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INCREASING PRODUCTIVITY OF NEWLY OPENED PADDY FIELD IN TIDAL SWAMPY AREAS USING A LOCAL SPECIFIC TECHNOLOGY

Peningkatan Produktivitas Sawah Bukaan Baru di Lahan Pasang Surut dengan Teknologi Spesifik Lokasi

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ABSTRACT

Expansion of new paddy field in tidal swampy area experienced Fe toxicity for rice growth. Specific efforts are required to solve the problem by implementing a proper cultivation technology. The study aimed to increase a new paddy field productivity in tidal swampy areas using a specific cultivation technology. The treatments were five technology packages which were established by integrating the intermittent flooding and drying with various rates of NPK fertilizer, organic manure and lime. The experiment was arranged using a randomized block design with five replications. The results showed that in the dry season, the technology package of intermittent 1 week flooding and 1 week drying with 2 tons lime ha^{-1} and 112.5 N, 22.5 P_2O_5 and 65.5 K_2O kg ha^{-1} was the best treatment as revealed by the increase in rice yield of 237% and the decrease in Fe content of 50%. For the rainy season, the best technology package was intermittent 1 week flooding and 2 weeks drying accompanied by 2 tons lime and 5 tons organic manure ha^{-1}, and 112.5 kg N, 22.5 kg P_2O_5 and 67.5 kg K_2O ha^{-1}. This package increased rice yield of 272% and reduced Fe content of 52%. The best technology package could increase rice yield by 200% over farmer's technology package. Hence, increasing the newly opened paddy field productivity should consider intermittent flooding and drying and appropriate fertilizer dosage. The technology package tested could be adopted in other swampy areas throughout Indonesia with little modification based on local specific conditions.

[**Keywords**: ameliorant, drainage management, iron toxicity, newly opened paddy field, rice]

ABSTRAK

*Perluasan lahan sawah baru di daerah rawa pasang surut menghadapi masalah keracunan Fe untuk pertumbuhan padi. Upaya khusus diperlukan untuk memecahkan masalah tersebut dengan menerapkan teknologi budi daya yang tepat. Penelitian ini bertujuan untuk meningkatkan produktivitas sawah baru untuk tanaman padi di daerah rawa pasang surut dengan menggunakan teknologi budi daya spesifik lokasi. Perlakuan penelitian adalah lima paket teknologi yang dibuat dengan mengintegrasikan penggenangan dan pengeringan secara bergantian dikombinasikan dengan berbagai dosis pupuk NPK, pupuk organik, dan kapur. Percobaan disusun menggunakan rancangan acak kelompok dengan lima ulangan. Hasil penelitian menunjukkan bahwa pada musim kemarau, paket teknologi penggenangan 1 minggu dan pengeringan 1 minggu secara bergantian, dikombinasikan 2 ton kapur ha^{-1} dan 112,5 kg N, 22,5 kg P_2O_5, dan 65,5 kg K_2O merupakan perlakuan terbaik seperti yang ditunjukkan oleh kenaikan hasil panen padi sebesar 237% dan penurunan kadar Fe 50%. Untuk musim hujan, paket teknologi terbaik adalah penggenangan 1 minggu dan pengeringan 2 minggu secara bergantian disertai 2 ton kapur dan 5 ton pupuk organik ha^{-1}, dan 112,5 kg N, 22,5 kg P_2O_5, dan 67,5 kg K_2O. Paket teknologi tersebut dapat meningkatkan hasil padi 272% dan mengurangi kadar Fe 52%. Paket teknologi terbaik dalam penelitian ini dapat meningkatkan hasil padi 200% di atas paket teknologi petani. Oleh karena itu, peningkatan produktivitas sawah yang baru dibuka harus mempertimbangkan teknologi pengairan berselang (*intermittent*) dan dosis pupuk yang tepat. Paket teknologi yang diuji dalam penelitian ini dapat diadopsi di daerah rawa pasang surut lainnya di Indonesia dengan sedikit modifikasi berdasarkan kondisi spesifik setempat.*

[**Kata kunci**: amelioran, pengelolaan drainase, keracuan besi, sawah bukaan baru]

INTRODUCTION

Sustaining rice self-sufficiency and strengthening national food security continue to be the Indonesian government priority in agricultural development through intensification and extension programs (Simatupang and Peter 2008). The programs had successfully increased rice production in the last 5 years. In 2015, for example, rice production reached 75.361 million tons of grain, equivalent to 43.830 million tons of rice, or increased by 4.515 million tons (6.37 %) compared to the production in 2014 amounted to 70.846 million tons of grain (BPS 2016). If the Indonesian rice consumption in 2015 reached 33.368 million tons, there was a surplus of 10.52 million tons of rice. However, the national demand for rice was continuously increasing with the growing population. Indonesian population in 2015 was about 255.462 million and the per capita consumption of rice and other rice needs annually amounted to 124.89 kg (BPS 2016). On the other hands, about 200,000 ha of agricultural land was converted to non-agricultural land annually. Based on these conditions, increasing national rice production is very important to sustain rice self-sufficiency and strengthen national food security (Mariyono 2015).

One effort to increase rice production of 5.22% per year is expansion of agricultural area by opening of new paddy field outside Java, such as in West Kalimantan. Opening of new paddy fields in West Kalimantan has been conducted in several districts occupied an area of 11,269 ha or 67% of the target of 19,000 ha in 2016 (Kantor Dinas Pertanian dan Hortikultura Kalimantan Barat 2016). However, land in this area is dominated by dry land and wetlands which are mostly acidic (Sukristiyonubowo et al. 2011).

Rice cultivation in newly opened paddy fields in tidal swampy land faced some problems especially low soil productivity due to toxic concentrations of Fe, Al and Mn and nutrients deficiencies, especially P, K, Ca, Mg and Zn (Sukristiyonubowo et al. 2013). Nursyamsi et al. (1996) stated that the problems in opening of new paddy fields include Fe and Mn toxicity, water needs to siltation and low soil productivity.

The newly opened paddy fields in tidal swampy land have not formed a plow layer. It is a layer formed under the top soil which is created by the oxidation and reduction processes, washing of Fe and Mn deposited in the subsoil (Suriadikarta and Hartatik 2004). Formation of the plow layer requires a long time of 10-40 years (Kawaguchi and Kyuma 1977). The plow layer typically aimed to reduce drainage losses (Linh et al. 2013).

Opening of new paddy fields should consider technical and non-technical issues. Technical considerations include water supply, drainage and soil chemical properties (CEC, salinity, alkalinity, pyrite), flood hazard and toxic substance concentrations (Fe, Al and Mn) (Ritung et al. 2008). One of the strategic challenges to increase the productivity of newly opened paddy field in tidal area is alleviaton of Fe toxicity and management of site-specific. Specific cultivation technology such as soil amelioration based on the conditions and characteristics nutrients of the land should be applied to control the presence of toxic irons, such as Fe^{2+} (Suriyagoda et al. 2016).

Some studies regarding increasing rice productivity in newly opened swampy land have been done. Sukristiyonubowo et al. (2011) reported that application of urea, SP-36 and KCl at 250, 100 and 100 kg ha^{-1}, respectively, 2 tons dolomite and 2 tons compost ha^{-1} increased the rice grain yield by 1.78 t ha^{-1} in the newly opened paddy fields of Bulungan District. Based on study of Sukristiyonubowo et al. (2012), arrangement of pounding water layers in newly opened paddy fields significantly improved rice grain yield from 3.37 to 4.47 t ha^{-1} with the enhancement of about 0.47–1.10 t ha^{-1}. Further more, Mildaerizanti and Handoko (2016) found that application of integrated crop management, consisted of Inpara 3 and Inpari 30 rice varieties, path row planting (locally known *jajar legowo*) 4:1, 1 t ha^{-1} organic matter, and fertilization based on soil test kit results increased rice yield in newly opened paddy fields at Tambang Emas Village. All those above studies have not particularly shown the comprehensive improvement of rice productivity through drainage management, balance fertilizer application, and giving of ameliorant simultaneously. Therefore, the study on increasing newly opened paddy field productivity in tidal swamps using a location specific technology is important to be conducted. The study aimed to increase rice productivity in newly opened tidal swampy land through drainage management, balance fertilization and giving of ameliorant against iron toxicity.

MATERIALS AND METHODS

Experimental Site

The study was conducted in the newly opened paddy fields in tidal swampy land of Sungai Nipah Village, Siantan Sub-District, Mempawah District, West Kalimantan Province in 2014 dry season and 2015 rainy season. The study site located at 0º 05’ 10’’ SL 109º 12’ 4’’ ES. The typical soil type in this area is Typic Sulfaquents (Soil Taxonomy), silty clay soil texture with soil solumn depth of >150 cm and sulfidic layer depth of 25 – 30 cm with clay sediments (Soil Survey Staff 2014). In the Indonesian soil classification, this soil is grouped as Aluvial Tionik (Subardja et al. 2014). It is generally dominated by slopes of <8 % and altitude between 0 and 200 m above sea level. This soil includes potentially acid sulphate soils that can be classified on shallow sulfidic alluvial soils (Adhi et al. 2000).

Most of the Siantan District, Mempawah Regency is flat (with a slope of 0–2 %) spread extending from north to south coastal areas at an altitude of 0–25 m. In this coastal area, there are many relatively low land areas of the highest tide of sea water so it is prone to flooding. Flood situation is very prone to occur during the high tide, especially in the months that have high rainfall (October–January).

The average monthly rainfall was 5.1–304.1 mm. The highest monthly rainfall occurred in January at 304.1 mm, while the lowest average rainfall occurred in September, reaching 5.1 mm. The number of rainy days was 6–26 rainy days. The highest number of rainy days occurred in January at 26 rainy days and the lowest number of rainy days occurred in September which reached 6 days. Air humidity (relative humidity) was relatively high on average ranging from 80 to 85 %. Average air temperature ranged from 26.0 to 27.8 ^oC. Maximum air temperature occurred in May, July and August at 32.3 ^oC, while the minimum air temperature occurred in April, which amounted to 23.2 ^oC. Average wind speeds were 4.0–5.0 knots (Siantan Climatology Station 2016).

Experimental Design

The study was arranged in a randomized block design (RBD) with five treatments and five replications as presented in Table 1. The plot size was 1,000 m^2 and the total plot was 25 plots so that the overall area was 25,000 m^2 (2.5 ha).

Planting Preparation

Soil preparation was done by no tillage on each experimental plot. The plots were equipped with drainage channel that serves to dry and flood the plots in accordance with the treatments. Lime at 2 t ha^{-1} and organic fertilizer (manure) at 5 t ha^{-1} were given to the plots according to treatments. Inpara 3 rice seedlings were planted on each plot by path row planting system (locally known *jajar legowo*) 4:1. The legowo 4:1 cropping system is an intermittent cropping pattern between four rows of rice plants and one empty row. This cropping pattern is suitable to be applied to less fertile soil conditions such as newly opened paddy fields in tidal swampy land. With this cropping pattern, the plant population reaches 256,000 clumps per hectare or increased by 60% compared to the farmer's usual population (Abdulrachman et al. 2013). Initial fertilization was done on 7 days after planting with the appropriate dose of treatments. The second fertilization was applied at 28 days after planting (paddy out of seedling), and the third fertilization was done on 38

Table 1. Package of cultivation technology tested in the newly opened paddy fields at tidal swampy land.

Treatments	Technology components	Dry season	Rainy season
T0	Intermittent flooding-drying (week)	Naturally	Naturally
	Lime (t ha^{-1})	-	-
	N, P_2O_5, K_2O (kg ha^{-1})	90, 45, 60	90, 45, 60
	Organic manure (t ha^{-1})	-	-
T1	Intermittent flooding-drying (week)	2-1	2-1
	Lime (t ha^{-1})	2	2
	N, P_2O_5, K_2O (kg ha^{-1})	112.5, 22.5, 67.5	86.25, 30, 15
	Organic manure (t ha^{-1})	-	-
T2	Intermittent flooding-drying (week)	1-2	1-2
	Lime (t ha^{-1})	2	2
	N, P_2O_5, K_2O (kg ha^{-1}	112.5, 22.5, 67.5	86.25, 30, 15
	Organic manure (t ha^{-1})	-	-
T3	Intermittent flooding-drying (week)	1-1	1-1
	Lime (t ha^{-1})	2	2
	N, P_2O_5, K_2O (kg ha^{-1}	112.5, 22.5, 67.5	86.25, 30, 15
	Organic manure (t ha^{-1})	5	5
T4	Intermittent flooding-drying (week)	1-2	1-2
	Lime (t ha^{-1})	2	2
	N, P_2O_5, K_2O (kg ha^{-1})	112.5, 22.5, 67.5	86.25, 30, 15
	Organic manure (t ha^{-1})	5	5

days after planting (primordial stage). Harvesting was conducted using a serrated sickle and the harvested grains were then weighed.

Data Collection

Soil sampling was done by drilling the ground at each experimental plot. The soil was then analyzed to determine the soil characteristics and the dosages of lime, fertilizer and ameliorant. The soil samples were analyzed in the laboratory to obtain data such as pH (H_2O 1:2.5), organic matter, N (Kjeldahl method), organic-C (Walkley and Black method), Bray P-1 and exchangeable K, Na, Ca, and Mg (NH_4OAc. pH 7.0), micro-nutrient content of Fe and Al (DTPA extract), as well as texture (pipette method).

Field experiment was conducted in the newly opened paddy fields of tidal swampy land in the dry season and rainy season. Parameters observed were plant height, panicle length, grain weight per panicle 1,000 grain weight, dry grain yield per hectare, and soil Fe content.

Data Analyses

All analyses were carried out on the five replicates. The data were analyzed statistically by analysis of variance (ANOVA) procedure. If the test result was significant, the analyses was continued with the Duncan's test at 5% confidence level. All statistical analyses were performed with R statistic version 3.3.2.

RESULTS AND DISCUSSION

Soil Properties

The physicochemical properties of the soil collected from newly opened paddy field in tidal swampy land are shown in Table 2. The soil reaction was acid (pH 5.94). The acid pH would cause high in reduced Fe (Ritvo et al. 2003). According to Widowati and Sukristyonubowo (2012), reduction of Fe^{3+} to Fe^{2+} occurred in submerged acid soil of newly opened paddy field. Fe content in this soil reached 1167.81 ppm or classified as very high. The high concentration of Fe in the soil solution could cause iron toxicity and harm to plants. It was marked by slow growth and rust spots on older leaves. The critical limit of Fe toxicity to rice planted in tidal area is 260 ppm (Sulaiman et al. 1997).

The newly opened paddy soil had a high nutrient retaining ability which can be seen from the high value of the soil CEC (34.04 cmol (+) kg^{-1}) (Table 2). The high soil CEC was caused by the high clay content amounted to 56.56%. According to Kleber et al. (2015), one causing the high soil CEC is the content of

Table 2. The characteristics of newly opened paddy soil in tidal swampy land of Sungai Nipah Village, Siantan Sub-District, Mempawah District, West Kalimantan Province.

Soil properties	Value	Status[1]
pH H_2O 1:2	4.7	Acid
pH KCl 1:2	4.4	Very acid
Organic -C (%)	2.10	Medium
Total N (%)	0.24	Medium
P Bray I (ppm)	63.6	Very high
Extract NH_4OAc 1N pH 7		
K (cmol (+) kg^{-1})	0.92	High
Ca (cmol (+) kg^{-1})	9.93	Medium
Mg (cmol (+) kg^{-1})	13.98	Very high
Na (cmol (+) kg^{-1})	7.87	Very high
CEC (cmol (+) kg^{-1})	34.04	High
BS (%)	95.98	Very high
Fe (ppm)	1167.81	Very high
Texture		
Sand (%)	2.18	
Silt (%)	41.26	Silty clay
Clay (%)	56.56	

[1]According to Balai Penelitian Tanah (2009).

clay as a source of soil negative charge. Soil mineral fraction that was dominated by clay will lead to the high ability of the soil to store water and nutrients (Ba et al. 2016). Result of analysis of soil nutrient contents (Table 1) showed the very high values for total P (63.6 ppm), Mg (13.98 cmol (+) kg^{-1}) and Na (7.87 cmol (+) kg^{-1}), while the content of P and Ca was medium, each of 0.24% and 9.93 ppm.

Plant Height

The result of analysis of variance showed that the plant height in the T0 was significantly different from those in the T1, T2, T3 and T4 treatments, while the T1, T2, T3 and T4 showed no significant difference in the dry season. This suggests that drying and leaching and provision of ameliorant (lime and organic matter) in the newly opened paddy fields of tidal swampy land in the dry season increased the average plant height of 8.37 cm (Table 3). However, in the rainy season, the plant height of the T0, T1, T2, T3 and T4 was not significantly different. This is because Fe leaching in the rainy season does not take place due to a lot of water in the drainage channel.

Panicle Length

The result of analysis of variance showed that panicle length in T0, T1, T2, T3 and T4 treatments was not significantly different in the dry season, while in the rainy season T0 was significantly different from T1, T2, T3 and T4. This suggests that drying and leaching and provision of lime and organic matter in the newly opened paddy fields in tidal swampy land influenced panicle length in the rainy season (Table 3). In the rainy season, only a little water comes out of the rice fields as much water in the drainage channel, so that more nutrients, lime and organic matter are found in the fields. This can support the plant to grow better as reflected in a longer panicle. Widowati and Sukristyonubowo (2012) stated that lime served as ameliorant that could raise soil pH and increase the supply of Ca and Mg. The newly opened paddy fields require Ca and Mg fertilizer is because the original levels of the nutrients were very low. It is lower than the critical level for finest rice growth, i.e. < 100 cmol Ca kg^{-1} (Dobermann and Fairhurst 2000).

Grain Weight per Hill

Grain weight per panicle in T0, T1, T2, T3 and T4 in the dry season was significantly different. In the T3 treatment consisting of intermittent 1 week drying and 1 week flooding from the time of planting until 30 days before harvest accompanied by 2 t lime, 112.5 kg N, 22.5 kg P_2O_5, 67.5 kg K_2O, and 5 t organic matter ha^{-1} produced the highest grain weight per panicle (27.8 g). The lowest grain weight of 14.74 g was obtained from T0 treatment (Table 3). In the rainy season, T4 treatment consisting of intermittent 1 week flooding and 2 weeks drying from the time of planting until 30 days before harvest, 2 t lime, 86.25 kg N, 30 kg P_2O_5, 15 kg K_2O and 5 t organic matter ha^{-1} provided the highest grain weight per panicle of 26.96 g. The lowest value of 14.64 g was obtained from T0 treatment.

Table 3. Agronomic parameters, rice yield and soil iron content affected by application of different packages of cultivation technology in dry and rainy season.

Treatment	Plant height (g)	Panicle length (cm)	Grain weight per hill (g)	Weight of 1000 grains (g)	Dry grain yield (t ha^{-1})	Fe concentration (ppm)
Dry season						
T0	89.84 a	16.80 a	14.74 a	12.26 a	1.40 a	384 a
T1	98.04 b	22.25 a	22.00 b	19.98 b	2.96 b	307 b
T2	97.48 b	21.07 a	18.60 c	16.02 c	2.25 c	321 c
T3	99.40 b	22.91 a	27.84 d	25.40 d	4.72 d	192 d
T4	97.92 b	22.84 a	25.38 e	23.84 e	3.97 e	279 e
Rainy season						
T0	89.44 a	15.80 a	14.64 a	11.58 a	1.21 a	1168 a
T1	96.24 a	21.88 b	18.10 b	15.70 b	2.58 b	904 b
T2	97.52 a	23.26 b	22.30 c	19.62 c	2.95 c	785 c
T3	97.48 a	23.18 b	25.98 d	23.06 d	3.60 d	886 b
T4	98.64 a	23.52 b	26.96 e	24.82 e	4.50 e	769 c

Numbers in the same column followed by the same letter are not significantly different at 5% DMRT.

Weight of 1,000 Grains

In the dry season, the weights of 1,000 grains in T0, T1, T2, T3 and T4 treatment were significantly different. The highest grain weight of 25.4 g was observed on T3 treatment consisting of intermittent 1 week flooding and 1 week drying from the time of planting until 30 days before harvest accompanied by 2 t lime, 112.5 kg N, 22.5 kg P_2O_5, 67.5 kg K_2O, and 5 t organic matter ha^{-1}. The lowest 1,000 grain weight of 12.3 g was shown by T0 treatment (Table 3).

In the rainy season, the T4 treatment (intermittent 1 week flooding and 2 weeks drying from the time of planting until 30 days before harvest, 2 t lime, 86.25 kg N, 30 kg P_2O_5, 15 kg K_2O and 5 t organic matter ha^{-1}) provided the highest 1,000 grain weight of 24.82 g, while the T0 treatment gave the lowest grain weight of 11.58 g.

Dry Grain Yield per Hectare

The dry grain yield from all of the technology packages tested differed significantly. Application of the package T3 in dry season, i.e intermittent 1 week flooding and 1 week drying from the time of planting until 30 days before harvest accompanied by 2 t lime, 112.5 kg N, 22.5 kg P_2O_5, 67.5 kg K_2O and 5 t organic matter ha^{-1} produced the highest dry grain of 4.7 t ha^{-1} (14% moisture content). According to Widowati and Sukristyonubowo (2012), addition of Ca and Mg in newly opened paddy fields increased rice yield because the plant became more resistant to disease or Fe toxicity. The lowest yield of1.4 t ha^{-1} was obtained from T0 treatment (Table 3).

In the rainy season, T4 treatment (intermittent 1 week flooding and 2 weeks drying from the time of planting until 30 days before harvest, 2 t lime, 86.25 kg N, 30 kg P_2O_5, 15 kg K_2O and 5 t organic matter ha^{-1}) provided the highest dry grain at 4.50 t ha^{-1}. Whereas the untreated control yielded the lowest dry grain of 1.21 t ha^{-1}. The result is in accordance with that reported by Sukristiyonubowo et al. (2011) that application of cultivation technology in newly opened paddy fields produced higher rice grain yield than farmers practices (control). Application of cultivation technology produced rice dry grain of 2.97–4.29 t ha^{-1} while the control was only 2.51 t ha^{-1}.

Soil Fe Content

The level of soil Fe at the dry season in T0 was significantly different from those in T1, T2, T3 and T4 treatments. The T3 treatment consisted of intermittent 1 week flooding and 1 week drying from the time of planting until 30 days before harvest accompanied by 2 t lime and 112.5 kg N, 22.5 kg P_2O_5, 67.5 kg K_2O, and 5 t organic matter ha^{-1} provided the lowest levels of Fe content of 192 ppm (50 %) and significantly different from other treatments. Fe content in T3 treatment was lower than the critical limit of Fe toxicity in IR64 rice plant of 200 mg kg^{-1} Fe. The high level of Fe in the soil can cause iron toxicity to rice plant in tidal area (Lubis *et al*. 2016). Result of study by Zaini et al. (1987) showed that intermittent irrigation can control iron toxicity on newly opened paddy fields. Intermittent watering of 1 week drying and 1-2 weeks flooding from the time of planting until 30 days before harvest increased rice yields by 37-51 % compared with continuous flooding. The highest Fe content was observed in T0 treatment of 384 ppm (Table 3).

In the rainy season, T4 treatment consisted of intermittent 1 week flooding and 2 weeks drying from the time of planting until 30 days before harvest, 2 t lime, 86.25 kg N, 30 kg P_2O_5, 15 kg K_2O and 5 t organic matter ha^{-1} provided the lowest soil Fe level of 769 ppm. The highest Fe content at 1,168 ppm was obtained from T0 treatment. The high soil Fe can caused plant toxicity resulting in poor growth and limited tillering and as a consequence it would decrease grain yield or cause failed harvest (Audebert and Sahrawat 2000; de Souza et al. 2015). Results of the study were in line with that conducted by Prasetyo et al. (2006) who reported that water management with water-logged and dried conditions in recently opened paddy fields decreased Fe concentration by 720–1,882 ppm.

CONCLUSION

Management of newly opened paddy fields in tidal swampy land for rice farming is very specific, especially different water management in the dry and rainy seasons. These conditions require a specific cultivation technology. In the dry season, it is necessary to have intermittent drying (drainage) and flooding for 1 week each, while in the rainy season it needs 1 week flooding and 2 weeks drying. Provision of ameliorant and intermittent drying and flooding for one week each in the dry season increased rice dry grain yield by 237.14 % compared to control. In the rainy season, the increasing grain yield reached 271.90 % with the technological package consisted of 2 weeks drying and 1 week flooding accompanied by ameliorant, and organic and inorganic fertilizer applications.

Productivity of newly opened paddy fields in tidal swampy land could be increased by applying water management and ameliorant such as lime and organic matter. Intermittent flooding and draining are very effective in controlling iron toxicity in newly opened paddy fields in tidal swampy land.

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