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Adaptive Agricultural Practices and Land Use Cycles on Pyritic Sediments in South Kalimantan

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Abstract

The reclamation of potential acid sulfate soils for agriculture involves the danger that pyritic minerals present in the soil will be oxidized and produce unfavorable conditions for plant growth. Pyritic minerals are oxidized when swamp is reclaimed by forest cutting, canal excavation, and destruction of the covering peat layer.

In South Kalimantan, Banjarese people use an "adaptive" agricultural technique to cultivate rice and perennial crops on potential acid sulfate soils. Its characteristic features are as follows.

(1) Drainage is kept to the minimum needed for the reclamation, so as to depress the oxidation of pyritic sediments.

(2) The traditional method of swamp-land rice cultivation is employed.

(3) The secondary *Melaleuca* forest is conserved by the shifting cultivation of rice cultivation with long-term planting and long-term fallowing periods.

This paper presents details of the adaptive rice culture techniques and the cycle of land use in South Kalimantan. The chemical and geomorphic characters of the sediments will be presented in forthcoming papers.

I Introduction

Indonesia has wide areas of coastal swamp that are flat and have good water supplies, and are therefore attractive for development as making paddy fields. Many of the sediments, however, were formed in brackish water environments and contain high amounts of pyritic minerals, their maximum sulfur content reaching 4.7%. In the reduced state, they are not toxic for plants, but, when the stagnant water is drained from them by constructing canals for land reclamation, these pyritic sediments are oxidized and transformed into acidic and toxic materials with high amounts of Al^{3+}, $So_4{}^{2-}$ and Fe^{3+}, e.g., acid sulfate soils.

Attempts have been made to improve acid sulfate soils by liming or by polder dyking to control water levels. But these are impractical because of the huge amounts of lime and costs are involved.

The Banjarese people have developed an "adaptive" technique for rice cultivation as well as for upland crops on potential acid sulfate soils in the swampy areas of South Kalimantan. The characteristic features of the "adaptive" Banjarese agricultural technique are firstly, that drainage is kept to the minimum required for reclamation in order to maintain the plots in the reduced state for as long as possible. This is done by digging shallow drainage canals with simple water gates. Operation of the water gates enables ponding and draining of the rice fields. Secondly, since the

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rice fields remain in a swampy condition, the Banjarese use the traditional cultivation method which was developed in adaptation to the swampy conditions in the Barito River basin. Thirdly, they combine a centuries-old shifting cultivation design with the rice cultivation on the reclaimed swamp lands. The cycle of land use thus established comprises four stages: (1) regeneration of the secondary *Melaleuca* forest, (2) the opening of the forest and the subsequent stable phase of rice cultivation, (3) the transitional phase in which toxic acidity becomes apparent, and (4) the declining phase with the invasion of various grasses, ferns, *Melaleuca* trees and the abandonment of the rice plots.

This paper presents an account of the Banjarese rice cultivation in the coastal zone of the Barito River basin and clarifies their strategy for adapting to the prevailing environments, e.g., swamp forests and potentially toxic soils. This adaptive strategy provides a meaningful contrast to unstable rice production and apparent failure in some transmigration areas in the coastal wetlands of Indonesia.

Brief Description of The Study Area

The study area centers on Karya Tani village in the swampy area of South Kalimantan (Fig. 1). Annual precipitation is about 2,300 mm concentrated on the average in 7–9 wet months (>100 mm/month). The rainy season extends from October through May.

The sediments of this swampy area comprise those deposited in marine, brackish water, and freshwater environments. When the marine sediments were exposed on a sub-aerial surface, they were covered by mangrove forest. Therefore, pyritic sediments occupy most parts of the area. Subsequently, after the final regression about 2,000 years ago, a serial succession of vegetation developed, eventually resulting in a peat swamp forest covering the area. Owing to the high production of organic matter from the swamp forest and the low rate of decomposition of such organic matter under unaerobic conditions, peat accumulated on the surface of the sediments. A soil map prepared by Van Wijk [1951] shows that nearly all of this swampy area was covered by peat about forty years ago.

Related to the reclamation of this area, a report by a local extension worker [Idak 1982] notes that even before 1920 local people had opened farms in the swampy areas near the rivers. Around 1920, extensive land reclamation began; many "upstream" (*Hulu Sungai*) people arrived and planted rubber, coconut, and other fruit crops in the swampy coastal area near Banjarmasin city and around Serapat. However, after rubber and coconut trees had been destroyed by fire, rice became the main crop for economic reasons. Then, when the rice production decreased due to the appearance of toxicity, farmers abandoned the plots and opened new ones in other areas.

From field observation it is clear that stable rice cultivation on acid sulfate soils is possible only where good drainage systems are established, and those are the areas along the Barito River and the Tamban and Serapat canals where the toxic acidity caned away by tide-affected water movements. If tidal fluctuation does not affect the farm, the cultivation becomes uncertain. For example, there are good rice fields in Karya Tani and Pindahan Baru villages, but there are also many abandoned rice fields on poorly drained plots which are covered by ***purun kudung*** (***Eleocharis*** sp.) grass, ferns

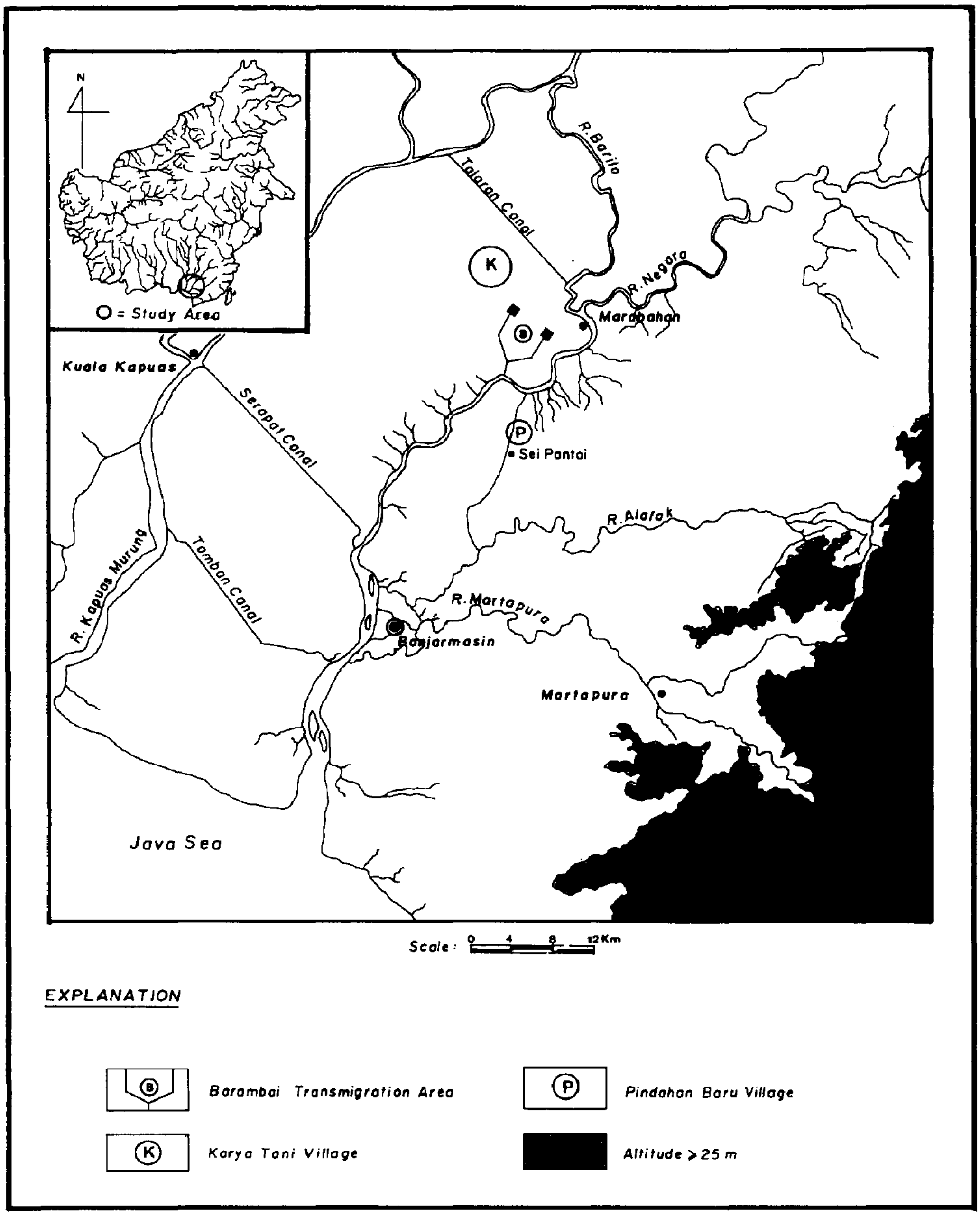

Fig. 1 The Situation Map of the South Kalimantan Study Area

or *gelam* (*Melaleuca leucadendron*) forest. These plots are common in the Sei Pantai area and Talaran areas.

The Karya Tani area, which was opened for rice cultivation in around 1975, after the completion of the Barambai transmigration project, gives an interesting example of a possible strategy to cope with prevailing hazardous conditions. It was opened by a group of Palingkau farmers, who abandoned their plots on Palingkau where they had cultivated rice for about 20 years. A reduced harvest and the development of acidic soils were the main reasons for their migration. Acidity emergence is recognized in the initial stage by the appearance of red-yellow substances, which are gelatinous iron hydroxides, precipitated in ditches and rice plots. With the intensified release of acids in the later stages, the dissolution of these gels results in the predominance of clear water in the ditches.

According to the farmers, the Karya Tani area was initially covered by swamp forest on peat. The thickness of the peat was about 1–1.5 m. The traditional technique of land reclamation was used, by which a strip of forest was first cleared, then narrow ditches were dug by hand (*handil*) using a paddle-like tool (*sundak*). After the land was partially drained, the trees were cut and burned at the end of the dry season. Primary ditches were then enlarged until they reached a normal size of about 2.5 "*depa*" (1 *depa* is about 1.7 m) in width and 0.5 *depa* in depth. A schematic diagram of the canal system and the division of rice plots in the Karya Tani area is presented in Fig. 2.

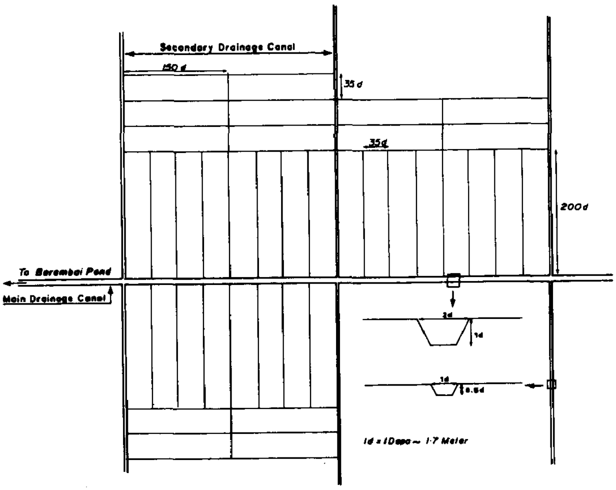

Fig. 2 The Canal System and Division of Rice Plots in Karya Tani Area

After the land had been reclaimed, the thickness of peat decreased sharply because of subsidence and also fire. The people use fire during the land clearing process and also to burn the peat, because rice does not grow well on the thick peat soils. The firing is repeated every year during the dry season until the peat layer is exhausted. Frequent failure to control fires, has caused nearly all of the peat swamp forests to be burned and lost. The devastated areas are covered by regenerated *gelam* forest, under which the present thickness of peat is about 70–100 cm.

The areas covered by peat swamp forest have been progressively reduced through their conversion to rice fields. Over the years rice fields have increased, as many people from other areas arrived and opened farms. At present, rice plots in the Karya Tani area encompass about 2,000 hectares.

II Agricultural Practices in Swampy Areas

1. *Rice Cultivation*

The rice cultivation adapted to swampy conditions is characterized by four points as explained below.

a. Rice Varieties

Late-maturing varieties are generally preferred in the South Kalimantan swampy area. These are chosen because they can tolerate the deep flooding which often happens in swampy coastal areas.

They include *Bayar putih, Bayar Kuning,* and *Lemo,* which require about 10–11 months from seeding until harvest. These varieties even appear in a report from Dutch times. Schophuys [1936] noted that they have a unique character for non-seasonal flowering.

b. Multiple Transplanting

The first seedbeds (*teradakan*) are prepared in October or November. There are two types of the first seedbed: those are prepared on dry soils using dry seeds; and those prepared on the raft using pre-germinated seeds. The first technique is carried out on relatively high places such as roadside verges or paddy field bunds. After grasses have been removed, about 60–70 seeds are placed in a hole and covered with soil. The holes are made with an *asak* or *tetujah* (goat's hoof), being spaced about 10 cm apart. The second technique is often carried out on a raft floating in a stream in areas that are still under water. The rafts are covered with mud, then pre-germinated seeds are sown on the mud surface and covered with additional mud.

When the seedlings (*bibit teradakan*) have developed for 40 days in the dry beds, or 15 days on the rafts, they are moved to the second seedbeds (*ampakan*) in one corner of each paddy plot. The usual width of the *ampakan* is about 2.5 *depa,* but the length is variable. The planting space is about 20–30 cm and usually two *teradakan* seedlings are planted in one hole punched out with an *asak.* Seedlings transplanted from the *teradakan* to the *ampakan* are kept there for 40 days, then transplanted again to the third seedbeds (*lacakan*).

The *lacakan* are prepared inside the periphery of each paddy plot. To allow for tillering, the spacing of seedlings in *lacakan* is larger than in the *ampakan.* The seedlings are kept in the *lacakan* for 60 days, then planted out (*tanam*) in the plots. Two *lacakan* seedlings are normally placed in a single hole, at a spacing of about 30×30 cm. At each transplanting, old, decayed roots are cut off, leaving only a few new root buds. The rice is harvested in August and September, after developing for 4–5 months. By using this multiple transplanting method, the farmers need only 5 kg of seeds to plant a one-hectare rice plot. The sequence of rice transplanting is presented in Fig. 3.

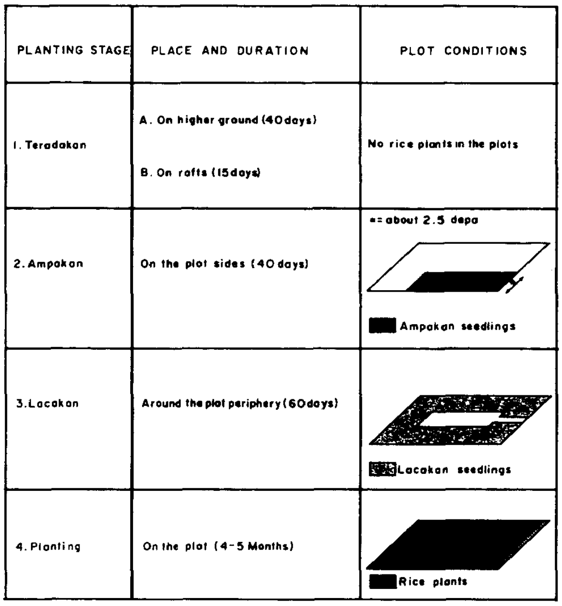

Fig. 3 The Sequence of Rice Planting in Swampy Area of South Kalimantan

c. Water Control

The water level in the plots is controlled by simple water gates which are assembled by pilling up tree trunks or branches in a primary ditch. Similar but smaller water gates are prepared on the secondary ditches dug at a right angle to the main ditch. In early November, the rainy season starts, but the water gates are kept open so that the acids produced during the dry period can be leached out from the rice fields and drained off through the main ditch. In late December, the water gates are sucessively closed by piling up soil blocks and plastering. The black water draining from the *gelam* forest through the main ditch is held up by the water gates and led to the rice fields. Due to the irrigation water and the intensified rainfall as well, the fields start to be inundated. In the

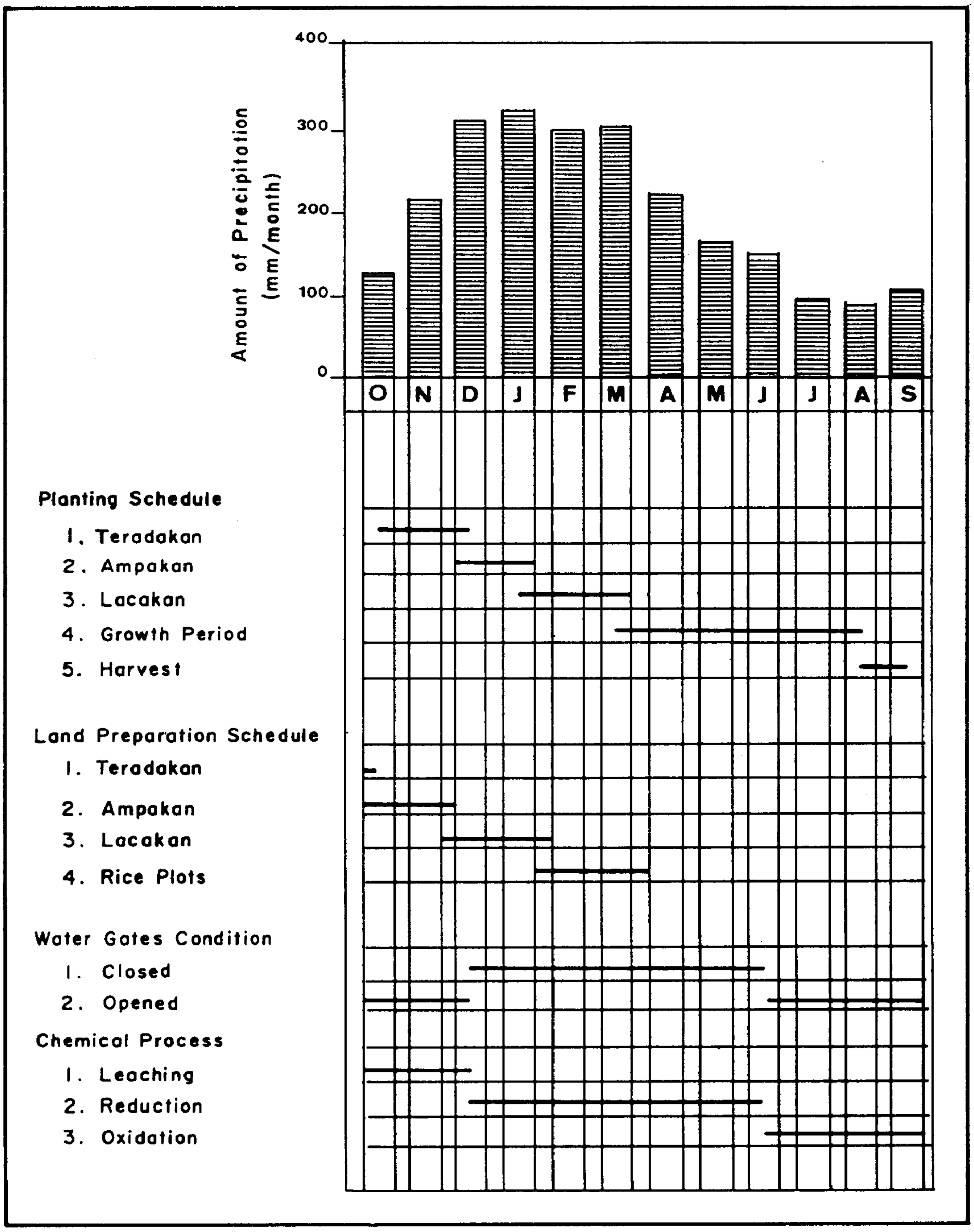

Fig. 4 Relationships between the Amount of Precipitation, Water Control, Planting Time and Land Preparation

inundated fields, villagers prepare the land by cutting the grass and successively transplant their seedlings. The final transplanting is carried out in March. The water gates are kept closed until June. Thus from land preparation to the end of the vegetative phase of plant growth, the plots are kept submerged. The relationship between the amount of precipitation, planting time, and water control are presented in Fig. 4.

d. Land Preparation Technique

Land preparation for the second seedbeds (*ampakan*) is carried out by cutting the grasses with a scythe-like tool (*tajak*) or a long knife (*parang*) and allowing them to decompose. The *parang* is usually chosen if the water is deeper than 30 cm, while the *tajak* is used in shallowly inundated plots. To promote decomposition, the grass cuttings are distributed around the plots and kept under water for 15–20 days. The rotted grasses are then collected into mounds, of which the upper part is above water and the lower part submerged. After 20 days, the mounds are turned over and left for a further 10 days. After this process, nearly all cuttings are decomposed. If the plots are predominantly covered by *purun kudung* (*Eleocharis* sp.) grass, which decomposes very slowly, the cuttings are usually collected and piled up along the bunds.

Land preparation is done step by step, and only as needed. It begins with the preparation of a small area for the *ampakan*. When *ampakan* seedlings are transplanted to the *lacakan*, the entire plots are prepared for the final transplanting (see also Fig. 4).

2. Rice Cultivation and Chemical Processes

Water management in Banjarese rice cultivation involves three processes: 1. drying of plots in the generative stages of rice plants; 2. draining of plots in the early rainy season; 3. continuous inundation of plots after final transplanting until the end of the vegetative stage. The author proposes a hypothetical interpretation of the chemical processes taking place in each stage of the water management practice.

a. Oxidation

When the water gates are opened (see Fig. 4), stagnant water from the plots finds its way into the ditches, and the upper part of the soil is exposed to aerobic conditions. In the dry season, the soil surface is mostly cracked and the soil in plots with pyritic layers becomes highly acidic under aerobic conditions. Red substances are precipitated on the soil and ditch surfaces.

While various authors have proposed different mechanisms related to the production of sulfate ions on drying of pyrite sediments, direct oxidation by aerial contact cannot explain the situation fully; jarosite mottles, the product of the oxidation of pyrite, are often observed on wood surfaces and peaty material occluded inside blue clay blocks. This field observation indicates that the oxidation of pyrite takes place in preferential spots and it is accelerated by agents other than the aerial oxidation. The rate of oxidation in these preferential spots is presumed to be distinctly higher than the rate of overall aerial penetration within the whole clay block. In this context, the hypothesis proposed by Silverman [1967] is attractive in stressing the role of chemoautotropic bacteria (*Thiobacillus* sp.) in increasing the rate of oxidation.

According to Silverman, there are dual mechanisms of pyrite oxidation which operate concurrently. The first is a direct contact mechanism, which requires physical contact between bacteria and pyrite particles for enzymatic reaction. The end-products of this reaction are Fe^{3+} and $SO_4{}^{2-}$. The second step is an indirect contact mechanism where the pyrite minerals are chemically oxidized. The pyrite minerals reduce dissolved ferric ions, then producing ferrous ions, sulfate ions and hydrogen ions. The ferrous ions can be oxidized chemically by oxygen or biologically by the first mechanism to ferric ions. The ferric ions then become the oxidant in the pyrite oxidation reaction.

At higher pH (moderately acid to alkaline), the Fe^{3+} ions will be precipitated as ferric hydroxide [Singer and Stumm 1970]. In the field, ferric hydroxides are recognized as red substances which precipitate on the ditch surface. Therefore, the evidence that we have observed in the field parallels the finding of Silverman [1967] and Singer and Stumm [1970] in the laboratories.

Although the oxidation of pyrite produces unfavorable conditions for plant growth, oxidizing conditions are needed for another reason: that under strongly reducing conditions, sulfate ions will be reduced to H_2S via elemental sulfur. A high concentration of H_2S can damage rice roots in the generative stage. As explained previously, the water gates are first opened when the rice plants reach the generative stage, and the surface soils are brought into oxidizing conditions. This operation is effective in depressing the production of H_2S. Of course, soil oxidation inevitably causes the appearance of acidity, but there appears to be a lag before the toxic acidity is produced. Therefore, by the time the plots become highly acidic, the rice plants have reached maturity.

b. Leaching

The toxic acidity produced in the previous stage is leached away during the first two months of the rainy season (see Fig. 4). The leaching process will be more effective if peat remains in the area around the plots (as in the Karya Tani area), because the peat accumulates rainwater, which is released and continues the leaching process during periods of no rain.

c. Reduction

When the water gates are closed in mid-December, the plots are quickly inundated and gradually the farmers cultivate the plots. Continuous submergence with the addition of organic matter from grass cuttings produces neutral soil and the rice plants grow well.

The submergence and addition of organic matter is suggested to produce favorable conditions for chemoheterotropic bacteria such as ***Desulfovibrio*** sp., which multiply rapidly. These bacteria reduce sulfate ions to elemental sulfur or H_2S [Postgate 1951].

The H_2S then chemically reduces insoluble ferric compounds, producing FeS or FeS_2 [Tuttle *et al.* 1969]. The pH of the soil increases because of the reduction processes, and the solubility of aluminum decreases. From these reactions, it might be concluded that the organic matter supplied by grass cutting plays an important role. It not only provides useful nutrients, but also promotes important reduction processes.

3. *Culture of Perennial Crops*

Perennial crops which are successfully grown on potential acid sulfate soils include coconut, citrus and other fruit crops. These crops are not planted as extensively as rice, but the traditional technique is interesting with regard to hazardous environments and the local means of overcoming the hazard.

The crops are usually planted on bench-like structures (*tembokan*), built by piling up soil and grass, which when complete, measure 1.0 meter square by 0.5 m high. The benches must be left bare for about two years before planting in order for the toxic materials to be leached out.

After planting, the bench surface is covered with a mulch of rice straw or grass or sometimes grass and soil during the dry season. The benches also need to be enlarged as the roots require additional space. According to the farmers, if mulch is not added during the dry season the plants do not grow well.

Although there are insufficient data to explain the role of mulch during the dry season, it is probably important in conserving water, preventing the plants from suffering from water shortage during the dry season. The importance of conserving water on the benches can be summarized as follows: if the water table falls bellow the pyritic layers, the pyrite minerals will be oxidized and produce an excess of toxic materials which affect the plants. Because of evapotranspiration, toxic substances produced at a lower level will be transported by capillary action to a higher level and eventually enter the root zone, with the result that plant growth will be hampered. The addition of mulch will reduce the amount of water lost by evaporation. The toxic materials present at lower levels will remain *in situ*, and not strongly influence the plants.

III Land Use Cycle on Potential Acid Sulfate Soils

Plots reclaimed for cultivating rice on potential acid sulfate soils are less stable than permanent plots on normal soils. As mentioned previously, the farmers leave their plots when the harvest drops sharply, and migrate to other areas to open new plots.

From interviews and field observation, the land use cycle on potential acid sulfate soils in Karya Tani is as shown in Fig. 5.

1. *Natural Forest Stage*

Under steady-state conditions, these areas were covered by natural forest (Fig. 5A), in which the soil surface was largely covered by peat, as reported by Van Wijk [1951]. Under the natural conditions of peat swamp forest, the sediments are water-saturated and pyritic minerals remain in a reduced condition. The water on the peat areas appears black, owing to the high content of humic and fulvic acids.

Natural fires and human activities have gradually destroyed the natural forest, which is now difficult to find in the swampy areas of South Kalimantan. The former natural forest areas are now covered by *gelam* (*Melaleuca leucadendron*) forest.

In earlier periods, land reclamation in this swampy area was carried out with the objective of cultivating perennial crops such as coconut and rubber on the peat soils. But, as mentioned before, because of fires and economic factors, rice has replaced these as the primary crop in this area. The change in land use from forest to paddy field is accomplished gradually, so that the first stage of land use may be called forest and paddy field (see Fig. 5B).

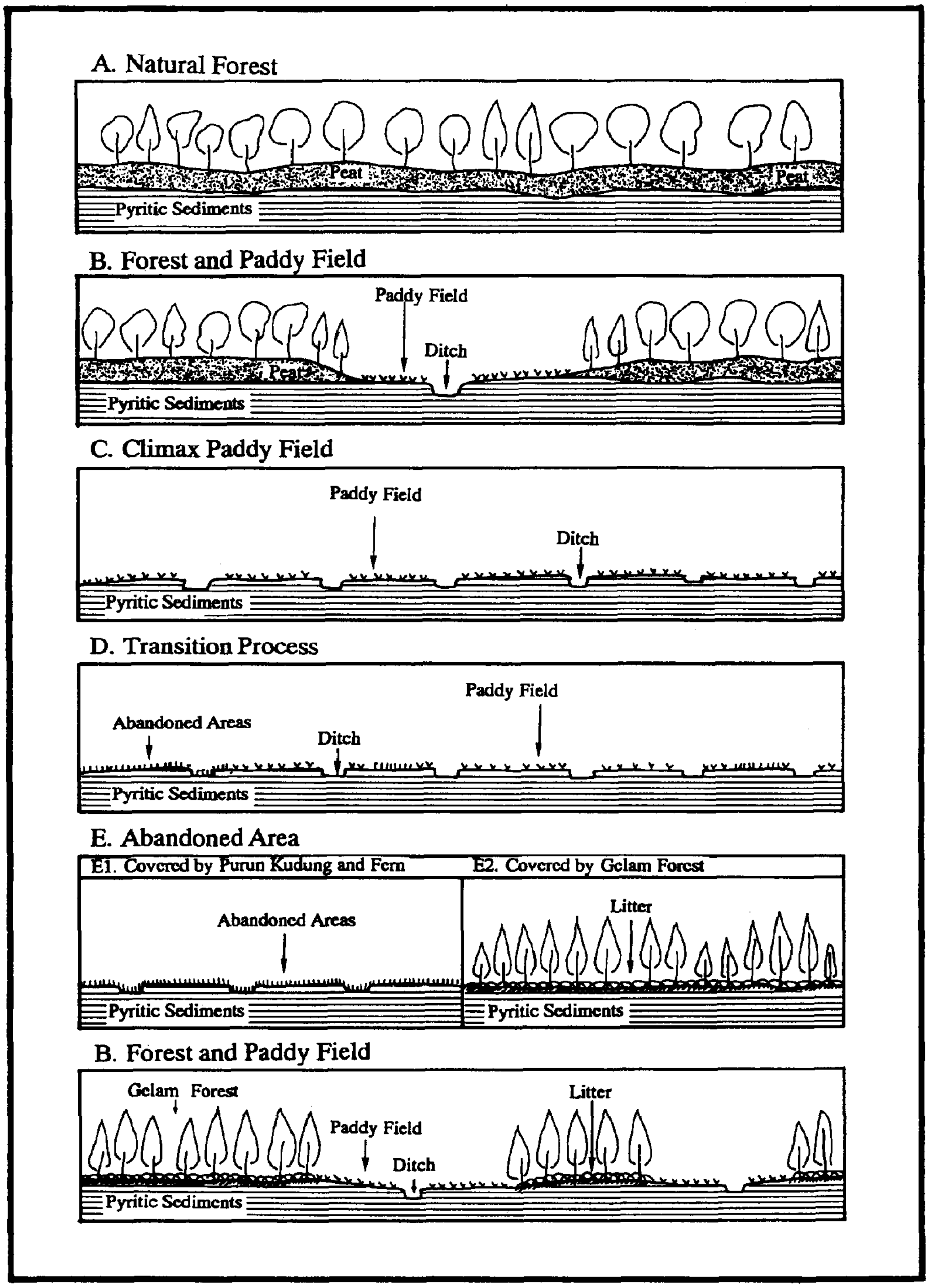

Fig. 5 Sequence of Land Use in Swampy Areas of South Kalimantan

2. *Forest and Paddy Field Stage*

Although under paddy field conditions the thickness of peat is greatly reduced because of subsidence and firing, moderately thick peat is still present in the *gelam* forest. The most important role of this forest in rice cultivation on potential acid sulfate soils is as a reservoir for non-acidic water, which is important in leaching out toxic substances. For example, the Karya Tani area which still maintains *gelam* forest as reservoirs, still has satisfactory rice production (1.5–2 ton unhusked rice/ha). The pH of main canal water at the end of March 1989 is 5.8 and the concentration of sulfate ions is 13.44 ppm. The ditches still work well because they are carefully maintained, and non-acidic water is available from the peat forest. *Purun kudung* (*Eleocharis* sp.), which may be used as an indicator of highly acidic conditions, is absent.

The success of paddy cultivation in this stage might also be explained as the result of thorough leaching, which prevents the development of acidic conditions. As a result, various species of vegetation can grow well during dry season and provide a source of organic matter. This organic matter, as mentioned, is very important in reduction processes and also as a nutrient source.

3. *Climax Paddy Field Stage*

Success in cultivating rice under these conditions invites people to reclaim additional forest areas and develop rice fields. The rice plots become increasingly dominant, and finally no forest remains in the area. This land use is called climax paddy field (see Fig. 5C).

In this stage, the rice yields decrease slightly, *purun kudung* grass appears on the plots during the dry season, and under submerged conditions red ferric hydroxides are precipitated on the soil surface. Because no forest remains leaching water is supplied only by rainfall.

Extensive rice cultivation causes the oxidized area to expand, and the toxic materials produced on oxidation of pyritic minerals to become increasingly abundant. For example, plots at this stage can be found in the Sei Pantai area, where the pH of the soil falls as low as 4.2 at the end of March. Because leaching is limited, the soils gradually become more acidic, and subsequently *purun kudung* grass invade the plots. As mentioned previously, this grass decomposes very slow, and the farmers usually pile it up along the bunds during land preparation. The plots containing *purun kudung* grass therefore contain less added organic matter than those covered by other grasses. This in turn affects the reduction processes and the supply of nutrients to the rice plants, and consequently the rice yield decreases.

4. *Transitional Land Use Stage*

There is a transitional stage from the climax stage to the abandoned stage. Many plots have been abandoned while many are still cultivated (see Fig. 5D). This is called the transitional land use stage.

During this stage, the red iron hydroxide gel on soil surfaces and ditches disappears, and the water becomes very clear and strongly acidic. The pH of water on the Barambai plots at the end of March 1989 was as low as 3.3, and the concentration of sulfate reach 168.9 ppm. Since many plots are already abandoned, and the dense growth of *purun kudung* grass impedes drainage, reducing the usefulness of the ditches.

When many ditches are not functioning, the condition of the rice plots deteriorates because the leaching process cannot occur effectively, and *purun kudung* competes vigorously with the rice plants in the plots. Rice production thus becomes very low or nil. For these reasons, the rice fields are gradually abandoned, and finally all the plots in an area are abandoned (Fig. 5E).

5. *Abandoned Stage*

The abandoned plots and ditches are first occupied by very dense ***purun kudung*** grass, which grows in stagnant water. This vegetation is then succeeded by mixed association of ***purun kudung*** and ferns.

After many more years, this association then shifts to ***gelam*** forest associated with an understory of ferns. Under ***gelam*** forest conditions, the ditches have totally collapsed and the red substances are no longer observed. Because of the poor drainage, it is difficult to accept the idea that ferric compounds have been leached from such areas. Stagnant water with a high organic matter content from litter fall produces favorable conditions for heterotropic organisms including sulfate-reducing bacteria. Under these conditions, it is possible that sulfate ions and ferric compounds are reduced to FeS, FeS_2, and other reduced forms of iron and sulfur.

Under reduced conditions, the soil pH becomes nearly neutral, so that other toxic substances such as aluminum may be precipitated. When the toxic substances have been reduced or precipitated, the abandoned areas can then be used again for cultivating rice. During field observations we noted that many farmers in the Marabahan area had again reclaimed the ***gelam*** forest areas and started to plant rice. The fallowing period is about 20–30 years.

If the ***gelam*** forest remains in the swampy areas, this land use cycle is considered to be sustainable as a stable land use cycle. This land use cycle could be considered a modified form of shifting cultivation with long-term planting and long-term fallowing stages.

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