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SIMULATION OF CO_2 EMISSION AND LAND SUBSIDENCE IN RECLAIMED TIDAL PEAT SWAMP IN BERBAK DELTA, JAMBI-INDONESIA

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ABSTRACT: Environmental impacts of agricultural drainage in a reclaimed tidal peat swamp in Jambi, Indonesia are investigated. A 3-Dimensional (x,y,t) model is developed to simulate the drainage-driven CO_2 emission and land subsidence. The initial condition of water table was obtained from a coupled groundwater-canal model. In the first simulation, several scenarios of drainage width ranged from 0.1 m to 1.5 m are analyzed. Model output for 100-year simulation shows that the 0.8 m drainage (e.g. real condition) releases about 794,000 ton of CO_2 or equal to IDR 61.2 billion. In addition, the 0.8 m drainage also causes land subsidence of about 52 cm, and reduces the drainable area up to 62.3%. Note that the impacts are robustly lower (higher) when shallower (deeper) drainage depths are applied. The second simulation uses drainages that are appropriate for particular plants and analyze the selling-profit/emission-loss ratio. Among 16 plantation scenarios, it is found that the highest CO_2 emission and land subsidence is caused by industrial forest (e.g., oil palm). Therefore, it reduces the profit significantly. On the other hand, the food crops, such as paddy field, have higher profit/loss ratios than the industrial forests.

Keywords: peat land, CO_2 and subsidence simulation, drainage

1. INTRODUCTION

A drained peat swamp could release significant CO_2 emission and cause rapid land subsidence due to peat oxidation [1]. However, the method used for calculating the CO_2 emission is still under debate. This study, therefore, propose a numerical method to simulate groundwater flow in peat swamp and estimate the impact of various drainage scenarios.

Recently, a previous study has developed a groundwater model for a tidal peat swamp, which was coupled with open-canal system in 3-dimensional (x,y,t) frame [2]. They named the model as Groundwater-Canal Flow (GCFlow) model. Based on their model, this study introduces a model for simulating CO_2 emission and land subsidence, so-called the Emission-Subsidence (EmSub) model. The EmSub model uses predefined water table map calculated by GCFlow model to estimate the amount of CO_2 loss and subsidence in various drainage scenarios. Based on estimated CO_2 emission and land subsidence, we evaluate the impact of drainage on food crops and various forest scenarios.

2. METHODOLOGY

The study area is located in an irrigated block in Berbak Delta, Jambi, Indonesia, with an area of ±100 ha bounded by two primary canals and two secondary canals (Fig. 1). It is B/C typology class land where always inundated during high tide, or where the water will come only during high tide.

In this study, two main models were developed. The first model is the GCFlow model, which has been developed in our previous study [2]. The second model is the EmSub model, which simulates CO_2 emission and land subsidence. Firstly, the GCFlow model is run for 365 days to get 1-year averaged water table. Outputs from the GCFlow model were used as input for 100-years simulation of the EmSub model. As the land subsides, drainability limit of the land is calculated which is used to reveal "age of usable land" and percentage of land condition in each year. Finally, we calculated the profit/lost ration by comparing the crop productions and profit with CO_2 losses.

2.1 Groundwater and canal flow model

The GCFlow model was used to simulate flows in the irrigation system [2]. It has two main components: (1) open-channel flow system and (2) groundwater flow system. These two components run simultaneously and interact each other. The former uses the basic equation of Saint-Venant and the Manning equation. The latter uses the conservation of mass with assuming 1-layer aquifer system. A designated assimilation technique is used to include the effect of tidal on the water height in the canal. Using a high spatial resolution (10 m) dataset, the GCFlow model can simulate groundwater height accurately. The correlation coefficients with observations are greater than 0.8 for two years simulations [2].

2.2 CO_2 emission and subsidence model

The EmSub model uses horizontal partitions on *X-Y* axis with an annual time-step. There are two main components in the EmSub model, those are the CO_2 emission and the land subsidence. We use a proxy that relates annual average of CO_2 emissions rate per one meter of water table depth. Thus, this component uses the annual average of ground water table as the input. While the component of land subsidence consists of two sub-components; (a) subsidence due to oxidation of peat mass loss (S_E) and (b) physical compaction (also called consolidation) as a result of changes in effective stress in Terzaghi model (S_C) [3]. Therefore, total Subsidence (S) is sum of:

$$S = S_E + S_C \quad (1)$$

S_E uses annual CO_2 emission rate based on the content of C and bulk density of peat. While S_C uses the lowest ground water level as input [4].

The CO_2 emission using the annual groundwater level can be formulated as follows.

$$E_{i,j,k} = c\left(H_{top,i,jk} - H_{i,jk}\right) \quad (2)$$

$$H_{top,i,j,k} = H_{top,i,j,k-1} - S_{i,j,k-1} \quad (3)$$

where E is the rate of annual CO_2 emissions due to peat oxidation, H_{top} is the elevation of the land surface relative to the averaged sea level (L) and S is the subsidence (L). In addition, the coefficient of CO_2 emissions rate in the peat land is defined as c ($ML^{-3}T^{-1}$) (M, L, and T are unit for mass, length, and time, respectively). i, j, k are the indices representing the column, row, and layer, respectively. Hooijer proxy explains that for each depth of the ground water level of 1 m, the rate of CO_2 emissions amount to 90 ton ha^{-1} per year, or 9 kg m^{-3} per year [1, 5]. Thus, S_E is defined as below

$$S_{E,i,j,k} = \frac{E_{i,j,k}\left(\frac{M_C}{M_C + 2M_O}\right)}{\rho_{b,i,j,k} N_C} \quad (4)$$

where M_C and M_O are the atomic weight of carbon and oxygen (kg mol^{-1}), respectively. Meanwhile, ρ_b and N_C are bulk density (L^3M^{-3}) and fraction carbon content of peat (MM^{-1}), respectively On the other hand, S_C consists of primary and secondary consolidation components, which can be calculated with the following equation,

$$S_{C,i,j,k} = L_{0,i,j,k}\frac{C_c}{1+e_{0,j,j,k}} log\left(\frac{P_{0,i,j,k}+\Delta P_{i,j,k}}{P_{0,i,j,k}}\right) + L_{0,i,j,k}\frac{C_\alpha}{1+e_0} log\left(\frac{t}{t_0}\right) \quad \textbf{(5)}$$

where L_0 is the initial thickness of the peat layer, C_c and C_α are the indices for primary and secondary compression (no units), e_0 is the initial void ratio (LL^{-1}), while P_0 and ΔP respectively represent the initial effective stress and change in effective stress due to decrease in ground water level ($ML^{-1}T^{-2}$). Meanwhile, t and t_0 respectively represent the time parameter and the time at the beginning of secondary consolidation. The first term in the right hand side of Eq. (5) represents primary consolidation, while the second term represents secondary consolidation. The primary takes place very quickly (in a few days or weeks), while the secondary is lasting longer in years. In our simulation, the primary is defined as zero because the simulation area was already drained from several years ago. Effective stress is assumed as weight of peat mass minus buoyancy of groundwater.

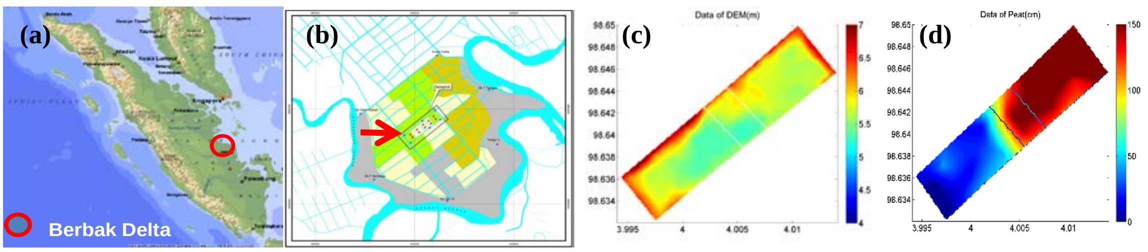

Fig.1 (a) Location of the study area as shown by red circle in Sumatra Island. (b) A-block type land in Berbak Delta pointed by red arrow. Initial condition for (c) DEM and (d) peat depth data are shown.

Table 1. Field variables and parameters in EmSub model

No	Name	Value and unit
1	Annual water table elevation (from *GCFlow* model)	m
2	Peat depth	m
3	Surface elevation (DEM)	m
4	Soil characteristics (general)	
	• Hydraulic conductivity	m day^{-1}
	• Storage coefficient	0.3 m^3 m^{-3}
5	Soil characteristics (CO_2 emission)	
	• CO_2 content	0.58 kg kg^{-1}
	• Couwenberg coefficient	9 kg m^{-2} $year^{-1}$ m^{-1}
6	Soil characteristics (consolidation)	
	• Bulk density	200 kg m^{-3}
	• Particle density	1200 kg m^{-3}
	• Primary compression index	2.2
	• Secondary compression index	0.06
7	Time step output	1 year
8	Drainability limit	
	• Gravity-drainability coefficient	0.00002 km km^{-1}
	• Distance to the river	3 km
	• Elevation of the nearest river	5 m

Effective stress increases when the water level decreases (deeper water table). Effective stress during pre-drainage (or pre-dredging) is calculated based on the lowest ground water level before the drainage, and it is written as

$$P_0 = \rho_b g L_0 - \frac{\rho_b}{\rho_s}\rho_w g H_0 \quad \textbf{(6)}$$

where P_0 is the largest effective stress at initial pre-drainage or pre-dredging ($ML^{-1}T^{-2}$). g is the gravitational acceleration constant (LT^{-2}). ρ_b, ρ_s and ρ_w are respectively the bulk density of peat, the density of peat particles, and the density of water (ML^{-3}). H_0 is ground water level calculated from the water table to the bottom of peat (L).

During drainage, effective stress can increase due to lowering of water table and can be calculated as follows,

$$P = \rho_b g L - \frac{\rho_b}{\rho_s}\rho_w g\left(H_0 - \Delta H\right) \quad \textbf{(7)}$$

P is the largest effective stress after drainage ($ML^{-1}T^{-2}$) and ΔH is the change in ground water level depth (L). By calculating the subsidence, the surface elevation can be simulated dynamically. Note that the simulated subsidence is used for estimating the surface elevation, the peat depth and the ground water level of the next year. Therefore, we may say that our model can simulate the spatial and dynamical process of the water table.

As the peats were drainaged, the land subsidence reduces the elevation until the land is inundated and impossible to be used. The spatial-map of age of usable land can be calculated based on the output of elevation that has been simulated. First, we calculate gravity-drainability limit with Euclidian distance method which is controlled by the nearest boundaries of the river or the sea. Drainability limit (E_{dr}) is calculated as,

$$E_{dr} = E_b + 0.00002D \quad \textbf{(8)}$$

where E_b is the elevation of the nearest river or sea, D is the shortest distance to the boundary of the river or the sea, and the constant of 0.00002 is the gravity-drainability slope coefficient, which means 2 cm/km. If the elevation is lower than E_{dr}, then the land is no longer used and thus reduces the productivity of the crop. This map will be created in a grid format with a unit cell size of 10 m [5, 6, 7].

Size of the usable zone tends to decrease due to subsidence. Agricultural cultivation can only be done on a drainable zone (i.e gravity-drainable zone), by assuming that there is no mechanical pumping performed gravity-drainability when the limit is reached. Therefore, the 100 maps will be generated for annual production of each crop scenario. Combination of 100 maps can be useful to create an "*age of usable land*" map. Similarly, there will be also a spatial summation of the 100 maps of CO_2 emissions, to produce the total CO_2 emissions over the lifespan of the land.

2.3 Profit/loss ratio of crops production

This is a simple model that aims to calculate the ratio of profit/loss of a crop scenario. The model takes into account the potential revenue from the sales profits and potential losses due to emission and/or subsidence, and then calculates their ratio. Calculation period is divided into per-life of each plant and per 100 years. In this model, we assumed that 1 ton CO_2 loss costs about USD 5.5 or equivalent roughly to IDR 77,000 (Indonesian Rupiah).

2.4 Model resolutions and assumptions

The spatial models run with 10 × 10 m spatial resolution. *EmSub* model uses 1-year time step for calculation. In profit/loss model, it is assumed that the crop prices and expenses are constant. For each crop scenario, the harvest time is only once a year. The drainage values for combined-plants scenarios are weighted based on the age of the plant. For example, plant A has life time of 3 months with 0.3 m drainage depth, while plant B has life time 5 months with 0.5 m drainage depth. Scenario for combined plant A and B has annual drainage depth of (0.3 × 3/8) + (0.5 × 5/8) = 0.425 m.

3. RESULT AND DISCUSSION

3.1 Data preparation and model evaluation

Fundamental parameters such as channel map, DEM, peat depth, and hydraulic conductivity are spatially prepared. The scattered data from the observational points are interpolated spatially. Other parameters are non-spatial and assumed homogeneous for all grids. DEM and peat depth data are shown in Fig. 1c and 1d.

The main data for the *GCFlow* consists of hydraulic conductivity, storage coefficient, DEM, daily rainfall, channel structure and manning roughness coefficient [2, 8]. We used daily rainfall data for a period of April 1st, 2012 to March 31st, 2013. Note that we assumed the daily rainfall data for that period also applies to other years on the same date. The output is daily water table (WT), which is, then, annually averaged. For *EmSub* models, data and parameters are shown in Table 1. In particular, it uses annual WT from *GCFlow* and peat depth as the input. Dataset of peat, DEM, and hydraulic conductivity vary spatially. The CO_2 content parameter is based on several findings from similar areas in Indonesia. We use *Couwenberg*'s CO_2 emission coefficient for every 1 meter of drainage depth based on Hooijer *et al*. in [1, 9, 10] and other researches in [5, 11, 12]. The primary and secondary compression indices are obtained by following previous study [13]. Other soil characteristic data are based on *in-situ* observation. Meanwhile, data for crop prices in the market and crop expenses are obtained through direct observation and interview with the farmers.

3.2. Model evaluation from short-term simulation

In order to evaluate the accuracy of the model, we first run *EmSub* model for 4 years and compare the outputs with data from *in-situ* observation. The observed parameter is land subsidence from 2011 to 2014 at 10 observation points, which are uniformly scattered over the domain. Using these data, Table 2 quantifies the model accuracy. It is found that the values of *r*-squared are generally high, which ranges from 0.54 to 0.99. In addition, the results have small root mean square error (RMSE), which indicates reasonable result for subsidence simulation. The model only yields 0.58 – 1.66 cm error.

Table 2 R-squared value and RMSE (cm) of simulated subsidence in the 7 observation points

Stats.	A	B	C	D	E	F	G
R^2	0.82	0.54	0.80	0.57	0.66	0.98	0.85
RMSE	0.67	1.65	1.35	1.66	0.58	1.31	1.34

3.3 Impact of different drainage scenarios in 100 years simulation

3.3.1 Model output in the 100th year simulation

Table 3 exhibits the projected CO_2 emission, land subsidence, and the percentage of usable land cover in different drainage scenarios (selected from 0.1 m to the maximum level of 1.5 m) in the end of simulation (100th year). Deep water table is proportional to strong subsidence and thus affects the land cover. Model shows that scenario of 0.8 m drainage (current condition) potentially releases about 794,000 ton of CO_2 or equivalent to IDR 61.2 billion. In addition, the 0.8 cm drainage

Table 3 Projection of CO_2 emission and subsidence in the 100^{th} year using different drainage scenarios

Drainage scenario (m)	**Result for 100 years simulation**			
	CO_2 emission (1000 ton)	**CO_2 loss (IDR billion)**	**Subsidence (cm)**	**Land condition (%)**
1.5 (*max*)	1407.1	108.3	90.6	35.9%
1.2	1283.8	98.9	82.8	36.3%
1.0	1093.7	84.2	70.9	48.2%
0.8 (*real*)	794.9	61.2	52.1	62.3%
0.6	595.8	45.9	39.6	76.6%
0.4	450.7	34.7	30.5	89.1%
0.3	412.9	31.8	28.1	95.2%
0.2	364.4	28.1	25.1	99.4%
0.1	279.5	21.5	19.8	100%

scenario causes 52 cm subsidence and leaves 62% of usable land cover. The losses become smaller (bigger) in the shallower (deeper) drainage scenario. For instance, the drainage scenario of 0.1 m has potential CO_2 emission of about 279,500 ton (IDR 21.5 billion), 19.8 cm subsidence, and no damage on the land cover. However, the drainage scenario of 1.5 m can result in 1.4 million ton CO_2 emission (IDR 108 billion), 90.6 cm subsidence, and only 35.9% usable land left.

3.3.2 Spatial features

One advantage of the EmSub model is its capability in spatially simulating the land subsidence, emission, and profit/loss ratio. Therefore, detail analysis on the area can be carried out. Fig. 2 reveals spatial distribution of the DEM, cumulative CO2 emissions, peat depth, and age of usable land at 100th year simulation. It is shown that the most affected areas reside on the northeastern block, in which the peat depth in this region is very thick. Since the subsidence is large, the emission is very high and the lifetime of usable land is very short. On the other hand, the southwestern block receives less impact due to thin layer of peat (i.e., less emission and subsidence). Thus, the lifetime of usable land in the southwestern block can reach more than 100 years.

We found that the soils near to canal's boundary will suffer most subsidence and emission (Fig. 2). This is probably due to deeper water table in this location than the water table in the center of block (curvature effect of water table surface). DEM data shows that the lowest elevation area resides in the middle block (tertiary block), which is vulnerable to inundation.

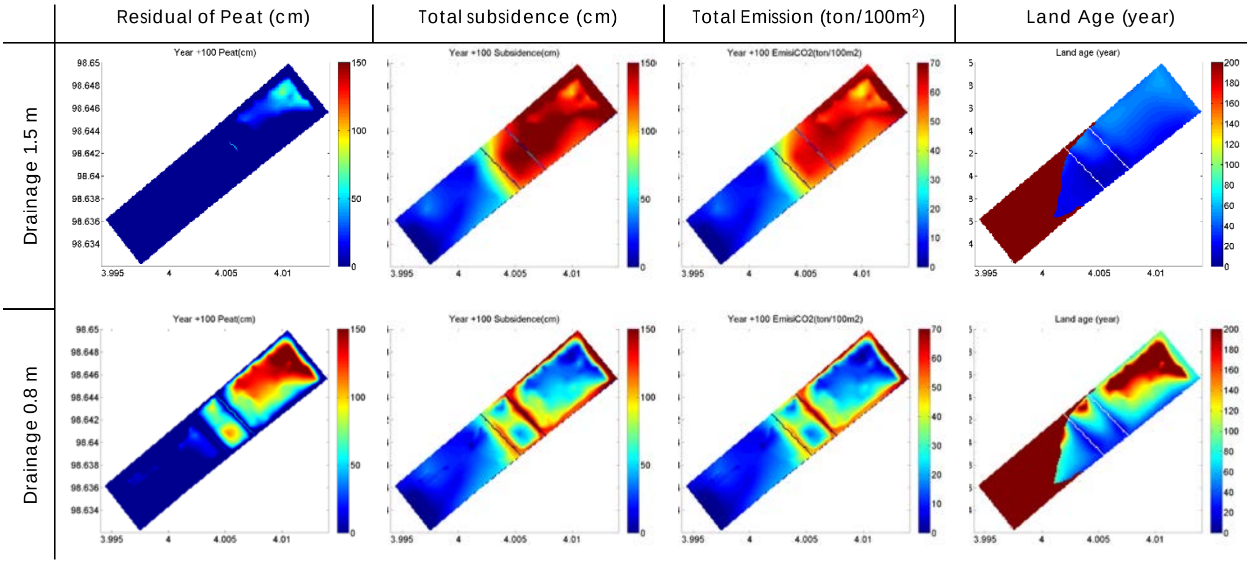

Fig. 2 Model result from 100 year simulation using mean drainage (top row) 1.5 m and (bottom row) 0.8 m. From left to right: residual peat depth (color range(CR): 0-150 cm), total subsidence (CR: 0-150 cm), total emission (CR: 0-70 ton/(100 m^2)), and age of drainable land or land age (simulation extended until 200 years) (CR: 0-200 year), respectively.

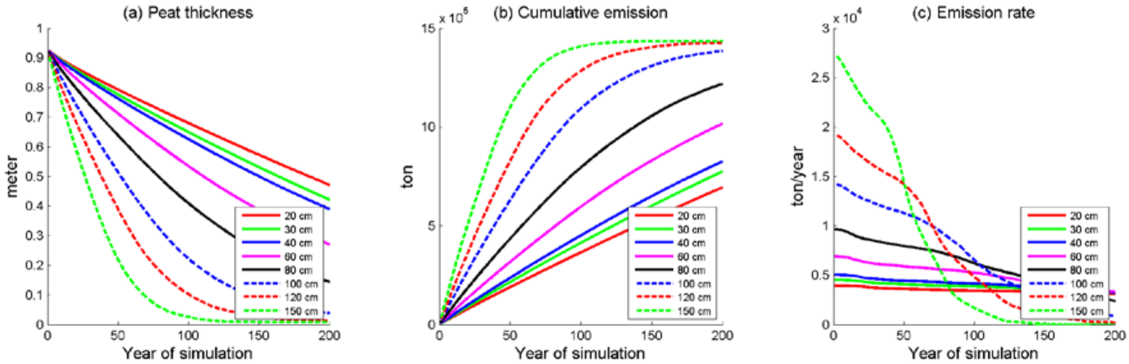

Fig. 3 Time-series of *EmSub* model outputs. (a) peat depth, (b) Cumulative emission, and (c) emission rate per year. The model runs are extended to 200 years

Therefore, the lifetime of this area is very short as clearly noticed in the simulation of 0.3 m scenario.

3.3.3 Time-series

In order to evaluate longer-time projection, the simulations are extended to 200 year, especially to predict thet time when the subsidence and emission will be stagnant due to complete loss of peat. Fig. 3 shows the time-series of peat depth, cumulative emissions, and rate of emission per year. We can clearly see that peat amount is reduced which impacts on the increasing CO_2 emission (Fig 3a,b). Shallow drainage scenarios are seen to have small impact, while deep drainage scenarios show large impact. In the early years, their values increase or decrease rapidly.

After long simulation, their impacts are reduced logarithmically, especially for deep WT scenarios (above 1 m). Therefore, its rate is reduced and stopped in particular year (Fig. 3c). It indicates that only few peat amounts are left (Fig. 3a). For 1.5 m and 1.2 m scenarios, the peat is predicted to disappear around 90th year and 120th year, respectively. However, the shallower WT simulations show that the peat still exists, at least until 200th year in the future. These results suggest that deeper WT scenarios release more CO_2 rapidly, which directly contributes to the speed of global warming.

3.4 Profit/loss ratio for several plantations and crops

In order to evaluate the impact of emission and subsidence to the plantations and crops, we run several particular drainage scenarios for each plant, so-called plant scenario. The information of the plants (i.e., typical drainage depth, age, production, price, and expense) are shown in the Table 4. For example, paddy uses drainages of about 0.1 - 0.2 m depth. Then, in the simulation scenario, we run the model twice using both data so that we obtain the approximate impact caused by paddy. The emission released by plant is considered as the losses, which can be converted into money loss. The amount of crop production is affected by land condition (active usable area that can be drainaged).

Overall, there are 16 plant scenarios (Table 4). Plants in the first group have deep drainage scenario and live for long time, while plants in the second group basically use shallow water table and their age is quite short (shorter than one year). The combined group is created in order to find possibility if we can plant multiple crops in one year. Fig. 4 and 5 show the simulation results in all groups for 100 years simulation-time. Fig. 4 shows CO_2 emission and subsidence and Figure 5 exhibits the profit/loss ratio in each plant.

The plants in the first group release high CO_2 emission (Fig. 4 left, red lines). Among plants in the first group, *acacia* is the highest contributor (795 - 1094 thousand ton), followed by palm oil (596 – 795 thousand ton), rubber (451 – 596 thousand ton), and *jelutong* (364 – 451 thousand ton).

The largest subsidence is also caused by *acacia* with averaged subsidence of 52 – 71 cm, while the smallest subsidence is caused by *jelutong* (25 – 31 cm) (Fig. 4 middle). The percentage drainable area due to subsidence in the last year (i.e., small percentage indicates big damage to land cover) is

Table 4 Configuration of 16 crops scenarios which are divided into 3 groups

No	Plant scenario	Drain Min	Drain Max	Lifetime
	Group I			
1	Acacia	80	100	5 year
3	Oil Palm	60	80	25 year
2	Rubber	40	60	50 year
4	Jelutong	20	40	100 year
	Group II			
1	Paddy	10	20	3 month
2	Corn	30	40	4 month
3	Soybean	30	40	3 month
4	Cassava	30	40	5 month
5	Red Chilli	20	30	4 month
6	Long bean	20	30	2 month
7	Peanut	30	40	3 month
	Group III			
1	1 Paddy + 1 Corn	21.4	31.4	7 month
2	1 Paddy + 1 Peanut + 1 Corn	24.0	34.0	10 month
3	1 Paddy + 1 Soybean + 1 Corn	24.0	34.0	10 month
4	1 Paddy + 1 Cassava	22.5	32.5	8 month
5	1 Paddy + 1 Red Chilli	15.7	25.7	7 month

presented in Fig. 4 (right). Using *acacia* scenario, farmers can only use about 50% area coverage for crop/plantation, while the other 50% is inundated. Meanwhile, the *jelutong* scenario could save the drainable area up to 89 – 99%. *Acacia* lives in the deep drained land of about 80 – 100 cm depth. Palm oil and rubber are also considered using deep drainage of about 60 – 80 cm and 40 – 60 cm depth, respectively. We may suggest that the deep drainages are susceptible and inappropriate to the peat swamp because it could affect the peat substantially, release more CO_2 emissions, and trigger strong subsidence. On the other hand, *jelutong* has been shown to contribute be friendly to the environment (Fig. 4, ID 4). *Jelutong* also lives quite long (Table 4, lifetime). In 100 years, farmers need only 1 time planting, compared to *acacia*, palm oil and rubber that need 20 times, 4 times, and 2 times planting in 100 year, respectively. Finally, Fig. 5 (red line) confirms that *jelutong* gives the highest profit/loss ratio among industrial forests, which is very profitable to be applied. Therefore, *acacia*, palm oil and rubber are less appropriate in the study area and should be avoided. In individual food crops scenarios, corn, soybean, cassava and peanut are the largest contributors of CO_2 emission (413 – 451 thousand ton). The second contributors for CO_2 emission are red chilli and long bean (364 – 413 thousand ton). We found that corn, soybean, cassava, and peanut force land subsidence of about 28 – 31 cm. The lowest emission is coming from paddy (280 - 364 thousand tons). Land subsidence in paddy is also the smallest (about 20 – 25 cm). It is know that paddy needs shallow water table (10 – 20 cm) to live. This may be a reason why paddy contributes very small CO_2 emission and land subsidence.

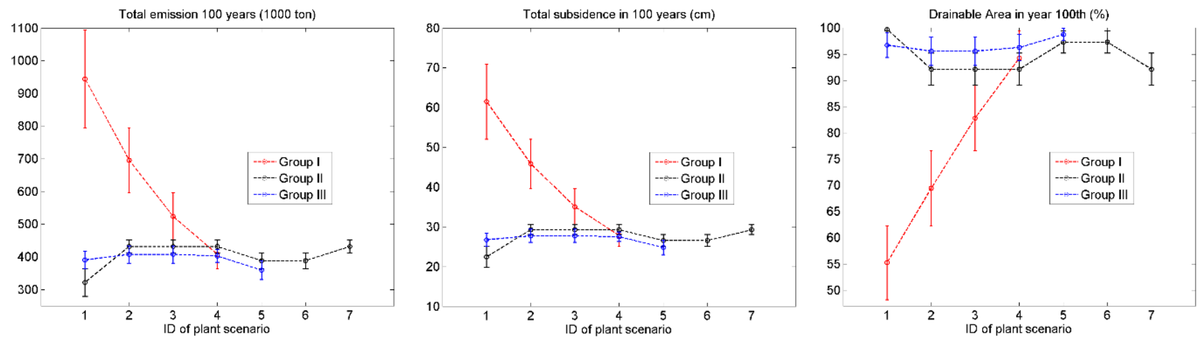

Fig. 4 CO_2 Emission (*left;* unit in 10^3 ton), subsidence (*middle;* unit in 100 years), and land condition (*right;* unit in %) simulated by crop scenarios. Horizontal axis denotes the IDs. The IDs in Group I represent, (1) *Acacia*, (2) Palm oil, (3) Rubber, (4) *Jelutong*; In Group II: (1) Paddy, (2) Corn, (3) Soybean, (4) Cassava, (5) Red Chilli, (6) Long bean, (7) Peanut. Group III has 5 combinations, refer Table 4 to see the combination. The vertical lines denote the maximum and minimum ratio.

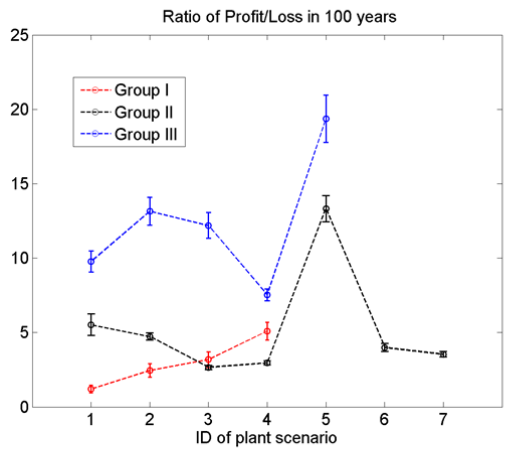

Fig. 5 As in Fig. 4 except for the profit/loss ratio in each plant scenario for 100 years simulation

Generally, food crops scenarios release lower CO_2 emission and cause smaller land subsidence than then the industrial forests scenario. Percentages drainable areas are quite secured in food crops scenario (Fig. 4 right). Farmers should consider changing the forest into food crops in order to both save the environment and stabilize the profit. The profit/loss ratio of paddy is higher than all industrial forest (Fig. 5, black line, ID 1). However, in term of profitable crop, the red chili becomes the most profitable crop (ID 5). This is due to its higher profit-selling opportunity.

In the 3rd group (combined plant scenarios), we intend to maximize the utilization of the peat swamp by creating a combination from two or three types of plants in one year. The results are shown in Fig. 4 and 5 (blue lines). The scenario-2 (paddy-peanut-corn) and scenario-3 (paddy-soybean-corn) release the highest CO_2 emission (381 - 434 thousand tons) and cause the largest subsidence (26.1 – 29.4 cm). The scenario-5 (paddy and red chilli) releases the lowest CO_2 emission (331-388 thousand tons) and causes the smallest subsidence (23 – 26.6 cm). Overall, this group releases the lowest CO_2 and causes the smallest land subsidence, so that it offers the highest profit/loss ratio compare to other groups. We found that the combination of paddy and red chilli results in the most suitable crops from our selection.

4. CONCLUSION

Our research focuses on the projection of an irrigated tidal peat-swamp in the Rantau Makmur village, Jambi, Indonesia, particularly to assess the impact of peat losses due to drainage system. Several drainages scenarios were considered carefully to find the best scenario suitable for the region. In order to quantify the impact of drainage, we develop 3-D (x,y,t) EmSub model. The model can be used to estimate the CO_2 emission due to the peat oxidation, as well as to estimate the subsidence based on soil consolidation and peat losses. This model uses water table input simulated by GCFlow model [2]. Short-term simulation for 4 years shows good agreement between simulated subsidence and the observational data. Therefore, the utilization of this model for a long-term projection may be promising.

The impacts from various scenarios are investigated using 100 years simulation. The drainage depth scenarios are ranged from 0.1 m to 1.5 m (maximum drainage). The model shows clearly that the deep water table causes more CO_2 emission and more subsidence than the shallow water table. In addition, the lowered soils may cause wide-inundated area which is not suitable for plantation. Drainage with 0.8 meter (current condition) potentially releases CO_2 emission as much as 794,000 ton or equivalent to IDR 61.2 billion. In addition, this scenario causes 52 cm average subsidence in such that the usable land left only 62.3% in the 100th year. The effects can be smaller and higher depending on the depth of drainage.

The 10 m spatial resolution allows us to see detail change in the elevation, peat amount, emission, and degraded land. In general, the northeastern part of the area is the most affected region, in which the peat depth in this region is very thick. Since the subsidence is large, the emission is very high and the lifetime of usable land is very short. On the other hand, the southwestern part relatively receives lesser impacts. It is known that the southwestern area has thin peat, so that it releases less CO_2 emission and experiences small subsidence.

In order to evaluate the impact of emission and subsidence to the plantations and crops, sensitivity experiments using selected and combined plantations are conducted. We investigate 16 types of plant scenario for 100 years simulation. In general, the model has shown that the industrial plantation group (e.g. acacia, palm oil, rubber, jelutong) contributes largely to the CO_2 emission and subsidence. This may be related to the depth of drainage. In addition, high CO_2 emission and large subsidence could reduce profit significantly. In particular, the highest rate of the CO_2 emission and subsidence is triggered by acacia, which needs very deep water table.

The impacts caused by food crops group (e.g. paddy, corn, soybean, cassava, red chilli, long bean, peanut) are much smaller. The paddy contributes the smallest CO_2 emission and subsidence. Nevertheless, the highest ratio of profit/loss is obtained in red chilli plantation. We found that the red chilli plantation has shallow water table and very high potential profit. Using combined crops scenarios group, the profit/loss ratio is much higher compare with other group in the 100 years simulation. The combination of paddy and red chilli has the highest profit/loss ratio. We conclude that the combination of crops in a year can increase the productivity of land cover for long term planning.

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