Economic valuation of SRI paddy

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Abstract. From an economic perspective, rice is an important crop. The System of Rice Intensification (SRI) is known as a rice production technology with a high economic value. The economic value varies depending on different implementations of water level in the SRI paddy field. This study was conducted to determine the best water level for SRI paddy cultivation based on its economic value regarding paddy field ecosystem service. In this study, SRI paddy rice was cultivated in experimental pots, and the water levels were regulated at -12, -7, -5, -3, 0 and +2 cm from the soil surface by using Mariotte tubes. The economic value can be calculated using the Total Economic Value (TEV) framework, namely, by considering the amount of irrigation water used, the reduction of greenhouse gas emissions and the yields. The value is then optimized by Excel solver to maximize the balance in economic value as the objective. The water level was set as a changing water with the constraint not less than -12 and not more than +2. This analysis found that the best water level for SRI paddy cultivation is -5.88 cm from the soil surface based on its economic value (49.708 million IDR per hectare).

1. Introduction

Globally, the shift in paddy cultivation techniques, from conventional puddled, transplanted and constantly flooded rice cultivation, to a no-tillage system of rice intensification (SRI) is effectively raising the yield, the level of water conservation, and the farmers’ revenue while also reducing greenhouse gas (GHG) emissions because of the differentiation management practices of land, water and nutrients [1,2]. In water management practice, the farmers tended to maintain water levels sufficient to ensure good soil moisture and get more air to plant roots, which is important in SRI. However, the SRI farmers in Indonesia use different water levels. More specifically, West Java Province is around +2 cm to -10 cm from the soil surface when hair crack occurs [3].

Irrigation or rain water has inundated paddy fields spanning across the cultivation season, e.g., from the land preparation to the grain filling stage [4]. The irrigation of the rice production accounted for 40% of the global irrigation water; approximately one-third of the available land faces a lack of water [5]. In fact, the irrigation water has a price that serves to signal the limited availability of resources and give rise to proper agricultural water utilization [6]. Should be noted, different amounts of water level applied in the SRI paddy field could relate to different irrigation water costs: the direct cost use value used in this study.

Serving better rootzone is a great approach to increasing rice production, including in SRI. Different amounts of water level used on the field affect the biophysical condition of the soil in the rootzone [7]; this could cause different yields in different set-point. By implementing a better paddy cultivation
technique, the resulting increase in yield could raise interest rates and have a positive impact on the farmers’ revenue [8]. Therefore, the yield became the direct benefit use value used in this study.

Rice cropping systems are major contributors to anthropogenic GHG emissions, which raises serious concerns. In order to mitigate the negative effects of climate change, it is imperative to reduce GHG emission rates [5]. GHG emission reduction is the indirect use value used in this study. However, the potential of GHG emission reduction could be different in each water level application related to the biophysical condition [7].

A simple economic analysis is needed to determine the best water level applied in the SRI paddy field. Therefore, this study aims to determine the economic value of SRI paddy cultivated in different water level applications and find out the maximum value that can be reached with an optimum water level application. The Total Economic Value (TEV) framework, a monetary valuation approach extensively applied, was used in this study. TEV approach is applicable in the paddy field area with ecosystem goods and a services perspective as a beneficial impact from nature to humans [9]. By calculating this economic valuation assessment, farmers can predict their potential value if they are willing to change the water level on their field. The farmers’ skepticism towards the SRI cultivation (unflooding) method can also be addressed [10].

2. Materials and Method

2.1. Experimental site and research design

Using SRI technology, Paddy (Ciherang sp.) was cultivated during one cultivation season in Bogor, Indonesia (S 6.55635°; E 106.72914°), at an altitude of 191.0 m. This location is classified as being very humid due to rainfall [11]. An installed weather station was equipped with ECRN50, 5TE and EHT sensors (Decagon Devices, Inc., USA) for an automated measuring of precipitation, soil moisture and air temperature, respectively. These measurements were carried out every half hour.

In this experiment, single young seedlings were transplanted horizontally in shallow soil, in the pot with a diameter of 40 cm and a 27-cm root zone (Figure 1). The pots containing compost-amended silt loam soil are shown in Table 1. Pot experiment is required rather than in field to have a high degree of precision in measuring each economic valuation parameter.

![Figure 1. Paddy cultivation](image)

A post-flooding was conducted before the enforcement of water management by regulating water levels using Mariotte tubes set at -12, -7, -5, -3, 0 and +2 cm from the soil surface. Manual weeding in the vegetative state is repeated every 10 days, e.g. 9, 19, 29, 39 days after transplantation (DAT). The sudden flooding practices combined with fertilizing are carried out on the following day to obtain wetting in a previously dry condition, impacting additional soil-air exchange [12].

Local or indigenous microorganism (MOL) is a liquid organic fertilizer that can be made from locally available materials used in the SRI method developed in Indonesia [13]. In this study, the maja fruit (Aegle marmelos) as MOL was given in various dosages (1:10 to 1:5), at 10, 20, 30, 40 and 60 DAT. A mixture of maja fruit and cooked rice MOL were provided simultaneously at 47-95 DAT every 8 days, in a 1:5 dosage.
Table 1. Soil characteristic

| Parameter          | Unit | Value  |
|--------------------|------|--------|
| Sand               | %    | 27.00  |
| Silt               | %    | 62.00  |
| Clay               | %    | 11.00  |
| Bulk Density       | g/cc | 0.55   |
| Particle Density   | g/cc | 2.05   |
| Soil moisture      | pF 1 | % Volume 71.00 |
|                    | pF 2 | % Volume 27.50 |
|                    | pF 2.54 | % Volume 21.10 |
|                    | pF 4.2 | % Volume 13.30 |

2.2. Economic valuation

In calculating the economic value, we use the TEV framework. The values are assessed by following the paddy field, as ecosystem services support people's own consumption (use values that consist of direct and indirect use value) and provide intangible human benefits (non-use values) [9]. In this study, it is necessary to consider the amount of irrigation water needed and the yields as direct use value, and the reduction of GHG emissions as indirect use value. These three components were calculated in IDR value. Aesthetic information, inspiration, spiritual experience and education are the non-use benefit values obtained from the paddy field; however, we did not take them into account in this study.

2.2.1. Irrigation water

The irrigation water (Q) used comes from the mariotte. Q (mm) can be obtained by measuring the water level difference in the mariotte tube every day. It can be calculated using equation (1) [14].

\[ Q = \frac{\Delta h_{\text{mariotte}} A_{sm}}{A_{sp}} \times \text{day} \]

With:
- \( \Delta h_{\text{mariotte}} \) = daily water level difference in mariotte tube, mm
- \( A_{sm} \) = mariotte tube surface area, m\(^2\)
- \( A_{sp} \) = pot surface area, m\(^2\)
- \( \text{day} \) = the number of cultivation day

This irrigation water is supporting precipitation in fulfilling water demand. The precipitation (mm) data revealed in the study shows the accumulation of precipitation during one cultivation season, which is measured automatically every 30 minutes. Meanwhile, the total water consumption is represented by the crop evapotranspiration. In this study, the crop coefficient used comes from the newly developed modified water balance method, which is simply the estimated crop coefficient, with irrigation, precipitation and soil moisture change as input parameters [14]. This value is then multiplied with the evapotranspiration potential calculated by the Hargreaves method using temperature data. The daily crop evapotranspiration was also documented during one cultivation season.

2.2.2. Yield

In this research, the yields (\( Y_a \)), provided in kg/m\(^2\), were not measured directly. Therefore, the value of the yields is presumed by the Equation 2, as stated by Hasanah et al [15].

\[ Y_a = N_p b_m m_{1000} \]

\( N_p, b_m, \) and \( m_{1000} \) are productive tiller (panicle), totally filled grain per panicle (gram/panicle) and the weight of 1000 filled grain (gram/1000 grain), respectively. \( N_p \) is obtained from the calculation on harvest day. The values of \( b_m \) and \( m_{1000} \) are 1684.75 grains/panicle and 27.75 grams/1000 grains, which represent secondary data from a SRI paddy cultivation research with the same variety [16].
2.2.3. GHG emission
It uses previous GHG emission data (total CO$_{2eq}$ during one cultivation season) of different water level applications in the SRI paddy field generated using Simpson numerical analysis [17]. Meanwhile, the conventional GHG emission data use data from Xiue et al. [18] and Towprayoon et al. [19] for CO$_2$ and non-CO$_2$ emission, respectively, where each flux is multiplied with its global warming potential (GWP). The GHG emission reduction ($E_r$) in SRI compared to the conventional one is calculated in unit kg CO$_{2eq}$/kg yield. It is then further used as a carbon offset value and will be valued using a carbon credit mechanism.

2.3. Economic value calculation and optimization
The TEV of SRI paddy cultivation on a cultivation area of 1 hectare is calculated using Equation 3-5. The calculation method is based on the ecosystem service and the type of economic valuation. Some price standards are used to calculate the direct-indirect use value ($dv$ and $iv$) [20]. In this study, the direct use value can be seen in the water used (cost) and the yield (benefit) that serve provisioning services (food and water).

$$\text{TEV} = dv + iv$$ (3)

$$dv = 10,000Y_aP_g - 10QP_w$$ (4)

$$iv = 10E_rY_aP_c$$ (5)

The price of irrigation water ($P_w$) is 15.75 IDR/m$^3$ based on Sumaryanto and Sinaga [21]. The yield price ($P_g$) is 5,250.00 IDR/kg yield [22]. It was assumed that the dry unhusked rice has the highest water content quality, namely, of 14%, and the highest emptiness/dirt level, of 3%. In carbon credit, Japanese organizations from the private are pushed by their government to support Low Carbon Development activities in Indonesia through the joint crediting mechanism (JCM), although they have not had any price and are not tradable. Therefore, the carbon credit price ($P_c$) obtained using the New Zealand Emissions Trading Scheme (NZ ETS) comprises agriculture in its carbon credits scheme, i.e., 24.82 NZD/ton CO$_{2eq}$ which is equivalent to 247,370.47 IDR/ton CO$_{2eq}$ emission reduction ($E_r$) [23].

An economic value model is built using TableCurve 2D v4.0, a powerful curve-fitting program that is capable of finding the suitable equation to trace two-dimensional evidence-based data [10]. The model shows the water level on the x-axis and Ev on the y-axis. Optimization is ensured by using Excel solver to get the best water level for the SRI Paddy cultivation.

3. Result and Discussion
The standard technology for growing irrigated paddy worldwide is inundating and maintaining high standing water on field to keep a saturated condition [24]; it is usually called conventional. On the other hand, a lower water level, possibly below the soil surface, leads to less water storage and a drier condition (SRI practices).

According to Hasanah et al. [17], water level control in the SRI paddy field is one of the local water management activities that are conducted by farmers to maintain a sufficient quantity of water on the field. Varied water levels are related to the different amounts of irrigation water used. This affects biomass production (yield) and greenhouse gas emissions.

3.1. Irrigation water
Different water level applications on paddy cultivation activities affect the fluctuation of physical soil parameters, such as soil moisture and soil temperature. Those parameters affect evapotranspiration, which is the main cause of water loss in cultivated land [25]. The crop evapotranspiration value is determined by multiplying the crop coefficient value and evapotranspiration potential. The crop coefficient value fluctuates depending on climate and weather conditions, as well as the phase of plant growth [14].
In this study, it rains nearly every week (32 rainy days), with cumulative rainfall during one cultivation season at 795 mm, a daily average of 8.6 mm and a peak at 173 mm (53 DAT). The climatic water budget is positive, because the value of evapotranspiration (606-691 mm) is still smaller than the accumulation of rainfall. Nevertheless, irrigation is still needed, as can be seen in Figure 2.

Irrigation and precipitation indicate the amount of water demand. In this case, this value is different from the value of water consumption, which is indicated by the crop evapotranspiration. Irrigation supplies 40-63% of water demand and 32-47% of it is evapotranspired. In general, it can be seen that the value of water consumption and demand is proportional to the water level applied during rice cultivation. This is because the higher the water level in SRI, the more water will be available in the land, allowing for evapotranspiration. When the evapotranspiration value increases, which indicates water consumption, the water supply needed to meet the needs of the land will also increase [15].

![Figure 2. Water demand and consumption in different water levels](image)

3.2. Paddy yield

In SRI methodology, the importance of keeping the soil mostly unsaturated to bring more air to plant roots and advantageous soil organisms, is evident. The different water level applications could affect the biophysical properties of the soil and the availability of oxygen associated with biomass production [27].

This paddy biomass consists of yield, roots and straw. Table 2 shows the SRI biomass in different water levels. The goal of paddy cultivation is yield; it has a high economic value.

The productive tiller is the yield determinant among all other biomass formed during one cultivation season. The -5 cm treatment has the highest yield (the highest productive tiller). Based on the explanation provided by Hasanah et al. [15, 17], we can affirm that the -5 cm treatment is the best water level setpoint for SRI cultivation, where better aeration conditions in the soil are suspected to occur.
better than other treatments. However, the yield is not the only component in biomass. The total biomass in SRI paddy cultivation under various water level treatments has an average of 2.10 kg/m².

| Items     | Unit      | Water level (cm from the soil surface) |
|-----------|-----------|----------------------------------------|
|           | -12      | -7          | -5          | -3          | 0          | 2          |
| Np        | tillers  | 30          | 27          | 31          | 25         | 26         | 24         |
| Yields    | gram/plant | 73.47      | 66.12       | 75.92       | 61.22      | 63.67      | 58.78      |
|           | kg/m²    | 0.82        | 0.73        | 0.84        | 0.68       | 0.71       | 0.65       |
|           | ton/ha   | 8.16        | 7.35        | 8.44        | 6.8        | 7.07       | 6.53       |
|           | % of biomass | 20%        | 13%         | 23%         | 18%        | 19%        | 16%        |
| Roots     | gram/plant | 55.75      | 95.3        | 41.7        | 42.45      | 37.7       | 58.4       |
|           | kg/m²    | 0.62        | 1.06        | 0.46        | 0.47       | 0.42       | 0.65       |
|           | ton/ha   | 6.19        | 10.59       | 4.63        | 4.72       | 4.19       | 6.49       |
|           | % of biomass | 15%        | 19%         | 12%         | 12%        | 11%        | 15%        |
| Straws    | gram/plant | 53.65      | 91          | 51          | 71         | 65.4       | 71.3       |
|           | kg/m²    | 0.6         | 1.01        | 0.57        | 0.79       | 0.73       | 0.79       |
|           | ton/ha   | 5.96        | 10.11       | 5.67        | 7.89       | 7.27       | 7.92       |
|           | % of biomass | 15%        | 18%         | 15%         | 20%        | 20%        | 19%        |
| Biomass   | gram/plant | 182.87     | 252.42      | 168.62      | 174.67     | 166.77     | 188.48     |
|           | kg/m²    | 2.03        | 2.8         | 1.87        | 1.94       | 1.85       | 2.09       |
|           | ton/ha   | 20.32       | 28.05       | 18.74       | 19.41      | 18.53      | 20.94      |

Environmental factors and water management practices play a vital role in jeopardizing the rice root systems. More grain tends to be reached with a larger root dry biomass, which indicates powerful water and nutrient absorption capacity [28]. The higher the water level applied to the field, the less root dominates the total value of biomass. This condition is identical to Mishra [29], where the water level (not the water regime) significantly influences the development of the roots.

Root biomass of more than 0.3 kg/m² in SRI paddy is also found in the study conducted by Dass et al. [30]. In this research project, the maximum root biomass was achieved at -7 cm from the soil surface, then followed by -12 and -12 cm treatments. However, a high number of tillers is also seen in water level treatment at -12 and -7 cm. This indicates that, throughout the application of this treatment, the paddy has escaped drought and is able to regulate growth plasticity or complete its life cycle before drought [31]. However, the formation of early tillering occurs at -5 cm, not in -12 and -7 cm treatment. This is closely related to the photosynthetic capacity of tillers. Sutoro et al. [32] affirm that older tillers have a higher capacity, so their productivity levels are also higher when producing panicles. This causes -12 and -7 cm treatments to have a less productive tiller and yield than -5 cm ones. By comparison, in case of a +2 cm treatment, aerenchyma that inhibit the removal of nutrients might be formed even though the root biomass appears big. In case of floods, roots also have a shorter life span. This makes this +2 cm treatment have the least productive tiller and less yield.

Towprayoon et al. [19] used a continuous flooding conventional system with a water level of 5 cm, reaching a yield of 0.44 kg/m². If we compare this information with the data from this study, we can prove that the overall SRI paddy yield is higher than the conventional yield (almost double the conventional yield).
3.3. GHG emission factor

CO₂, CH₄, and N₂O are major contributors to GHG emissions from SRI paddy cultivation. Iqbal et al. [33] stated that the soil CO₂ flux under field conditions depends on its percentage of water-filled pore space (WFPS) which is relative to soil temperature and relative water content. Meanwhile, the emission of CH₄ and N₂O from a paddy field depends on the source and sink process conforming with the redox reaction [34]. The various uses of water level in the SRI paddy field could stir those conditions, which may lead to a different GHG flux. The emission factor in this study can be seen in Figure 3.

![Figure 3. GHG emission factor in different water levels](image)

The result revealed that a water level of −5 cm had the least emission factor in SRI, as well as the highest yield production. The same phenomena are also found in Setiawan et al. [35]. The level of emissions is almost 150% less than that of a conventional flooded paddy field, e.g., 1.97 kg CO₂ekg/yield. It is worth pointing out that managing the water level to ensure favorable soil moisture in SRI provides the opportunity to reduce GHG emission (compared with the conventional system) while still giving good yield. This is proof that in SRI, rice was recognized as possessing enormous unattained potency for tillering, and the idea was to create an ideal environment for the plant to manifest such potential [36].

3.4. Economic valuation

In this study, the economic valuation consists of three categories of value, i.e., direct cost, direct benefit, and indirect use value. Different water level applications have a different economic value; this can be seen in Figure 4.

The grain is a direct benefit of the paddy, serving as staple food in Indonesia [37]. This direct use value contributes to the highest value, i.e., 95% to 97% of economic value, followed by the indirect benefit use value, giving 3% to 5% of the economic value.

The cost-share of economic value is very small because it only relates to water. The cost is made up of the sum of all inputs (cash and noncash) uses over a specific period [38]. However, this study did not calculate other costs because it assumed they would be the same in all treatments.

This study found a model with r² of 99% that can be used to estimate the economic value (y) using the water level (x) as input:

\[ y = 38.651634 - 0.8635248x^2 + 0.088590194x^4 - 0.0018886505x^6 + (9.146483/10^6)x^8 \]

The model can be seen in Figure 5.

Optimization is done using Excel solver, then conducted to get the best water level based on the economic value approach in SRI Paddy cultivation. In an Excel solver, the objective is to maximize the balance in economic value. The water level was set as a changing value with the constraint not less than
Based on this analysis, we found that -5.88 cm from the soil surface is the prime water level for SRI paddy cultivation, with the economic value of 49.708 million IDR per hectare. However, water level management in the paddy field involves a top tier labor in retaining a fixed water height (-5.88 cm) in paddy fields; the farmer still manually adjusts the field input and output flow. Nevertheless, this study proves that the optimum economic value of SRI paddy can be reached by lowering the water level in the field. We believe that if farmers could adapt this paddy cultivation method, keeping the water level under the soil surface with flexible customization, they would gain more economic value; in other words, they would obtain a higher yield while using less water compared to the conventional method. This will convince other farmers to plant using this climate-friendly cultivation method.

**Figure 4.** Economic value in different water levels of SRI paddy field

**Figure 5.** Total economic value model based on the water level in field

### 4. Conclusion
The higher the water level applied in SRI, the more irrigation water is needed to meet water demands. The practice of keeping the water level of -5 cm from the soil surface on the SRI rice cultivation is the best water level capable of producing the highest yield and reducing GHG emissions at the same time.
However, we found out that lowering that level by 0.88 cm could help reach optimum conditions with the highest economic value of 49.708 million IDR per hectare. This study proves that optimum economic value of SRI paddy can be obtained by lowering the water level, even if this level may be hard to maintain.

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