PROBLEMS IN RECLAIMING AND MANAGING TIDAL LANDS OF SUMATRA AND KALIMANTAN, INDONESIA

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1 Summary

Tidal lands of Indonesia are cultivated already on a large scale. Spontaneous or government-sponsored transmigration and reclamation proceed at a very fast rate at present. The soils of tidal lands reclaimed for rice cultivation in Indonesia are highly permeable and therefore have no or only a shallow water layer on the fields during the peak of the wet season. Yet they have high ground watertables throughout the year. Tidal irrigation is confined only to areas close to the rivers. Deep flooding can occur only where tidal action is weak or absent.

Continuous availability of water without flooding causes profuse growth of weeds, which is a major agronomic problem in tidal lands.

Potential acid sulfate soils occur over large areas, but the upper 30 cm is mostly free of potential acidity. In soils with potential acidity at shallow depth ground watertables should be kept high to prevent strong oxidation of pyrite. An important inherent limitation of the land is the occurrence of organic soils. They are unsuitable for rice when organic surface layers are thicker than 70 cm before reclamation. In these soils maintaining the field in a flooded condition is even more difficult than in clay soils, due to a still higher permeability. Moreover the organic soils are generally low in plant nutrients, they may give toxic organic compounds in stagnant surface water, while the surface soil may dry out irreversibly in the dry season.

Double cropping in tidal lands hardly exists so far. Irrigation in the dry season is limited by scarcity of good quality irrigation water.

Rainfed dry season rice may suffer from drought, despite high ground watertables. A short duration dryland crop, following the wet season rice cultivation suffers from insufficient drainage in most years. Stoplog structures in the canals to maintain high water levels in the drainage canals should help to keep fields flooded. Field bunds with clay cores built after removal of organic surface layers, would have the same effect and should further improve the productivity for rice. Yet some flushing of surface water should be allowed to prevent stagnant water conditions which apparently have an unfavourable effect on rice.

In South and Central Kalimantan experiments with a rainfed double rice cropping system using drought-resistant varieties seem promising. For the tidal lands project, sponsored by the World Bank (IBRD), a short duration dryland crop after rice is proposed. A gradual lowering of ground watertables over the years to improve conditions for the dryland crop is probably necessary. Preliminary observations in farmers fields indicate that such a dryland crop is possible even in potential acid sulphate soils. An additional positive effect of such a system is easier weed control.

A dense network of shallow field ditches with automatic flapgates to control water levels would provide the required dry-season water management. Excessive lowering of the ground watertable at the end of the dry season can be prevented by letting in tidal water through the flapgate structure. Upland tree crops can be grown well in tidal lands. By means of locally developed reclamation and planting techniques, coconut cultivation has become quite successful.

2 Introduction

The Indonesian government is opening up vast areas of tidal swamps for its transmigration program. This paper describes and discusses soils and reclamation techniques in existing tidal lands projects and provides proposals for improvements.

A number of tidal lands projects are sponsored by the World Bank (IBRD). The Directorate of Swamps, Tidal Swamps Reclamation Project (P4S) of the Ministry of Public Works has assigned Nedeco (Euroconsult) to supervise and assist the surveys and design for these projects which are carried out by IPB (Institut Pertanian Bogor), ITB (Institut Teknology Bandung) and UGM (Universitas Gajah Mada, Yogjakarta).

The principle of low-cost development for reclamation is applied in the most recent tidal lands projects, sponsored by the World Bank and is dealt with here. Other systems for rice growing exist, or are being developed, but will not be discussed here. In this regard it should be stressed that the viewpoints expressed in this paper do not necessarily reflect official viewpoints.

Tidal lands can be defined as coastal swamplands where water in wells and canals is subject to tidal fluctuations throughout the year. Further inland, water-levels in the rivers along swamps are so high that, at least during an appreciable part of the year, no daily tidal movements can be distinguished.

The majority of the soils in tidal lands are organic; most of the mineral soils are potentially acid at some depth.

Sizable areas have already been reclaimed, either by spontaneous settlers or by government sponsored transmigrants. The area now in use probably exceeds 500,000 ha (Collier 1979) out of a total of approximately 2×10^6 ha of tidal land in Sumatra and Kalimantan.

Conform present Government policies most of the tidal lands in the transmigration projects will be used for wetland rice. In the projects sponsored by the World Bank only soils with less than 50 cm organic surface layers after reclamation are considered suitable for rice. This is equal to maximally 70 cm peat in virgin conditions. As will be discussed later, thicker peat soils need costly measures for proper water management. Land covered by mangrove is preserved in view of its importance for marine life.

3 Environmental conditions in tidal lands

Under natural conditions tidal lands in Indonesia are covered by a dense fresh-water swamp forest of moderate logging quality. These forests can extend more than 100 km land inwards. Logging or shifting cultivation practices, combined with repeated fires have a detrimental effect on quality of wood and result in a dense forest of gelam (Meulaleuca leucadendron) with an undergrowth of a reed and grass-like vegetation. Mangrove forest occurs only in a 2-3 km wide belt, dominated by brackish water, along the coasts and in narrow strips along rivers and creeks. The climate is characterized by abundant rainfall moderately well distributed over the year. In most places monthly rainfall is below 100 mm only for about 2 months per year.

In the major tidal lands of Kalimantan and Sumatra the daily tidal fluctuations are predominantly diurnal (= one tidal cycle per day). Maximum tidal amplitudes are reached at springtide, minimum amplitudes at neaptide. The mean tidal range along Sumatra's east coast is about 1 m in the extreme south and north of the island and more than 4 m near the Strait of Malacca. In South and Central Kalimantan the mean tidal range is just over 2 m.

The mineral soils and the shallow peats are situated at about mean high tide level and in places up to several meters higher. Because the majority of tidal lands borders rivers having a mean tidal range of over 2 m throughout the year, drainage by gravity is not a problem, even after considerable subsidence due to reclamation.

A variety of soils is found in tidal lands, often in a complex pattern. The most common mineral soils are: Sulfaquents, Fluvaquents, Hydraquents and Tropaquents. Soils of the latter three Great Groups often have sulfidic materials within 1 m depth. Of these the Hydraquents are probably most widespread. The presence of potentially acid (sulfidic) materials is easily seen from the conspicuous pale yellow jarosite mottling and low field pH developed in gray clay dug up from ditches. Results from soil surveys, including analytical data on pyrite, show that indeed sulfidic material is ubiquitous at depths below 50 - 100 cm and occurs still closer to the surface in places (see profiles 1 and 2 and IPB soil survey reports).

Profile 1. Soil: Typic Sulfaquent, fine clayey, acid

No. Profile : 1435, Karang Agung Area
No. Mapping Unit : 9
Soil materials : Surface : Very fine clayey
Subsurface : Fine clayey
Drainage : Poorly drained
Topography : Level
Vegetation : *Melaleuca leucadendron*
Land use : Idle land
Observed water level : + 10 cm

Depth (cm)	Description and chemical data
0 - 20	Grayish brown (10 YR 5/2) clay; ripe; pH H_2O 4.1; C-org. 4.1%; pyrite 0.4%; CEC 32.4 me/100 g
20 - 80	Light brownish gray (10 YR 6/2) clay loam; half ripe; pH H_2O 3.0; C-org. 4.5%; pyrite 1.0%; CEC 31.9 me/100 g
80 - 120	Greenish gray (5 GY 5/1) clay; half ripe; pH H_2O 3.0; C-org. 5.1%; pyrite 1.2%; CEC 33.2 me/100 g

Profile 2. Soil: Haplic Hydraquent, very fine clayey, acid

No. Profile : 44, Mesuji Area
No. Mapping Unit : 11
Soil materials : Surface : Fibric materials
Subsurface : Very fine clayey
Drainage : Poorly drained
Topography : Level
Land use : Shrubs
Observed water level : 0 cm

Depth (cm)	Description and chemical data
0 - 20	Dark reddish brown (5 YR 3/2); fibric materials; pH H_2O 4.6; pyrite 0.2%; C-org. 37.74%; CEC 92.2 me/100 g
12 - 29	Dark grayish brown (10 YR 4/2) with dark gray (2.5 Y 3/0) clay loam; nearly ripe; pH H_2O 5.0; pyrite 0.15%; C-org. 9.64%; n-value 0.81; CEC 35.3 me/100 g
29 - 43	Light brownish gray (2.5 Y 6/2 + 10 YR 6/2) clay; nearly ripe; pH H_2O 4.8; C-org. 5.20%; n-value 0.71; CEC 36.8 me/100 g
43 - 95	Light gray to gray (5 Y 6/1) with greenish gray (5 BG 6/1) clay; half ripe; pH H_2O 5.2; pyrite 0.06%; C-org. 1.18%; n-value 1.3; CEC 33.7 me/100 g
95 - 120	Bluish gray (5 B 6/1) clay; unripe; pH H_2O 3.6; pyrite 1.56%; C-org. 1.92%; n-value 2.3; CEC 33.9 me/100 g

The organic soils are mainly Tropofibrists, Tropohemists, Troposaprists and Sulfihemists. Among the ripened soils, often mottled, the Tropaquepts are the most common. Up to now Sulfaquepts or Sulfic Tropaquepts have not been observed. The absence of sulfuric horizons with jarosite mottling in the profile, may be related in part to the continuously wet conditions due to well-distributed high rainfall. If this is true, Sulfaquents develop to Tropaquents or Tropaquepts, without an intermediate stage of Sulfaquepts or Sulfic Tropaquepts. The absence of a sulfuric horizon does not mean that there are no acidity problems in the tidal lands of Indonesia. But, favoured by the climate, the local cultivation and reclamation practices apparently keep the acidity at an acceptable level.

The nutrient status of the Entisols is quite good, partly because of relatively high contents of 2:1 clay minerals and organic matter. The CEC for mineral soils is mostly in the range of 20-40 me/100 gram soil (pH 7.0) for fine and very fine clays. This probably explains why with proper cultivation and water management, but without fertilizer or nutrient-rich irrigation water, rice yields of over 2 ton/ha have been obtained for about 40 years in tidal lands of South Kalimantan.

In thick organic soils the nutrient status is considerably less favourable and nutrient deficiencies are often a major constraint.

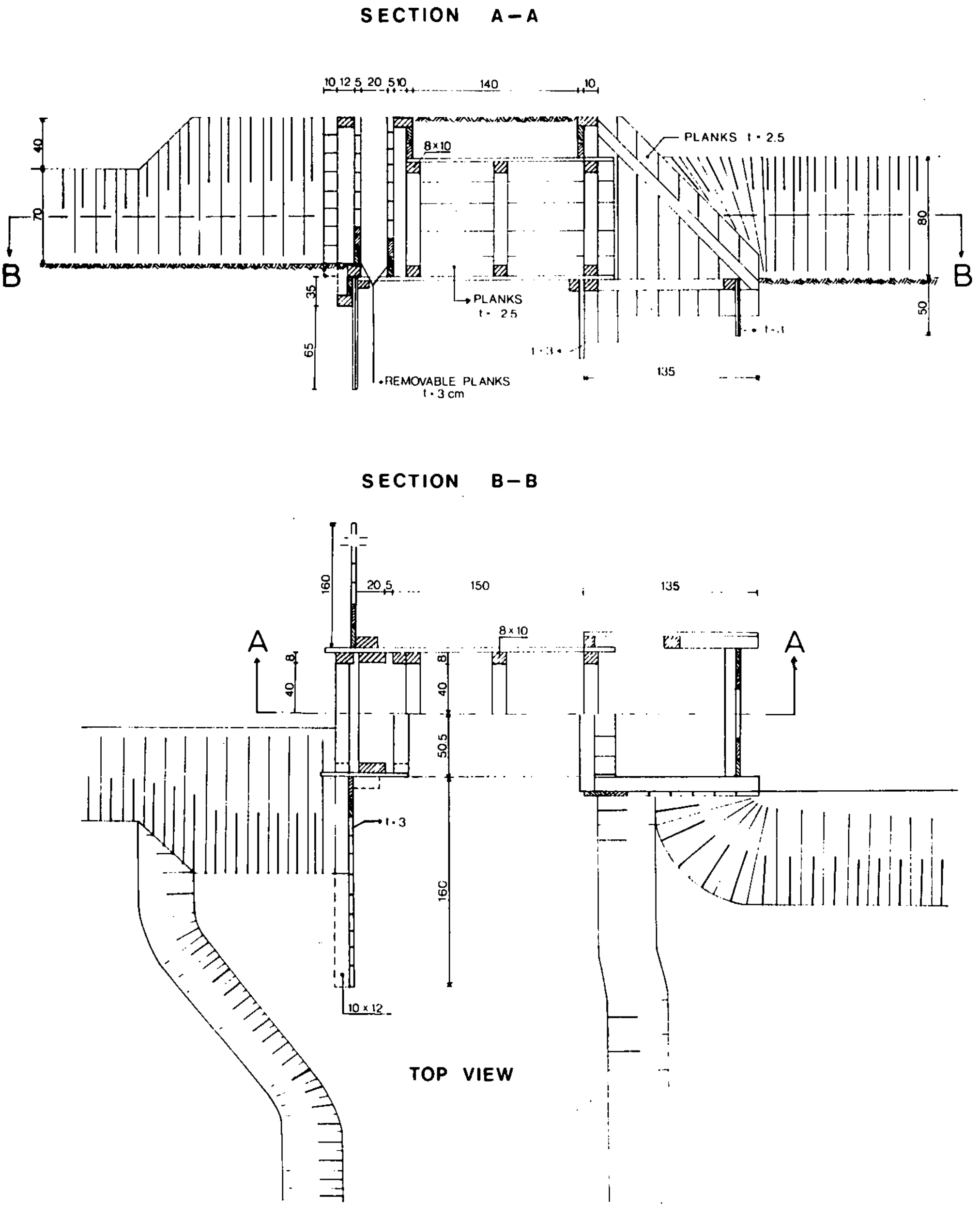
4 Soils and water management for rice-based cropping systems

4.1 Existing water management systems

Most of the reclaimed tidal lands have a so-called open system of water management: the drainage system is in open connection with the tidal rivers. In these conditions most tidal sawahs have a water regime similar to the phreatic regime, described by Moormann and Van Breemen (1978), characterized by high ground watertables throughout the year. Usually there is no or little surface water on the field. This is caused by percolation losses due to high permeability of the soils and by lack of tidal flooding. Tidal flooding is mainly restricted to areas adjacent to rivers and big canals. The percolation losses from the flooded fields are in some schemes in the order of 20-50 mm/day (the ponded water case, Luthin 1957).

In places, mostly confined to the homesteads of transmigrants, upland crops are grown on raised beds and wetland rice in ditches between the beds (sorjan system).

In older settlements in South Kalimantan stoplog structures (Figure 1) or seasonally constructed earthen or wooden dams are used.



SECTION A–A

SECTION B–B

TOP VIEW

Source: LAPI-ITB. 1980

Figure 1. Stoplog structure

4.2 Formulation of problems

4.2.1 Water retention in rice growing season

Wetland rice grows optimally if there is a surface water layer of about 10 cm on the field. The main advantages of the water layer are:

- a buffer for sufficient water supply during dry spells in the growing season. Rice is one of the least drought-resistant food crops.
- simplified weed control by wetland preparation and flooding. Only a limited number of weed species can grow and compete with rice under flooding.
- greater availability of plant nutrients, such as nitrogen, phosphorus and several minor elements (with the exception of zinc and copper). In acid soils the pH of the soil will increase on flooding by reduction.

The absence of a water layer in the tidal lands during the growing season causes a considerable yield depression, and the lack of surface water for rice is a major problem in tidal lands.

However, if measures are taken to keep ponded water on fields, there may arise some problems unless the surface water is refreshed regularly:

- In places that during the dry season have a low pH in the soil (pH < 4.5), on flooding the soil pH will increase by reduction, but at the same time ferrous iron will be mobilized to reach the soil surface and the overlying water, where oxidation of the ferrous iron brings about acidification (van Breemen 1975), which in stagnant surface water may affect rice growth.
- In peat soils as well as mineral soils with a humic surface stagnant water contains organic compounds toxic to rice (Ponnamperuma 1976).

4.2.2 High ground watertables

If tidal movement is allowed in canals, drainage as well as lateral tidal intrusion in the soil takes place. The net result is that watertables stay close to the soil surface. The phenomenon is most pronounced in relatively low-lying areas with a strong tidal movement in the adjacent canals.

Such permanently high ground watertables give rise to major problems.

The most important are:

- weed problems. In the dry season the sawahs are fallow for a long period. When farmers grow modern high-yielding varieties this period may last as much as eight months. High ground watertables, long fallow periods and the absence of flooding during the growth of rice promote abundant weed growth. This aggravates rat problems because the tall weeds in the sawahs provide excellent hiding places for rats.
- drainage problem for dryland crops. To facilitate a palawija crop (= dryland crop following rice) in the sawahs of the tidal lands, lower ground water levels are required for considerable periods of its growing season.

4.2.3 *Acidity hazard*

When the tidal recharge is small, e.g. due to wide drain spacing and little tidal movement, ground watertables may drop to 70 cm below surface during long dry spells and surface layers dry out considerably. This causes strong acidification in Sulfaquents. This problem is at present limited to relatively small areas. Preliminary observations indicate that for most tidal lands in Sumatra and Kalimantan an artificial lowering of ground watertables to 30 - 50 cm will not cause strong acidification; even not in Sulfaquents.

4.2.4 *Organic surface layers*

The organic surface layers are often highly detrimental to rice cultivation. The problem is widespread in tidal lands.

- Irreversible drying of the surface layer in half-decomposed and non-decomposed peat is a major problem. Planting in irreversibly dried peat will often be a complete failure because of insufficient water supply to the plant roots. Also in later stages of the crop, dry spells may cause considerable loss of yield.
- Prolonged flooding in peat soils may cause zinc and copper deficiencies (Ponnamperuma 1976).

- Pyritic layers often underly the organic layers in peat soils. After oxidation of the peat they will be close to the surface and strong acidification is possible.

4.2.5 Cropping systems and availability of water in the dry season

Lack of water in the dry season is a serious limitation for crops. Suitable cropping systems still have to be developed for large-scale application.

- Water balance calculations indicate that a rainfed dryland crop and a rainfed short duration second rice crop will suffer from drought if their growing season extends far into the dry season.
- Irrigated rice requires the availability of good quality irrigation water during dry spells. Development of large-scale irrigation is limited by salt intrusion during low rainfall periods. Construction of cheap storage reservoirs, e.g. in small tributaries, will be difficult, and proper locations for dams are rare.

In South Kalimantan certain local varieties are transplanted two to three times with the growing season extending into the dry season. Although farmers sometimes complain about a considerable risk of drought for this crop, it is apparently grown with success in large areas. It is not clear what causes the good results. Perhaps the crop receives somehow additional water, either by surface flow from adjoining higher areas or from tidal intrusion. Another explanation is that local rice varieties are adapted to a gradual decrease of soil moisture after the surface water has been drained off.

This transplanting system makes two rice crops a year possible, as will be explained in section 4.4).

4.3 Improved water management systems

Better water control on the sawahs is the primary requirement for an increase of food production in tidal lands. The present low level of water management explains failures to improve yields of rice and other crops. The raised bed system (sorjan system), introduced by the Javanese

transmigrants, provides a major improvement of water management; with better drainage for upland crops and reduced percolation losses for rice. However, the sorjan system has two important disadvantages. First much labour is required for construction of the beds, therefore farmers limit the system to homeyards and nearby sawahs. Second, during the construction of beds, potentially acid soil in the troughs is exposed to the atmosphere and acidifies with harmful effects on rice.
For the projects sponsored by the World Bank a less labour intensive system is proposed. It is discussed below.

4.3.1 *Maintaining water layers on sawahs*

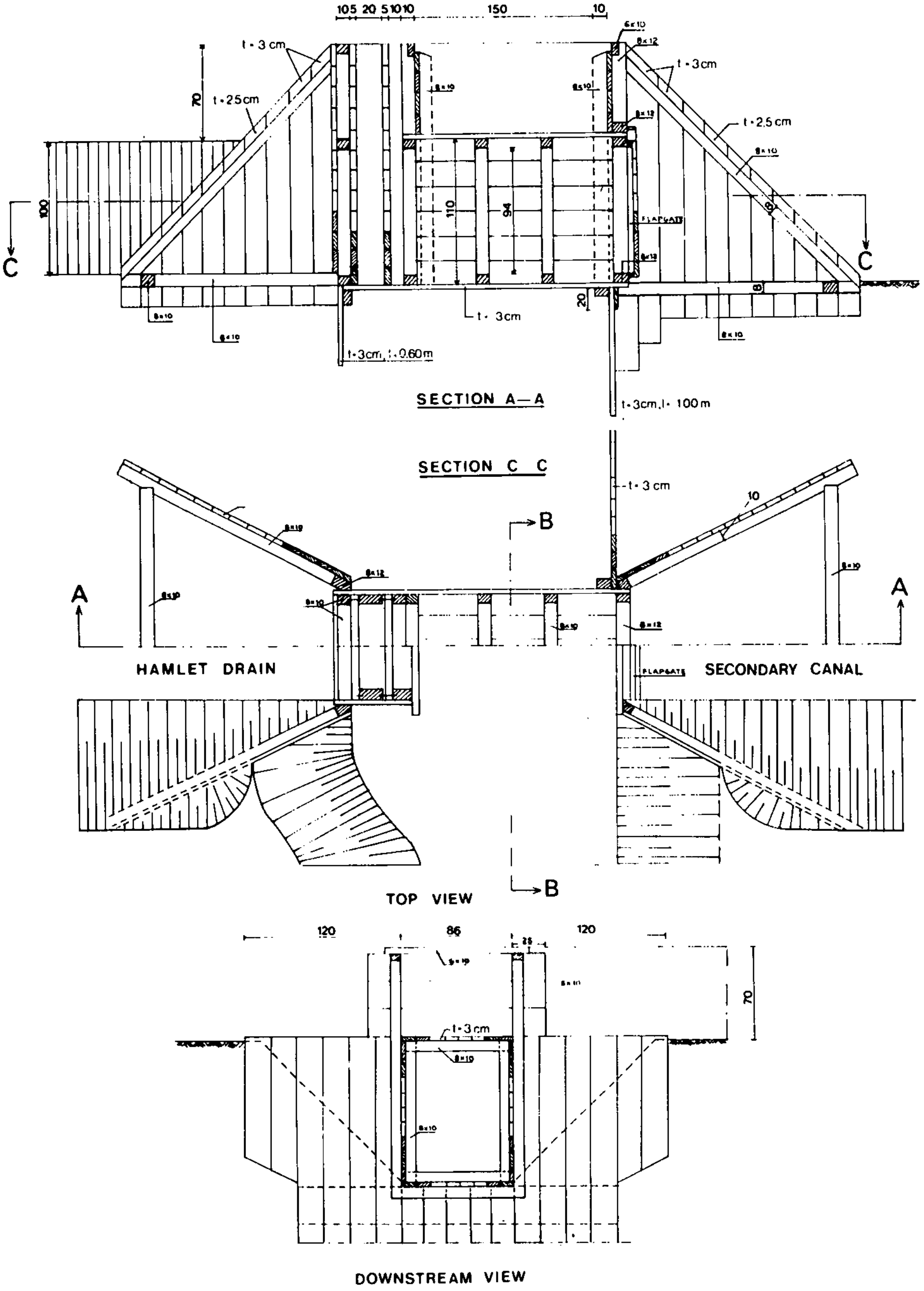
In general, rainfall is sufficient for one rice crop per year including some extra flushing of surface water, provided that percolation losses do not exceed 1 - 2 mm/day. The percolation losses can be reduced to this level by the following measures:

- Keeping adjacent water levels in the drainage canals of the sawahs high. This can be accomplished by the construction of stoplog structures (see Figure 1) in the tertiary or secondary canals. Water levels on the sawahs are regulated by means of the stoplogs. The location of such stoplog structures is determined by the local topography and the need for well-drained hamlet areas.
- Field bunds around sawahs will only work properly if any organic surface layers have been removed before construction of clay bunds. The costs to construct such bunds in thick peats are a major limiting factor of these soils for rice cropping.
- Large percolation losses are likely to occur at the boundary between sawahs and areas without surface water (fields under upland crops, homeyards, etc.). Although still in an experimental phase, those losses may be reduced by placing plastic sheets vertically until 1.5 m depth along boundaries. Alternatives to the plastic sheets may be a wide uncultivated strip, or deep ripping of the subsoil and the subsequent compaction of the soil material at boundaries.

4.3.2 *Control of ground watertables*

In the low-cost simple technology approach adopted in the transmigration projects, control of ground watertables can be obtained by digging of small field ditches and the construction of automatic flapgates ('pintu klep') by farmers. The ditches should be 30 - 90 cm deep, may have vertical side slopes and should be between 20 to 80 m apart. Flapgates in secondary or tertiary canals must always be combined with stoplog structures to control the water levels upstream of the flapgate structure (see Figure 2). Low dikes are required along watercourses with tidal movements.

In areas below highest tide levels and with strong tidal movements in canals, an artificial lowering of the ground water is obtained only by a flapgate in combination with low dikes. The tidal influence can be restored by the opening of the flapgate structures. In the presence of tidal influence many small field ditches will keep the ground water levels high in sawahs, even during long dry spells.



Source: LAPI-ITB 1980

Figure 2. Flapgate structure

4.4 Improved cultivation techniques

To optimize the production in the low-cost simple technology approach a number of agronomic recommendations are suggested.

4.4.1 Water layer on sawah (wet season)

Before planting rice and at the end of the growing season, toxic compounds should be leached by subsurface drainage and surface flushing after a period of saturation and flooding. During the growing season water layers on the sawah should be maintained at a constant level of 10 cm by means of stoplog structures.

4.4.2 Artificial lowering of ground watertables

Controlled lowering of the ground watertable during part of the year has the following advantages:

- A palawija (dry) crop can be grown in sawahs.
- During fallow periods weeds can be burnt more easily, which facilitates both weed and rat control.
- Alternating periods with flooding and with a relatively deep watertable will alter the environmental conditions for weeds and should reduce the number of weeds that compete with rice. This is important if short duration rice crops are grown.
- Irreversibly dried peat is easily burned after lowering of ground watertables.
- In peat soils toxic organic compounds are oxidized and nitrogen, copper and zinc will become better available for plants.

Sudden exposure to air of underlying pyritic layers is a hazard and a gradual lowering of watertables is advisable. This is particularly true where peat has been burnt.

4.4.3 *Acidity control*

So far Sulfaquents were found only in land below high tide levels. Under these conditions tidal intrusion is relatively easy. Acid or saline water entering fields by tidal intrusion or tidal flooding probably has no or little effect on the following rice crop.

In Sulfaquents, watertables must be kept high in periods of extreme drought, and leaching of toxic compounds, including free acids, after oxidation periods is important.

4.4.4 *Weeding and puddling*

Weeds in tidal lands are mainly controlled by slashing them during land preparation. The weeds are often collected in heaps and later spread over the land.

In mineral soils puddling reduces percolation losses and controls weeds. At present only zero-tillage or light superficial tillage are carried out by farmers in tidal lands. Use of draft animals is difficult because of the soft soils and the many large tree remnants at shallow depth. Perhaps the high permeability of the surface layer is important for leaching of toxic compounds. Intensive puddling could lead to a strong decrease of this permeability. Long-term trials should be conducted to assess whether puddling offers advantages for tidal lands.

4.4.5 *Doubling cropping systems*

Double cropping of rainfed rice is possible if two crops can be grown within about 9 consecutive months. Locally in S-Kalimantan, the two-three times transplanted, traditional variety is preceeded by a modern short-duration, high yielding variety on a small part of individual farms. The availability of labour is a major constraint for this cropping system, especially between harvest of the first crop and transplanting of the second crop. Experiments are carried out with a less labour intensive double cropping system involving broadcast rainfed high yielding varieties. This method looks attractive and may be promising;

comparable experiments are carried out in the Philippines, but for different land systems (Morris and Zandstra 1979). However, high inputs for pest and weed control are required for this cropping system. At present a palawija crop after rice may have better prospects. This rotation would involve periodic lowering of the ground watertable, which would further facilitate pests and weed control. Moreover, the cropping system rice-palawija is less labour-intensive which makes it more favourable for tidal lands under the present conditions.

5 Reclamation and water management for upland tree crops

Extensive tracts of tidal lands are definitely unsuitable for rice due to the presence of deep peat. However, coconut can be grown successfully on soils with, in virgin conditions, 1.5 - 2.0 m of peat over clay. Experience in Malaysia shows that also oil-palm has a considerable potential in tidal lands. For mineral soils and shallow peats yields of both tree crops are in general 20-40% higher than in upland areas. But in peats of about 1.5 - 2 m thickness yields will be about the same as for upland areas, provided proper drainage is applied.

Successful reclamation methods for coconut in tidal lands of Indonesia are the raised bed system (Banjarese method, South and Central Kalimantan) and the drainage system (Buginese method used in Rian, Jambi and West Kalimantan). In the *raised bed system*, perpendicular to a main canal with a strong tidal movement, ditches are dug in open connection with the main canal. They are spaced 50 m apart and are up to 1 m deep. Coconut is planted in an 8 × 8 m grid on mounds. In the course of seven years the mounds are connected with each other, developing into a raised bed-trough system. In the first two or three years the coconut is intercropped with a (poor) rice crop during the wet season. This rice crop probably suffers from acidity in many cases. No adverse effects are noted for the coconut and after a few years also crops like coffee do well on the raised beds. The main disadvantages of the system are the laborious construction of the raised beds and the need for continued maintenance due to subsidence of the beds.

In the *Buginese drainage system*, the land is drained by preventing tidal intrusion, using flapgate structures and low dikes and by constructing a dense network of shallow drains. The flapgate structures are often of the culvert type (= polongan klep), made of wood. Watertables are gradually lowered by deepening the ditches. To control the water levels in the canals, stoplog structures are required. In the first years the watertables in the soils are kept at about 30-40 cm below surface, later at 60-70 cm depth. In clay soil, coconut is planted at very shallow depth, while some soil is added around the nut, forming a small mound. In peat coconut seedlings are planted in 40 to 60 cm deep holes and are covered by peat to compensate for future subsidence. From the first year of reclamation onwards, coconuts are interplanted with upland crops, including maize and bananas, even in Sulfaquents. In later years only the perennial crops prevail. In the first years shallow drainage apparently does not harm the crops. Presumably the higher nutrient status of the virgin soils compensates for adverse effects of drainage. This has been noted in Surinam too (Kamerling 1974).

The drainage system is far less labour-intensive than the Banjarese raised bed system, both initially and later during maintenance.

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