REVIEW OF WATER MANAGEMENT ASPECTS
PULAU PETAK, SOUTH KALIMANTAN, INDONESIA

Mission Report 39
Research Project on Acid Sulphate (Sulfate) Soils in the Humid Tropics

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August, 1990

On website www.waterlog.info

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1. HYDROLOGY, SOILS AND AGRICULTURE IN PULAU PETAK

1.1 Topography, tides and land use

The island of Pulau Petak (fig. 1.1.1), near the town of Bandjermasin, is about 100 km long and 30 km wide. Its topography is flat with no appreciable slope from the NW to SE (i.e. parallel to the coast line), and an upward slope of 2 cm/km from the SW to NE. Owing to the large transport capacity of the rivers surrounding the island, flooding of the island during periods of high discharge seldom occurs.

The hydrological conditions of the island are mainly determined by the topographic levels, the tidal movements and the seasonal rainfalls. The first two factors determine the land categories (0, A, B and C).

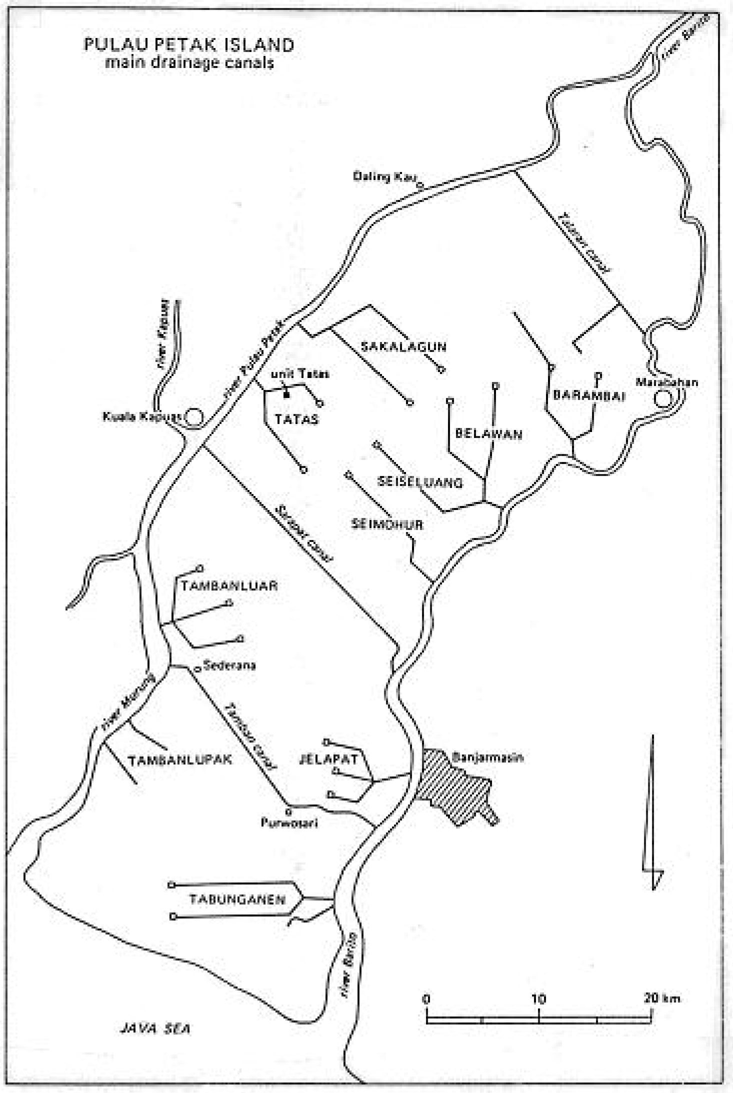

Figure 1.1.1 The island of Pulau Petak

Land categories 0 and A

The South of the Tamban canal, that runs through the southern part of the island, part of the land surface id found below mean sea level. This land (of category 0) is almost permanently drowned, the water is brackish and it is partly forested with mangrove and nipa-palm.

The land with surface level between the mean sea level and the maximum of the neap tide is called category A land (fig. 1.1.2). The maximum level of the neap tide occurs during the wet season when the rivers have a high discharge.

Due to the presence of large rivers, the tidal water in the category A land is usually fresh, but in the dry season it may become brackish.

As a result of the continuous wetness of the category A land the problems associated with sulfuric acidity are limited. The agricultural land use consists mainly of lowland rice growing as other crops do not produce well. Sometimes even the rice crop is risky due to elevated water levels in the field, as was experienced in part of the Tabunganen experimental fields. Therefore, fisheries and forest exploitation are also important rural activities here.

The mapping boundaries of category 0 and A land are not exactly known, as the penetration of the tidal waves into the interior of the island depends on the geometry of the natural creeks and artificial canal systems. For this reason, lands with the same surface elevation in different parts of the island may come in different categories.

Land category B

To the NE of the Tamban canal the tidal movements are mainly apparent in and around the rivers and main canals. In the smaller canal systems in the island’s interior the tides are hardly noticeable. Much of the land to the NE of the Tamban canal near the main waterways come under category B (fig. 1.1.2), i.e. its surface elevation is between the levels of the maximum neap tide and the maximum spring tide. The exact boundaries of the B land is, like those of the A land, are difficult to outline. The categorization is further complicated by topographic variations in the order of 30 to 50 cm. The variations are mainly determined by the presence or absence of remnants of peat layers that must have originally covered the major part of the island, but that have been destroyed by fires. The peaty soils that are still present have a somewhat higher elevation than the mineral soils from which the peat cover has disappeared.

Many of the peaty soils are used for tree crops (coconut, *rambutan* or *leechee*, citrus, banana, coffee, *nanka*, rubber, etc.) interspersed with annual upland crops (cassava, ananas or pineapple, sweet potatoes etc.) and lowland rice fields (*sawah*’s).

When the elevation of the land is not high enough, the *sorjan* (raised bed) system is introduced for the tree crops and upland crops, whereas the rice is planted between the *sorjans*.

The productivity of the rice crop in the peat land is not high (2 t/ha or less), but this is enough for home consumption. The production of rice on mineral soil is not high either (3 t/ha, yields as low as 1 t/ha have also been recorded on account of the

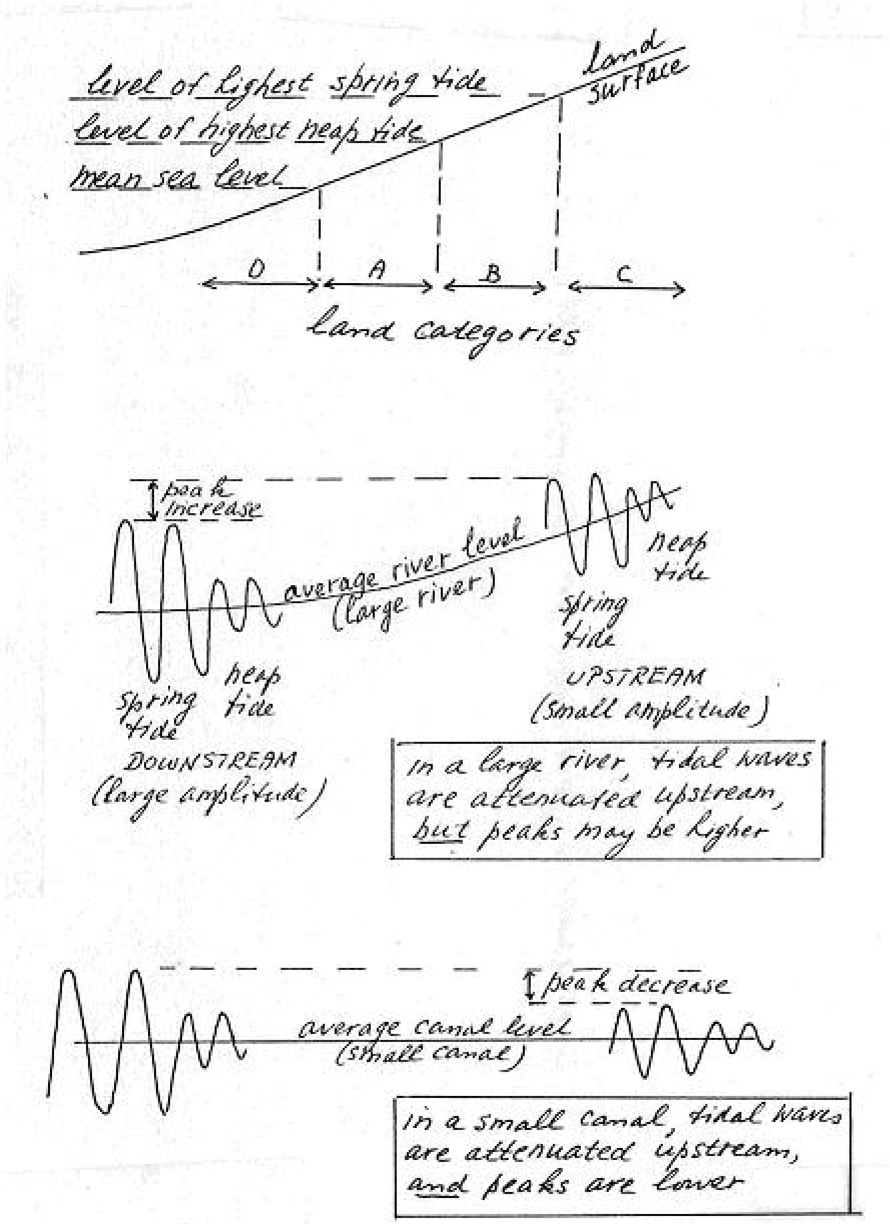

Figure 1.1.2 Land categories in relation to tidal levels

prevalence of sulfuric acidity problems). Sometimes the rice production is not sufficient to recover the costs of the inputs. Therefore, the input level is usually low.

In principle, the land of the B category can be irrigated during high spring tide, which occurs during a period of 4 days every two weeks. Hereby it must be taken into account that the high spring tide level is higher during the rainy season than during the dry season since the river levels are on average higher during the former than during the latter season. Further, the irrigation possibility is higher near the rivers and main canals and it reduces towards the interior of the island, where the tidal movements are attenuated. In general, the farming population makes little us of the irrigation possibilities.

During low tides and during the prolonged periods outside the peaks of the spring tide the rivers, creeks and canals function as drains (chap. 1.3). In the interior of the island, the area density of the water course system is strongly reduced and the water level in the system is relatively high, so that here rainwater-swamps prevail. These back-swamps become dry only during the dry season (July to September).

Land category C

To the NE of the Serapat canal that runs approximately through the middle of the island (fig. 1.1.1), the tidal fluctuations have a smaller amplitude than those more downstream, yet at high river discharges the peaks of the tidal waves may reach a somewhat higher level owing to the back-water effect. As a result, the boundaries of the B category land change in time and part of the land comes temporarily in the C category, in which the level of the land surface is above the maximum level of the spring tide.

More to the North, i.e. towards the Talaran canal, the lands are permanently of the C category. Again, the boundaries between B and C category are difficult to map due to the dependence on the tidal levels, on the season, and the presence of micro relief.

The topographic variations and land use conditions of the areas of the C category are similar to those of the B category, but the incidence of swamp forest is higher and shifting cultivation is more apparent than in the lands of the B category. The lands of the C category cannot be irrigated at high tides.

In the back-swamps and in the recently drained areas of the reclamation schemes considerable amount of pyrite are still present at shallow depth (say 50 cm) so that drainage and subsequent oxidation of the soil leads to an increase of the problems associated with sulfuric acidity.

The rice fields at the outskirts of the swamp forests and in the cleared forest areas are often temporary: many of the previous rice fields have been left as bush fallow and fallow land can be reinstated as rice crop land. According to Collier (1979) the shifting cultivation (also known as slash and burn cultivation) has been a long standing practice. The explanations for the traditional shifting cultivation are:
1 – the weed problem: after a few years of cropping the weed growth would become so vigorous that the cropped lands have to be abandoned in favor of the newly cleared bush land;
2 – new land is cleared annually anyway resulting from tree felling to obtain timber, fire wood and wood for other uses;
3 – the newly cleared land is set to fire to facilitate the preparation o cultivable land and at the same time the ashes contribute to the otherwise poor soil fertility;
4 – the soil fertility reduces after a few years of cropping, the weed problem returns, the and is left to bush fallow, and the cycle of shifting cultivation is closed.

The present views on the shifting cultivation are different from the above, and one is inclined to using the term “shifting *sawah*’s”) instead, to avoid confusion with the shifting cultivation practices in the high lands. Further it is felt that the shifting *sawah*’s are more the result of random processes related to short terms successes and failures of the crop and social and economic conditions of the farmers than to a systematic agricultural practice.

In the transects of Tatas and Belawan (chap. 2) and in the experimental fields of Tatas (chap. 3) it was noted that the pH value of the soil increases considerably during dry periods, i.e. the soil becomes less acid. Also, the acidity indicators of the drained *palawidja* (dry land crops) field in Tatas show a favorable development. When the land does not get the opportunity to become dry from time to time a reverse tendency may occur: the pH value of the soil drops. Therefore there is an indication that a prolonged use of the back-swamp areas for lowland rice cropping, together with water conservation, could have a deteriorating effect on the fertility of the soil and its agricultural potential. Perhaps, this deterioration is also related to the quality of the organic matter. It is not clear to what extent the problem of the depreciating soil qualities described here occurs and to what extent it explains the subsequent abandonment and reinstatement of the *sawah*’s.

Conclusions

The above introductory notes on topography, tides and land use lead to the formulation of three tentative conclusions:
1 – the classification of the area of Pulau Petak using the land categories 0, A, B and C needs further elaboration before it can be applied for the purpose of identifying practical water management options per category: the relation between tidal levels, land levels and water management possibilities is strongly dependent on the distance of the land to the rivers and the main canals as well as on the micro relief (these aspects were already recognized by Sevenhuijsen and Kselik, 1988);
2 – the degree to which the problems associated with the soil acidity become manifest are not only dependent on the qualities of the soil but also on the land’s drainage conditions, the cropping systems, the development history, and their interaction (Sevenhuijsen and Kselik, 1988, see also chap. 4);
3 – a rotation of lowland rice with upland crops has possibly a beneficial effect on the quality of the organic matter, on the degree of acidity, and on the soil’s fertility (chap. 5).

1.2 Human settlement patterns and infrastructure

Of old, the people of Pulau Petak have setlled along the borders of the rivers, even though pronounced river levees are absent. The rivers were the main traffic ways and transport occurred mainly by boat. Owing to the high hydraulic capacity of the rivers, which are hundreds of m wide and up to 50 m deep, flooding of the island at high tide and high discharge seldom occurs, except in the land of the O category.

Several decades ago the island was traversed by newly dug main canals and settlements have also developed along their shores. Figure 1.2.1 shows a sketch of part of the Pulau Petak river and the Serapat canal. It illustrates the dens network of tertiary, hand dug, canals (the *handils*) perpendicular to the river and the main canal and leading to the back-swamps. The *handils* have a stretch of 5 to 10 km and a spacing of 300 to 500 m. In hydrological sense they have mainly a drainage function (chap 1.3), but they are provided with stop-logs to raise their water levels when required, e.g. early in the raining season when the rice is being transplanted and during the following months of crop growth.

In the older settlements, many fruit tree plantations and *palawidja* (upland crops) fields were developed along the rivers and main canals and along the downstream part of the *handils*. Towards the back-swamps, however, lowland rice fields (*sawah*’s) dominate the landscape. The traditional agriculture is apparently based on a plantation/*palawidja* farming system with a supplemental rice crop in shifting cultivation in the back-swamps, combined with off-farm economic activities like fishing, collecting forest products and offering labor elsewhere.

Figure 1.2.1 also illustrates how the new settlements sponsored by the Indonesian government (e.g. the Tatas and Sakalagun units) are based on the penetration of forked canal systems (the secondary canals) into the back-swamps. The new settlers (trans-migrants from Java and Bali) were permitted to develop relatively small tree gardens, but the main stay of the farming system was supposed to be the rice crop. Therefore, the settlers were restricted in their land use, and they were to develop *sawah*’s on the relatively infertile soils, in lands that were only partly cleared, without the possibility to rely on a firmly based garden/*palawidja* cropping system. Thus, due to poor living conditions, some of the settlers (amongst whom were people without a farming background) abandoned their land.

It can be seen that the spoil banks of the of the recently dug secondary canals are occasionally used for the growing of fruit trees (e.g. banana) and *palawidja* crops (e.g. cassava), even though the banks must contain many potentially acid soil materials, which are exposed to intensive oxidation and thus converted into actual acidity. Perhaps this planting has become possible because the banks are well drained. However, the agricultural use of the banks has not always been successful. This subject merits closer inspection.

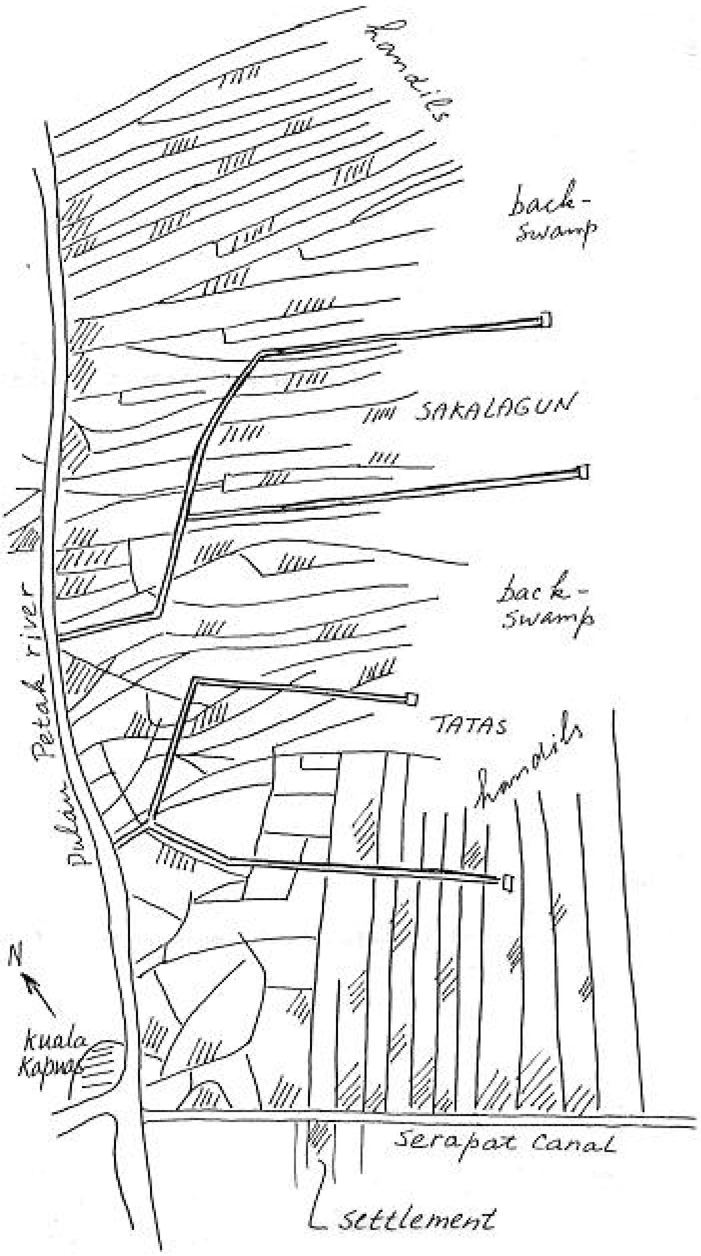

Figure 1.2.1. Sketch of the infrastructure of part of the island of Pulau Petak

<u>Conclusions</u>

The settlement patterns support the conclusions of chap. 1.2: the potential of the soils of Pulau Petak for agricultural use does not only depend on the soil's characteristics, but also (and to a large extent) on the agro-socio-economic conditions, the infrastructure (accessibility, traffic facilities, drainage) and the possibility of progressive diversification of the cropping system. This is confirmed by the observations in the monitoring fields (chap. 4) and the results of the experimental fields in Tatas (chap. 5).

1.3 Rainfall, drainage and soil acidity

Figure 1.3.1 pictures the cumulative value of the monthly rainfalls less the monthly potential evapo-transpiration (Sevenhuijsen and Kselik 1988). In the period from November to June the rainfall excess is about 1200 mm in an average year and 800 mm in a dry year. The average daily drainage rate in this period is thus about 5 mm. Since there is no annual accumulation of water on the island of Pulau Petak, the rainfall excess is all drained, either over the soil as surface drainage or through the soil as subsurface drainage.

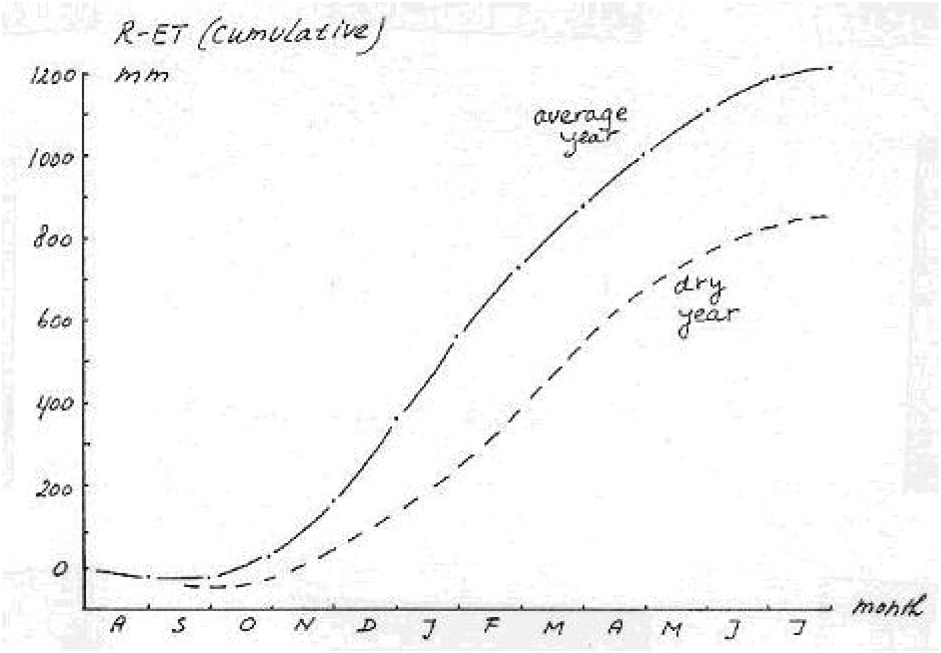

Figure 1.3.1. Cumulative values of rainfall minus evaporation during the year

The soils of Pulau Petak possess an enormously high hydraulic conductivity (100 to 300 m/day) over a depth of about 2 m. The soil's hydraulic transmissivity are therefore in the order of 200 to 900 m^2/day (Boonstra, 1989, Hamming, 1989).

Figure 1.3.2 depicts a hypothetical of a soil with transmissivity $T=500\ m^2$/day. The soil is dissected by *handils* , spaced at a distance of L=500 m. The net recharge (percolation to the water table) from rainfall is assumed to be a steady 0.005 m/day. Under these conditions the hydraulic head (h) – i.e. the level of the water table midway between the *handils* relative to the level of the water table inside the *handils* - can be approximated using Hooghoudt's equation:

$$h = qL^2/8T = 0.005x25000/8x500 = 0.3\ m$$

Thus it requires only a head of 30 cm over a distance L/2 = 250 m to make sure that all rainfall excess passes through the soil before entering the drain. When the water table does not stay below the soil surface and surface ponding of water occurs, the head requirement for subsurface drainage becomes even smaller (this is known as the ponded water case). Due to the topographic variations of the land surface, the tidal movements in the canals, and the presence of bunded *sawah*'s, the above hydraulic head requirement is often amply satisfied.

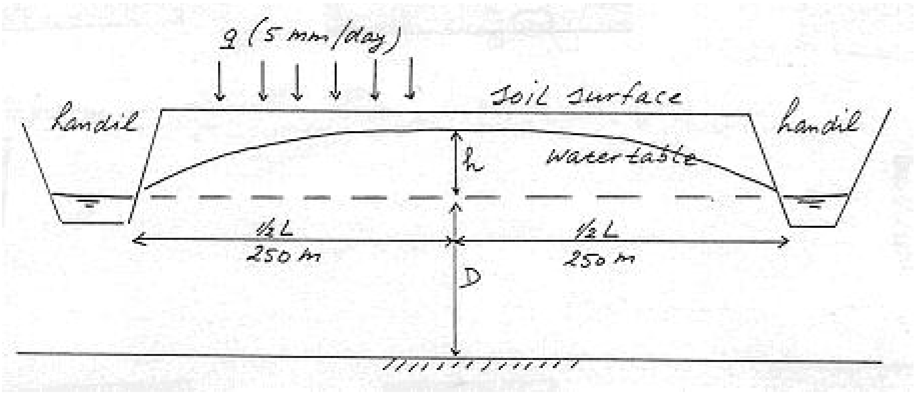

Figure 1.3.2. Symbols used in the example of Hooghoudt's drainage equation

In the areas with a sparse drainage network, the head required to evacuate the water is more. Here one encounters truly swampy conditions. Yet the water is not stagnant but there is a continuous drainage flow.

The given examples represent of course a simplified situation, whereas in practice many deviations from the simplified situation occur. Therefore, the example has not been provided to prove that the entire rainfall excess always passes though the subsoil and that no surface drainage occurs over he soil, but it clarifies that chances are high that anyay the major part of the rainfall excess acts to leach both topsoil and subsoil to a depth of about 2 m, where root holes and cracks are still present.

Hence, it is likely that a considerable fraction of the island of Pulau Petak has been subject to a permanent leaching of more than 600 mm of rainfall each year during many decades. This is a large amount of water, which adds up to at least 6000 m^3/ha per year.

It is often observed that rice fields lose their standing surface water within two days after a period of intensive rainfall, even when field bunds are present and the stop-logs in the canals are closed. This confirms the high intensity of drainage flow. Additional confirmation is found in the deep levels of the water table during the dry season. Although this seasons is not really very dry, but the difference between rainfall and evaporation is small (fig. 1.3.1) , the water table drops to 1 m depth or more, even in the swamp forests. Such a drop under the given hydrologic conditions can only be caused by the presence of a considerable natural drainage in the underground.

The leaching of the soil and the subsequent transport of the leachate in the underground leads to a poor quality of the groundwater. As this groundwater is ultimately discharged into the rivers and ocean, the dissolved minerals are exported. Where in the process groundwater comes close to the soil surface, it locally affects the soil's agricultural potential negatively.

In the back-swamps of the island the density of the drainage network than along he rivers and the main canals, where the *handil* system has been established. Therefore, the hydraulic head required to effectuate the necessary discharge of the excess rainfall through the soil during the wet season is higher than the 30 cm calculated before. The head is still higher in the swamp forests. With an increasing head, the land becomes more waterlogged and in the forests the head may each an average level of about 1 m above the drainage base. Therefore, the back-swamps may contain more acidifying materials than the better developed lands (chap. 3.2).

It is important to note that a restricted drainage, either due to a sparse or shallow drainage network or by closure of the stop-logs in the drains, does usually not lead to a reduced drainage discharge but rather to higher water levels required to evacuate the excess water, the amount of which is merely determined by the water balance. In other words, the intensity of the drainage system does not exert much influence on the total discharge but rather on the water level at which the discharge occurs and consequently the proportion of surface and subsurface drainage.

The land of the B and C categories of Pulau Petak consist of actual acid sulfate soils which have originated from the potential acid sulfate soils upon oxidation. The degree of conversion of potential to actual acidity is varied.

In the back-swamps, which have normally high water tables, the oxidation occurs mainly during the dry season. In the areas drained by canals that are discharging freely at the lower tidal phases, the oxidation process may occur as well during several dry spells in the rainy season. In the lands of the C category, the oxidation occurs probably ver frequently.

In the periods that the water table is below the soil surface the oxidation process occurs under influence of the diffusion of oxygen form the air into the soil’s pores and cracks that are free of water. This process is enhanced by mass transport of air in the soil: the air is pushed out of the soil when rainfall infiltrates, and it is sucked in during spells with strong evaporation. The oxygen contribution by the rainfall itself is relatively small.

Only the lands of category 0 and A are seldom dry and the rainfall is prevented from infiltrating into the soil: it drains mainly over the soil surface. Therefore, these soils have a much higher potential acidity.

Despite the large amount of annual leaching water, the sulfuric acids (H_2SO_4) nor the toxic amounts of iron (Fe^{2+}) or aluminum (Al^{3+}) have been fully removed from the soil. To the contrary, these substances are still abundantly present (chap. 2, 3 and 4). This proves that he leaching efficiency of the soil is quite low and/or the soil keeps releasing the mentioned substances. The low leaching efficiency is explained y the proven fact that the flow of groundwater largely passes through root holes and cracks (Hamming, 1989), leaving the soil’s matrix unaffected.

The role of organic matter, which abounds in the soil, in the acidification process is not yet clear. However, there are indications that the organic matter produces more acidity than the soil minerals, because the total actual acidity (TAA) is usually higher than the total content of cat-ions and an-ions (chap. 3, 4 and 5). It is, however, contested that the ion contents are undervalued, perhaps by a factor 10.

Also there are indications that the organic matter produces more acidity when waterlogged than when above the water table (chap. 3, 4,, and 5), but these indications need substantiation.

Yet, it may be tentatively hypothesized that the establishment of a modest drainage system in the back-swamps in the area may promote its agricultural productivity.

Conclusions

1- The area of Pulau Petak has been subjected for ages to a large amount of annual rainfall excess over evaporation;
2 – the traditional *handils* have predominantly s drainage and transport function, not irrigation;
3 – owing to he large hydraulic conductivity of the soil, even a widely spaced drainage system requires a small hydraulic had to assure that the rainfall excess passes through the soil;
4 – consequently, the soil has been subjected to a continuous leaching, yet the acidity indicators have remained high;
5 – the oxygen required for the production of acids from the chemically reduced soil minerals is supplied by diffusion and mass transport of gasses during the relatively dry season when the water tables are deep;
6 – the acidity and fertility of the soils are more related to the water table regime than the amount of leaching, whereby the organic matter may play an important role as it is abundantly present in the soil and it produces a considerable acidity, which production seems higher when the soil is waterlogged than when it is relatively dry;
7 – the traditional reclamation practices based on drainage by *handils* and diverse cropping have proved that a relatively successful agricultural development is possible in Pulau Petak;
8 – if one wishes to investigate the reclamation possibilities of the back-swamps for agricultural use, it seems advisable to continue the experimentation with the simultaneous introduction of an improved drainage system, and adequately diversified cropping system (including leguminous crops, upland crops and fruit trees), efficient soil tillage practices (to homogenize the topsoil and promote the leaching efficiency), as well as effective fertilizers (e.g. the application of lime, Smilde 1989).

2. CHEMICAL PARAMETERS OF SOIL AND WATER IN TRANSECTS

A study was made of chemical soil and water parameters in two transects (fig. 2.1.1). One transect is called Ray29 and it runs from the left to the right secondary canal of the Tatas unit, whereas the other transect is called Ray0 and it stretches between the left and right secondary canal of the Belawan unit.

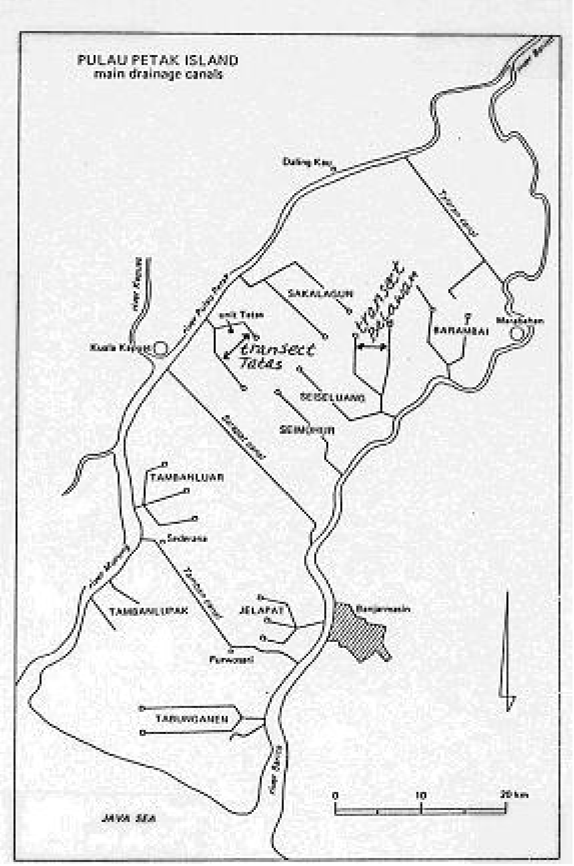

Figure 2.1.1. Location of the two transects

In the following paragraphs the similarities and differences between the values of the parameters are discussed for various groupings. The differences can be checked for their statistical significance using Student's t-test. The necessary data for this test are are supplied in the tables.

While interpreting the data it may be kept in mind that the points in the left-hand and right-hand extremes of the transects are situated on or near the spoil banks of the excavated secondary canals.

2.1 The transect of Tatas

Figure 2.1.2 shows the topographic and water level conditions of the Tatas transect, There is a general terrain slope of about 10 cm/km downward towards the right-hand secondary canal, but the gradient is irregular. The transect is intersected by creeks, see the points E, H and K in the figure.

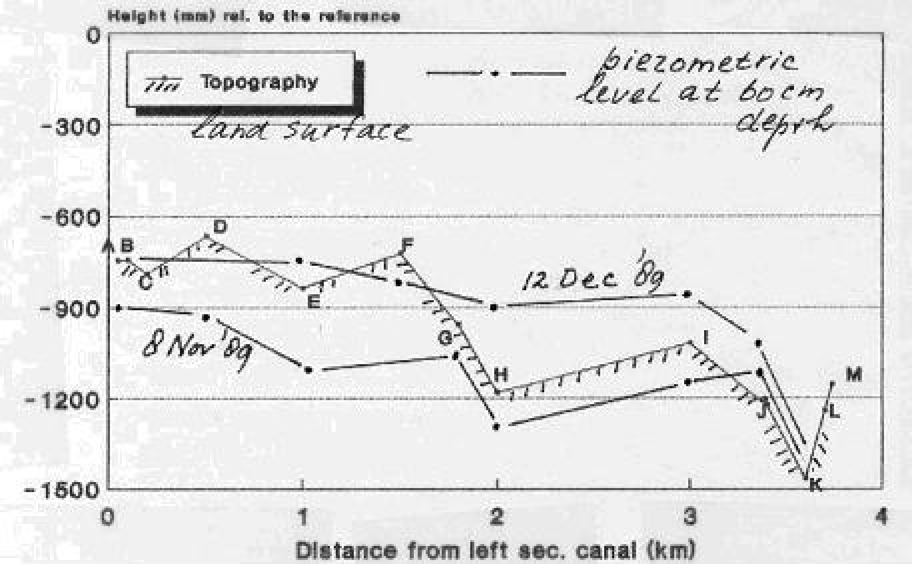

Figure 2.1.2 Topography and water levels in the transect of Tatas..

Judging form the piezometric levels given in the figure, there is a flow of groundwater to the creeks.

A large part of the transect traverses a dense *Gelam* forest (from km 1.5 to 3.0). At either side of the forest one encounters both cultivated and fallow lands. This part has been provided with tertiary canals as a part of a settlement scheme, which is now largely abandoned.

2.1.1 Chemical parameters of the soil

Table 2.1.1 shows the results of measurements of the chemical soil parameters at two different depths in the transect of Tatas during the dry season (July to October, 1989). The data were provided by Mr. Kasdi Subagyono.

The table reveals that the chemical soil parameters at 0-20 and 20-40 cm depth are almost identical. It also reveals that the total potential acidity is high (TPA=500 me/kg), and that the greater part of it (80%) is actual acidity (TAA). As the soluble Fe^{2+} content of the soil is low, one may assume that the major part of the iron is immobilized as insoluble Fe^{3+}, or else the iron has been leached to the underground as explained in the next paragraph.

Table 2.1.1. Chemical soil parameters, transect Tatas, dry season (July to September 1989)

	0-20 cm depth		20-40 cm depth	
	mean *)	st. dev.	mean *)	st. dev
org. mat. (%)	14	7.7	8.2	5.6
pH (H_2O)	3.7	0.28	3.6	0.27
TAA (me/kg)	380	59	400	120
TPA (me/kg)	500	87	530	114
Fe^{2+} (me/kg)		0.11	0.12	0.08
0.09				
Al^{3+} (me/kg)	55	17	66	17
EC (mS/cm)	0.19	0.09	0.24	0.17

*) based on 13 data
TAA = total actual acidity, TPA = total potential acidity, EC = electric conductivity

Table 2.1.2 gives similar data as the former table, but it concerns the wet season of 1989/90 (November to June) instead of the dry season. Comparison of the two tables shows that the pH decreased considerably during the wet season, i.e. the acidity has increased. Similar results were obtained in the transect of Belawan (chap. 2.1) and in the experimental fields of Tatas (chap. 3). These phenomena are contrary to expectation, because during the wet season a chemical reduction of the soil minerals and a subsequent de-acidification are expected to occur, whereas in the dry season oxygenation and acidification are expected. In reality, the reverse has happened, which is difficult to explain.

Table 2.1.2. Chemical soil parameters, transect Tatas, wet season (October 1989 to April 1990)

	0-20 cm depth		20-40 cm depth	
	mean *)	st. dev.	mean *)	st. dev
org. mat. (%)	16	8.3	7.7	2.3
pH (H_2O)	3.0	0.37	2.9	0.25
TAA (me/kg)	370	74	300	91
TPA (me/kg)	540	24	360	120
Fe^{2+} (me/kg)	0.46	0.69	0.23	0.49
Al^{3+} (me/kg)	25	5.0	29	1.3
EC (mS/cm)	0.19	0.14	0.18	0.09

*) base don 13 data
TAA = total actual acidity, TPA = total potential acidity, EC = electric conductivity

Van Breemen (1986) has suggested that the above unexpected reaction may be explained by the desorption of the SO_4^{2-} ions from the exchange complex of the soil particles with simultaneous adsorption of OH^- ions so that the H^+ ions (protons) are released from water. However, the concentration of OH^- ions in acid water is very low and adsorption of (negatively charged) an-ions to the exchange complex is, contrary to that of (positively charged) cat-ions, very small because the surface of the soil particles in the exchange complex is negatively charged. Hence the chemical process suggested by Van Breemen is perhaps not significant.

It was also suggested that the hydrolysis of Al^{3+} ions to $Al(OH)_3$ releases 3 H^+ ions which would explain acidification during the wet season. This implies that, during the dry season, the reverse reaction occurs. Some evidence of the disappearance of the Al^{3+} ions during the wet season is given in chap. 2.3

The value of TPA (total potential acidity) in the layer at 20-40 cm depth is relatively low. The same holds for the Al3+ content as well as its standard deviation. Otherwise the tables 2.1.1 and 2.1.2 do not show appreciable differences.

The chemical soil parameters do not reveal a clear trend with distance along the transect, so that it can be concluded that the soil in the *Gelam* forest from km 1.5 to km 3.0 has virtually the same chemical parameters as the soil of the open land at either side of the forest (see fig. 2.1.3 and 2.1.4).

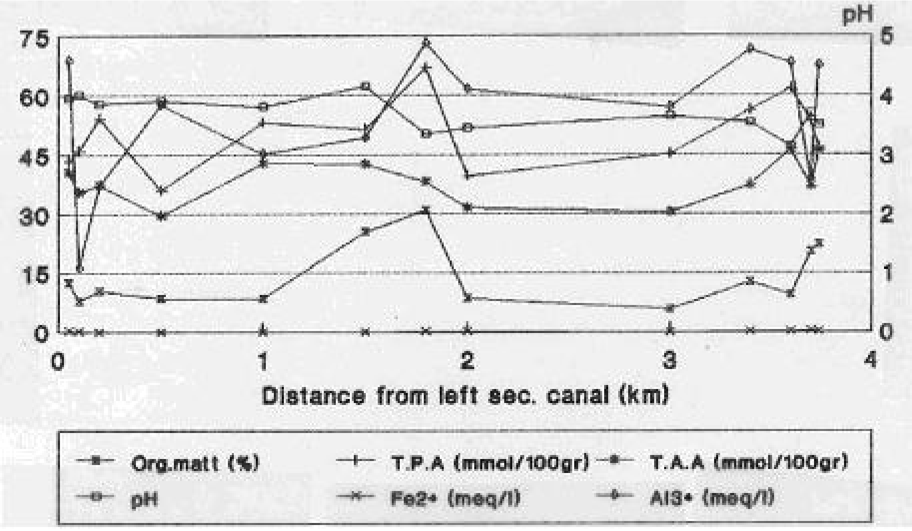

Figure 2.1.3. Chemical parameters of the soil in the transect of Tatas at 0-20 cm depth, dry season 1989

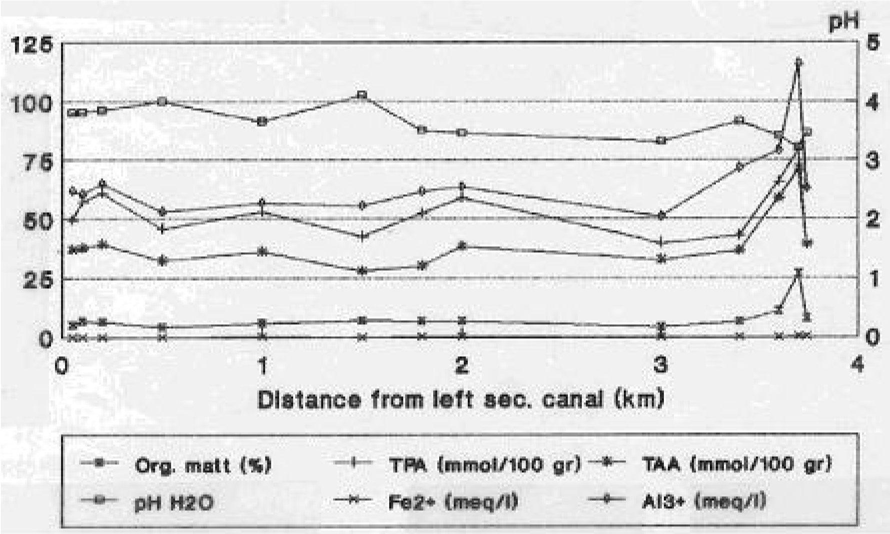

Figure 2.1.4. Chemical parameters of the soil in the transect of Tatas at 20-40 cm depth, dry season 1989.

2.1.2 Chemical parameters of the groundwater

The data on the chemical parameters of the groundwater and the surface water are summarized in table 2.1.3. The data were provided by Mr. R.A.L.Kselik and the refer to the months of October 1989 to April 1990.

Table 2.1.3 Chemical groundwater parameters, transect Tatas, wet season (October 1989 to April 1990)

	surface			60 cm deep			100 cm deep		
	mean	st. dev.	N*)	mean	st. dev.	N*)	mean	st. dev	N*)
SO_4^{2-}	4.1 ^)	3.6	75	17 ^)	24	117	6.5 ^)	3.8	84
me/l	10 “)	6.4	75	48 “)	29	31	57 “)	26	30
Fe^{2+}	1.0 ^)	1.1	75	6.3 ^)	11	117	1.6 ^)	1.5	84
me/l	6.1 “)	11	75	19 “)	15	31	28 ^)	15	30
Al^{3+}	0.93 ^)	0.92	75	1.6 ^)	0.76	117	1.2 ^)	0.76	84
me/l	1.7 “)	0.66	75	1.8 “)	0.52	31	1.8 “)	0.52	30
Mg^{2+}	0.84 ^)	0.60	75	11 ^)	3.7	117	1.4 ^)	0.75	84
me/l	1.7 ^)	0.74	75	7.7 “)	4.3	31	10 “)	4.0	30
pH	3.4 ^)	0.66	75	3.3 ^)	0.40	117	3.2 ^)	0.60	84
(H_2O)	2.9 “)	0.20	75	3.0 ^)	0.40	31	3.9 “)	0.40	30

*) N = number of data, ^) from km 0 to 1.5 and from km 3.0 to 3.8, “) from km 1.5 to 3.0

Contrary to the soil parameters, the chemical parameters of the groundwater do show a trend with distance along the transect, see figure 2.1.5. Table 2.1.3, in which the data are separated into two groups representing respectively the *Gelam* forest (from km. 1.5 to 3.0) and the adjacent open land (from km 0.0 to 1.5 and from km 3.0 to 3.8), illustrates that the concentrations of most of the dissolved minerals is much higher in the forest than in the open land.

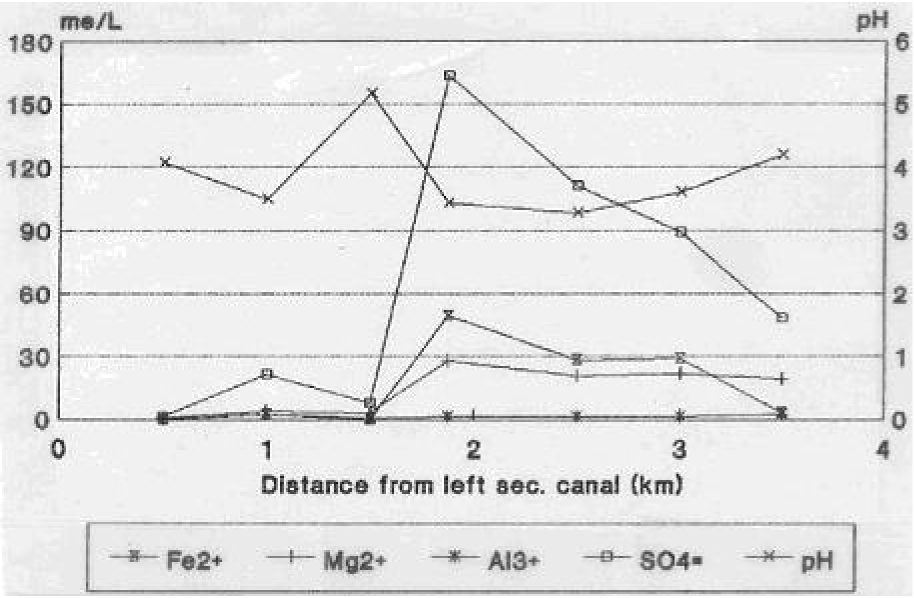

Figure 2.1.5. Chemical parameters of the groundwater, transect of Tatas, dry season 1989.

The concentrations of Al3+, although varying, do not change much with depth and remain at a fairly low level. Comparison with the much higher values of Al3+ in table 2.1.1 and 2.1.2 learns that this ion is not very mobile, but it is largely adsorbed to the soil's cat-ion exchange complex. The Fe2+ concentrations, on he other hand, do increase rapidly with depth, but only in the forest, which appears to mobilize much iron.

The fact that the high concentration of the soluble minerals in the forest is not manifested in the surrounding open land indicates that the forest has a drainage system which is effective in evacuating the dissolved minerals so that the do not spread through the underground to the adjoining areas. The drainage has an interception function. Studies on water movements in the forest by Mr. Kasdi Subyagono seem to confirm th above statement. Another explanation is that the hydraulic conductivity of the soil in the forest is much higher than that in the fringe-lands of the transect, so that the flow of groundwater to the fringe-lands is restricted. Alternatively it may be postulated that any groundwater moving from the forest to the fringe-lands is diluted by percolation water.

As it is believed that the quality of the groundwater exerts an influence on the crop production and that this quality may be influenced by the forest, the above phenomena deserve to be a subject of further study.

2.2 The transect of Belawan

Figure 2.2.1 shows the topographic and water level conditions of the Belawan transect. There is a general terrain slope of about 12 cm/km to the right, but the gradient is irregular. At the point E there seems to be a water divide separating water flowing to the left and right. From left to right the transect passes through tree gardens, *sawah*'s and fallow land, a small patch of *Gelam* forest (at point H), followed by open land and tree gardens.

2.2.1 Chemical parameters of the soil

Table 2.2.1 shows the results of the measurements of the chemical soil parameters in the Belawan transect during the dry season (July to September 1989). The data were provided by Mr. Kasdi Subagyono. In the table, the values of pH, TAA and Al3+ of the top layer (0-20 cm depth) have been divided into two groups: a group representing the transect from km 0 to 1.8 and the other group representing km 1.5 to 3.8. This is done on the basis of figure 2.2.2, which suggests that there are differences in some of the parameters to the left and right of km 1.5. The differences in the subsoil (20-40 cm depth) are less conspicuous).

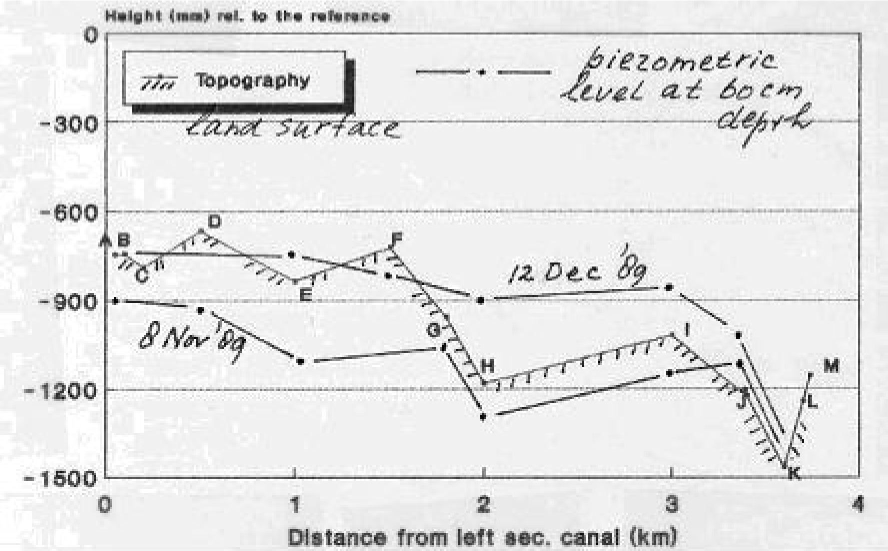

Figure 2.2.1. Topography and water levels in the transect of Belawan

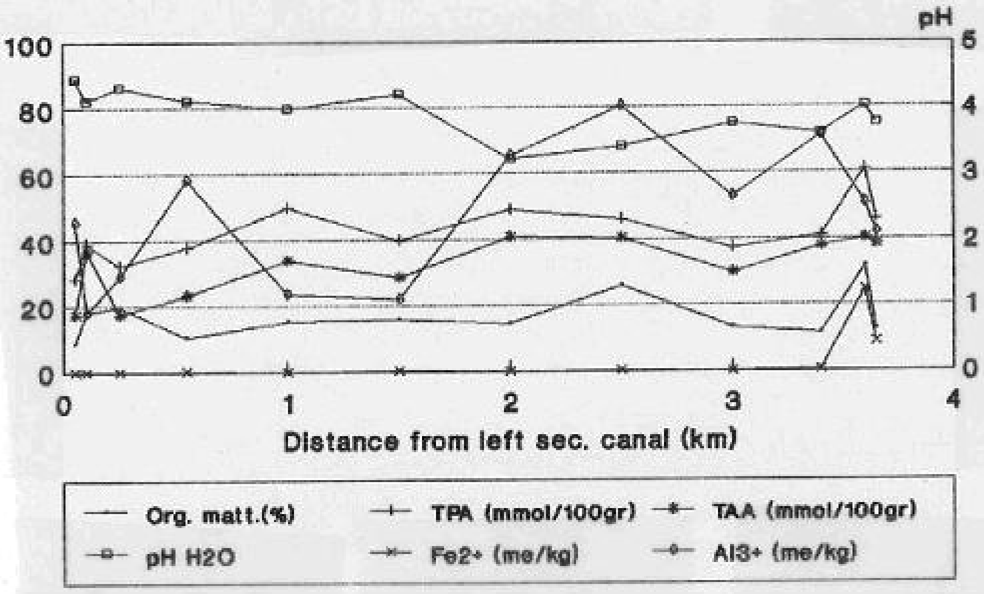

Figure 2.2.2. Chemical parameters of the soil in the transect of Belawan at 0-20 cm depth, dry season 1989

Table 2.2.1 reveals that the topsoil quality is better between km 0 and 1.5 than further on, because the pH values in the first part are higher (pH=4.2) than in the second part (pH=3.6), whereas the actual acidity in the first part is less (TAA=280 respectively 380 me/kg) and also the Al^{3+} content is less in the first part (33 and 60 me/kg respectively), as well as the EC value (respectively 0.11 and 0.23 mS/cm).
The TPA values (total potential acidity) and Fe^{2+} contents are almost the same in both parts of the transect. Further, the chemical parameters of the top soil between km 1.5 and 3.8 and those of the subsoil are virtually identical.

Table 2.2.1. Chemical soil parameters, transect Belawan, dry season (Jul. to Sep. 1989)

	0-20 cm depth		20-40 cm depth	
	mean *)	st. dev.	mean *)	st. dev.
org. mat. (%)	16	6.6	12	7.3
pH (H_2O)	4.2 ^)	0.16	3.6	0.23
	3.6 “)	0.28		
TAA (me/kg)	280 ^)	69	360	105
	380 “)	42		
TPA (me/kg)	420	89	430	84
Fe^{2+} (me/kg)	0.89	2.5	0.47	1.0
Al^{3+} (me/kg)	33 ^)	16	66	12
	60 “)	14		
EC (mS/cm)	0.11 ^)	0.09	0.22	0.14
	0.22 “)	0.09		

*) based on 12 data, ^) from km 0 to 1.5, 6 data, “) from km 1.5 to 3.8 ,6data
TAA = total actual acidity, TPA = total potential acidity, EC = electric conductivity

The above information suggests that the topsoil in the first part has been improved in the course of time. The explanation for this can perhaps be found from the (history of the) agriculture along the transect. However, the reverse may also be true: the differences in the quality of the top soil may explain the differences in the status of agriculture. The issue on cause/effect relations is worth a further study.

Table 2.2.2 present the same as the former table, but it concerns the wet season (October 1989 to April 1990) instead of the dry season. The difference between the pH values of the tip soil in the two parts of the transect shown in table 2.2.1 does not persist in table 2.2.2. Also, the difference in Al^{3+} content has vanished.

Hence, during the wet season the relatively favorable qualities of the top soil in the first part of the transect have disappeared. A similar feature was also noted in the Tatas transect (chap. 2.1.1). The differences between TAA and EC values, however, are maintained. This suggests that there might be a significant relation between both magnitudes, but in reality the relation between TAA and EC is not clear. It is believed that the absence of a clear relation is due to exchange reactions between Al and Mg ions at the soil's exchange complex.

Table 2.2.2. Chemical soil parameters, transect Belawan, wet season (October 1989 to April 1990)

	0-20 cm depth		20-40 cm depth	
	mean *)	st. dev.	mean *)	st. dev.
org. mat. (%)	20	14	19	21
pH (H_2O)	3.4 ^)	0.26	3.0	0.30
	3.2 “)	0.31		
TAA (me/kg)	280 ^)	49	380	170
	390 “)	143		
TPA (me/kg)	330	129	350	195
Fe^{2+} (me/kg)	5.0	4.6	3.9	4.1
Al^{3+} (me/kg)	25 ^)	5.4	27	5.6
	26 “)	5.7		
EC (mS/cm)	0.13 ^)	0.06	0.22	0.20
	0.25 “)	0.14		

*) for symbols see table 2.2.1

2.2.2 Chemical parameters of the groundwater

Table 2.2.3 summarizes the chemical parameters of the groundwater at two different depths and the surface water in the Belawan transect for the period of October 1989 to April 1990, the wet season. The data were provided by Mr. R.A.L.Kselik.

The table excludes the results of the measurements in the point at km 2.5 (which is the only point located in the *Gelam* forest) as this is the only point showing exceptionally high concentration values, but it is not known how representative such a single point is. Nevertheless, the chemical characteristics observed in this point confirm what is found in the transect of Tatas: the groundwater in the forest area has more acidity than that in the surrounding areas. This could be an effect of the forest vegetation. Another explanation offered is that the forest is located in a topographical depression (fig. 2.2.1, point H at km 2.5) and therefore collects the acid groundwater. The latter explanation, however, does not seem likely because the flow of groundwater is a continuous process: annually the flow of water towards and away from the depression are equal and there can be no accumulation of acids. Further, the acidity of the water flowing to the depression originates from the surroundings where its acidity is less than in the depression so that one must assume that the acidification occurs underway.

Table 2.2.3 demonstrates the (except or the point at km 2.5) there are no major changes in the quality of the groundwater with distance along the transect. The table also shows that the groundwater quality at 60 and 100 cm depth are not appreciably different, but the surface water has markedly lower concentrations of the dissolved water than the groundwater.

Table 2.2.3 Chemical groundwater parameters, transect Belawan, wet season (October 1989 to February 1990)

	surface			60 cm deep			100 cm deep		
	mean	st. dev.	N*)	mean	st. dev.	N*)	mean	st. dev	N*)
SO_4^{2-} me/l	4.1	2.8	75	10	15	92	11	8.7	103
Fe^{2+} me/l	0.36	0.55	75	3.4	5.6	92	3.0	4.3	103
Al^{3+} me/l	0.98	0.67	75	1.7	0.66	92	1.6	0.68	103
Mg^{2+} me/l	1.1	0.67	75	2.3	2.3	92	2.9	1.8	103
pH (H_2O)	3.2	0.57	75	3.2	0.33	92	3.2	0.41	103

*) N = number of data

2.3 Comparing the parameters of the two transects

The chemical soil parameters studied in the transects of Tatas and Belawan are essentially he same, except the TPA (total potential acidity) values, which are higher in Tatas (TPA>500 me/kg) than in Belawan (TPA<430 me/kg). An other exception is found in he top soil (0-20 cm depth) in he part of the Belawan transect between km 0 and 1.5 during the dry season, where most of the acidity indicators have smaller values than elsewhere. However, this difference vanishes during the wet season. Also, the difference is hardly existent in the subsoil (20-40 cm depth) nor in the remaining part of the Belawan transect.

In is remarkable that in the wet season the pH values of the soil drop from values of pH=3.6 or higher to values of pH=3.0 or less in both transects. At the same time the contents of Al^{3+} drop from 600 me/kg or more to 300 me/kg or less. Also the TPA values in Belawan are influenced by the season: they drop from over 400 me/kg in the dry season to under 350 me/kg in the wet season. These phenomena are difficult to explain (chap. 2.1.1) and need further study.

The individual data in both transects show a large scatter when plotted one against the other. However, both transects exhibit almost equal mean values and standard deviations of the measured parameters, which points to a high degree of homogeneity in the heterogeneity of the in Pulau Petak. In other words, it appears that the macro variability of the parameters is small compared to the micro variability. Similarly, the variability of the parameters within the soil layers is large compared to the variability between the layers.

3. CHEMICAL PARAMETERS OF SOIL AND WATER IN THE EXPERIMENTAL FIELDS OF TATAS

The effects of the various treatments of yields of lowland rice in the experimental field of Tatas has been analyzed by Smilde (1989). In chapter 5, the yield of the upland crops in the drained *palawidja* field of Tatas is discussed. Therfore, the following paragraphs consider only the effects of the treatments on the chemical parameters of the soil and the groundwater.

3.1 Chemical parameters of the soil

Tables 3.1.1 to 3.1.5 summarize the results of the measurements of the chemical parameters of the soil in the experimental fields of Tatas. The data were provided by Mr. R.A.L. Kselik.

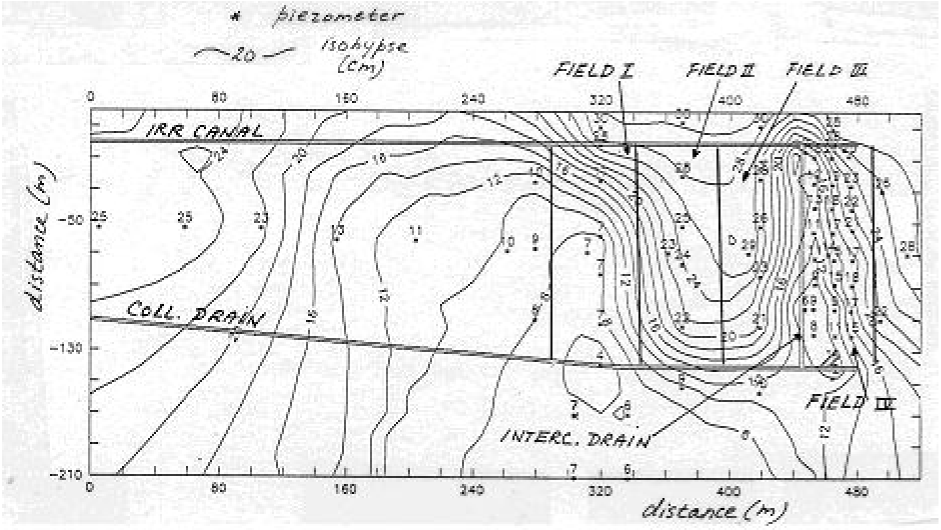

Figure 3.1.1. Field numbers and groundwater contours, Tatas

Table 3.1.1 gives a separation of the data according to field number (fig. 3.1.1). It shows that there are no appreciable differences between the parameters in the different fields, except that there is a trend of the EC (electric conductivity of the soil's extract) to increase gradually from field I to field IV. Further one notices that the Fe^{2+} and Al^{3+} contents of the soil in field I are less than in the other fields. As field I is equipped with a subsurface drainage system (i.e. a system of parallel ditches that evacuate the groundwater), and as in this field an upland rice crop was cultivated followed by *palawidja* crops, whereas the other fields have no subsurface drains and they were double cropped with high yielding lowland rice varieties or single cropped with a traditional lowland rice variety, it seems that the practice of subsurface drainage and/or the cultivation of upland crops has a favorable effect on the soil's chemical parameters. The introduction of green manure (chap. 5) has perhaps fortified this effect.

Table 3.1.2 gives a separation of the chemical parameters of the soil according to depth. It shows that there are practically no differences between the values of the parameters at 20 and 40 cm depth, except the organic matter content, which decrease with 20% or more with depth.

Table 3.1.3 gives a separation of the chemical parameters of the soil according to lime treatment. It shows hat the are virtually no differences between the values of the parameters of the limed and un-limed plots. This may be explained by the small quantities of lime applied (up to 2 t/ha): the lime is given as a fertilizer (or as an activator of organic matter) rather than as a neutralizer of the soil's acidity. For the latter purpose, the lime application would need to be at least 30 times higher.

Table 3.1.1 Chemical parameters of the soil in the experimental fields of Tatas by field number

	Organic matter (%)	TPA (me/kg)	TAA (me/kg)	pH (H_2O)	EC (mS/cm)	Fe^{2+} (me/kg)	Al^{3+} (me/kg)
Field I *)							
mean	9.4	309	308	3.4	0.102	0.57	41
st.dev.	3.3	105	66	0.26	0.023	1.1	17
Field II ^)							
mean	9.8	326	314	3.5	0.127	3.4	49
st.dev.	5.3	130	72	0.34	0.056	6.5	14
Field III ^)							
mean	9.4	306	316	3.4	0.142	3.1	49
st.dev.	4.4	118	61	0.19	0.053	5.7	13
Field IV ^)							
mean	9.1	319	309	3.4	0.149	3.0	47
st.dev.	4.5	134	60	0.22	0.062	7.2	12

*) N=64

^) N=176

Table 3.1.2. Chemical soil parameters, Tatas experimental fields, by depth of soil, based on N=296 data

	0-20 cm depth		20-40 cm depth	
	mean *)	st. dev.	mean *)	st. dev.
org. mat. (%)	11	5.4	7.6	2.6
pH (H_2O)	4.2	0.39	4.1	0.25
TAA (me/kg)	315	71	309	62
TPA (me/kg)	338	150	295	89
Fe^{2+} (me/kg)	3.5	7.5	2.2	4.4
Al^{3+} (me/kg)	46	16	50	11
EC (mS/cm)	0.15	0.071	0.22	0.030

*) for symbols see table 2.2.1

Table 3.1.3. Chemical soil parameters, Tatas experimental fields, by lime treatment

	no lime , N=368		with lime, N=224	
	mean *)	st. dev.	mean *)	st. dev.
org. mat. (%)	9.5	4.8	9.3	4.4
pH (H_2O)	4.2	0.38	4.1	0.29
TAA (me/kg)	313	66	311	69
TPA (me/kg)	326	135	299	105
Fe^{2+} (me/kg)	2.9	6.2	2.8	6.1
Al^{3+} (me/kg)	50	12	44	16
EC (mS/cm)	0.13	0.048	0.14	0.067

*) for symbols see table 2.2.1

Table 3.1.4 gives a separation of the chemical parameters of the soil according to puddling treatment. It shows that there are no important differences between the values of the parameters of the puddled and the non- puddled plots, except the Fe^{2+} content, which decreases with more than 80% in the pudled fields compared to the non-puddled fields. The reason for this difference is not yet clear.

Table 3.1.4. Chemical soil parameters, Tatas experimental fields, by puddling treatment N=296 data

	puddling		no puddling	
	mean *)	st. dev.	mean *)	st. dev.
org. mat. (%)	9.2	4.0	9.7	5.2
pH (H_2O)	4.1	0.29	4.2	0.36
TAA (me/kg)	336	65	311	110
TPA (me/kg)	322	139	288	60
Fe^{2+} (me/kg)	1.1	2.4	4.7	8.0
Al^{3+} (me/kg)	50	12	45	15
EC (mS/cm)	0.12	0.054	0.14	0.058

*) for symbols see table 2.2.1

Table 3.1.5 gives a separation of the chemical parameters of the soil according to irrigation treatment. It concerns only plots in the fields II to IV, where only lowland rice is planted. The table shows that there are virtually no differences between the values of the parameters for the different irrigation treatments: irrigation with tidal canal water, irrigation with swamp water and no irrigation (rain fed only). The large amounts of irrigation water applied have apparently had no leaching effect. This is in agreement with the statements made on natural leaching and leaching efficiency in chapter 1.3. In the wet season 1989/1990 the irrigation management and leaching trials were altered and the data are awaiting evaluation.

Table 3.1.5. Chemical soil parameters, Tatas experimental fields, by water management treatment, N=176 data

	irrig. with canal water		irrig. with swamp water		no irrig. only rain-fed	
	mean	st.dev.	mean	st. dev.	mean	st. dev.
org. mat. (%)	10	5.1	9.0	4.3	9.3	4.9
pH (H_2O)	4.3	0.34	4.1	0.31	4.1	0.31
TAA (me/kg)	322	63	311	64	306	73
TPA (me/kg)	314	126	309	107	328	146
Fe^{2+} (me/kg)	2.8	4.9	2.7	5.6	3.9	8.4
Al^{3+} (me/kg)	48	24	48	13	49	13
EC (mS/cm)	0.13	0.050	0.16	0.059	0.14	0.060

*) for symbols see table 2.2.1

In all the tables it can be seen that the standard deviation of measured Fe^{2+} values is extremely high: more than twice the mean value. This indicates that the frequency distribution of Fe2+ values is strongly skewed to the right and very wide. The high standard deviations are also observed in the transects (chap. 2). Therefore the interpretation of the iron content of the soil must be done with great caution.

The acidity conditions of the soils in the experimental fields of Tatas are relatively mild. This can perhaps be explained by the fact that the fields were under a bush fallow before the experiments started, but it may also be due to the absence of potential acidity, as can be deduced from the tables in which the difference between potential and actual acidity (TPA – TAA) is negligibly small. Hendro et al. (1990) point out that the experimental fields are located at the transition of a (low) river levee and the back-swamp. Further they report that the area around Tatas used to be a productive *sawah* area which was strongly acidified upon the reconstruction of the secondary canal system and subsequently became much less productive (information from local farmers). The agronomic results of the experimental fields, however, seem to indicate that profitable agriculture in such areas is not altogether impossible.

3.2 Chemical parameters of the groundwater

The tables 3.2.1 to summarize the results of the measurements of the chemical parameters of the groundwater in the experimental fields of Tatas. The data were prepared by Mr. R.A.L. Kselik. The data cover the period from the dry season 1988, the wet season 1988/89, and the dry season 1989.

Table 3.2.1 gives a breakdown of the chemical parameters of the groundwater by field number (fig. 3.1.1). It shows that the pH value in field I is relatively high (pH=4.7), whereas in the other fields the pH values are much lower (pH=3.7) and mutually not much different. Also the SO_4^{2-} concentration of the groundwater in field I (2.1 me/l) is lower than in any other field,, whereas in field IV this concentration is the highest of all (4.7 me/l). Similar trends exist for the cat-ions Fe^{2+}, Mg^{2+} and Al^{3+}.

The above features indicate hat the groundwater in field I is of a better quality than in the other fields. Since field I is equipped with subsurface drains (i.e. a system of parallel ditches that evacuate the groundwater) and cultivated with upland crops, whereas the other fields have no internal drains and they are cultivated with lowland rice (paddy) only, it may be tentatively concluded that *the drains and/or the cultivation of upland crops have a favorable effect on the quality of the groundwater*. It may be added that the yields of the upland crops of field I are promising (chap. 5).

Table 3.2.2 presents the breakdown of the chemical parameters of the groundwater by sequential growing seasons. The table shows that the pH value of the groundwater dropped in the wet season (January to July 1989) from a previous value of pH=4.2 to pH=3.7, and in the following dry season it rose again to pH=4.1. This process was also observed in he topsoil in the transects of Tatas and Belawan (chap. 2.3). and it confirms that, contrary to expectation, reduced conditions do not raise the pH, but rather lower it. Also the simultaneous rise of the SO_4^{2-} concentration in the wet season (to 5.0 me/l) compared to its value in both dry seasons (2.5 me/l or less) is unexpected. The concentrations of Fe^{2+} and Mg^{2+} follow a similar trend. On the other hand, the concentration of Al^{3+} dropped during the second dry season, but it was fairly constant during the previous wet and dry seasons.

Table 3.2.1 Chemical parameters of the groundwater in the experimental fields of Tatas by field number

	pH (H2O)	SO_4^{2-} (me/l)	Fe^{2+} (me/l)	Mg^{2+} (me/l)	Al^{3+} (me/l)
Field I N=208					
mean	4.7	2.1	0.69	0.57	0.61
st.dev.	1.7	1.1	0.30	0.40	0.39
Field II N=602					
mean	3.7	2.9	0.75	0.71	0.82
st.dev.	0.58	1.8	0.48	0.47	0.68
Field III N=599					
mean	3.7	3.8	0.87	0.87	1.0
st.dev.	0.58	2.0	0.47	0.47	0.67
Field IV N=548					
mean	3.8	4.7	1.1	1.1	1.2
st.dev.	0.51	1.7	0.45	0.45	0.67

Table 3.2.2 Chemical parameters of the groundwater in all experimental fields of Tatas by sequential growing season

	pH (H2O)	SO_4^{2-} (me/l)	Fe^{2+} (me/l)	Mg^{2+} (me/l)	Al^{3+} (me/l)
Dry season ’88 N=323					
mean	4.2	2.5	0.57	0.55	1.1
st.dev.	0.60	1.0	0.22	0.16	1.0
Wet season ’89 N=1032					
mean	3.7	5.0	1.1	1.2	1.2
st.dev.	0.43	1.3	0.49	0.44	0.45
Dry season ’89 N=600					
mean	4.1	1.8	0.80	0.50	0.60
st.dev.	0.90	1.4	0.80	0.20	0.60

The difference of the groundwater quality of field I with that of the other fields (II,III and IV) would justify a further analysis of a trend or fluctuation in time by kind of field. Comparison of tables 3.2.3 and 3.2.4 shows that the fluctuation of the pH values in the “upland field” (I) is hardly present in the “lowland fields”. In addition, the “upland field” shows a clear time trend: in the second dry season of 1989 the pH value of the groundwater has even gone up to pH=5.9, whereas in the “lowland fields” hardly any trend is visible. As the pH value equals the absolute value of the logarithm of the concentration of the protons (H^+ ions), the fluctuation of the proton concentration shows an opposite trend. In this respect it would be important to investigate which of the two acidity indicators has greater economic significance in terms of crop production.

Table 3.2.3 Chemical parameters of the groundwater only in the “upland” experimental field (I) of Tatas by sequential growing season

	pH (H2O)	SO_4^{2-} (me/l)	Fe^{2+} (me/l)	Mg^{2+} (me/l)	Al^{3+} (me/l)
Dry season ’88 N=58					
mean	5.0	2.0	0.68	0.39	0.71
st.dev.	0.64	0.53	0.15	0.19	0.29
Wet season ’89 N=78					
mean	4.3	3.1	0.82	0.90	0.90
st.dev.	0.50	1.1	0.24	0.46	0.32
Dry season ’89 N=72					
mean	5.9	1.2	0.58	0.36	0.34
st.dev.	1.2	0.58	0.37	0.11	0.38

Table 3.2.4 Chemical parameters of the groundwater only in the “lowland” experimental fields (II, III, IV) of Tatas by sequential growing season

	pH (H2O)	SO_4^{2-} (me/l)	Fe^{2+} (me/l)	Mg^{2+} (me/l)	Al^{3+} (me/l)
Dry season ’88 N=267					
mean	3.9	2.7	0.55	0.58	1.1
st.dev.	0.40	1.1	0.23	0.12	1.1
Wet season ’89 N=954					
mean	3.6	5.1	1.1	1.2	1.2
st.dev.	0.38	1.2	0.49	0.43	0.44
Dry season ’89 N=528					
mean	3.8	1.8	0.77	0.48	0.64
st.dev.	0.34	1.4	0.78	0.24	0.62

Since initial data of the groundwater quality (i.e. before the start of the first crops in the dry season of 1998) need a further analysis, it is presently difficult to decide whether the “upland field” had an initial advantage over the “lowland fields”. Anyway, during the first dry season the pH value of the groundwater in the “upland field” was already higher than in the “lowland fields”, and the reverse is true of the concentrations of the an-ions and cat-ions.

Note. In the previous tables, the dry season was taken from July to December instead of July to October (which is the period of the actually reduced rainfall, fig. 1.3.1) to take into account an eventual time lag of the dry-seasonal effects and to divide the year into two equal parts. It would perhaps be worth the trouble to repeat the analysis with the shorter dry season.

Table 3.2.5 gives a breakdown of the chemical parameters of the groundwater of the Tatas experimental fields according to depth of sampling. It shows that there is no important change of the values with depth, except that the SO42- concentration tends to decrease with depth.

Table 3.2.5. Chemical parameters of the groundwater, Tatas experimental fields, by depth of soil

	0-20 cm depth, N=793		20-40 cm depth, N= 1104	
	mean *)	st. dev.	mean *)	st. dev.
pH	3.8	0.73	3.9	0.58
$SO4^{2-}$ (me/l)	3.9	1.9	3.4	2.0
Fe^{2+} (me/l)	0.93	0.57	0.95	0.62
Mg^{2+} (me/l)	0.96	0.53	0.80	0.51
Al^{3+} (me/l)	1.0	0.61	0.91	0.69

*) for symbols see table 2.2.1

Table 3.2.6 gives a breakdown of the chemical parameters of the groundwater of the Tatas experimental fields according to puddling practice. The table excludes the data of the "upland field". It shows that the parameters are almost identical in the pudled and non-puddled fields.

Table 3.2.6. Chemical parameters of the groundwater, Tatas experimental fields, by puddling treatment

	puddled, N=737		not puddled, N=996	
	mean *)	st. dev.	mean *)	st. dev.
pH	3.7	0.39	3.7	0.39
SO_4^{2-} (me/l)	3.8	2.0	3.8	1.9
Fe^{2+} (me/l)	0.91	0.64	0.99	0.62
Mg2+ (me/l)	0.95	0.59	0.86	0.46
Al^{3+} (me/l)	0.99	0.66	0.98	0.67

*) for symbols see table 2.2.1

Table 3.2.7 gives a breakdown of the chemical parameters of the groundwater of the Tatas experimental fields according to water management trial. The table excludes the data of the "upland field". The pH values do not differ much for the different trials. There is a slight tendency of the concentrations of dissolved minerals to increase from the plots irrigated with canal water via the (un-irrigated) rain-fed plots to the plots irrigated with swamp water, which is of a lesser quality.

Table 3.2.7. Chemical parameters of the groundwater, Tatas experimental fields, by water management trial

	irrig. with canal water N=597		irrig. with swamp water N=597		no irrig. only rain-fed N=576	
	mean	st.dev.	mean	st. dev.	mean	st. dev.
pH	3.8	0.43	3.7	0.37	3.7	0.37
SO_4^{2-} (me/l)	3.4	1.9	4.3	1.9	3.7	1.9
Fe^{2+} (me/l)	0.85	0.54	1.1	0.68	0.90	0.64
Mg2+ (me/l)	0.82	0.50	0.98	0.52	0.88	0.54
Al^{3+} (me/l)	0.86	0.64	1.1	0.63	0.96	0.71

*) for symbols see table 2.2.1

3.3 The influence of the drains

Table 3.3.1 shows the chemical parameters of the groundwater of the Tatas experimental fields separately for the “lowland fields” II, III, and IV as well as for the sequential cropping seasons. The table was prepared to assist in the evaluation of the interceptor drain, which was dug during the dry season 1989 between field IV (the up-slope field) and field III (down-slope), with field II situated still further down-slope, below field III. The table may give a clue about the influence of the interceptor drain on the quality of the groundwater, especially when new data of the next wet season are included. An interpretation of the table is postponed until such data become available.

Table 3.3.1 Mean values of the chemical parameters of the groundwater in the ”lowland” experimental fields of Tatas by sequential growing season

	Field I	Field III	Field IV
Dry season ‘88			
pH	4.0	3.9	3.9
SO_4^{2-} (me/l)	2.3	2.8	2.8
Fe^{2+} (me/l)	0.51	0.59	0.53
Mg2+ (me/l)	0.52	0.58	0.63
Al^{3+} (me/l)	1.1	1.1	1.1
Wet season ‘89			
pH	3.9	3.8	3.7
SO_4^{2-} (me/l)	1.1	1.7	2.5
Fe^{2+} (me/l)	0.56	0.79	1.1
Mg2+ (me/l)	0.43	0.58	0.69
Al^{3+} (me/l)	0.36	0.55	0.74
Dry season ‘89			
pH	3.6	3.6	3.6
SO_4^{2-} (me/l)	4.3	5.3	5.8
Fe^{2+} (me/l)	0.93	1.2	1.2
Mg2+ (me/l)	1.0	1.2	1.3
Al^{3+} (me/l)	0.95	1.2	1.3

Figure 3.1.1 (from P. de Wit) shows a typical pattern of groundwater contours (isohypses) in the experimental fields of Tatas. Unfortunately, the number of observation wells between the distances 0 and 240 m is insufficient for a reibale reconstruction of the isohypses, but between the distances 240 to 500 m there is an ample provision of wells,

so that here reliable isohypses are obtained. The drained *palawidja* fieldis found between the distances 290 and 340 m and the interceptor drain at the distance 445 m. Figure 3..1.1 clearly shows that field I exerts a great influence on the pattern of isohypses and it does not only drain field I itself, but also field II. Field III is drained towards the interceptor, and so is field IV. Between the distances 370 and 420 m it is the collector drain that withdraws the part of the groundwater of the fields II and III that is not drained to field I or the interceptor.

In the practice of subsurface drainage, it is a general rule that it is more the density of the drainage network that determines its effectiveness than the direction of the drains relative to the ground slope. In the experimental fields of Tatas any drain, whether parallel to the collector or perpendicular to it (i.e. parallel to the interceptor) would function equally well.

The fact that the acidity indicators of field I have changed favorably in the course of the time and that they are also positively influenced by the dry season suggests that subsurface drainage may be one of the most effective water management measures in conditions as those encountered in the Tatas fields. It appears that its effectiveness is greater than that of the irrigation measures, which is understandable in the light of the large annual rainfall excesses, which render additional leaching by irrigation superfluous.

Further, it is not unthinkable that the positive effects of subsurface drainage are related to the activation of the otherwise inert organic matter, in a similar fashion as a lime treatment may do. Experiments with soils from Pulau Petak have shown a negative relation between water content and decomposition rate of organic matter, which is probably due to a restricted oxygen supply under wet conditions (O. Keppler, personal communication). Such relations have been frequently reported in literature.

The Tatas experiments have also proved that successful *palawidja* crops can be grown in a drained field during the wet season. This already occurs in the home gardens of transmigrants (C. Consten, personal communication).

Conclusions

In the light of the foregoing observations, it deserves recommendation o intensify the drainage trial research, in combination with lime treatments, crop diversification and studies on the role of organic matter in different parts of the island of Pulau Petak.

4. CHEMICAL PARAMETERS OF SOIL/WATER AND CROP YIELDS IN THE MONITORING FIELDS

Figure 4.1 shows the monitoring fields in farmer’s areas. Here the chemical parameters of soil and groundwater were regularly measured and the yields of lowland crops were observed. In the monitoring fields, the rice is of a local variety with a growing period of at least 8 months. It is transplanted more than once, which is probably related to the tillering characteristics of the plants and/or to the need to suppress the weed growth.

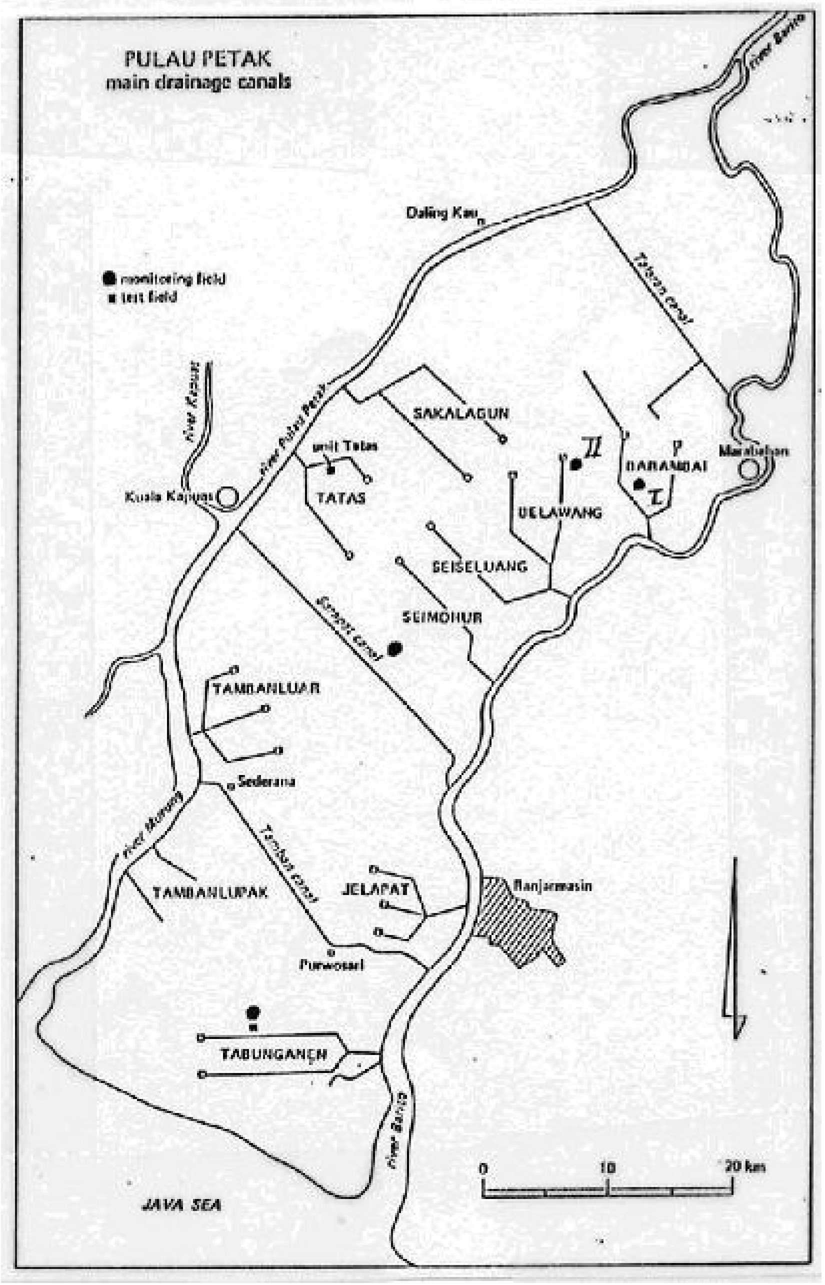

Figure 4.1. Location of the monitoring fields

Agronomists often advocate the introduction of high yielding varieties (short straw, short growing period). These varieties (HYV) would enhance double cropping, either in a sequence of two HYV's or in a sequence of one HYV and one traditional variety.

In Pulau Petak the HYV's do generally not yield a higher production per crop than the local varieties (Smilde 1989), but the yearly production with a double crop is higher than with only one crop. The farmers, however, are not keen on HYV's. The reasons for this are not clear, but may be related to the dependence on external inputs, the increased risk incurred if the crop fails, the difficulty of harvesting and drying the rice in the wet season, and perhaps environmental factors, e.g. rat plagues. The introduction of two ric crops per year will undoubtedly enhance the rat population and increase the damages to the plants inflicted by them. In addition, isolated plots of HYV's may attract the existing rat population. Also, the local varieties are photosensitive, which implies that the harvest time of the rice is predictable and dependable. A further reason may be found in the market: at present the market prices are higher than the guaranteed minimum price, but when more rice is produced, the market price will probably come down. Further, the market price of the traditional variety is higher than of the HYV's and their taste is preferred. Finally, the HYV's are more susceptible to crop failure under deep flooding than the local varieties. On account of the occurrence of high water levels on the fields in category A lands, high yielding varieties are risky here.

The monitoring fields were chosen to represent a range of environmental conditions. The fields Barambai I and II are in he land category C, i.e. their level is above the highest level of the spring tide.

The field Barambai I is encountered in an intensively drained area, prepared for trans-migrants less than 20 years ago.

The field Barambai II is encountered in an area with low drainage intensity where recent spontaneous settlements too place. The soil is potentially acid and it has a very high value of TPA (total potential acidity). The quality of surface and groundwater is good (i.e. during the wet season), which is thought to be owing to the nearbu presence of a small extension of primary forest, its last remnant on the island.

The Serapat field is found in the Category B land, i.e. below the highest level of the spring tide but above the highest level of the neap tide. The area is intensively drained and already in cultivation for more than 50 years.

The Tabunganen field is situated in Catgory A land, i.e. below the highest level of the neap tide but above mean sea level. Here, the actual acidity indicators are low, but the potential acidity is high.

Table 4.1 presents some chemical characteristics of the soil and groundwater of the monitoring fields, together with the dry grain paddy yields obtained. The data were provided by Mr. Masganti. The table shows that the relatively high yield in Tabunganen can probably be explained by the relatively high pH values, the low concentration of SO_4^{2-}, and the low actual acidity (TAA). In the other fields, however, the parameters used provide little explanation of the yield differences observed. Also, it is difficult to detect mutual relations between the magnitudes of the various parameters.

Conclusions

The above observations confirm the earlier conclusions (chap. 2.3) that the macro-variability of the chemical parameters of soil and water in Pulau Petak is not great, and (chap 1.2) that the crop yields are determined by other factors than only the soil and water parameters, and that the parameters are relatively independent of each other. On the other hand, the elements that played a role in the selection of the monitoring fields (i.e. the hydrological conditions and the development history) seem to provide a better explanation of the yield variation. More certainty about this last statement can be obtained by continuing the observations and including replications.

Table 4.1 Average values of the chemical parameters of the monitoring fields and yields of traditional rice varieties

	Name of the monitoring field			
	Barambai I	Barambai II	Serapat	Tabunganen
	Parameters of the groundwater by period*)			
pH (canal)	- - -	3.8 (Mar-Apr)	3.0 (Apr-Jan) >4.0 (Jan-Mar)	- - -
pH (surf. water)	3.0 (Jan-May)	4.0 (Dec-Feb) 5.0 (Mar-May)	5.0 (Jan-Apr)	6.0 (Jan-Sep)
pH (40 cm depth)	3.5 (Apr-Jul)	4.0 (Nov-Jun) 3.5 (Jul-Sep)	3.5 (Jan-Oct)	>5.5 (Nov-Aug) 4.0 (Sep)
SO_4^{2-} (me/l 40 cm depth)	11 (Dec-Apr)	13 (Nov-Apr) 4.0 (Apr)	3.5 (Apr-Jun)	2.0 (Nov-Sep)
	Parameters of the soils by depth ^)			
pH (H_2O)	3.7 (0-45cm) >4.0 (>65cm)	3.5 (0-25cm) >5 (>35cm)	3.2 (0-90cm) >4 (>90cm)	5.5 (0-40cm)
TAA (me/kg)	300 (0-65cm) <200 (>65cm)	300 (0-35cm) 100 (>35cm)	350 (0-90cm) <100 (>90 cm)	200 (0-20cm) <100 (<20cm)
TPA (me/kg)	>300 (0-1.6m)	>900 (0-1.5m)	200 (0-50cm) >300 (>50cm)	>300 (0-1.5m)
EC (mS/cm)	0.30 (0-45cm) 0.45 (>45cm)	0.50 (0-65cm) 0.30 (>65cm)	0.20 (0-70cm) 0.50 (>70cm)	0.60 (0-40cm)

*) The varying time periods were chosen so that the parameter values within the periods have a relatively small variation

^) The varying thicknesses of the soil layers were chosen so that the parameter values within the layers have a relatively small variation

5. SOIL CONDITIONS AND CROP YIELDS OF THE DRAINED “UPLAND CROPS” FIELD OF TATAS

Crop trials were made in the drained *palawidja* (upland crops) field I of Tatas. The cropping schedule was:

planting date	crops
1988 Oct/Nov	cassava, maize, upland rice
1989 Feb	cassava (ctd.), mung bean (legume, green manure)
1989 May	peanut, soybean
1989 Oct/Nov	maize, peanut, soybean

At the same time different fertilizer and soil tillage treatments were made. The treatments and yields are summarized in tables 5.1 to 5.4.

Table 5.1 shows that the yield of the upland rice crop had much variation, but there are good indications that yields of more than 2t/ha can be obtained. The upland rice can be grown twice a year. It would be interesting to repeat the experiment, especially because the *palawidja* field is manifesting a gradual improvement of its fertility. (chap. 3, see also the following tables). The introduction of the green manure after the cultivation of the upland rice may have contributed to the improvement, which might become evident when the crop trial with upland rice is repeated. As already signaled in chapter 3, an intensified drainage is perhaps instrumental in improving the quality of the organic matter and subsequently the fertility of the soil.

Table 5.1. Yield (t/ha) of upland rice, Feb ’88, by fertilizer treatment with one replication in the *palawidja* field (I) of Tatas

Fertilizer treatment	first trial	second trial
No fertilizer	0.64	0.94
Lime only	1.92	1.29
Phosphate only	1.06	1.11
Lime and phosphate	1.89	2.10

Table 5.2 shows the yields of maize in 1990, which were generally very poor. The previous maize yields were also disappointing and part of the maize crop was consumed by wild bores. Maize seems no attractive crop for Pulau Petak.

Table 5.2. Yield of maize (t/ha), Feb ’90, by soil tillage and lime treatment with one replication in the *palawidja* field (I) of Tatas

Fertilizer treatment	tillage by hand (with *cangkul*)		tillage by tractor	
No lime	0.02	0.02	0.05	0.02
Residual lime *)	0.68	0.52	0.28	0.42
Lime, first time	0.78	0.65	0.55	0.37
Lime, continued ^)	0.50	0.35	0.68	0.29

*) No lime is given, but there may be a residual effect of the lime treatment of the previous crop

^) Lime is given and there may be a residual effect of the lime treatment of the previous crop

Table 5.3 shows promising results for peanut. With the lime treatment, the yields surpass the level of 1 t/ha, and also yields of over 2 t/ha were obtained. Without lime the yields are less than 0.7 t/ha. Due to the large variations in yield and the limited number of replications, the exact effect of the fertilizer and tillage trials is difficult to assess. The general impression is that the tillage by tractor is not superior to the tillage by hand. The lime treatments have definitely a positive effect. It is also clear that the effect of the lime treatment persists over more than one cropping season. Although the data collected are sufficient to conclude that the yield differences are statistically significant using lime as the explanatory variable, they are insufficient to determine with reasonable accuracy the yield increases that are to be expected from the various treatments. As the experiments with peanut are continued, it is likely that a more precise evaluation of the effects of the treatments is possible in the near future.

Table 5.3. Yield of peanut (t/ha), Aug ’90, by soil tillage and lime treatment with one replication in the *palawidja* field (I) of Tatas

Fertilizer treatment	tillage by hand (with *cangkul*)		tillage by tractor	
No lime	0.41	0.41	0.64	0.69
Residual lime *)	1.79	0.98	1.08	1.02
Lime, first time	2.32	0.96	1.10	1.70
Lime, continued ^)	2.49	1.14	1.29	1.54

*) No lime is given, but there may be a residual effect of the lime treatment of the previous crop
^) Lime is given and there may be a residual effect of the lime treatment of the previous crop

Like the peanut, also the soybean shows promising results (table 5.4). With the lime treatment, the yields surpass the level of 1.0 t/ha, and also yield of more than 1.5 t/ha were obtained. Without lime, the yields are less than 0.7 t/ha. This tendency is quite in agreement with the tendency signaled above for peanut. The other conclusion drawn for peanut are equally valid for soybean.

Table 5.4. Yield of soybean (t/ha), Aug ’90, by soil tillage and lime treatment with one replication in the *palawidja* field (I) of Tatas

Fertilizer treatment	tillage by hand (with *cangkul*)		tillage by tractor	
No lime	0.39	0.39	0.68	0.63
Residual lime *)	1.32	1.06	1.03	1.02
Lime, first time	1.58	1.18	1.10	1.64
Lime, continued ^)	1.73	1.37	1.50	1.50

*) No lime is given, but there may be a residual effect of the lime treatment of the previous crop
^) Lime is given and there may be a residual effect of the lime treatment of the previous crop

Conclusions

In relation to the potentialities of crop diversification mentioned in chapter 1.1 and 1.2, and he promising results of intensified drainage together with the prospects of improved quality of the organic matter mentioned in chapter 3.2 (and above, in the resent chapter), the experiments in the drained *palawidja* field of Tatas not only provide confirmations but they also indicate that further research on these aspects is probably worth the effort, not only in Tatas, but also in other parts of Pulau Petak.

Note

The global research on acid sulfate soils in the tropics has more often taken place in climatic zones with a pronounced and prolonged dry season than in zones with a per-humid climate as in South Kalimantan. The reasons for this may have been that coastal per-humid climates do not occur as extensively as the monsoon-type climates, and if they occur (as e.g. in the Orinoco delta in Venezuela), the rainfall excess is not as high as in South Kalimantan. Further, in regions with a markedly dry season, the acid sulfate soils are not so strongly associated with organic matter as in the per-humid regions. In the monsoon-type climates, the effects of subsurface land drainage and/or flood protection in areas with acid sulfate soils have usually proved to be disastrous, although a modest from of surface drainage is sometimes beneficial. In South Kalimantan, a surface drainage system has little effect on account of the enormously high hydraulic conductivity of the underground, which is not common in acid sulfate soils even though their hydraulic conductivity is usually still considerable. On the other hand, the subsurface drainage systems in South Kalimantan seem to make sense. I appears necessary that the studies of the potential wise use of acid sulfate soils and the corresponding appropriate reclamation methods need to discern and incorporate more strongly the diversity of environmental and socio-economic conditions in regions where these soils are found.

6. SUMMARY OF CONCLUSIONS

Chapter 1.1

1 – the classification of the area of Pulau Petak using the land categories 0, A, B and C needs further elaboration before it can be applied for the purpose of identifying practical water management options per category: the relation between tidal levels, land levels and water management possibilities is strongly dependent on the distance of the land to the rivers and the main canals as well as on the micro relief (these aspects were already recognized by Sevenhuijsen and Kselik, 1988);
2 – the degree to which the problems associated with the soil acidity become manifest are not only dependent on the qualities of the soil but also on the land's drainage conditions, the cropping systems, the development history, and their interaction (Sevenhuijsen and Kselik, 1988, see also chap. 4);

3 – a rotation of lowland rice with upland crops has possibly a beneficial effect on the quality of the organic matter, on the degree of acidity, and on the soil's fertility (chap. 5).

Chapter 1.2

The potential of the soils of Pulau Petak for agricultural use does not only depend on the soil's characteristics, but also (and to a large extent) on the agro-socio-economic conditions, the infrastructure (accessibility, traffic facilities, drainage) and the possibility of progressive diversification of the cropping system. This is confirmed by the observations in the monitoring fields (chap. 4) and the results of the experimental fields in Tatas (chap. 5).

Chapter 1.3

1- The area of Pulau Petak has been subjected for ages to a large amount of annual rainfall excess over evaporation;
2 – the traditional *handils* have predominantly s drainage and transport function, not irrigation;
3 – owing to he large hydraulic conductivity of the soil, even a widely spaced drainage system requires a small hydraulic had to assure that the rainfall excess passes through the soil;
4 – consequently, the soil has been subjected to a continuous leaching, yet the acidity indicators have remained high;
5 – the oxygen required for the production of acids from the chemically reduced soil minerals is supplied by diffusion and mass transport of gasses during the relatively dry season when the water tables are deep;
6 – the acidity and fertility of the soils are more related to the water table regime than the amount of leaching, whereby the organic matter may play an important role as it is abundantly present in the soil and it produces a considerable acidity, which production seems higher when the soil is waterlogged than when it is relatively dry;
7 – the traditional reclamation practices based on drainage by *handils* and diverse cropping have proved that a relatively successful agricultural development is possible in Pulau Petak;
8 – if one wishes to investigate the reclamation possibilities of the back-swamps for agricultural use, it seems advisable to continue the experimentation with the simultaneous introduction of an improved drainage system, and adequately diversified cropping system (including leguminous crops, upland crops and fruit trees), efficient soil tillage practices (to homogenize the topsoil and promote the leaching efficiency), as well as effective fertilizers (e.g. the application of lime, Smilde 1989).

Chapter 2

1 - The chemical soil parameters studied in the transects of Tatas and Belawan are essentially he same, except the TPA are higher in Tatas than in Belawan.
2 – In the dry season the pH of the topsoil in the transects increases from pH=3.0 or less to pH=3.6 or more.

3 – The above observation is in contrast to the generally accepted theory on acid sulfate soils but may perhaps be related to the quality changes of the organic matter as a result of its drying/wetting and respectively oxidation/reduction or to certain exchange reactions.
4 – The micro variability of the chemical parameters of the soil is much greater than the macro variability.
5 – The various chemical parameters of the soil, when plotted against each other, show a large scatter and not much trend: the are quite independent of each other.
6 – The acidity indicators of the groundwater show consistently much higher values in forests than in open land. This is perhaps related to the type of vegetation and the properties of the organic matter. The eventual influence of the groundwater movement is not (yet) clear and subject of further study.
7 – As the acidity indicators of the groundwater at 60 cm depth and 100 cm depth are practically identical, the sampling procedure of groundwater mey be limited to one depth only (say 60 cm) to save time, effort and costs.

Chapter 3

1 – It appears that the practice of subsurface drainage by ditches combined with the cultivation of dry-land crops has a favorable effect on the acidity indicators of the soil and of the groundwater. This is perhaps related to the quality of the organic matter.
2 – In the drained fields, the pH of the groundwater were higher in the dry season than in the wet season and they showed an increase with time, whereas in the other fields such features did not occur. This is conform to the findings in he previous chapters but not conform to the general theory of acid sulfate soils.
3 – The other trials in the experimental fields of Tatas (liming, puddling, irrigation) did not have an appreciable influence on the chemical parameters of the soil and the groundwater.
4 - The chemical parameters of the soil and the groundwater change little with depth up to 40 cm. Eventual changes beyond this depth have not been verified.
5 – The gradient of the groundwater quality, which improves when going from field IV (near the *Gelam* forest) to field I (away from the forest) is a subject of detailed study as it appears to depend strongly on he drainage situation. The influence of the groundwater quality on the crop performance remains to be investigated.

Chapter 4

1- The relatively high yield of the local rice variety in the Tabunganen monitoring fild can be attributed to the relatively high pH value, the low concentration of sulfates and the low total actual acidity, which is inherent to the properties of the category A land.
2 – In the other monitoring fields the chemical parameters of the soil and the groundwater showed some differences, but they do no explain much of the yield variation.
3 – It is likely that the hydrological conditions and the development history of the agriculture determine the yield levels to a great extent, but more observations are required to verify and further specify this statement.

Chapter 5

1- Peanut and soybean are promising crops on drained soils and, perhaps, they contribute to the improvement of the soil fertility and the quality of the organic matter.
2 – The application to the soil of relatively small amounts of lime is essential for obtaining good yields.
3 – The applied lime works as a fertilizer and it possible activates or improves the organic matter present in the soil. It does not de-acidify the soil unless given in enormous quantities.
4 – It appears necessary that studies on the wise use of acid sulfate soils and the corresponding reclamation techniques need to discern and incorporate more strongly the diversity of the environmental and socio-economic conditions where these soils are found.

7. RECOMMENDATIONS FOR FURTHER STUDY

1- The experiments in Unit Tatas are to be continued with a lesser number of trial combinations and a reduced intensity and frequency of observations, i.e. the (number of) observed chemical parameters and of sampling depths may be adjusted in the light of their physical/chemical significance experienced an their known variation with time and space; the experiment with upland rice may be resumed.
2 – The observation program in the two transects may be discontinued as they have fulfilled their purpose.
3 – The number of monitoring fields may be extended with the aim to obtain a clearer picture about the prevailing relations between the crop yields, the indicative chemical parameters of soil and groundwater, the drainage conditions, the development history and the agro-socio-economic situation. The monitoring fields may include rice fields, *palawidja* fields, *sorjans,* spoil banks, and tree gardens. The frequency and intensity of observations per field may be reduced, see recommendation 1.
4 – In the back-swamps some on-farm experimental fields may be selected to study the possibility of introducing *palawidja* crops and a more intensified subsurface drainage system by ditches, and to study the effects of crop rotations rice-*palawidja* and drainage on the crop production, on the soil’s acidity and fertility, on the quality of the organic matter, and their mutual influences. The rice varieties used may be limited to the local varieties.
5 – Experiments may be set up in drums under natural rainfall conditions, using top soils with different organic matter contents, different crop rotations and different drainage intensities with the aim to study the (de)acidification processes as a function of the variables mentioned. The drum experiments, by nature, cannot include a study of the effects if in-seepage of poor quality groundwater, but in most soils of Pulau Petak there is annually a considerable net downward percolation of rainwater so that the quality of the water in the underground has a limited influence. The “horizontal flushing” experiments that are presently underway in the underground in a part of the Barambai area should be

able to yield conclusions about the impact of changes in the groundwater quality on the quality of the soil and its agricultural potential.
6 – The effects of Nitrogen fertilizer on crop yields in relation to lime application may be studied in Unit Tatas, the monitoring fields, and/or the on-farm experimental fields, to detect to which degree liming substitutes N-fertilization.
7 – In addition to the proposed consultancy program, consultants on cropping systems and agro-socio-economics may be invited.

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