of Public Work 2013, the value of effective rain for rice is calculated as 70% of mainstay rain which is 80%. Moreover, it can also be calculated based on the monthly minimum rainfall (R80) with 5 year-reset periods multiplied by rain coefficient and rotation system. Meanwhile, for soy, the amount of effective rainfall is determined by a biweekly method which is related to monthly average rainfall (fulfilled 50%) and monthly average plant evapotranspiration.

Water necessity for preparing the land determines the maximum necessity of irrigation water. The amount of water necessity for land preparation depends on the amount of land saturation, the length of land cultivation and the amount of evaporation and percolation. The calculation of water necessity during land preparation for rice is shown in Table 3.

### Table 1. Evapotranspiration Calculation Result with Penman Method

| Month    | Eto |
|----------|-----|
| January  | 1.97|
| February | 1.65|
| March    | 1.75|
| April    | 1.59|
| May      | 1.45|
| June     | 1.46|
| July     | 1.56|
| August   | 1.86|
| September| 2.04|
| October  | 2.23|
| November | 2.07|
| December | 1.86|

### Table 2. 80% Rain Calculation Result (R80)

| Month    | R80 (Daily) |
|----------|-------------|
| January  | 6.09        |
| February | 6.55        |
| March    | 4.75        |
| April    | 5.21        |
| May      | 1.70        |
| June     | 0.00        |
| July     | 0.00        |
| August   | 0.00        |
| September| 0.00        |
| October  | 0.00        |
| November | 2.69        |
| December | 7.59        |

### Table 3. Water Necessity during Land Preparation for Rice

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Eto | Eto |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Eo    | 2.17| 1.81| 1.94| 1.75| 1.60| 1.61| 1.71| 2.04| 2.25| 2.45| 2.28| 2.05| 2.05|
| M=Eo+P| 3.67| 3.31| 3.42| 3.25| 3.10| 3.11| 3.21| 3.54| 3.75| 3.95| 3.78| 3.55| 3.55|
| K=MT/S| 0.55| 0.50| 0.51| 0.49| 0.46| 0.47| 0.48| 0.53| 0.56| 0.59| 0.57| 0.53| 0.53|
| e<sup>k</sup> | 1.73| 1.64| 1.67| 1.63| 1.59| 1.59| 1.62| 1.70| 1.75| 1.81| 1.76| 1.70| 200 |
| IR=Me<sup>2</sup>/e<sup>-1</sup> | 8.67| 8.46| 8.52| 8.43| 8.34| 8.34| 8.40| 8.59| 8.72| 8.84| 8.74| 8.60| 8.60 |

Water necessity for Soy is needed to cultivate the land which is going to be planted and create a humid condition for newly growing seedbed. The amount of needed water is between 50-100mm. The calculation of water necessity during land preparation for rice is shown in Table 4.

### Table 4. Water Necessity during Land Cultivation for Soy

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Eto | Eto |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Eo    | 2.17| 1.81| 1.94| 1.75| 1.60| 1.61| 1.71| 2.04| 2.25| 2.45| 2.28| 2.05| 2.05|
| M=Eo+P| 3.67| 3.31| 3.42| 3.25| 3.10| 3.11| 3.21| 3.54| 3.75| 3.95| 3.78| 3.55| 3.55|
| K=MT/S| 2.20| 1.99| 2.05| 1.95| 1.86| 1.86| 1.93| 2.13| 2.25| 2.37| 2.27| 2.13| 2.13|
| e<sup>k</sup> | 9.02| 7.30| 7.79| 7.05| 6.42| 6.45| 6.88| 8.28| 9.48| 10.71| 9.67| 8.41| 50 |
| IR=Me<sup>2</sup>/e<sup>-1</sup> | 4.12| 3.84| 3.93| 3.79| 3.67| 3.68| 3.76| 4.02| 4.19| 4.36| 4.22| 4.03| 4.03 |

In improving the performance of irrigation network based on the plant productivity aspect refers to three things such as water necessity fulfillment analysis (k factor), the realization of planting area and rice productivity. For the calculation of the water balance, the taking necessity which is produced for used cropping pattern will be compared to mainstay debit. If the river debit is abundant, the water necessity of irrigation area will be fulfilled. If the river debit is not abundant or even sometimes lacked
debit, there will be three choices which must be considered (KP-01, 2013). Those choices are the width of irrigation area reduction, cropping pattern modification and technical rotation. In this study, the fulfillment of the necessity is by modifying the cropping pattern. From the simulation of cropping pattern alternative, it is expected to get optimal k factor value (=1), so that it can improve the value of irrigation network performance. The existing cropping pattern dan some cropping pattern alternatives are shown in Table 5.

Table 5. The Existing Cropping Pattern and Alternative Cropping Pattern

| Condition | Plant Season | Crop Pattern | Planting Area (ha) |
|-----------|--------------|--------------|--------------------|
|           |              | Rice | Soy |                |
| Existing  | I            | Paddy| 1.111 | - |
|           | II           | Paddy| 1.111 | - |
|           | III          | Paddy - Palawija| 221 | 214 |
| Alternative 1 | I | Paddy| 1.232 | - |
|           | II          | Paddy - Palawija| 830 | 281 |
|           | III         | Paddy - Palawija| 350 | 574 |
| Alternative 2 | I | Paddy| 1.232 | - |
|           | II          | Paddy - Palawija| 649 | 462 |
|           | III         | Paddy - Palawija| 350 | 574 |

From the existing cropping pattern and alternative cropping pattern, it can be got the value of irrigation water necessity. The stability of water balance can be obtained by comparing the value of water necessity and the value of water availability (k factor). Next, the value of physical condition of k factor analysis can be seen and in the form of a percentage. The calculation of physical condition of k factor analysis can be seen in Table 6.

Table 6. The Value of k Factor Analysis Physical Condition

| Condition | Planting Season | "k" factor | Information | The Value of the Physical Condition (%) |
|-----------|-----------------|------------|-------------|----------------------------------------|
| (1)       | (2)             | (3)        | (4)         | (5)                                    |
| Existing  | I               | 1.00       | Fulfilled   | 91.00                                  |
|           | II              | 0.73       | Not Fulfilled | 91.00                                  |
|           | III             | 1.00       | Fulfilled   |                                        |
| Alternative 1 | I | 1.00       | Fulfilled   | 95.00                                  |
|           | II              | 0.85       | Not Fulfilled | 95.00                                  |
|           | III             | 1.00       | Fulfilled   |                                        |
| Alternative 2 | I | 1.00       | Fulfilled   | 100.00                                 |
|           | II              | 1.00       | Fulfilled   |                                        |
|           | III             | 1.00       | Fulfilled   |                                        |

The value of irrigation network performance from the plant productivity aspect, appropriate to the Regulation of Ministry of Public Work and Public Housing Number:12/PRT/M/2015, has value as much as 15.00. That value includes 9.00% of factor analysis, 4.00% of planting area realization, and 2.00% of rice productivity. The value of physical condition which has been found out and multiplied by the value of weight condition will gain the value of weight condition. The calculation of the value of weight condition is explained in Table 7.
Table 7. The Value of The Weight Condition of Plant productivity Aspect

| planting productivity aspect | Weight Value (%) | The Value of the Physical Condition (%) | Weight Condition Value (%) |
|------------------------------|------------------|----------------------------------------|---------------------------|
|                              | (1)              | Existing (2) | Alternative 1 (3) | Alternative 2 (4)=(2)*(3)/100 | Existing | Alternative 1 | Alternative 2 |
| "k" factor realization of planting area | 9,00 | 91,00 | 95,00 | 100,00 | 8,19 | 8,55 | 9,00 |
| paddy productivity | 4,00 | 71,89 | 88,39 | 88,39 | 2,88 | 3,54 | 3,54 |
| Amount | 15,00 | 13,07 | 14,09 | 14,54 |

The value of irrigation network performance from plant productivity aspect can be obtained by comparing the value of weight condition and the expected value of weight condition. The performance value obtained is in the form of a percentage (%). The calculation of the performance value of irrigation network from plant productivity aspect can be seen in Table 8.

Table 8. The Value of Irrigation Network Performance from Plant Productivity Aspect

| Condition | Weight Value (%) | Weight Condition Value (%) | the value of plant productivity performance |
|-----------|------------------|---------------------------|--------------------------------------------|
| (1)       | (2)              | (3)                       | (4)=(3)/(2)*100 |
| Existing  | 15,00            | 13,07                     | 87,10                                      |
| Alternative 1 | 14,09            | 93,90                     |
| Alternative 2 | 14,54            | 96,90                     |

The result of the calculation value of plant productivity performance shows that the existing condition is 85.10%; the first cropping pattern alternative simulation is 88,10%, and the second alternative cropping pattern simulation is 92,50%. It means the first alternative simulation has 3.00% of performance value improvement compared to the existing condition. Meanwhile, the second alternative simulation has 7.4% of performance value improvement. The graph comparing the value of plant productivity performance of the existing condition, alternative 1 and alternative 2 is shown in Figure 1.

![Figure 1](image)

**Figure 1.** The comparison between k Factor value and the value of Plant Productivity Performance From the cropping pattern alternative simulation, it can be concluded that cropping pattern alternative 2 is chosen.
4. Conclusion

From the analysis result on the existing condition in Cau Irrigation area, it shows that the water availability is still sufficient for planting season I and III. Yet, it is insufficient in the planting season II. The simulation of cropping pattern is done by determining some alternatives of the possible cropping pattern. From the analysis result, the simulation of cropping pattern alternative 2 can improve the plant productivity performance with rice cropping pattern with 1.232 Ha of width during planting season I; Rice with 649 Ha of width and Soy with 462 Ha of width during planting season II; Rice with 350 Ha of width and Soy with 574 Ha during planting season III. With Public Work Plan Criteria Method (KP-01), the value of k factor in cropping pattern alternative 2 is considered fulfilling in water necessity fulfillment. Based on the regulation of Ministry of Public Work and Housing Number 12/PRT/M/2015, it can improve the performance of irrigation network in plant productivity aspect which is improving 9.80%. It means the performance of irrigation network can be improved from plant productivity aspect apart from the other aspects as listed in the regulation of Ministry of Public Work and Housing Number 12/PRT/M/2015. The improvement of plant productivity is meant to be other alternatives in improving irrigation network performance without including budget like physic infrastructure aspect.

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