Water level arrangement in the drainage channel on peat chemical characteristics, growth and corn yield

B Widiarso$^{1,3}$, S Minardi$^{2}$, Komariah$^{3}$, and T O Chandra$^{1}$

$^1$Department of Soil Science, Faculty of Agriculture, Tanjungpura University, Pontianak, West Kalimantan, Indonesia
$^2$Department of Soil Science, Faculty of Agriculture, Sebelas Maret University, Surakarta, Central Java, Indonesia
$^3$Corresponding author, e-mail: widiarso.bambang@gmail.com

Abstract. This research was aimed to study the influence of water depth in the drainage channel arrangement on peat chemical characteristics, the growth, and corn yield. This research was conducted in Lasau Jaya Umum Village, Lasau Jaya Sub-district, Kubu Raya District, West Kalimantan Province, for ten months (February - December 2016). The research field consists of three plots of land, with the area of each plot of 0.2 ha (40 m x 50 m). The depth of water drainage channels arranged in the experimental plots: treated without drainage channel, depth of water drainage channel 30 cm and depth of water drainage channel 60 cm. Pioneer 21 (P21) variety of corn was planted in the research field with the spacing of 25 cm x 75 cm and given ameliorant of coastal sediment 8 tons/ha, urea fertilizer 400 kg/ha, SP 36 300 kg/ha, and KCl 100 kg/ha. The results showed that in the soil depth of 20-40 cm, the water depth of the drainage channel 60 cm influenced the decrease of organic carbon, total N, Cation Exchange Capacity (CEC) and available P. The water level depth in the drainage channel up to 60 cm did not affect the growth and corn yield. The arrangement depth of the water level in drainage channel 30 cm is the most ideal for corn growth and sustainability of peat.

1. Introduction

Peatland in Indonesia reaches 21 million hectares spread over the islands of Sumatra, Kalimantan, Papua and a little in Sulawesi [1]. Peatland in West Kalimantan reached 1.73 million ha [2]. Peat areas are widely used for agriculture, plantation, and housing. Utilization in agriculture, annual crops (especially corn) and horticulture (fruits and vegetables) are mostly cultivated on peatlands.

Drainage (decrease in groundwater level) in peatlands can cause a decrease in the soil surface due to the acceleration of peat decomposition [3] and [4]. This situation has the potential for large quantities of subsidence, which affect channel elevation, channel geometry, and channel configuration [5]. The peat domes in Kalimantan (Indonesia) are reported to have lost their domed form as a result of disruptions such as logging and artificial drainage [6]. Drainage can also lower soil moisture content. Low levels of peat soil water will cause the peat to dry and facilitate the occurrence of land fires. In drained peatlands and subsequent forest fires, peat bulk density increased by 14.1%, and water retention increased by 15.6%, compared with burnt peat but not drainage [7].

Communities widely cultivate peatlands for agricultural uses, and drainage arrangements are required by maintaining water level stability in the channel. Management of water by maintaining groundwater levels 30 to 50 cm in oil palm plantations in Sarawak is better for oil palm crops, while at the same time reducing peat decomposition and mineralization levels, and preventing excessive CO$_2$ emissions [8]. On the cultivation of oil palm on peatland, water containment efforts in tertiary channel
70 cm can raise the water 30-40 cm below the soil surface [9]. The effects of drainage and land-use change reported by [10], that peat pH, soil bulk density, and total nitrogen tend to increase, a significant decrease in C/N ratio at oil palm and agricultural sites, the water content and total organic carbon are relatively constant. In oil palm plantations on peatlands, effective water management (keeping the water level as high as possible) can reduce greenhouse gas emissions, land subsidence, and land fire risks [11]. Sago cultivation with the application of fertilizer and groundwater control does not cause damage to soil and water quality [12]. Drainage in peatlands can provide ideal humidity for plant growth by regulating the depth of groundwater [13]. The depth of the groundwater level highly correlated with soil moisture by increasingly shallow groundwater levels, cause higher soil moisture, and soil moisture increases by increasing soil depth [14].

Drainage can increase the pH of peat which contributes to rapidly dissolving phenolic concentrations directly (through effects on solubility) and indirectly as a driver of increased extracellular oxide activity [16]. Mustamo et al. [17] examined differences in physical properties (hydraulic conductivity, water retention curve, bulk density, porosity, decomposition rate) in the soil profile of two peatland forests, i.e. processed peatlands, peat extraction areas, and natural peatlands. Surface drainage of swamp forests through shallow channel networks has led to increased productivity of the South Taiga swamp forest in Yaroslavl oblast [18].

Research conducted by Dowrick et al. [19] shows that as temperature increases, nitrate availability decreases in pure peat but increases in drained peat, this indicates that drainage has transformed the nitrate process from denitrification to nitrification. Sulfate concentrations in natural peat show greater proportional decreases with temperature rises than in drained peat, and this suggests that drainage has decreased the effect of sulfate reduction on sulfate availability. Maciak and Harms [20] reported that the concentration of phenolic acid in the soil depends on the cropping system and the soil profile depth. Permanent grasses have the highest phenolic compounds in peat soils. The content of phenolic acid decreases with the depth of profile, but in some cases, the ground layer 25-30 cm contains more phenol than the 5-10 cm layer. Compared with the surface layer, deeper horizons (55-60 cm and 95-100 cm) have low levels of phenolic acids.

Tong and Ling [15] conducted observations at several sites in Sarawak and showed that peatlands in various locations could be categorized as acidic soils due to a pH range between 3.3-3.75. The lowest bulk density recorded in the Dalat sago plantation area, i.e. 0.14 g/cm³. The total value of carbon, peat soil from Laogan Bunut National Park is the lowest, which is 47.6%. Total nitrogen values, there was little difference between sites, with a range of 0.9% to 2.4%.

The planting of corn crops on peatlands requires proper soil and water management so that the negative impacts on peatlands can be controlled and maize production can be optimized. Corn and soybean cultivation in shallow peatlands requires 20-50 cm groundwater depth [21]. In greenhouse experiments, the results showed that formula ameliorant and dose affect the growth and uptake of NPK nutrients by sweet corn plants [22]. Hybrid corn MT-10 had grown in monoculture using non-fuel technology, giving with 2 tons/ha of compost, dolomite 500 kg/ha, Urea fertilizer 200 kg/ha, SP-18 200 kg/ha and KCI 100 kg/ha and added Cu (terusi 5 kg/ha) can provide 5.67 tons/ha of dried rice [23]. Giving coastal sediments 40 ton/ha (spread evenly) or 8 tons/ha (given on crop lines) and urea 400 kg/ha, SP-36 300 kg/ha and KCI 100 kg/ha on Rasau Jaya peatland West Kalimantan can increase the availability and uptake of nutrients and yield of pioneer varieties of corn 21 (P21) 11 - 13 ton/ha [24].

Although some research on the effect of drainage on peatland above has been doing, research on the arrangement of groundwater depth (30 - 60 cm) in the drainage channel for agricultural cultivation is infrequently discussed, so this research is very important to do. This research was aimed to study the influence of water depth in the drainage channel arrangement on peat chemistry characteristics, the growth, and corn yield.

2. Materials and methods
The research was conducted in Rasau Jaya Umum Village, Rasau Jaya Sub-district, Kubu Raya District, West Kalimantan Province. The study sites are located at coordinates S 0°13'49.02" and E 109°23'57.03". The research land is newly opened and has never been cultivated, with the origin of vegetation being shrubs/bushes. Land clearing and drainage channel construction were conducted for 2 months, starting on February 8, 2016. The coastal sediment as much as 14 tons of extracted and dried to a dry for 3 months. The destruction of sea mud and sieving (5 mesh) was carried out for 2 months. The corn planting on September 10, 2016, and the harvest did on December 20, 2016. The experimental plot consists of three plots of land, with the area of each plot being 0.2 Ha (40 m x 50 m). The experimental plot is shown in Figure 1, the drainage channel is shown in Figure 2, and the semi-permanent floodgate for water regulating is shown in Figure 3.

Figure 1. The experimental plot.
Figure 2. The drainage channel.

Figure 3. The semi-permanent floodgate for water regulating.

Figure 1 explains that the length of each plot is 50 m and between the research plots there is a buffer area of 10 m. Making of the drainage channel with width 60 cm (Figure 2) and depth according to treatment is 30 cm (T1) and 60 cm (T2). In addition, there are control areas without drainage channels (T0). Semi-permanent floodgate (Figure 3) is made of wood to maintain drainage water depth. The research field has varying peat thickness, which is 290 - 670 cm, with the maturity level of hemist to depth 100 cm and soil type Haplohemist. The initial soil characteristics of the study sites are presented in Table 1.

| No | Parameter                                      | Value  |
|----|------------------------------------------------|--------|
| 1  | pH                                            | 3.37   |
| 2  | Organic Carbon / Organic C (%)                | 55.05  |
| 3  | Total Nitrogen / Total N (%)                  | 1.79   |
| 4  | Available Phosphorus/P (ppm)                  | 150.67 |
| 5  | Exchangeable Calcium / Exch-Ca (cmol(+)/kg)   | 2.68   |
| 6  | Exchangeable Magnesium / Exch-Mg (cmol(+)/kg) | 0.97   |
| 7  | Exchangeable Potassium / Exch-K (cmol(+)/kg)  | 0.25   |
| 8  | Exchangeable Sodium / Exch-Na (cmol(+)/kg)    | 0.43   |
| 9  | Cation Exchange Capacity / CEC (cmol(+)/kg)   | 118.04 |
| 10 | Bases Saturation / BS (%)                     | 3.72   |

Source: Soil analysis results (2016)

Disturbed soil samples were taken at the end of the study (after harvesting the corn) at 13 observation points at each treatment in 0-20 cm and 20-40 cm depth were analyzed to obtain information on peatland characteristics. Analysis of peat soil characteristics was performed in the laboratory by observing variables of soil chemical characteristics including total N content (Kjeldahl method), available P (Bray I method), exch-K, exch-Na, exch-Ca, exch-Mg, Bases Saturation (extraction method NH₄OAC 1N pH: 7), soil acidity/pH (electrometric method using pH meter and extracting aquades), cation exchange capacity/CEC (extraction method NH₄OAC 1N pH: 7), and...
organic C content (Walkley and Black) [25]. Variables include observations of dry plant weight (dry weight of roots, stems, and leaves), plant height, stem circumference, and weight of dry corn seed.

Land preparation began with the application of coastal sediment 8 tons/ha were given array [24]. The corn seeds used were the hybrid Pioneer 21 (P21) variety, planted by hollowing the soil with wood with one seed per planting hole, and with space of 25 cm x 75 cm for each hollow. The dose of fertilization is urea 400 kg/ha, SP 36 300 kg/ha, KCl 100 kg/ha [24]. Fertilization I was done at plant age 5 - 7 days, with urea fertilizer (40% of the dose), SP 36 (100% of the dose), and KCl (50 % of the dose). Fertilization II was conducted at 28-30 days after planting, with urea fertilizer (30 % from dose), and KCl (50 % of the dose). Fertilization III was done at plant age 40-45 days, and with urea fertilizer (30 % of the dose).

The t-test was conducted to determine the differences between treatment groups (drainage water level settings) to soil chemical characteristics, growth, and corn crop yield. A Correlation test was also done to know the closeness of the relationship between observed variables. Before the statistical tests were performed, the normality of the data was observed/selected, and the outlier data were not included in the analysis, so the number of n for soil chemistry characteristics was 11.

3. Results and discussion

The measurement results of soil chemical characteristics are presented in Table 2, and the growth of corn plants is presented in Table 3. This research analyzes the impact of peatland that has been drying for ten months on soil chemical characteristics. To facilitate the discussion, the correlation between each parameter at depth 0 - 40 cm is presented in Table 4.

| No | Parameter      | Depth of Soil 0-20 cm | Depth of Soil 20-40 cm |
|----|----------------|-----------------------|-----------------------|
| 1  | pH             | 3.51 ± 0.22 *         | 3.33 ± 0.17 *         | 3.48 ± 0.22 *         | 3.39 ± 0.22 *         | 3.26 ± 0.14 *         | 3.40 ± 0.27 *         |
| 2  | Organic C (%)  | 56.07 ± 0.92 ab       | 55.54 ± 1.23 ab       | 54.91 ± 2.04 ab       | 57.19 ± 0.32 d        | 57.03 ± 0.41 cd       | 56.61 ± 0.71 b        |
| 3  | Total N (%)    | 1.96 ± 0.03 abc       | 1.98 ± 0.10 c         | 1.99 ± 0.13 c         | 1.92 ± 0.04 b         | 1.88 ± 0.07 ab        | 1.83 ± 0.04 a         |
| 4  | Available P (ppm) | 315.81 ± 86.19 d      | 277.73 ± 75.47 c      | 220.01 ± 126.80 ac    | 180.93 ± 56.14 ab     | 213.97 ± 59.79 b      | 146.50 ± 53.86 a      |
| 5  | Exch-Ca (cmol(+)/kg⁻¹) | 12.84 ± 2.48 cd      | 13.23 ± 3.73 d        | 11.78 ± 2.92 bc       | 7.84 ± 1.21 a         | 9.50 ± 1.94 ab        | 9.14 ± 4.41 abc       |
| 6  | Exch-Mg (cmol(+)/kg⁻¹) | 8.63 ± 1.01 c         | 8.08 ± 1.88bc         | 8.28 ± 2.42 c         | 5.31 ± 1.16 a         | 6.23 ± 1.24 a         | 5.54 ± 1.63 a         |
| 7  | Exch-K (cmol(+)/kg⁻¹) | 0.46 ± 0.09 c         | 0.52 ± 0.08 ab         | 0.84 ± 0.63 ab        | 0.47 ± 0.09 ab        | 0.49 ± 0.09 ab        | 0.66 ± 0.28 b         |
| 8  | Exch-Na (cmol(+)/kg⁻¹) | 0.78 ± 0.16 c         | 0.88 ± 0.14 ab         | 1.43 ± 1.06 ab        | 0.79 ± 0.14 ab        | 0.84 ± 0.14 ab        | 1.12 ± 0.48 b         |
| 9  | Cation Exchange Capacity | 117.74 ± 1.92 ab      | 116.30 ± 2.65 a        | 115.31 ± 4.28 a       | 120.10 ± 0.68 d       | 119.77 ± 0.87 cd      | 118.89 ± 1.50 bc      |
| 10 | Bases Saturation (%) | 19.28 ± 2.62 b        | 19.47 ± 4.36 b         | 19.35 ± 4.57 b        | 11.98 ± 2.02 a        | 13.91 ± 2.52 a        | 13.85 ± 5.33 a        |

Note: (Mean ± st.dev) followed by the same letter is not significantly different at α 0.05 in a row; n = 11.

T0: Without drainage channel, T1: Water channel depth is 30 cm, T2: Depth of drainage water channel is 60 cm.

| No | Parameter          | T0          | T1          | T2          |
|----|--------------------|-------------|-------------|-------------|
| 1  | Dry plant weight (g) | 166.20 ± 62.72 a | 184.28 ± 77.03 a | 174.97 ± 52.63 a |
| 2  | Plant height (cm)   | 172.95 ± 17.09 a | 180.80 ± 31.70 a | 175.70 ± 21.72 a |
| 3  | Stem circumference (cm) | 6.90 ± 1.02 a  | 7.30 ± 0.80 a  | 7.30 ± 1.03 a  |

Note: (Mean ± st.dev) followed by the same letter is not significantly different at α 0.05 in a row; n = 20.

T0: Without drainage channel, T1: Water channel depth is 30 cm, T2: Depth of drainage water channel is 60 cm.
Table 4. Correlation between Parameters

| No | Parameter           | pH    | C organic | Total N | P2O5 | Exch-Ca | Exch-Mg | Exch-K | Exch-Na | CEC  | BS    | Dry Plant Weight | Plant Height | Stem Circumference |
|----|---------------------|-------|-----------|---------|------|---------|---------|--------|---------|------|-------|------------------|-------------|-------------------|
| 1  | pH                  |       |           |         |      |         |         |        |         |      |       |                  |             |                   |
| 2  | Organic C           | -0.03 | 1         |         |      |         |         |        |         |      |       |                  |             |                   |
| 3  | Total N             | -0.07 | -0.49**   | 1       |      |         |         |        |         |      |       |                  |             |                   |
| 4  | P2O5                | 0     | 0.40**    | -0.02   | 1    |         |         |        |         |      |       |                  |             |                   |
| 5  | Exch-Ca             | 0.2   | 0.05      | 0.03    | 0.11 | 1       |         |        |         |      |       |                  |             |                   |
| 6  | Exch-Mg             | 0.16  | 0.03      | -0.2    | 0.35*| 0.69**  | 1       |        |         |      |       |                  |             |                   |
| 7  | Exch-K              | 0.05  | -0.13     | -0.14   | -0.40*| 0.35*   | 0.22    | 1      |         |      |       |                  |             |                   |
| 8  | Exch-Na             | 0.05  | -0.13     | -0.15   | -0.40*| 0.35*   | 0.22    | 1.00** | 1       |     |       |                  |             |                   |
| 9  | CEC                 | -0.03 | 0.98**    | -0.48** | 0.31 | 0       | -0.058  | -0.13  | -0.13   | 1   |     |                  |             |                   |
| 10 | BS                  | 0.21  | -0.06     | -0.03   | 0.08 | 0.94**  | 0.82**  | 0.51** | 0.51**  | -0.13| 1   |                  |             |                   |
| 16 | Dry Plant Weight    | -0.1  | 0.3       | -0.23   | -0.16| 0.27    | 0.07    | 0.33   | 0.33    | 0.29 | 0.26| 1                |             |                   |
| 17 | Plant Height        | 0.075 | -0.15     | 0.1     | -0.09| -0.09   | -0.14   | 0.09   | -0.14   | -0.08| 0.01| 1                |             |                   |
| 18 | Stem Circumference  | 0.142 | -0.37**   | 0.13    | -0.16| -0.14   | -0.14   | 0.17   | 0.17    | -0.33| 0.05| 0.44**           | 1           |                   |

Note: * Correlation is significant at the 0.05 level
** Correlation is significant at the 0.01 level

Table 2 shows that all soil chemical characteristics data at 0-20 cm depth were not significantly different between T0 (without drainage), T1 (30 cm drainage water depth), and T2 (30 cm drainage water depth). The same result is also observed in 6 soil chemical characteristics data (pH, Ca-exch, Mg-exch, K-exch, Na-exch, and Base Saturation) at a depth of 20 - 40 cm (not significantly different in all treatments). At a depth of 20-40 cm, organic C, total N, and CEC are significantly different between T0 and T2, and available P is significantly different between T1 and T2.

Comparison of chemical soil characteristics between 0 - 20 cm and 20 - 40 cm depth provide results that are quite varied. In non-drained soil (T0), soil pH differed significantly on depth between 0-20 cm (3.51 ± 0.22) and 20-40 cm (3.39 ± 0.22), whereas the depth on soil T1 and T2 were not significantly different between 0-20 cm and 20 - 40 cm. Organic C, exch-Mg, Cation Exchange Capacity (CEC), and Base Saturation (BS) showed a significantly different on depth between 0-20 cm and 20 to 40 cm in all treatments. The value of organic C and CEC at a depth of 20-40 cm higher than 0-20 cm, while the value of Mg-exch. and BS at a depth of 0-20 cm higher than 20-40 cm. exch-K and exch-Na showed no significant difference between the depth of 0 - 20 cm and 20 - 40 cm on all treatments. Total N showed a significantly different between on depth 0-20 cm and 20-40 cm on drained soil (T1 and T2), with total N values at a depth of 0-20 cm higher than 0 - 20 cm. available P and exch-Ca shows a significantly different between 0-20 cm and 20-40 cm depth on non-drained soil (T0) and drained soil at 30 cm (T1), with available P-value and exch-Ca at 0-20 cm higher rather than 20-40 cm.

The results of this research indicate that at 0-20 cm of depth, the drainage does not affect the soil chemical characteristics (pH, organic-C, total N, available P, exch-Ca, exch-Mg, exch-K, exch-Na, Cation Exchange Capacity and Base Saturation) (Table 2). At 20-40 cm of depth, on 60 cm water drainage channel affects the decrease of organic C, total N, Cation Exchange Capacity (CEC), and available P because the drainage on peatland can lead to increasing of pH, decreasing of organic C and total N of soil [26]. The observation result of soil pH that is no different in this research suspected because of the drainage period of 10 months is still not able to affect change in soil pH. The acidity of peat soils is closely related to the content of organic acids, humic acid and fulvic acid [27], and the upper layers of shallow peat tend to have a higher pH than thick peat [28].
The effect of drainage to the decline in soil organic C at 20-40 cm of depth (Table 2) is because of the increased release of CO₂ due to the increased in the decomposition rate of peat [29]. Soil decomposition is carried out by soil organisms [30], especially macro-fauna, such as millipedes, isopods, insects, mollusks and earthworms [31] and microflora (microorganisms) i.e. algae, actinomycetes, bacteria and fungi [30].

The decline in soil organic C will affect other soil chemical parameters. In this study, organic C is highly correlated with available P and CEC (Table 4), with lower organic C values than available P and CEC are also lower. The decrease in organic C leads to a decrease in total N of soil and available P at 20-40 cm of soil (Table 2), caused the decomposition and mineralization of organic matter by microorganisms lead to (1) protein reshuffling to free amino acids, (2) hydrolyzing cellulose to glucose and eventually fermented into lactic acid, ethanol, CO₂ and ammonia [32], therefore total N of the soil decreases. Available P on peat soils mostly found in organic P-form [33], so if there is a decrease in organic C it will be followed by a decrease in available P. Cation exchange capacity (CEC) of peat soil is determined by a negative charge that depends on pH which mostly from carboxyl groups and hydroxyl groups of phenol [1] derived from organic matter, so that if there is a decrease in organic matter or organic C, so CEC does.

The results showed that drainage does not affect the base saturation (Ca, Mg, K and Na) at 0-20 cm and 20-40 cm of depth because the maturity level of peat is relatively equal (hemist), and the availability of Ca, Mg, K and Na dependent on the level of peat decomposition (fibrist, hemist or saprist) [34]. In reclaimed sapric peat there is a decrease in available K levels between 38-50% in waterlogged conditions, whereas in natural peat (fibric) a decrease of available K is 34% on the soil [35], and this corresponds to the content of sapric peat ash that greater than than fibric peat [34]. Base saturation is associated with the availability of Ca, Mg, K, and Na, with low base saturation resulting in the availability of Ca, Mg, K, and Na is also low [34], and indicated by a positive correlation between base saturation and exch-Ca, exch-Mg, exch-K and exch-Na (Table 4).

Table 3 shows that the growth and yield of corn (dry plant weight, plant height, and stem circumference) showed not significant between T0, T1, and T2. Production of dried corn in this study was 1.96 tons/ha (T0), 2.89 tons/ha (T1), and 2.53 tons/ha (T2). The drainage water channel depth up to 60 cm does not affect the growth and yield of corn crops (dry weight, height, and stem circumference) due to chemical characteristics that relatively there is no difference at 0 - 20 cm depth (Table 2). Another thing is also shown by the chemical characteristics of the soil with the growth and yield of corn is not correlated (Table 4). Plant growth is also influenced by internal factors (genes and hormones in plants), in addition to external factors (nutrition, sunlight, soil moisture, temperature, and soil) [36].

4. Conclusion

The arrangement of water depth in the drainage channel on peatland for ten months did not generally affect the chemical characteristics of peat soil on the surface layer (0 - 20 cm). Still, it caused some soil chemical characteristics such as organic C, total N, CEC, and P available soil, at 20-40 cm depth. However, the water depth arrangement of the drainage channel does not contribute to the growth of corn crops. Considering the sustainability of peat as well as the efforts of peat utilization to support the production of corn crops, the arrangement of water depth in the 30 cm drainage channel is the most ideal of the results of this study, given the soil chemical characteristics do not differ between T1 (30 cm drainage water depth) and T2 (water depth of drainage channel 60 cm).

5. References

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