Perspectives on the changing properties of peat soils used for agriculture: the case of Talio Hulu Village

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Abstract. Rice fields in Talio Hulu Village, located in the Swamp Irrigation Area (SIA) Block B Pangkoh I, Pandih Batu District, Pulang Pisau Regency, Central Kalimantan is cleared peatlands which replanted with rice after being abandoned for years. This paper is a review of peatland research and development in Talio Hulu Village. This paper aims to provide an overview of sequential changes of peat soils since its opening in 1983, being developed by planting rice and secondary crops, subsequently abandoned, and afterwards managed and replanted in 2020. Soil chemical properties and fertility in 1987 showed that the top layer (0-30 cm) and below (>30 cm) were very acidic (pH 3.3-3.9); C-organic 36% and 53%; N total 2.3% and 1.2%; low base cation exchange capacity, and P₂O₅ 1.4 mg kg⁻¹ and 0.43 mg kg⁻¹, then the plant showed less than optimal growth. The identification of chemical properties and fertility of the top and bottom layers of the soil after rice development in 1993 showed improvements, including: decreasing soil acidity with pH H₂O 3.4-4.4 and 3.3-3.7; C-organic decreased to 11.46% and 54.52%; N total 0.33-1.11% and 0.48-1.53%; P₂O₅ 7-100 mg kg⁻¹ and 10-15 mg kg⁻¹. Rice yields reached 0.3-2.0 t ha⁻¹ for local rice varieties and 0.2-2.4 t ha⁻¹ for high-yielding varieties. The low yield of rice indicated the poor growth of rice plants measured from the high amount of empty grain. From the survey in 2020, we identified 80% of rice fields were categorized as peat and 20% as shallow peat (peat layer <100 cm). After land remediation, soil acidity decreased (pH increased) at pH 4.11 and 4.47, C-organic decreased by 34.89 % and 42.48%, P-available increased to 17.90 mg kg⁻¹ and 22.88 mg kg⁻¹, and no more deep peat was found. Meanwhile, rice productivity increased to 1.55-6.31 t ha⁻¹ or 3.27 t ha⁻¹ an average.

1. Introduction
Most of peatlands in Indonesia have experienced fires except those as primary forests. Conflagration during the 2015 El-Nino have scorched around 618,574 hectares of peatland [1]. Therefore, since 2016 the government has established the Peatland Restoration Agency (PRA) to improve the management and restoration of damaged peatlands, especially due to fires [2]. Indonesian Center for Agricultural Land Resources Research and Development (BBSDLP) [3] showed that around 4.40 million hectares of peatland used for agriculture and mining were degraded due to fires and “mismanaged”, requiring rehabilitation, 30.57% of which are in Kalimantan.

Clearing and utilization of peatlands, such as in Talio Hulu Village, Pandih Batu District, Pulang Pisau Regency, Central Kalimantan part of the SIA Pangkoh I, is designed for food crop cultivation, especially rice to support the transmigration program as well as national food production.
Generally, peatlands in Kalimantan are oligotropic and some are ombrogenic [4]. Local farmers (personal communication, 2019) said that almost every dry season the peatlands of Talio Hulu Village experience fires leading to degradation. Peat maturity varies from raw, generally hemic to sapric. The physical properties of peat changes from hydrophilic to hydrophobic due to fire and/or drought, indicated by floating materials on a water level of 10-40 cm. Land subsidence likely occurred when it is used for agriculture. In the last ten years, the peatlands have been neglected. Fires cause physical, ecological and socio-economic losses to the community [5]. Initially, the peatland of Talio Hulu Village have a thickness of >2 meters. Land clearing accompanied by the construction of drainage channels resulted in decreasing the ground water level. This resulted in peat subsidence. Intensive long-term drying causes various oxidation processes, irreversible dryness, and erosion leading to accelerated subsidence and land degradation both chemically and physically. Decreasing soil surface and irreversible dryness caused declining absorption capacity of the soil, so that the nutrients are easily run off. Peat subsidence reduced the thickness of peat material substantially to almost depleted and it is estimated that <50 cm remains.

In 1983-1990, transmigrant farmers from Talio Hulu Village planted rice yielding low productivity ranging from 0.3 to 2.0 t ha\(^{-1}\) [6], and subsequently they cultivated soybeans and corn with unsatisfactory yields. Some farmers have turned to look for better land in the surrounding area for crop cultivation. In 2019, after 11 years of being neglected, reclaimed peatlands since 1983 were re-cultivated for rice after remediation. In 2019, a quick assessment was carried out, soil samples were taken, and crop yields were calculated in tiles from the planting plots. This paper is a review of peatland research and development in Talio Hulu Village based on the properties and changes of soil from the initial clearing in 1983 and management until 2020. This paper also presents the level of rice productivity from the period before and after the re-clearing in 2020.

2. Development of peat soil properties of Talio Hulu village

2.1. Early development 1987-1990
Talio Hulu Village is a peat swamp influenced by tides from the Kahalayan River in the east and Sebangau in the west (Figure 1). According to Soil Research Center team, some areas of Talio Hulu Village are included in the flooding type A and B and some are in the flooding type C and D. Some of them are landform levee (river embankment) and most of the back swamp is peat soil. The peat thickness in the back swamp area reaches >2 m [7]. The chemical properties of the peatland in the Pangkoh area are presented in Table 1.
Figure 1. Swamp irrigation area Pangkoh, Pulang Pisau Regency, Central Kalimantan [7].

Table 1. Peat soil properties in Taliu Hulu Village, Pandih Batu District, Pulang Pisau Regency, Central Kalimantan, 1987.

| Type of peat | Soil layer (cm) | pH-H₂O | pH-KCl | C-organic (%) | N-total (%) | P₂O₅ (mg kg⁻¹) | K₂O (mg kg⁻¹) | CEC (cmol(+)kg⁻¹) | Base saturation (%) |
|--------------|----------------|--------|--------|---------------|-------------|---------------|---------------|------------------|-------------------|
| Shallow      | 0-50           | 3.9    | 3.1    | 55.0          | 1.06        | 1.59          | 0.25          | 25.1             | 42.3              |
|              | 50-80          | 3.9    | 3.3    | 7.9           | 0.06        | 0.28          | 0.21          | 22.5             | 26.6              |
| Deep         | 0-30           | 3.4    | 2.5    | 36.0          | 2.30        | 1.20          | 2.80          | 31.0             | 9.0               |
|              | 30-90          | 3.3    | 2.4    | 53.4          | 1.21        | 0.43          | 1.03          | 27.7             | 4.0               |
|              | 90-225         | 3.2    | 2.5    | 74.8          | 1.28        | 0.85          | 2.90          | 23.3             | 6.5               |

Source: [7]

In the initial conditions, rice or secondary crops were planted during the first season to the fourth season (years 1 and 2) on yards (0.25 hectares) and part of farming land (1.0 hectares). In the first two years, plant growth was remarkable even without fertilizing, but subsequently diminishing growth and yields were observed, so that the plants grew languidly without fertilization due to soil acidity and nutrient deficiency [8]. Chemical properties of samples in Table 1 demonstrates very acidic (pH 3.3-3.9), low bases exchange, and low N, P, K nutrient status, thus plants marginally grew as shown in Figure 2.
Figure 2. Performance of plant growth on peatlands in Talio Hulu Village, Pandih Batu District, Pulang Pisau Regency, Central Kalimantan [7]

2.2. Management and utilization 1990-2000

The feasibility study conducted by FP-IPB at DIR Pangkoh, including Talio Hulu Village (DIR Pangkoh I) in September and October 1992 reported that land management and utilization during ten years since the opening had shown trivial progress, indicated by: (1) the inundation of the tertiary canal (now called secondary canal) at the end of 1 km leading to dysfunctional canal, (2) low rice (both local and high yield varieties) and secondary crops yields due to inadequate utilization of seeds, fertilization, and pest and plant disease control, (3) single rice cropping at October-March with low yields of 0.1-2.6 t ha\(^{-1}\), and (4) severe pests and plant diseases infestations. Meanwhile, the peatland underwent (1) decreasing peat thickness due to burning and cultivation; (2) diminishing nutrient status and peat soil fertility due to leaching, decaying, and absorption by plants; (3) increasing peat soil acidity except a small areas where ameliorants and fertilizers were applied to improve the solubility and availability of soil nutrients (Table 2).

Table 2. Properties of peat soil in Talio Hulu Village (Pangkoh I), Pandih Batu District, Pulang Pisau Regency, Central Kalimantan, 1992

| No Sample | Layer (cm) | pH-H\(_2\)O | C-Org (%) | N-tot (%) | P\(_4\) available (mg kg\(^{-1}\)) | exchangeable base cation (cmol(+)kg\(^{-1}\)) |
|-----------|------------|-------------|-----------|-----------|-------------------------------|----------------------------------|
|           |            |             |           |           |                               | Ca     | Mg     | K      | Na      |
| 1         | 0-30       | 3.3         | 54.98     | 1.11      | 20.0                          | 0.78   | 0.78   | 0.09   | 0.15    |
| 2         | 0-30       | 3.4         | 54.52     | 0.99      | 8.8                           | 0.97   | 2.28   | 0.20   | 0.26    |
| 3         | 0-30       | 3.3         | 53.60     | 1.05      | 10.0                          | 0.89   | 1.54   | 0.14   | 0.20    |
| 4         | 0-30       | 4.4         | 48.20     | 0.92      | 100.0                         | 0.74   | 2.86   | 0.11   | 0.22    |
| 5         | 30-60      | 3.3         | 53.60     | 1.05      | 10.0                          | 3.72   | 3.32   | 0.23   | 0.11    |
| 6         | 30-60      | 3.7         | 54.72     | 0.49      | 36.0                          | 0.80   | 3.49   | 0.17   | 0.50    |
| 7         | 0-30       | 3.6         | 21.01     | 0.55      | 52.4                          | 0.72   | 2.48   | 0.14   | 0.23    |
| 8         | 30-60      | 3.9         | 50.76     | 0.33      | 29.0                          | 0.59   | 1.56   | 0.23   | 0.09    |
| 9         | 0-30       | 3.8         | 55.57     | 0.61      | 15.0                          | 0.75   | 2.04   | 0.21   | 0.20    |
| 10        | 0-30       | 3.4         | 48.03     | 0.73      | 8.4                           | 0.72   | 3.29   | 0.09   | 0.21    |

Source: [6]
2.3. Land remediation in 2019-2020

The soil survey observed that the peat land of this site have experienced subsidence, resulting in the thickness of the peat at 20-40 cm. The thickness confirmed that Talio Hulu Village area were peaty land. Utilizing peat soil as paddy field requires an appropriate water management system. If water system of the field is managed properly (wherein the water level can be controlled), then the field is potential for rice cultivation [9,10]. On the other hand, soil tillage and planting rice seed would be hardly to manage, when the water level uncontrolled [11]. This is due to the top layer of peat floating on the water surface (ambul). In floating peatland conditions, the rice seedlings are planted in the upper peat layer, the roots do not reach soil layer so that the growth of the rice is disrupted (Figure 3). The identification of peat thickness, pyrite depth, and water level in 22 paddy fields are presented in Table 3. Whereas, the peat land properties of samples taken from survey of Talio Hulu Village in 2020 are presented in Table 4.

**Table 3.** Peat thickness and pyrite depth from 22 paddy fields in Talio Hulu Village, Pandih Batu District, Pulang Pisau Regency, Central Kalimantan, 2020

| Parameter   | Class and criteria thickness/depth | Sum of point observation | Percentage |
|-------------|-----------------------------------|--------------------------|------------|
| Peat thickness | Peaty (< 50 cm)                  | 20                       | 80         |
|             | Shallow (50-100 cm)               | 5                        | 20         |
|             | Moderate (>100-200 cm)            | 0                        | 0          |
| Pyrite depth | Very shallow (< 25 cm)            | 2                        | 8          |
|             | Shallow (>25-50 cm)               | 9                        | 36         |
|             | Moderate (>50-75 cm)              | 10                       | 40         |
|             | Deep (> 75 cm)                    | 4                        | 16         |
| Water level | Very shallow (<5 cm)              | 5                        | 22         |
|             | Shallow (>5-10 cm)                | 3                        | 14         |
|             | Moderate (>10-20 cm)              | 3                        | 14         |
|             | Deep (>20-30 cm)                  | 9                        | 41         |
|             | Very deep (> 30 cm)               | 2                        | 9          |

Source: [12]
Table 4. Peat soil properties from 22 rice fields in Talio Hulu Village, Pandih Batu District, Palang Pisau Regency, Central Kalimantan, 2020.

| No. | pH (H2O) | C- Organic (%) | N (%) | P (mg kg⁻¹) | K (cmol(+)/kg⁻¹) | Ca (cmol(+)/kg⁻¹) | Mg (cmol(+)/kg⁻¹) | Al (cmol(+)/kg⁻¹) | Fe (mg kg⁻¹) | SO4 (mg kg⁻¹) |
|-----|----------|----------------|-------|-------------|------------------|------------------|------------------|------------------|--------------|--------------|
| 1   | 4.19     | 20.12          | 0.51  | 7.76        | 0.06             | 5.53             | 31.08            | 1.69             | 417.21       | 1,760.41     |
| 2   | 4.42     | 20.08          | 0.87  | 73.40       | 0.10             | 9.53             | 30.38            | Tu              | 317.75       | 2,862.69     |
| 3   | 4.18     | 36.91          | 0.96  | 9.12        | 0.01             | 11.52            | 63.79            | 1.06             | 428.82       | 2,787.07     |
| 4   | 4.59     | 35.85          | 1.06  | 23.97       | 0.33             | 13.74            | 54.72            | Tu              | 241.48       | 2,684.93     |
| 5   | 3.99     | 32.08          | 0.52  | 5.50        | Tu               | 2.32             | 30.18            | -               | 706.52       | 3,521.14     |
| 6   | 4.32     | 51.56          | 0.81  | 7.03        | 0.31             | 8.38             | 93.74            | 1.01             | 303.43       | 2,966.89     |
| 7   | 4.39     | 45.57          | 0.89  | 14.00       | 0.52             | 4.25             | 56.32            | 0.56             | 400.53       | 3,335.21     |
| 8   | 4.26     | 51.79          | 0.71  | 9.99        | 0.45             | 7.99             | 59.34            | 0.54             | 294.93       | 3,252.44     |
| 9   | 4.55     | 33.01          | 0.80  | 22.36       | 0.71             | 4.66             | 77.81            | 0.69             | 246.81       | 2,406.87     |
| 10  | 4.33     | 50.75          | 1.34  | 7.85        | 0.52             | 13.60            | 51.34            | Tu              | 326.54       | 3,955.64     |
| 11  | 4.67     | 48.20          | 0.61  | 15.20       | 0.66             | 8.22             | 60.21            | -               | 212.35       | 1,103.25     |
| 12  | 4.60     | 49.30          | 0.53  | 14.70       | 0.65             | 9.27             | 75.88            | Tu              | 184.33       | 1,518.35     |
| 13  | 4.59     | 49.94          | 0.57  | 12.56       | 0.52             | 4.22             | 69.33            | Tu              | 169.03       | 1,760.15     |
| 14  | 4.38     | 22.96          | 1.01  | 39.39       | 0.12             | 9.83             | 44.95            | 0.56             | 102.54       | 1,210.15     |
| 15  | 4.22     | 31.81          | 0.68  | 17.75       | 0.29             | 6.08             | 41.99            | 0.88             | 111.24       | 1,716.45     |
| 16  | 4.43     | 50.43          | 1.01  | 22.01       | 0.16             | 10.30            | 52.55            | Tu              | 199.15       | 2,362.11     |
| 17  | 5.31     | 42.00          | 0.92  | 42.02       | 1.13             | 6.41             | 68.78            | Tu              | 142.08       | 1,813.45     |
| 18  | 4.80     | 45.57          | 1.19  | 24.52       | 0.33             | 14.27            | 48.24            | Tu              | 179.64       | 2,448.65     |
| 19  | 4.31     | 44.47          | 1.03  | 7.79        | 0.39             | 4.51             | 67.99            | Tu              | 660.77       | 3,259.81     |
| 20  | 4.48     | 43.50          | 0.84  | 32.41       | 0.32             | 4.32             | 70.91            | Tu              | 217.05       | 3,012.16     |
| 21  | 4.32     | 47.45          | 0.88  | 28.12       | 0.37             | 4.55             | 53.04            | Tu              | 254.12       | 3,521.16     |
| 22  | 4.16     | 20.08          | 0.58  | 5.75        | Tu               | 4.67             | 30.38            | Tu              | 234.75       | 1,231.31     |

Value range 3.9-5.3  0.5-1.3  5.5-73.4  Tu-0.7  2.3-14.3  30.1-93.7  Tu-1.6  111.2-706.5  1.103-3.521

Tu = immeasurable.
Source: [12].

3. Changes in the properties of peat and rice productivity

3.1. Changes in the properties of peat soil

Recommendations for land remediation have been constructed based on the study to improve the chemical, physical and biological properties of the soil, including soil fertility. The initial chemical properties of the top and bottom layers of peat soil identified in 1987 were: pH H2O 3.4 and 3.3; C-organic 36% and 53%; N total 2.3% and 1.2%; P2O5 1.4 mg kg⁻¹ and 0.43 mg kg⁻¹. After ten-years of land management, in 1993, an increased level of soil fertility was observed, indicated by: pH H2O 3.4-4.4 and 3.3-3.7; C-organic 11.46% and 54.52%; N total 0.33-1.11% and 0.48-1.53%; and P2O5 7-100 mg kg⁻¹ and 10-15 mg kg⁻¹. The survey in 2020 identified that 80% of paddy fields is peaty land (<50 cm thickness), while about 20% is considered shallow peatland (<100 cm thickness) with chemical
properties of top and bottom layers were pH 4.11 and 4.47, C-organic 34.89% and 42.48%, and P-available 17.90 mg kg\(^{-1}\) and 22.88 mg kg\(^{-1}\) respectively.

Improving water management is essential land remediation to prevent drought and land fires leading to land degradation. Improving soil fertility by applying balanced ameliorant and fertilizer, including organic fertilizer and biological fertilizer to meet the requirements for crop growth are necessary to increase productivity [13] (Figure 3).

![Figure 3](https://example.com/figure3.jpg)

**Figure 3.** Degraded peatland such as pulp (called ambul) being planted after being applied remediation treatment (Photos by M. Noor/Balittra/2020).

### 3.2. Rice productivity on peat soil

The growth and yield of rice on peatland are highly dependent on water management system, land arrangement, soil tillage, and cultivation system including inputs for production facilities such as variety, fertilizer, and pesticide for the prevention of pests and plant diseases [13]. The rice yield cultivated in the peat land of Talio Hulu Village was reported low. During the development period in the 1990s, the yield was about 0.3-2.0 t ha\(^{-1}\) for local varieties and 0.2-2.4 t ha\(^{-1}\) for high yielding varieties. This low yield was caused by high acidity of the soil (pH < 4.0) and soil organic acids that disturbed plant physiology. In 2019-2020, after abandonment, implemented land remediation improved the yield up to 1.55 to 6.31 t ha\(^{-1}\). The average productivity was around 3.27 t ha\(^{-1}\) (Figure 4). This figure was higher than the previous year at about 0.25–0.50 t ha\(^{-1}\). The potential rice varieties were Inpara 2 (6.31 t ha\(^{-1}\)), Inpara 3 (5.46 t ha\(^{-1}\)), and Inpara 8 (6.28 t ha\(^{-1}\)). Since the Inpari 42 variety was ranged at 1.23-5.6 t ha\(^{-1}\), lower than Inpara, three Inparas (Inpara 2, 3, and 8) are recommended (Table 5). Rice yield is also affected by the depth of the pyrite layer. High rice yield obtained in an average pyrite depth of 60-65 cm. Generally, at a depth of pyrite < 40 cm rice yield was low. According to Noor [8] local varieties can yield around 2.0-2.8 t ha\(^{-1}\), while high yielding varieties (not Inpara) were 3.4-5.5 t ha\(^{-1}\).
Table 5. Rice productivity on peatlands in Talio Hulu Village, Pandih Batu District, Pulang Pisau Regency, Central Kalimantan 2020 (after land remediation).

| No. | Farmer name | Variety | Peat thickness (cm) | Pyrite depth (cm) | Rice yield (t ha⁻¹) |
|-----|-------------|---------|---------------------|-------------------|--------------------|
| 1.  | Nyono       | Inpara 2| 50                  | 65                | 6.31               |
| 2.  | Ponirah     | Inpara 3| 25                  | 30                | 5.46               |
| 3.  | Nyono       | Inpara 8| 50                  | 65                | 6.28               |
| 4.  | Sofiah      | Inpari 42| 30                 | 30                | 1.55               |
| 5.  | Tukijo      | Inpari 42| 25                 | 25                | 1.92               |
| 6.  | Suwoto      | Inpari 42| 40                 | 50                | 2.19               |
| 7.  | Sukiran     | Inpari 42| 50                 | 70                | 1.55               |
| 8.  | Karti       | Inpari 42| 40                 | 65                | 3.79               |
| 9.  | Juwari      | Inpari 42| 60                 | 70                | 2.08               |
| 10. | Rasidi      | Inpari 42| 35                 | 35                | 2.61               |
| 11. | Yayan       | Inpari 42| 30                 | 40                | 1.23               |
| 12. | Edi P       | Inpari 42| 40                 | 65                | 1.44               |
| 13. | Hermanto    | Inpari 42| 25                 | 25                | 5.33               |
| 14. | Paijem      | Inpari 42| 60                 | 60                | 5.60               |
| 15. | Winarno     | Inpari 42| 65                 | 75                | 1.65               |

Average: 3.27

Description: Inpara = swamp rice inbred; Inpari = irrigation rice inbred.

Source: [12].

Figure 4. Performance of high yielding rice variety (Inpara) on peatland in Talio Hulu Village, Pandih Batu District, Pulang Pisau Regency, Central Kalimantan 2020 (Photos by M. Noor/Balittra/2020).

According to Moormann and Breemen in Noor et al. [14] ideal peatland for rice cultivation should be (1) having a shallow layer of peat (organic matter) (<50 cm from the soil surface); (2) composing of soil material with 25% organic matter content after reclamation; and (3) having a mixed top layers of peat and mineral soil approximately 20 cm as is often found on the edges of peat areas covered with new sediment from rivers. After land remediation in 2020, it was indicated that degraded peatland can partially be restored except for the area experiencing severe degradation.

4. Conclusion and policy implication

To reach the stability of rice productivity on peatlands necessitates long time efforts and is highly affected by the level of land management. Improving the chemical properties and fertility of peatlands for rice farming requires remediation technology. This study reports the process of improving land quality for almost 37 years, from 1983 to 2020. After 2020, the rice yield reached an average of 3.27 t
It is necessary to maintain the water level, especially during the dry season to conserve soil and water, and to protect the peatlands from drought and fires.

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