Chapter 3. Results and Discussion --- Soil and Water Team

3-1 Hydrological Characteristics of the Dwinyan and Biem watershed

3-1-1 Introduction

The Dwenyan Watershed is formed by the Dwenyan stream which is a tributary of the Biem river. The stream is about 16 kilometers long and drains an area of 30km^2. It is not perennial; it starts flowing in May-June and it dries up in late November or early. As shown in the Fig. 3-1, it joins the Biem river near Atakrom a village about five kilometres south of Adugyama. In order to monitor the hydrological characteristics of the watershed meteorological and flow stations were established within the watershed. In addition eleven strategic transects were also established at various sections of the watershed as shown in the Fig. 3 of executive summary.

The Biem river at Biemso has a catchment area of 68km^2 and average flow was estimated to be 0.66 m^3/s. According to past flow measurement Dwinyan river has average flow 0.23 m^3/s (annual mean) at Adugyama of 29 km^2. This is equivalent to about 17% discharge of total rainfall. This flow, however, does not include ground water flow, which exists considerable amounts.

3-1-2 Hydrometeorological Stations

Two meteorological stations were established within the watershed; one upstream near the forest reserve at Asuodei and the other downstream at Potrikrom (Photo. 3-1). Parameters being monitored at these two stations are rainfall, temperature, relative humidity evaporation.(the pan A type). These parameters are to help in establishing the water balance of the Dwinyan Watershed which will in turn give an idea about the water resource of the watershed in terms of quantity and for that matter the area that can be successfully put under sawah.

In the case of the rainfall measurement at the two stations, improvised, as well as standard rain gauges were used. The improvised raingauge consist of a PVC pipe 40cm high with a diameter of 22cm, which is imbedded into the soil. A five litter plastic container (commonly used to carry water and other liquids) is placed inside the pipe in such a way that the neck of the container is at the level of the ground. A funnel of a known diameter is inserted into the neck of the container. The funnel receives the rain and directs it into the container. The cost is very low as compared with the standard raingauge and for the quality of data needed it quite adequate. An automatic rain gauge was also installed at Asuodei, which will help establish the rainfall intensity of the area. The values of the rainfall from the standard and improvised gauges are presented in Fig. 3-2 at Asuodei and Fig.3-3 at Potrikurom.

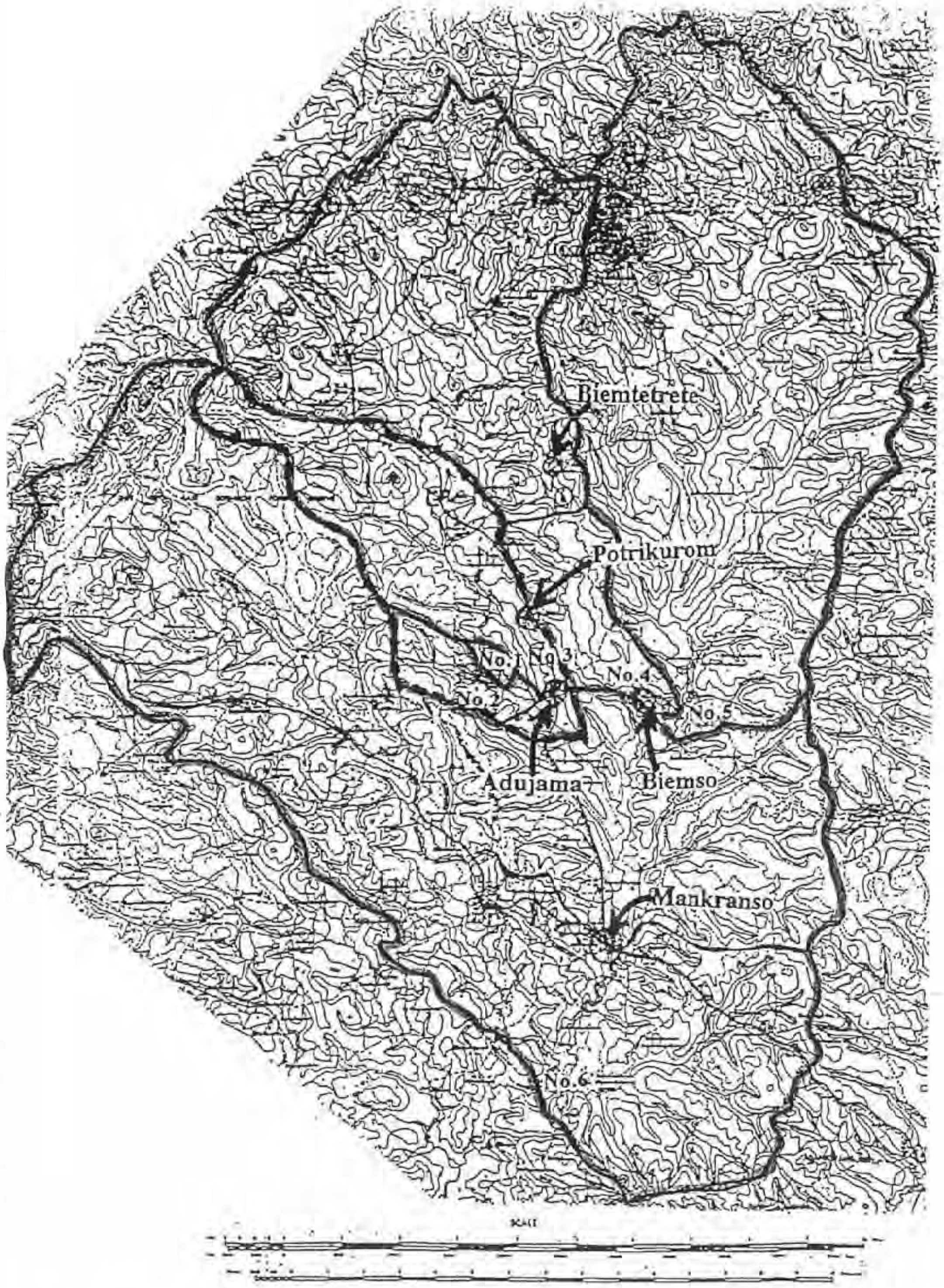


Fig. 3-1. Various sizes of benchmark watersheds. No.1 is Gold valley about 100 ha, No.3 is Rice valley about 500 ha, No.3 is Dwinyan river watersheds about 3,500 ha, No.4 is Biem river watershed about 7,000 ha. Biemso is the new site started from 1999.

Fig.3-2. Calibrating an improvsed raingauge - Asuodei

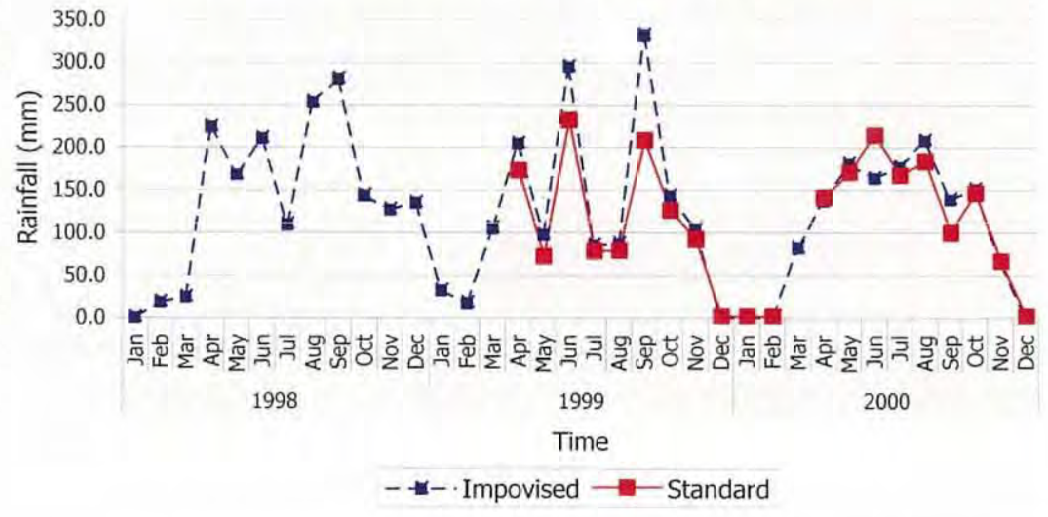


Fig. 3-3. Calibration of Improvised Rain Gauge - Potrikrom

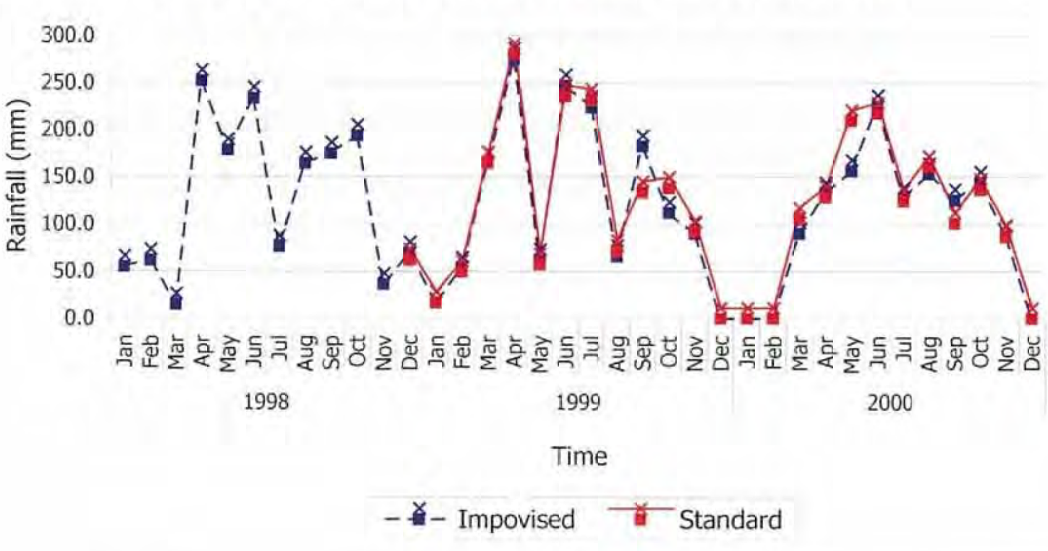


Photo. 3-1. Meteo Station

In the two figures, rainfall values from standard and improvised gauges are compared. The stations were located at the schools in the towns and the recordings are being done by the school children twice a day under the supervision of the teachers. The raw data as recorded at the meteorological stations. The mean monthly values of parameters at both stations are presented in Tables 3-1 & .3-2

It can be seen from the rainfall data that the annual values has been decreasing from 1998 to 2000 and this explains why, for example while there was enough water in the dugouts for Danyame site in1998 they were dry during the same period in the year 2000.

Table. 3-1. Meteorological Parameters at Asuodei

ASUODEI	Date	Temp.(°C)	R. Hum. (%)		Evap.(mm)	Rain (mm)	Rain - mm
		Mean	Max	Min		Vol.	Stand.
1998	Jan	25.1	73.5		5.4	0.0	
	Feb	27.6	79.8	44.0	7.2	0.0	
	Mar	29.6	85.5	49.9	6.3	24.1	
	Apr	28.0	88.4	61.5	5.2	224.4	
	May	27.2	84.9	72.4	5.0	168.0	
	Jun	25.4	93.2	79.4	3.3	210.7	
	Jul	24.9	93.3	78.8	3.5	109.5	
	Aug	24.0	92.6	86.3	3.2	253.2	
	Sep	24.9	90.3	79.3	3.1	280.2	
	Oct	25.6	91.6	75.6	4.6	143.2	
	Nov	26.3	86.9	68.3	4.3	126.7	
	Dec	26.7	85.3	62.8	6.6	134.9	
	Total				4.8	1674.9	
1999	Jan	23.1	85.2	79.3	4.0	32.4	
	Feb	25.5	78.5	72.1	6.1	17.2	
	Mar	16.0	65.5	64.3	7.6	105.3	
	Apr	23.9	86.4	72.4	5.5	204.5	171.3
	May	26.3	81.8	71.3	5.5	97.8	70.9
	Jun	26.0	88.4	81.7	5.6	294.6	230.6
	Jul	23.8	89.8	76.7	3.1	85.4	77.1
	Aug	23.7	89.8	76.7	2.7	87.1	77.6
	Sep	24.4	91.4	78.0	2.8	331.8	206.6
	Oct	24.7	87.9	75.8	3.1	143.2	124.0
	Nov	25.2	84.7	72.3	3.6	104.0	91.0
	Dec	24.6	80.4	60.4	3.4	0.0	0.0
	Total				4.4	1503.2	
2000	Jan	25.7	82.0	63.0	3.9	0.0	0.0
	Feb	25.6	60.7	47.1	6.8	0.0	0.0
	Mar	28.2	77.3	63.8	6.2	82.6	0.0
	Apr	26.7	82.8	64.0	4.6	137.0	139.4
	May	26.7	80.4	70.6	4.5	181.1	169.1
	Jun	25.1	87.7	77.3	2.8	263.7	212.5
	Jul	23.8	89.4	81.2	3.4	177.3	165.5
	Aug	23.9	89.3	83.5	2.2	207.9	181.5
	Sep	24.8	83.7	79.5	2.1	138.7	98.1
	Oct	25.3	85.3	71.9	3.4	150.4	144.5
	Nov	25.7	81.9	69.5	3.6	63.7	64.6
	Dec	27.5	77.2	60.5	3.4	0.0	0.0
	Total				3.9	1402.3	1175.2

Table 3-2. Meteorological Parameters at Potrikrom

Potrikrom	Date	Temp.(oC)	R. Hum. (%)		Evap.(mm)	Rain (mm)	Rain - mm
		Mean	Max	Min		Vol.	Stand.
1998	Jan	24.5	85.3		2.7	55.1	
	Feb	28.5	84.9	44.8	5.9	62.0	
	Mar	29.1	78.7	46.7	5.8	14.9	
	Apr	28.4	82.9	70.9	4.8	252.3	
	May	27.0	82.8	69.9	5.0	179.0	
	Jun	26.3	87.6	69.2	3.6	243.0	
	Jul	24.6	91.1	74.2	2.3	76.4	
	Aug	23.9	88.4	75.6	2.1	164.8	
	Sep	23.5	91.3	75.4	1.9	175.5	
	Oct	25.9	90.4	69.6	2.5	194.1	
	Nov	26.8	89.2	62.6		36.5	
	Dec	25.8	93.3	65.5	3.2	69.5	62.1
	Total				3.6	1523.1	
1999	Jan	30.5	86.5	60.4	3.4	17.2	17.0
	Feb	23.2	83.7	55.6	4.7	53.7	50.0
	Mar	27.7	88.4	59.2	4.6	165.4	164.9
	Apr	26.9	86.0	68.2	4.1	275.7	280.5
	May	27.0	79.3	63.6	3.8	62.0	57.6
	Jun	26.1	86.4	70.3	3.4	247.5	236.3
	Jul	25.0	91.4	73.9	2.2	224.4	232.2
	Aug	24.7	90.8	74.4	2.9	66.2	71.4
	Sep	23.0	91.6	78.5	2.5	182.8	134.0
	Oct	25.4	90.6	76.6	2.9	112.1	138.5
	Nov	25.8	90.6	66.8	0.8	90.0	92.0
	Dec	24.7	82.6	55.7	3.4	0.0	0.0
	Total				3.2	1497.0	1474.4
2000	Jan	25.3	85.1	59.7	3.4	0.0	0.0
	Feb	25.3	65.1	52.0	5.5	0.0	0.0
	Mar	28.5	83.1	55.2	4.5	90.4	106.0
	Apr	27.3	87.0	61.5	5.0	132.8	129.0
	May	26.8	88.7	65.4	4.3	256.9	210.0
	Jun	25.4	89.1	73.5	3.3	225.9	218.0
	Jul	23.9	88.0	79.2	3.0	127.7	125.0
	Aug	23.6	88.4	80.3	2.3	153.5	161.0
	Sep	23.0	87.0	79.2	2.5	125.6	101.0
	Oct	24.9	89.8	71.6	3.4	144.6	137.0
	Nov	25.6	91.3	74.4	3.7	87.8	87.0
	Dec	24.8	86.8	62.2	3.4	0.0	0.0
	Total				3.7	1345.3	1,274.0

3-1-3 Flow measurement of river Dwinyan at Adugyama

A v-notch was constructed across river Dwinyin at Adugyama to measure the flow. An automatic water level recorder was also installed at the site (Photo.3-2, 3-3, and 3-4). The v-notch has been calibrated and a rating curve for the station has been established as follows:

$$Q = 13.8H\ 2.5 \text{ (in litres/sec.)}$$

The generated flow, using the formula above and extracted levels from the water level recorder charts from 1st October to 14th January 1997. In October 2000 the water recorder was vandalized and it was replaced by a borrowed one from Water Research Institute. This gave data from25th November2000 to 8th January 2001 (Fig. 3-4, 3-5, and 3-6, Table 3-3).

Photo. 3-2. Measuring of the flow by v-notch

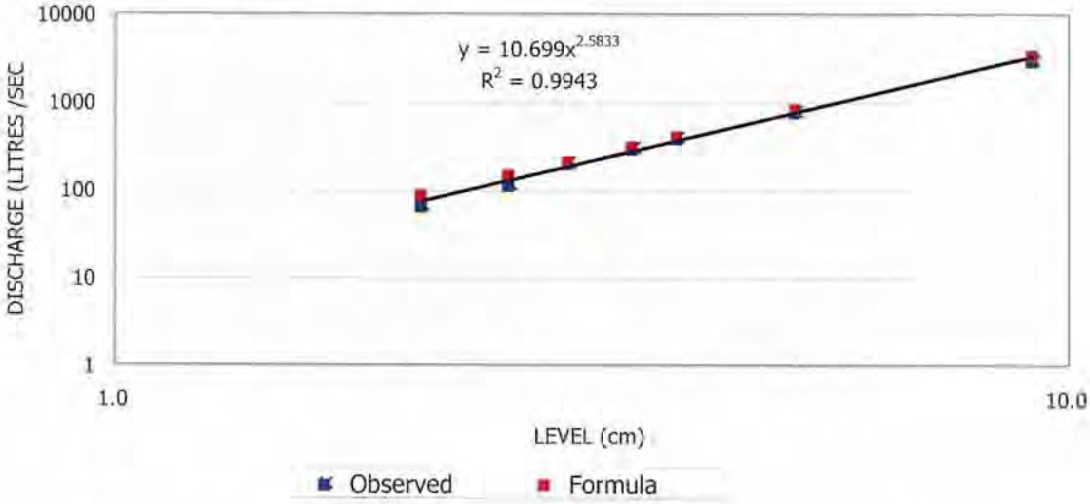
Photo. 3-3. Flow station

Photo. 3-4. Flow station with v-notch

Table 3-3. Flow of Dwinyin at Adugyama.

DATE	LEVEL (cm)	MEASURED FLOW (Litres/Sec)	FLOW BY V-NOTCH FORMULA (Litres/sec.)
18-09-97	3.5	296.7	316.3
23-09-97	3.9	389.4	414.5
26-09-97	3.0	203.1	215.1
27-09-97	2.6	114.3	150.4
04-10-97	2.1	65.3	88.2
06-10-97	9.2	3020.2	3542.8
07-10-97	5.2	776.5	850.9

Fig. 3-4. Dwenyai flows at Adugyama



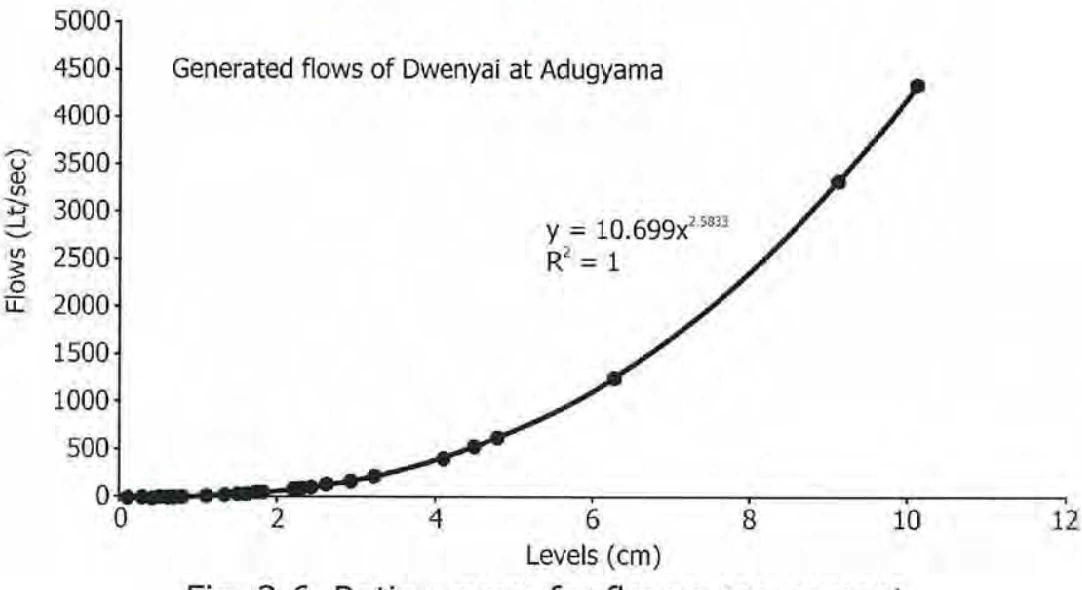
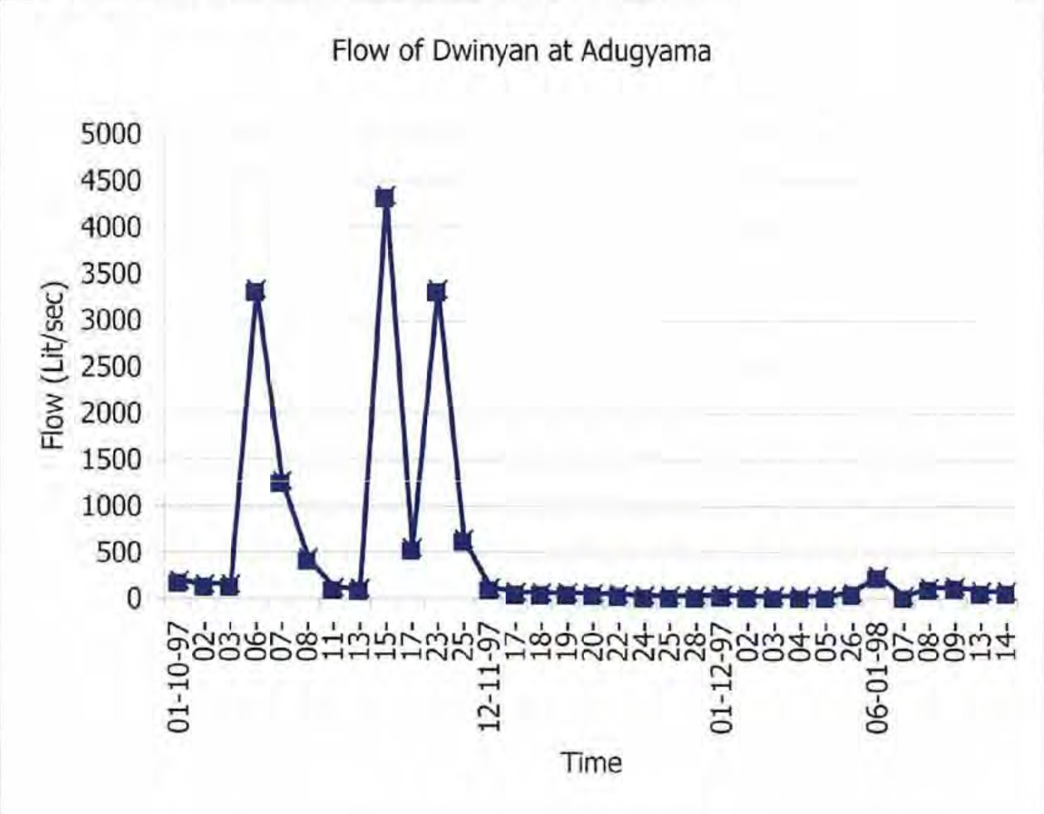
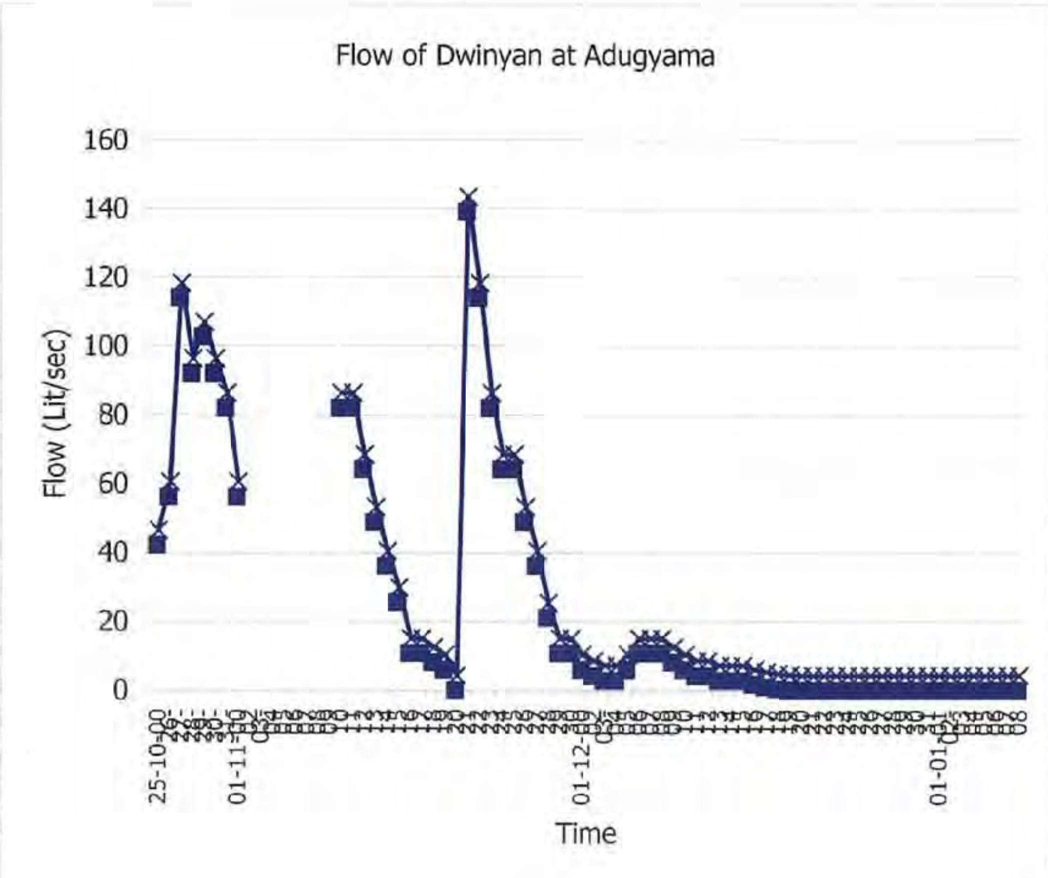


Fig. 3-6. Rating curve for flow measurement.

Fig. 3-5. Generated flows of Dwinyin at Adugyama





3-1-4 Water Balance of Dwinyan at Adugyama

In order to understand the hydrological processes in the catchment it was necessary to know the amount of water that the catchment receives(from rainfall) and how much is distributed to the groundwater, downstream and how much evaporates back into the atmosphere. The groundwater recharge of the catchment can be represented by the following simplified formula:

$$G = P - Q - E$$

Where G =groundwater recharge
P = Rainfall
Q = Runoff
E = Evapotranspiration

The computations for the water balance can not be carried out now because the vertical scale of the charts of the water level recorder is steel being worked out. The charts the with the levels for the whole period are available. Flows for most of the periods will only be computed after this. However the available flow data is presented in Fig. 3-4, 3-5, and 3-6, and Table 3-3.

3-2. Characterization and Evaluation of Benchmark Inland valley Watershed for Sustainable Agricultural Production

This section was cited by Kwame O. Asubonteng (SRI) et al, "Characterization and evaluation of inland valley watersheds for sustainable agricultural production: Case study of semi-deciduous forest zone in the Ashanti Region, Ghana", Tropics, Vol.10, No.4, 539-553, 2001

3-2-1 Data collection and analysis

3-2-1-1 Strategic transect line

Eight transects were laid within the study area along the different valley watersheds: the Gold Valley, the Rice Valley, and the Dwinyama Valley (Fig. 3-7). Soils were identified by means of minipits (dug to 60 cm) and supplemented by augering to 100 cm (where possible). Seven soil profiles (three in the valley bottoms, one at the fringe, and three on the upland soils along the transect line 5 (Fig. 3-7) were selected for profile pits and detailed descriptions of the main soils encountered, according to the FAO Guidelines for soil profile (FAO 1990). Each soil layer was sampled for laboratory analysis. Soil samples were air-dried, ground, and passed through a 2-mm mesh sieve. Soil pH was determined using a pH meter (with a glass electrode) with a soil-to-water ratio of 1:2.5, according to the methods described by IITA (1979) and McLean (1982). Total carbon content was determined by the wet combustion method (Walkley and Black 1934), and total nitrogen was determined by Macro-Kjeldahl method Bremner 1965). Total carbon and nitrogen content of some samples were determined using an NC analyzer (Sumigraph NC-90 A) as described by Geigher and Hardy (1971). Available P was determined by the Bray No. 1 method (Bray and Kurtz 1945). Exchangeable cations (Ca, Mg, K, Na) were first extracted with ammonium acetate (pH 7.0, 1.0 M NH_4OAc). Sodium and potassium in the extract were determined by atomic absorption spectrophotometry as described by Thomas (1982). Exchangeable Ca and Mg were determined by inductively coupled plasma atomic emission spectroscopy (Shimadzu ICPS 2000). Exchangeable acidity was determined by extracting with potassium chloride (1M KCL) solution, then by titrating the extract with sodium hydroxide as described by McLean (1965). Effective cation exchange capacity (ECEC) was calculated as the sum of the exchangeable cations (K, Ca, Mg, Na) and the exchangeable acidity. Particle size analysis was conducted by the pipette method as described by Gee and Bander (1986).

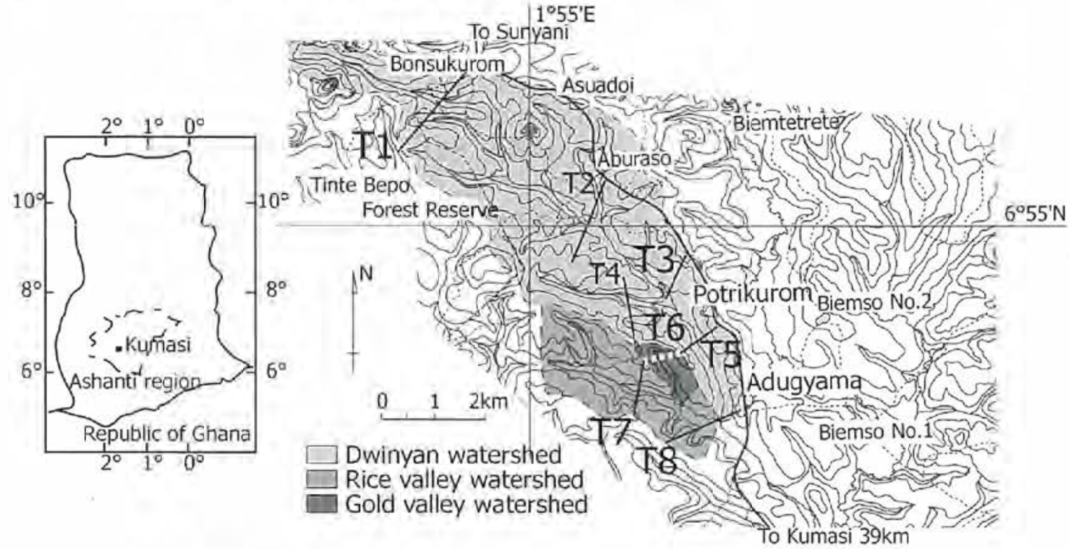


Fig. 3-7. Research site showing the locations of transects in the watersheds.

3-2-1-2 Land use survey

Along the eight transect lines, land use was described in terms of land cover at a width of 100 m on either side of each transect line every month for a period of three years (1997-1999). Monitoring of T2 and T4 were stopped because of their similarity to T1 and T7, respectively. Land use maps were drawn for the various inland valleys. The valley bottom areas were also quantified by using the Valley Bottom Ratio (VBR). The VBR is the ratio of the area occupied by the higher parts of the valley (crests, slopes, and fringes) (TVW) to the area of the valley bottom (VBW). Specifically, VBR = (TVW-VBW)/VBW. VBR is also a possible measure of the potential amount of water, related to the total rainfall, that may flow as runoff or as groundwater from the higher parts of the valley into the valley bottom.

3-2-1-3 Water table monitoring

Perforated polyvinyl chloride (PVC) pipes were installed for the monitoring of ground water and surface water dynamics along the eight transect lines for the three-year period. The water table was measured with a wooden meter rule at two-week intervals. Changes in groundwater depth, land use over time, and a rainfall histogram were plotted on the same graph to show the relationship between groundwater depth, rainfall, and land use within the year. The flood behaviour in the valley bottoms and the period of stream flow were also measured.

3-2-2 RESULTS AND DISCUSSION

3-2-2-1 Valley Morphology

The inland valleys in the study area are first-, second-, and third-order inland valley systems. We defined, tentatively here, that first-order systems are developed in watersheds of less than 500 ha; second-order systems are developed in watersheds of 500-3000 ha; and third-order systems are developed in watersheds bigger than 3000 ha. Transects 1, 6, and 7 (Figs. 3-7 and Fig. 3-8) are in first-order valley systems. They are very narrow and relatively asymmetrical. The crests are convex, with the slopes on both sides of the valley having similar morphologies. Their valley bottom widths ranged between 10 and 100 m. Transects 3 and 5 (Fig.3-9) are located in second-order valley systems and have straight slopes. The valley bottoms are almost flat (0-2%), have widths of between 100 and 300 m, and occur normally in the mid-sections of the valley systems. Transect 8 is in a third-order valley system (Fig. 3-10). Third-order systems are also symmetrical, and they occur in the downstream section of the valley systems. The valley fringes are much wider, though there were some irregularities resulting from the channels created by the Dwinyama River and other intermittent streams that flow in the valley. The width of the valley bottom is between 700 and 800 m.

Valley morphology plays a significant role in land husbandry, especially land leveling and the establishment of measures for water control and management. Hence, valley systems with gentle slopes, concave forms, and fairly broad valley bottoms, such as in Transects 5 and 8 described above, offer great potential for developing *sawah*.

3-2-2-2 Soil characterization along toposequence

Figure 3-11 shows a schematic description of the profile of the major soil series appearing on the toposequence of Transect 5. Tables 3-4 and 3-5 show some of the physico-chemical parameters analyzed and used in the classification of the soils encountered. Soils of the summit, with a relatively gentle slope, belonged to the Akumadan series, Pt1, which had a strong red colour, 2.5 YR, of the B horizons (Table 3-4). The Bekwai soil series, Pt2, and the Nzima series, Pt3, appeared in the next-lower topographic position. The yellow colour of their B horizons was increased, i.e., 5 YR and 7.5-10 YR for the Bekwai and Nzima series, respectively. These upland soils (Pt1 to Pt3) were classified as Ferric Lixisol, showing low-activity clay with discrete iron nodules (ISSS 1994). They are well drained on the summits and upper slopes, and become moderately well drained on the middle slopes. From the particle-size analysis, the clay contents of the soils of Pt1 and Pt2 under citrus or cocoa tree forest increased down the profile to values ranging between 28 and 58%. The effective cation exchange capacity (ECEC) of clay of subsoil layers (OR of the subsoil layer?) ranged from 6 to 23 cmol (+) kg^{-1}. Textures varied from loam (L) at the top through clay loam (CL) to clay (C) within the subsoil. The topsoil of Pt3, of the Nzima series, however, showed only 13% of clay under maize, cassava, cocoyam, and plantain mixed cropping. This may mean that once forest cover is removed, upland topsoils are susceptible to erosion.

Table 3-5 shows that the upland soils had reactions varying from slightly acidic (pH 5.4-5.9) in the topsoil to strongly acidic (pH 4.0-4.3) in the subsoils. ECEC values were between 6 and 20 cmol (+) kg^{-1} in the top 30 cm. However, ECEC decreases within the profile, showing the importance of organic matter. The organic matter content was high only on the topsoil (2-6%) but decreased sharply in the subsoil, up to 0.06%. The C/N ratio was below 10 and the nitrogen content was higher in the topsoil but decreased in the

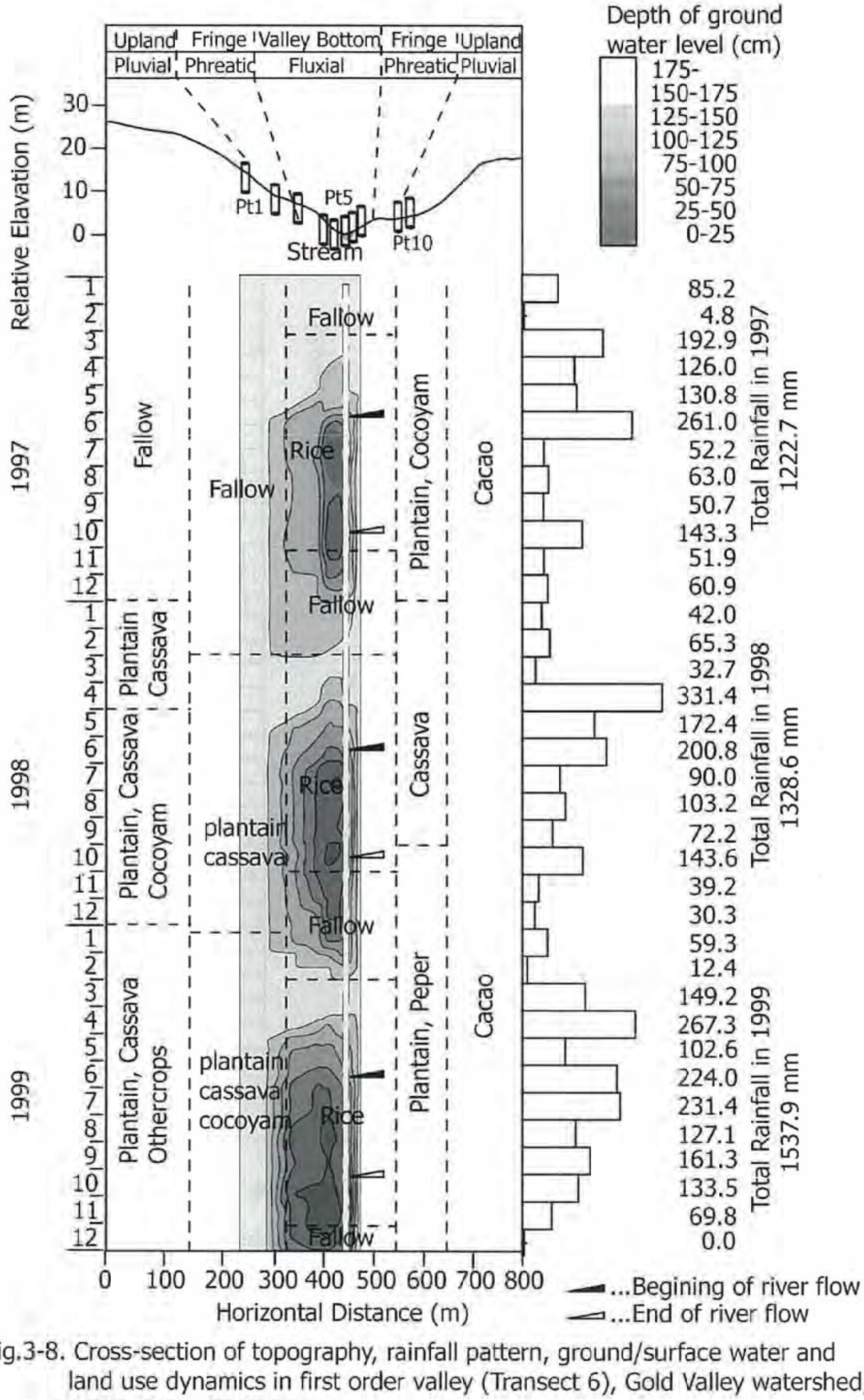
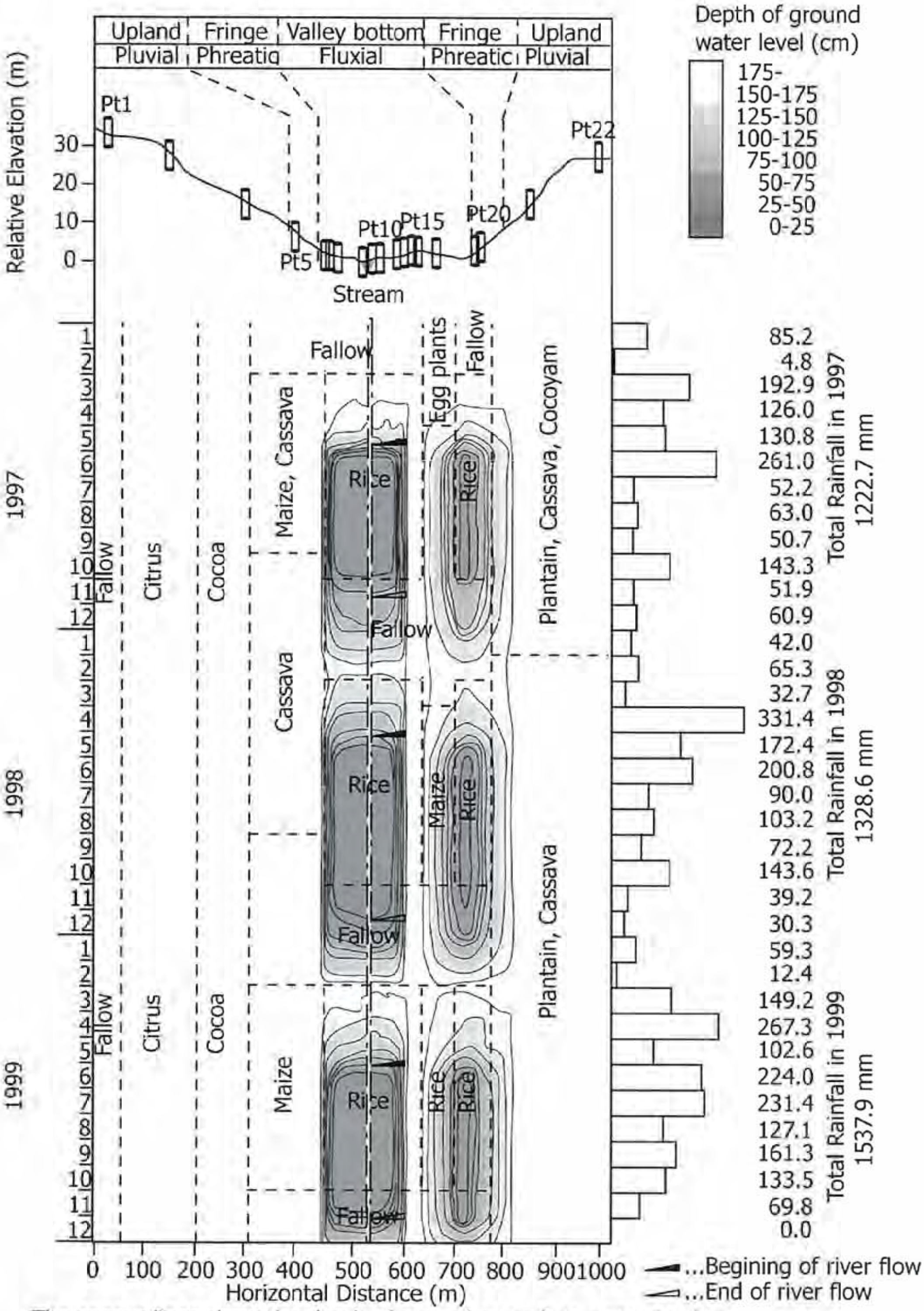
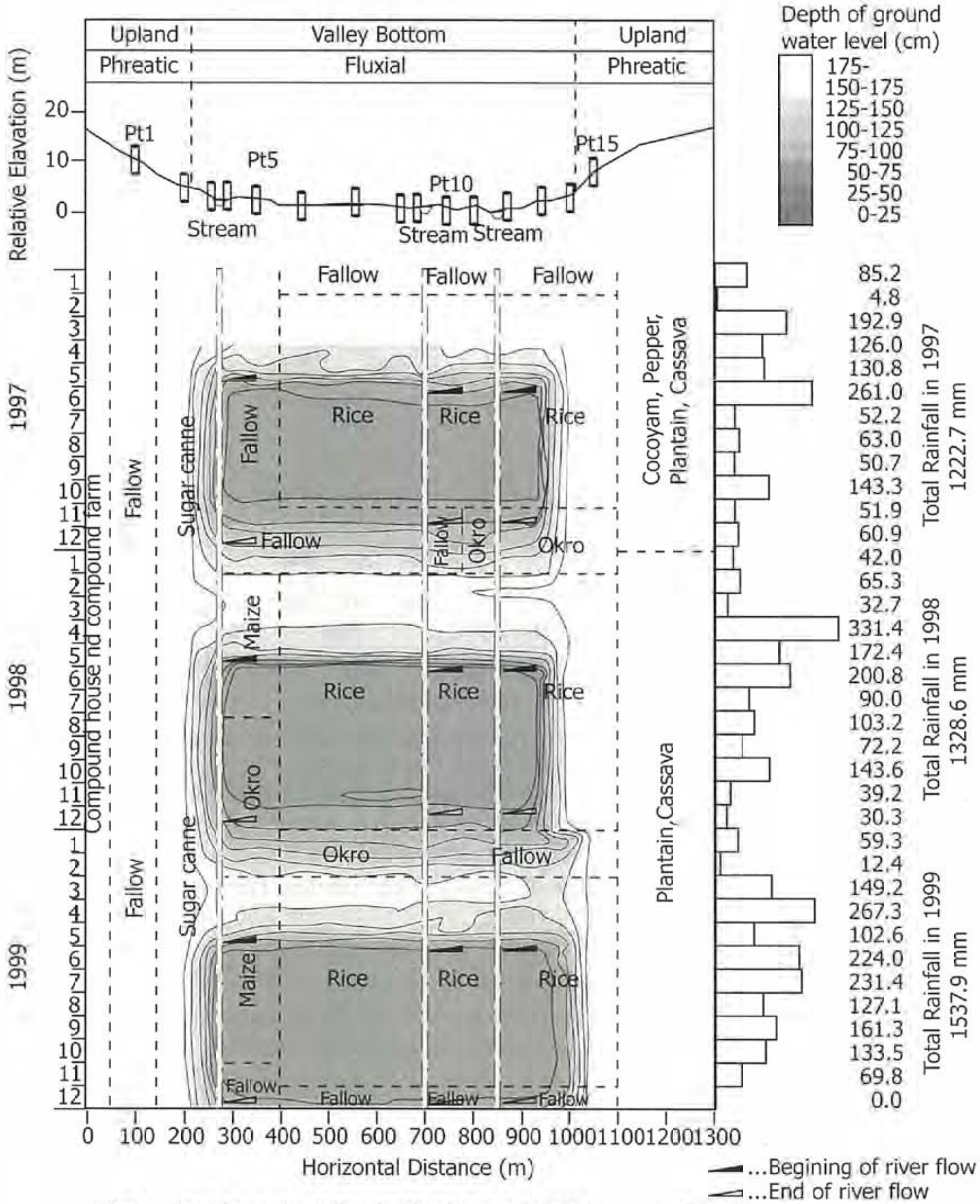


Fig.3-8. Cross-section of topography, rainfall pattern, ground/surface water and land use dynamics in first order valley (Transect 6), Gold Valley watershed, Ashanti Region, Ghana.



The conour lines show the depth of ground or surface water level in cm.

Fig. 3-9. Cross-section of topography, rainfall pattern, ground/surface water and land use dynamics in stream flow inland valley head (Transect 5), Dwinyan watershed , Ashanti Region, Ghana.



The contour lines show the depth of ground water or surface water.

Fig. 3-10. Cross-section of topography, rainfall pattern, ground/surface water and land use dynamics in third order Valley (Transect 8), Dwinyan watershed, Ashanti region, Ghana

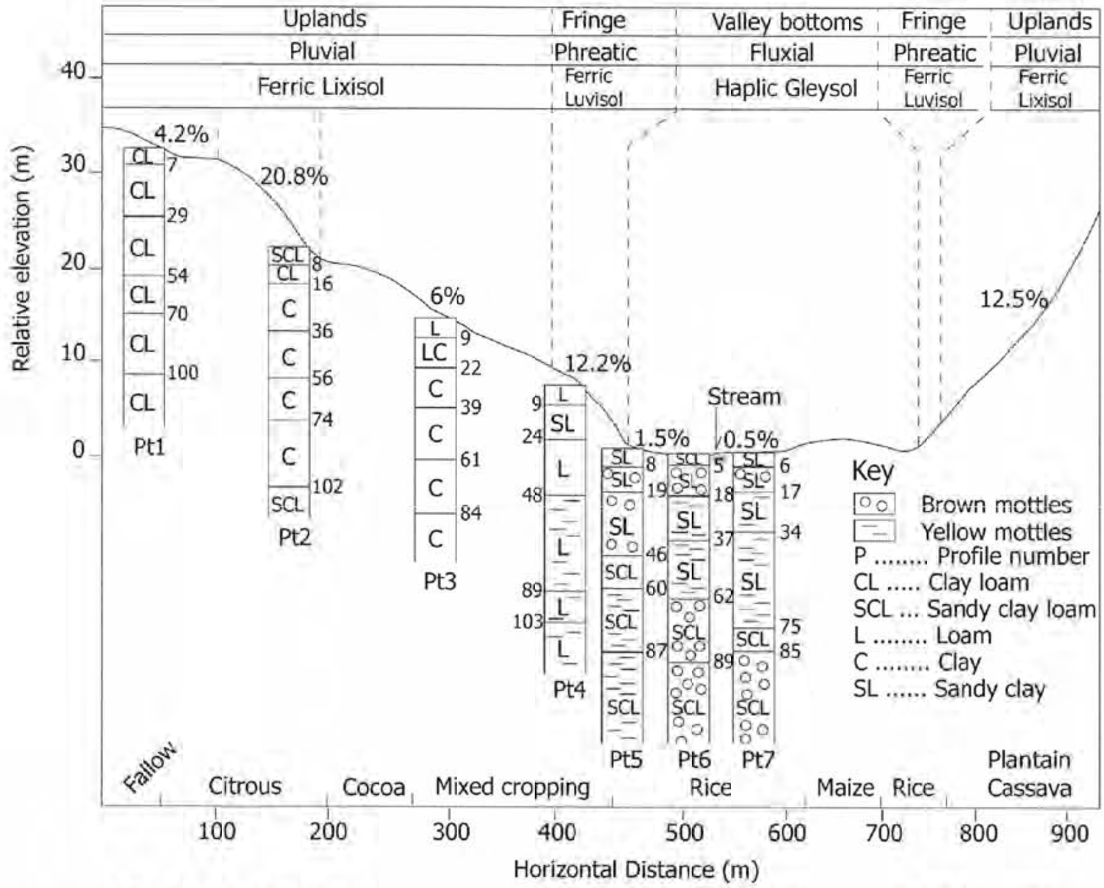


Fig. 3-11. A schematic cross-section of the profiles of the major soil series in the Dwinyan watershed, in transect 5, Potrikurom, Ashanti Region, Ghana.

subsoils (0.84-0.02%) in all the horizons. The topsoils showed low to moderate values of phosphorus. The topsoil values were much higher than the subsoil values, showing the effect of mineral cycling from the citrus and cacao trees. The fringe soil, Pit No. 4, shows higher clay activity, in the range of 29-49 cmol (+) kg^{-1} of clay. The soil was classified as luvisol (ISSS 1994).

The colours of the B horizons were dominated by yellow (Table 3-4). Although some morphologies, such as mottle characteristics, were similar to those of the upland soils, soil texture and general fertility characteristics, including available phosphorus, were more similar to the valley bottom soils (Table 3-5). The soils of the valley bottoms Pt5-Pt7 were slightly acidic in the topsoil (pH 5.2-5.9) but more acidic in the subsoils (4.2-4.5). The valley bottom soils are better supplied than the upland with exchangeable cations, especially the more mobile cations Ca and Mg. The soils have light to medium textures. The higher level of exchangeable cations may be attributed to the frequent supply of basic cations by runoff and floodwater, and through ground water. The moderate to high levels of organic matter associated with the soils' hydromorphism may contribute partly. Activities of clay, which in Table 3-5 are calculated as ECEC divided by clay content, were much higher in the lowland soils than in the upland soils. This also explains the richness in basic cations of the lowland soils in spite of their coarser texture than the upland soils. This suggests a difference in mineralogical characteristics between lowland and upland.

Table 3-4. Physical and morphological properties of the soils

Profile No. & Soil type	Depth	Horizon	Boundary	Sand	Silt	Clay	Textural Class	Matrix colours	Mottles	Structure
					%					
Pt1	0 - 7	Ap	as	34.5	37.0	28.0	cl	5 YR 4/4		m2gr
Akumadan	7-29	B21tc	ca	30.2	30.2	39.6	cl	7.5 YR 6/8		m1sbk
series	29 - 54	B22tc	cs	24.3	27.2	48.5	cl	5 YR 5/8		m2sbk
Ferric	54 - 70	B23	as	30.2	36.0	33.8	cl	2.5 YR 5/8		m2 sbk
Lixisol	70 - 100	B24	as	30.2	38.3	31.5	cl	2.5 YR 5/8		flsbk
	100 - 160	B25		40.8	33.2	26.0	cl	2.5 YR 5/8		flsbk
Pt2	0 - 8	AP	as	43.3	28.9	27.8	scl	5 YR 5/4		m1gr
Bekwai	8 - 36	BA	as	39.6	17.7	32.7	cl	7.5 YR 6/6		m2gr
series	36 - 56	Btcs1	as	27.5	14.7	57.8	c	5 YR 6/8		m2sbk
Ferric	56 - 74	Btcs2	as	24.3	19.5	56.2	c	5 YR 6/8		m2sbk
Lixisol	74 - 102	Btcs3	as	16.5	33.0	50.5	c	5 YR 6/8		m2sbk
	102 - 153	Bc1	as	12.2	40.0	47.8	scl	5 YR 6/8		m2sbk
Pt3	0 - 9	Ap	cs	49.2	37.8	13.0	l	10 YR 5/3		m1gr
Nzima	9-22	Bts	cs	35.8	31.5	32.7	lc	10 YR 6/4		m2gr
series	22 - 39	Bts1	gir	25.1	27.9	47.0	c	10 YR 7/6	Rusty	m2sbk
Ferric	39 - 61	Bts2	cs	23.5	29.5	47.0	c	10 YR 7/4		f1gr
Lixisol	61 - 84	Btsg1	cs	26.0	25.4	46.6	c	7.5 YR 7/6		m2sbk
	84 - 120	Btsg2		28.1	25.9	46.6	c	7.5 YR 6/8		m2sbk
Pt4	0 - 9	Ap	cs	37.0	42.0	21.0	l	10 YR 5/3		m1gr
Kokofu	9-24	AB	cs	44.5	41.5	14.0	l	10 YR 6/2		f1gr
series	24 - 48	Btsg1	cs	49.5	41.0	10.5	l	2.5 Y 7/6	Rusty	m2sbk
Ferric	48 - 89	Btsg2	as	41.0	34.5	24.5	l	2.5 Y 7/8		m2sbk
Luvisol	89 - 103	Btsg3	gir	36.5	39.0	24.5	l	2.5 Y 7/8		m2sbk
	103 - 134	Cg1		44.5	32.0	23.5	l	10 YR 7/8		m2sbk
Pt5	0-8	Apg	cs	60.0	29.0	11.0	sl	10 YR 4/2	Rusty	m2sbk
Oda series	8-19	Bacg	cs	62.5	29.0	10.5	sl	10 YR 3/2	Rusty	m2gr
Haplic	19 - 46	BCg1	cs	54.5	38.0	7.5	sl	10 YR 6/2	Yellow	m2cr
Gleysol	46 - 60	BCg2	cs	53.5	25.0	21.5	scl	10 YR 6/1	Yellow	m2cr
	60 - 87	Cg1	cs	64.5	21.5	14.0	scl	10 YR 6/1	Yellow rusty	f1gr
	87 - 137	Cg2	c	56.0	14.0	30.0	scl	10 YR 7/1		m2gr
Pt6	0 - 5	Apg	cs	57.0	31.5	13.5	sl	10 YR 3/1	Rusty	f1sbk
Oda series	5-18	Bacg	cs	58.5	29.0	12.0	cl	10 YR 3/2	Yellow	m2gr
Haplic	18 - 37	Bcg1	cs	67.4	21.6	11.0	sl	10 YR 6/2	Yellow	m2cr
Gleysol	37 - 62	Bcg2	cs	53.4	25.1	21.5	scl	10 YR 6/1	Rusty	f1gr
	62 - 89	Cg1	cs	55.0	15.0	30.0	scl	10 YR 6/2	Rusty	m2cr
	89 - 120	Cg2	cs	54.0	16.0	30.0	scl	10 YR 7/1		f1gr
Pt7	0 - 6	Apg	cs	62.0	26.5	11.5	sl	10 YR 4/2	Rusty	m2sbk
Oda series	6-17	Bacg	cw	58.1	30.0	11.1	sl	10 YR 3/2	Yellow	m2gr
Haplic	17 - 34	Bcg	cs	65.3	23.7	11.0	sl	10 YR 6/2	Yellow	m2cr
Gleysol	34 - 75	Bcg2	cs	55.4	24.1	19.5	scl	10 YR6/1	Rusty	f1gr
	75 - 89	Cg1	cs	56.0	14.0	30.0	scl	10 YR 6/2	Rusty	m2cr
	89 - 140	Cg2	cs	53.0	16.0	31.0	scl	10 YR 7/1		f1gr

Structure: as, abrupt smooth; cw, clear wavy; cs clear smooth; gs, gradual smooth; gir, gradual irregular; sl, sandy loam; ls, loamy sand; s, sand; c, clay; scl, sandy clay loam; f, fine; m, medium; l, weak; 3, moderate, sbk, subangular blocky; cr, crumbly; gr granular.

The nitrogen levels in the lowland soils, however, showed a trend similar to that of the upland soils. Although the topsoils were relatively rich in nitrogen, the subsoils were extremely poor in both T-N and organic C. The soils had low to moderate values of phosphorus, ranging from 2-10 mg kg^{-1}, with decreasing levels from the topsoil to the subsoils. However, the available phosphorus in subsoils of the valley bottoms was much higher than that in subsoils of the uplands, showing the effect of alluvial and colluvial deposition. By virtue of their geomorphic position, the soils are poorly drained, as reflected in their matrix colors (Table 3-4). The poor drainage of the valley bottom soils indicates that these soils can hold water. These soils would therefore be very useful for rice cultivation in the wet season and vegetable cultivation in the dry season. The most deficient nutrient was phosphorus followed by nitrogen. Some lowland soils, such as Pt6 soil, showed very low available potassium, too.

Table 3-5. Chemical characteristics of the soils (nutrient levels).

Profile No. & Soil Type	Horizon	pH H_2O	Org. C	T-N	O.M.	C/N	Exchangeable cations Ca	Mg	K	Na	TEB	Ex. Acid. Al + H	ECEC	Base Sat.	Avail. P_2O_5	ECEC/clay cmol(+)
	cm		%				cmol(+) kg^{-1}							%	mg/kg	kg^{-1}clay
Pt1	0-7	5.7	3.5	0.3	6.0	11.2	10.0	3.2	0.31	0.1	13.6	0.6	14.2	95.8	6.32	-
	7-29	4.9	1.3	0.1	2.2	9.7	4.0	1.4	0.09	0.1	5.6	1.1	6.7	83.5	7.08	-
Ferric	29-54	4.8	0.7	0.1	1.2	7.4	2.6	1.0	0.06	0.1	3.8	1.5	5.3	71.4	3.52	10.8
Lixisol	54-70	4.7	1.0	0.1	1.8	9.4	2.8	1.9	0.35	0.1	5.1	0.5	5.6	91.1	1.44	16.7
	70-100	4.6	1.3	0.1	2.2	9.8	3.6	2.4	0.46	0.1	6.5	0.8	7.3	89.1	1.00	23.2
	100-160	4.3	0.5	0.1	0.8	6.6	1.8	1.4	0.19	0.1	3.4	1.2	5.2	69.6	1.00	20.1
Pt2	0-8	5.2	3.4	0.5	5.9	7.3	5.4	2.5	0.54	0.8	10.3	0.8	11.1	92.8	4.80	-
	8-36	4.3	0.8	0.1	1.4	8.7	3.0	1.4	0.09	0.2	4.6	0.5	5.1	90.1	8.00	-
Ferric	36-56	5.5	0.5	0.1	0.8	9.4	1.6	1.1	0.04	0.0	2.8	0.5	3.3	84.6	1.86	5.6
Lixisol	56-74	5.7	0.5	0.1	0.6	6.4	4.7	1.7	0.20	0.3	6.9	0.6	7.5	92.0	0.67	13.4
	74-102	5.8	0.5	0.1	0.8	9.2	1.9	2.1	0.04	0.0	4.1	1.8	5.9	69.3	0.50	11.6
	102-153	4.7	0.4	0.1	0.7	7.2	2.5	2.1	0.07	0.1	4.8	1.9	6.7	71.6	0.00	14.0
Pt3	0-9	5.1	2.9	0.3	4.9	8.6	14.8	3.7	0.21	0.2	18.9	0.6	19.5	96.9	5.00	-
	9-22	4.9	1.2	0.2	2.1	6.2	10.1	1.1	0.16	0.2	11.5	0.5	12.0	95.8	7.12	-
Ferric	22-39	4.8	0.4	0	0.6	12.0	3.1	0.3	0.02	0.1	3.6	0.4	4.0	89.9	2.10	8.4
Lixisol	39-61	4.2	0.3	0.1	0.6	6.8	4.3	1.0	0.06	0.1	5.4	0.4	5.8	93.1	1.00	12.4
	61-84	4.2	0.4	0	0.6	9.3	3.9	1.5	0.03	0.1	5.5	0.5	6.0	91.7	0.96	12.9
	84-120	5.1	0.4	0	0.6	8.8	4.6	2.7	0.50	0.1	6.9	0.6	7.5	92.0	0.21	16.1
Pt4	0-9	5.9	2.4	0.3	4.1	7.6	14.8	4.5	0.55	0.2	20.0	0.5	20.5	97.6	6.68	-
	9-24	5.9	1.2	0.2	2.0	7.4	5.9	2.1	0.26	0.1	8.2	1.0	9.2	89.2	5.02	-
Ferric	24-48	5.1	1.0	0.8	1.7	1.2	2.7	1.3	0.02	0.2	4.2	1.0	5.2	80.7	4.04	49.3
Luvisol	48-89	4.3	0.3	0.1	0.5	5.8	3.8	1.2	0.03	0.2	5.9	1.4	7.3	81.5	3.08	29.7
	89-103	4.3	0.2	0	0.4	5.0	5.2	1.9	0.07	0.4	7.6	1.9	9.4	80.6	2.11	38.4
	103-134	4.7	0.2	0	0.3	8.0	2.3	1.8	0.02	0.6	4.7	2.0	6.7	70.3	2.00	28.6
Pt5	0-8	5.7	2.5	0.4	4.3	6.6	21.2	2.8	0.61	0.2	24.8	0.1	24.9	99.6	8.01	-
	8-19	5.2	1.2	0.1	2.0	8.8	12.8	4.0	0.22	0.3	17.3	0.1	17.4	99.4	9.01	-
Haplic	19-46	4.7	0.4	0.1	0.6	5.1	12.0	1.6	0.16	0.3	14.1	0.2	14.3	98.6	4.04	190.5
Gleysol	46-60	4.6	0.0	0.1	1.8	0.4	12.0	3.2	0.22	0.5	16.0	0.2	16.3	98.2	3.08	75.6
	60-87	4.6	0.1	0	0.2	2.5	13.6	4.4	0.26	0.7	19.0	0.6	19.6	96.9	2.11	139.8
	87-137	4.5	0.1	0.1	0.1	0.4	14.8	4.0	0.35	1.0	20.1	0.2	20.3	99.0	2.00	67.8
Pt6	0-5	5.4	1.5	0.1	2.6	11.6	11.9	1.5	0.13	0.1	13.6	0.1	13.6	99.6	10.11	-
	5-18	5.4	0.2	0	0.4	7.7	6.9	1.9	0.03	0.1	8.9	0.5	9.4	94.7	9.02	77.9
Haplic	18-37	4.6	0.2	0.1	0.2	3.6	5.5	1.4	0.06	0.1	7.0	0.5	7.5	93.3	5.04	67.9
Gleysol	37-62	5.7	0.5	0	0.8	23.0	4.5	2.2	0.06	0.1	6.9	0.5	7.4	93.2	5.01	34.4
	62-89	5.2	0.1	0	0.2	7.0	3.5	3.4	0.06	0.1	7.0	1.2	8.2	85.3	3.02	27.2
	89-120	5.2	0.1	0	0.2	10.0	2.5	3.0	0.05	0.1	5.6	1.2	6.8	82.3	4.01	22.7
Pt7	0-6	5.3	2.9	0.2	5.0	13.8	12.6	3.5	0.29	0.5	16.8	0.9	17.6	95.2	9.70	-
	6-17	4.7	0.5	0.2	1.0	3.4	7.4	1.5	0.20	0.4	9.4	0.9	10.3	91.6	8.40	-
Haplic	17-34	4.6	0.3	0.1	0.6	4.0	4.7	1.2	0.14	0.4	6.5	1.2	7.7	84.3	6.04	69.5
Gleysol	34-75	4.6	0.2	0.1	0.4	2.9	7.7	1.7	0.29	0.2	9.9	2.7	12.6	78.5	4.01	64.6
	75-89	4.5	0.1	0.1	0.2	1.6	5.6	0.9	0.55	0.1	7.0	3.6	10.6	66.5	3.20	35.3
	89-140	4.2	0.1	0.1	0.2	1.7	5.4	0.8	0.55	0.1	6.8	3.0	9.8	69.5	4.00	31.7

3-2-2-3 Water Table Dynamics

Figure 3-12 shows the mean depth of the ground water level at first-, second-, and third-order of the valley bottom in relation to monthly rainfall patterns. In 1997, the driest of the three years monitored, topsoil saturated (i.e., ground water level) was nearly equal to 0 cm and the saturation started only in June to July, except for Gold Valley. However, in the other two years topsoil started to saturate in May, an approximately one-month delay from the first peak of the rainfall. The months of lowest ground water levels were February and March. The water table at the study area was effectively monitored for 3 years from January 1997 to December 1999. Three years of results are shown in the following: Fig.3-8 of Transect 6 for Gold Valley, about 100 ha of catchment area, the first-order valley; Fig.3-9 of Transect 5 for the Potrikrom site, about 2500 ha of catchment area, the second-order valley; and Fig. 3-10 of Transect 8 for the Dwinyama site, about 3500 ha of catchment area, the third-order valley.

The results of T1-T4 and T7 are not shown because of their similarity to T5-T6. Monitoring points along each transect line are shown on the lines of the topography survey in Figs. 3-8---3-10. The depth of ground water dynamics was also shown with the monthly distribution of rainfall. At the time when the measurements started in January, the water table was still falling due to a lack of rain, increased solar radiation, and a rise in temperatures. Therefore, the evapo-transpiration effect was enhanced as a characteristic of this season (the dry season). The water table started to rise steadily at the beginning of the rains, from toward the end of March to May, despite the fact that rainfall did not stabilize until June, when the first peak was attained in all the valleys (Figs. 3-8---3-10).

The movement of the water table corresponds approximately to the flow of water in the seasonal streams; the streams dry up in the dry season, until the ground water table rises to the surface in the riverbed in late May or early June in this area, depending on the intensity of the rainfall that year. As the water table graph shows, water starts flowing in the riverbeds when the rains stabilize in June, but water flows in May if, in any year, the rains are heavy and stabilize early. The flow of water falls as soon as the rain stops in Rice and Gold Valleys, because their catchment areas are more exposed. The water flow in the Dwinyama watershed remains up to the end of December, depending on the time the rain stops. The stream in the first-order valley flowed for about four months during June to October (Fig.3-8), whereas the second-order valley stream flowed about 6 to 7 months during May to November (Fig. 3-9). The third-order valley stream

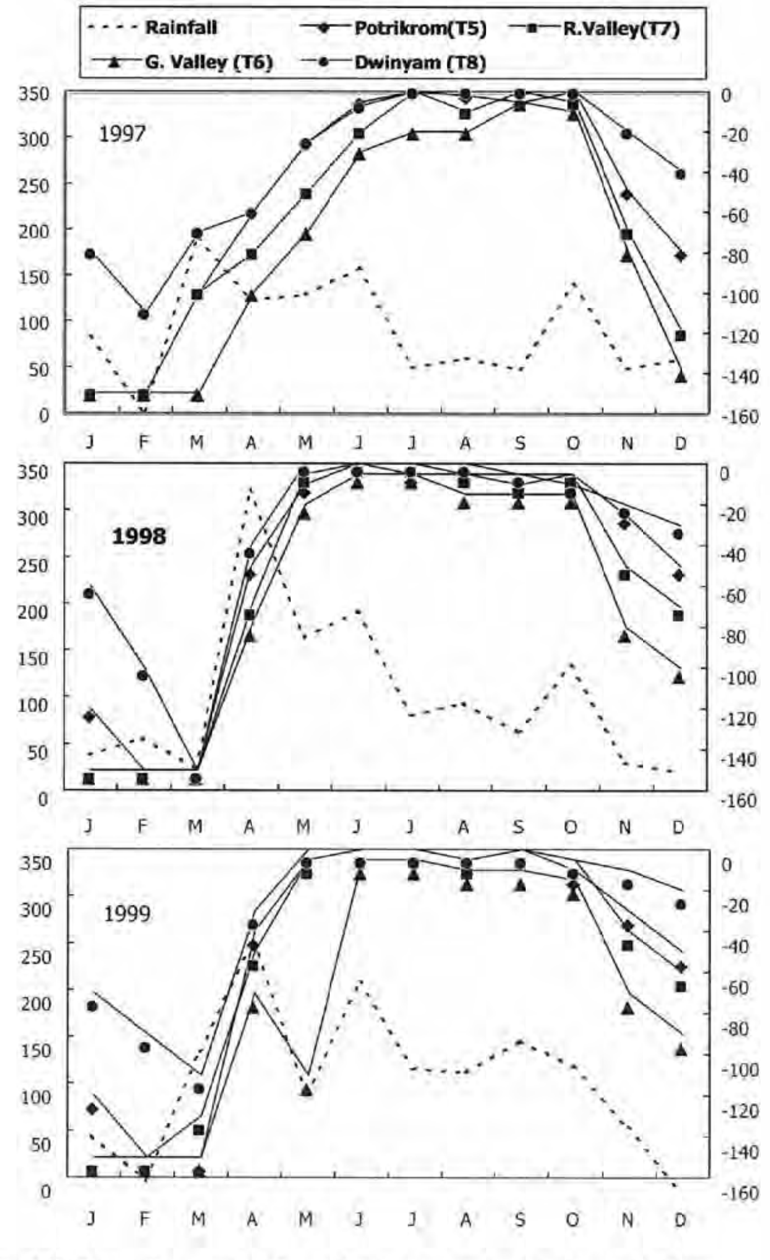


Fig. 3-12. Graphs of mean values of ground water movement at valley bottom in different valley order systems within the study area

flowed about 7 to 8 months during May to December (Fig. 3-12). The pattern of movement of the water table appears to be cyclical, surfacing in the rainy season and going into a trough in the dry season (Fig. 3-12). The water table rises to the surface, and sometimes above it, from the end of May to November, depending on the rainfall pattern, the relative size of the catchment area, and how exposed the watershed area is. The valleys, in terms of how long and how high the water stays on the surface of the lowland, are the second- and third-order valleys in Transects 5 (Potrikrom) and 8 (Dwinyama) (Figs. 3-9, 3-10 and 3-12). These are followed by the first-order inland valleys in Transects 6 (Gold Valley) and 7 (Rice Valley) (Figs. 3-8 and 3-12). The driest valley is Gold Valley. Although Rice Valley and Gold Valley are first-order valleys, Rice Valley has a smaller VBR, which means it has a bigger valley bottom and higher amounts of rainfall flowing as runoff or as groundwater from the higher parts of the valley.

The toposequence of the inland valley watershed was classified as an upland slope with a pluvial water regime, fringed with a phreatic water regime, and a valley bottom with a fluvial water regime (Moorman 1985). The upland slope has no ground water in the soil profile. The valley bottom has saturation or flooding of the whole soil profile during some of the rainy season. The fringe has ground water in the soil profile during some of the rainy season in any given year. The water table dynamics and the flooding regimes are very good indicators for planning appropriate water management and developing sustainable cropping systems in the inland valleys.

3-2-2-4 Interaction of water table and land use

From the schematic cross-sections of the different valley orders, a close relationship between water table movement and land use is apparent, especially in the valley bottoms. The largest valley bottom was found on Transect 8 (Fig. 3-10), a third-order valley. It has the best moisture regime during both the wet and dry seasons (Fig. 3-12). Although the fringe area is very small compared to the big valley bottom, the valley bottom is used and suitable for the cultivation of rice from April to December. It is also used and suitable for the cultivation of vegetables during the dry season because of the residual moisture available during that season (Fig. 3-10).

The valley fringes are used mainly for cereal, vegetables, root and tuber crops, and legumes. In the second valley order found on Transect 5 (Fig. 3-9), the land use pattern follows that of Transect 8. Rice is cultivated in the valley bottoms and the fringes during the wet season, but the valley bottoms are left to fallow during the dry season. This is because the water level drops more sharply after the rainy season (Fig. 3-12). The first-order valleys on Transects 6 and 7 are the driest and, as such, the valley bottoms are used mainly in the wet season for the cultivation of upland rice, maize, and sometimes oil palm (Fig. 3-8 and 3-12). The uplands of all of the valley systems are used to cultivate cereals like maize, root and tuber crops (cassava and cocoyam), and perennial crops (cocoa, citrus, oil palm, plantain). The lower slopes and fringes are used mainly for upland rice, vegetables, and sometimes cocoa cultivation (Fig. 3-8 ---3-10).

3-2-3 Conclusion

From the above results and observations it can be concluded that, given their assured water supply and relatively fertile soils, inland valleys can contribute to greater stabilization of food production (especially rice). It must be noted, however, that even though the valley bottom soils are richer than those of the uplands and fringes, their nutrient reserves are still low for intensive crop production. Observed nutrient levels reflect the need for improved nutrient management. Other observed constraints were water control and weed infestation. These valley may have a high potential for increased and sustainable food production (especially rice), if current production systems and practices could be further improved through the adoption of systems that promote nutrient accumulation and retention and improved water management systems (*sawah*). Nutrient retention, weed control, and water management could be improved under submerged conditions (Kyuma and Wakatsuki 1995).

3.3 Characterization of Soil and Water Dynamics in Biem Watershed

3-3-1 Survey Method

3-3-1-1 Setting up of the transect line

Three transect lines were set up in Biemso No.1 and 2, Biemtetrete (Fig.3-7) with demarcation of T-9, T-10 and T-11, respectively. The length of T-9 is about 0.5km, T-10 is about 1.0km and T-11 is about 1.5km. The work for the transect lines was done from the 25th of May to 13th of July.

3-3-1-2 Soil Sampling and Laboratory

Soil sampling along the transect lines was done in 2 different ways. Sampling along T-10 was done using the auger. Each sampling point was marked in the figure (Figs.3-13, 3-14(1), 3-14(2), 3-15 (1) and 3-15 (2)). The depth of the sample is 15 cm for each in one point. For T-11, 100 cc of core boxes were used from different depths of the soil profile. These soil samples were analyzed in terms of soil pH (H_2O, KCl), exchangeable base, total acidity, available-P, total-N and C, and particle size distribution.

3-3-1-3 Monitoring of ground water and land use dynamics

In order to get the hydrological information in the benchmark watershed, two meters of piezometer pipe was set at certain points along the transect lines. 12 pipes were set on T-9, 23 pipes were set on T-10, and 12 pipes were set on T-11.

3-3-1-4 Evaluation of potential of lowland in terms of Sawah development

From 1998 up to the present, several type of Sawah in 7 sites (Potrikurome, Nicolas, Tauya, Gold valley, Afreh, Rice valley, Biemso No.1 and 2) were constructed. However, detailed information of the potential for Sawah development has not yet been collected. The measeurement was done each 100 meters along the river then the width of the lowland and relative height of riverbed were measured from each point. Top soil sample were collected at about every one hectare of lowland.

3-3-1-5 Soil sampling in each Sawah field and in surrounded area in terms of soil fertility level

Although Sawah was constructed in different sites, no detailed survey on soil fertility of Sawah was done. In order to get necessary information on soil fertility, soil sampling was done in each site and in surrounded area as a comparison. A few Sawah in each site were selected and soil sampling was done in 5 points (each corner and middle of Sawah) by 200cc core box (used 2 of 100cc core box). As a comparison, soil in 100m down stream and 100m upstream from Sawah were collected (Fig.3-16).

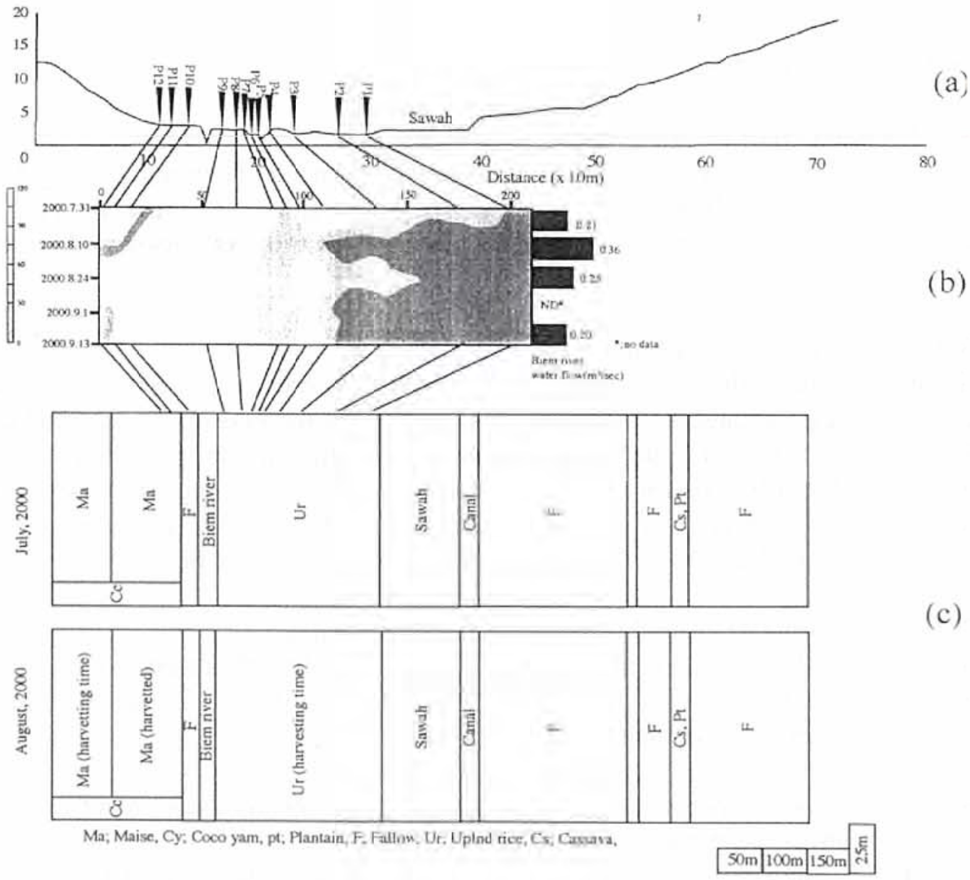


Fig. 3-13. Change in ground water level and land use along the transect line (T-9)

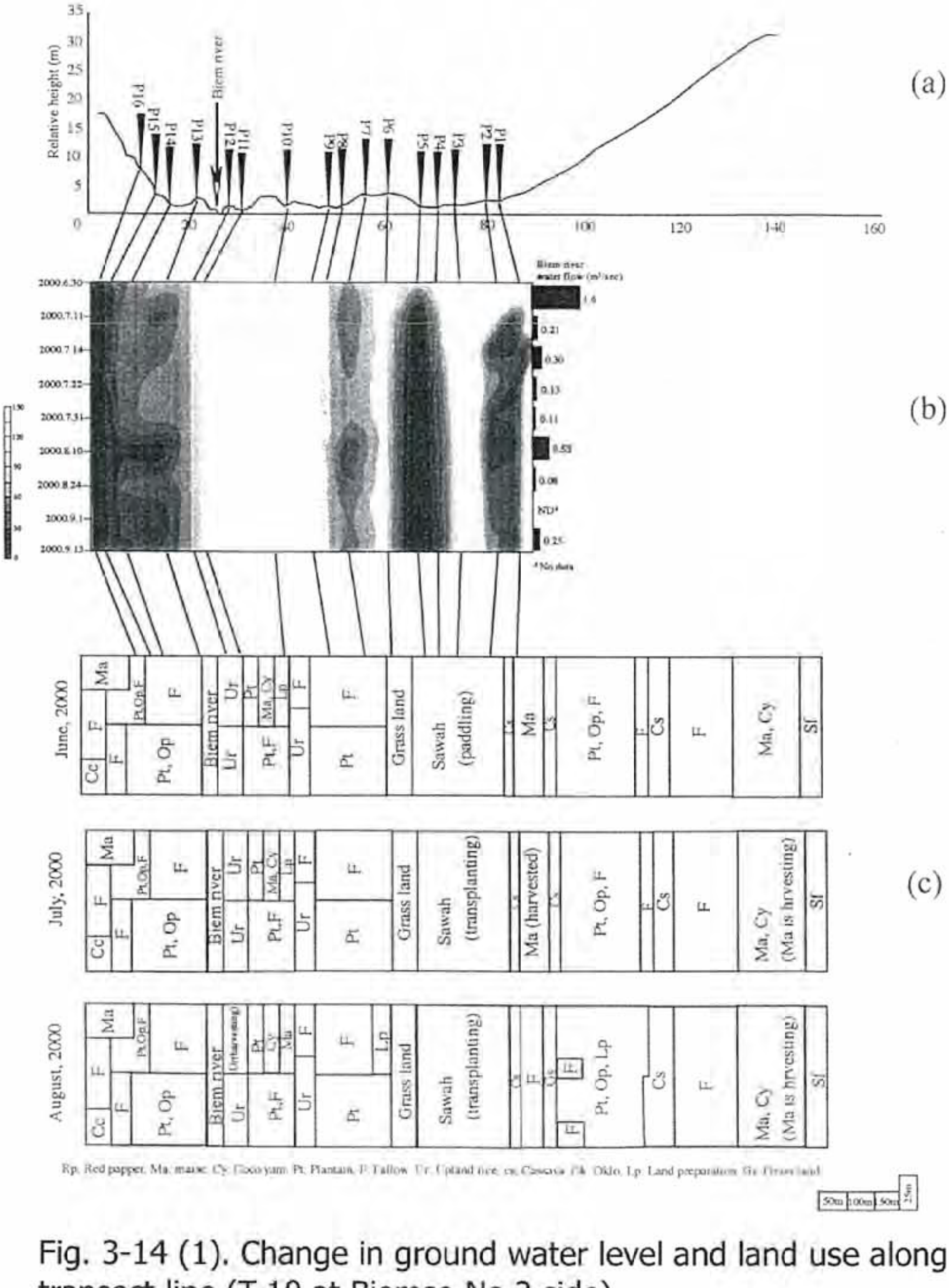
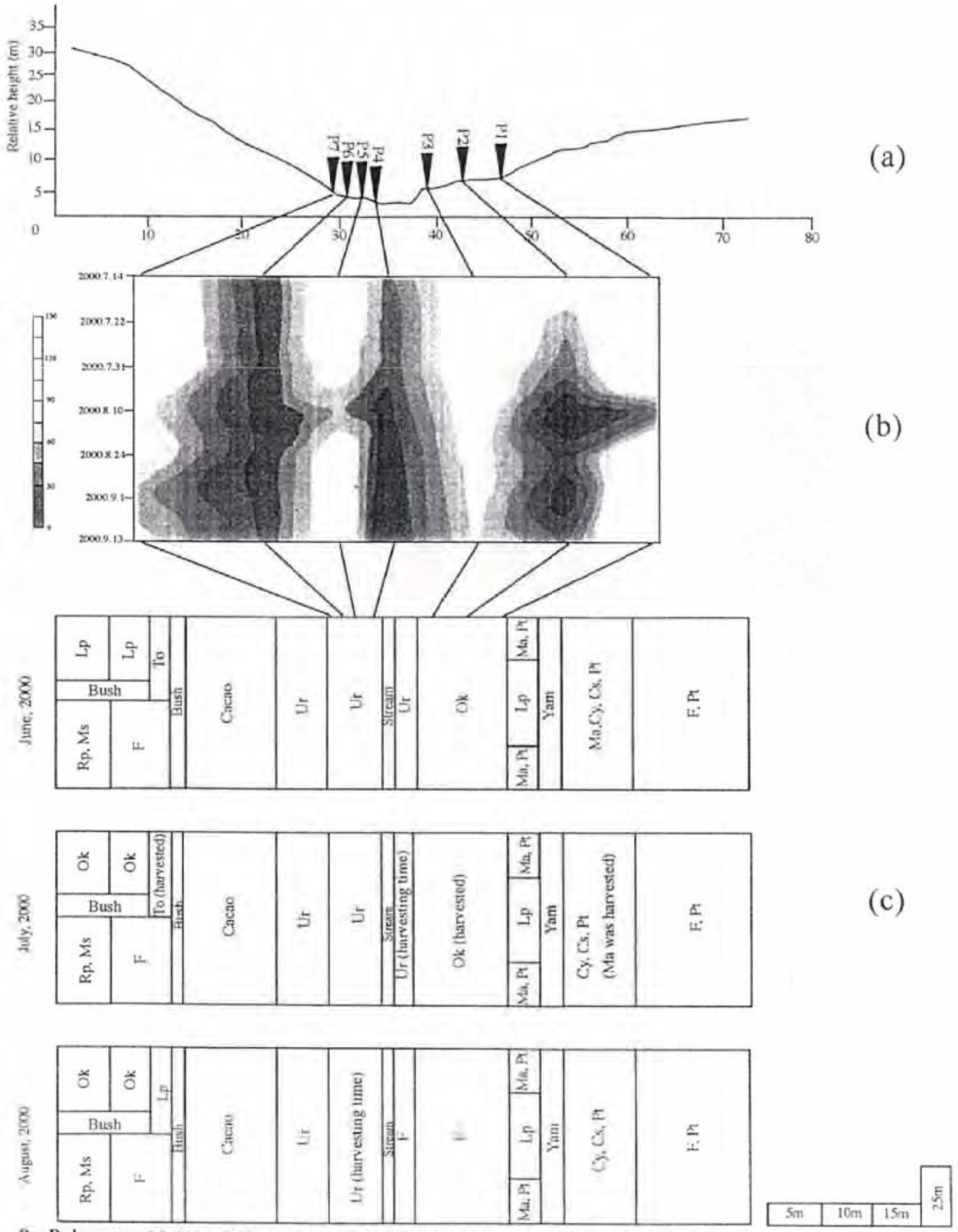


Fig. 3-14 (1). Change in ground water level and land use along the transect line (T-10 at Biemso No.2 side)



Rp: Red ppepper. Ma: Maise, Cy: Coco yam, Pt: Plantain, F: Fallow, Ur: Upland rice, Cs: Cassava, Ok: Oklo, Lp: Land preparation

Fig. 3-14 (2). Change in ground water level and land use along the transect line (T-10 at Potrikurom side)

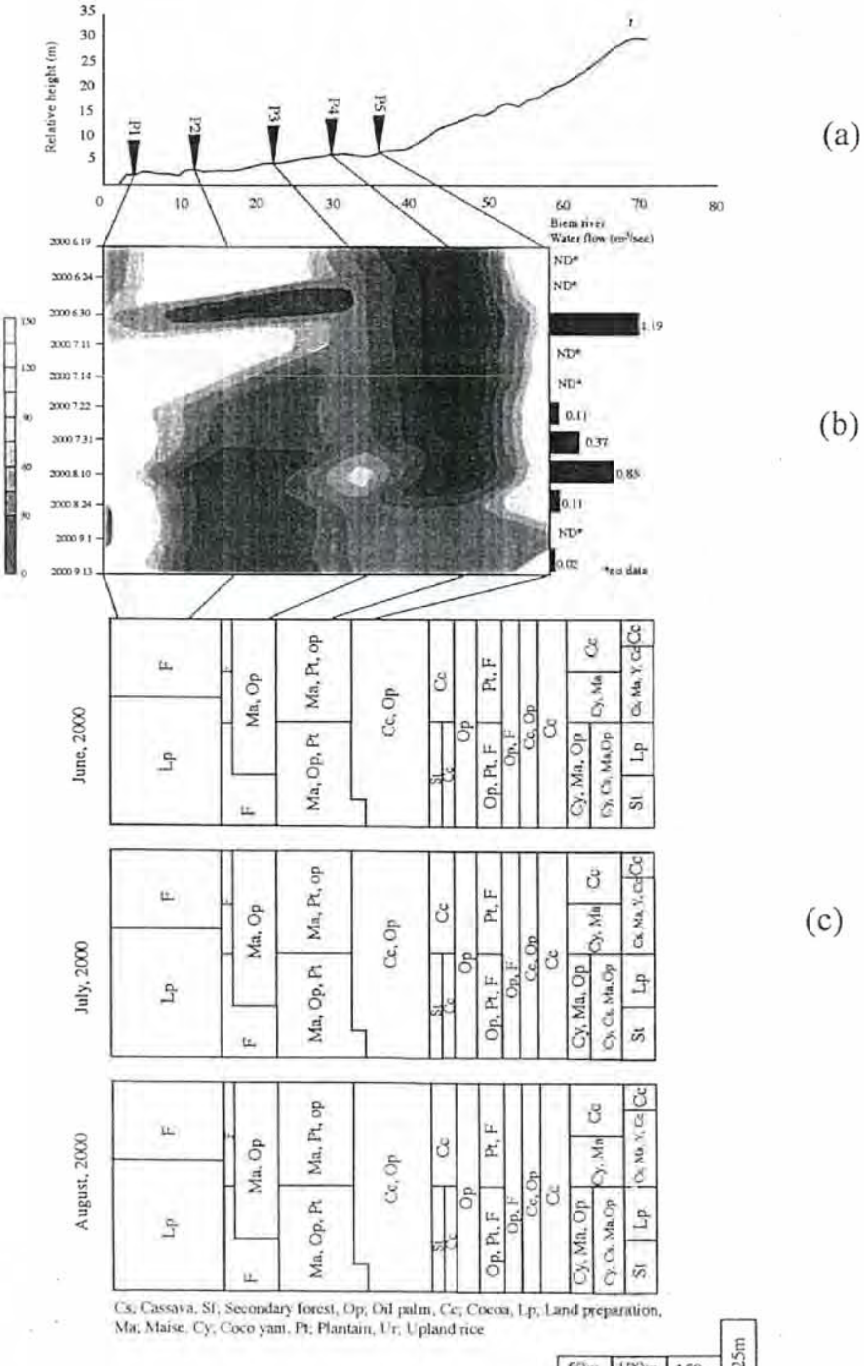


Fig. 3-15 (1). Change in water level land use along the transect line (Right side of T-11)

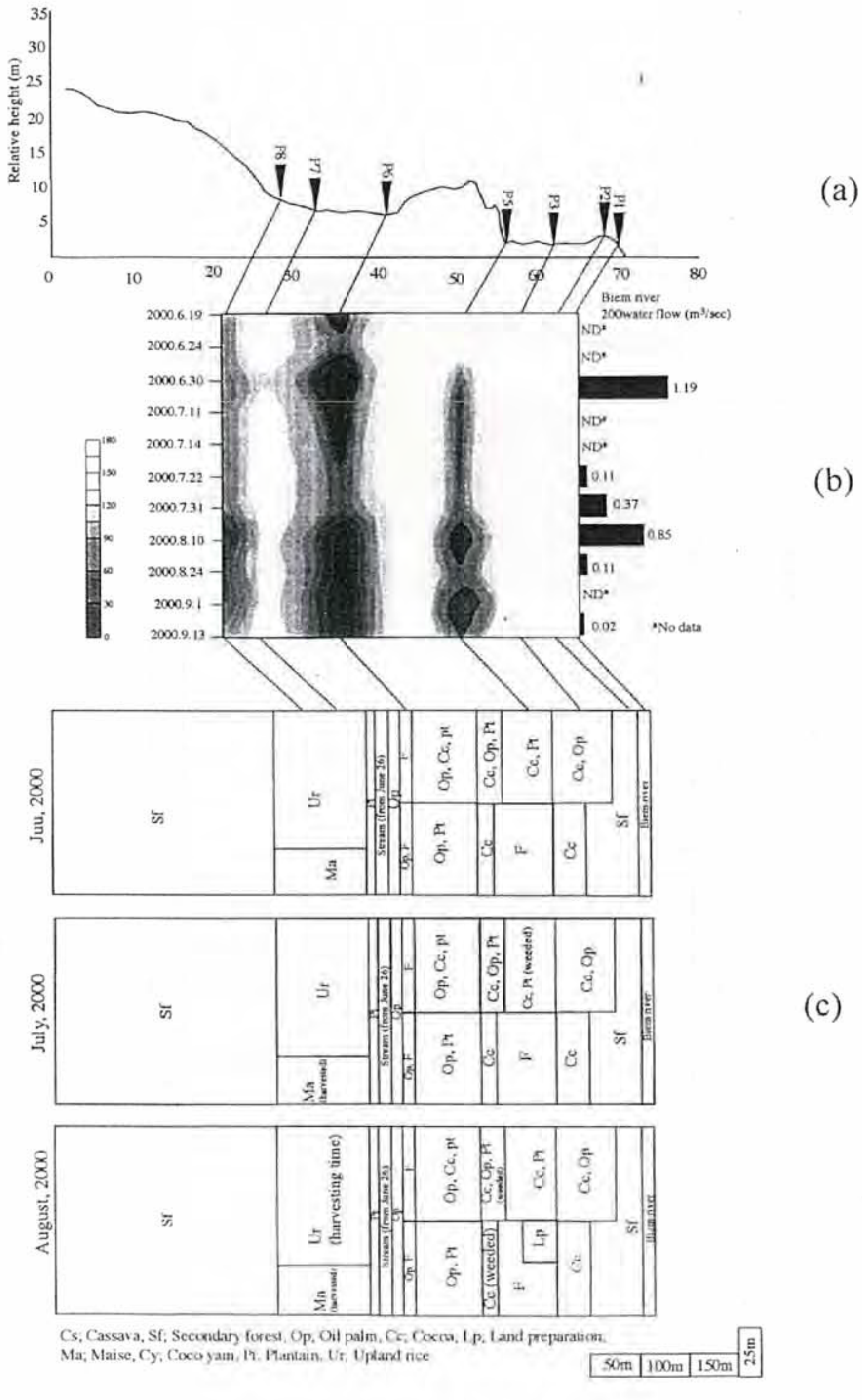


Fig. 3-15 (2). Change in ground water level and land use along the transect line (Left side of T-11)

3-3-2 RESULTS AND DISCUSSION

3-3-2-1 Topography along the transect lines

Five transect lines in three different sites were set in benchmark Biem watershed and topographic information was collected (Figs.3-13, 3-14(1), 3-14(2), 3-15(1) and 3-15(2)). As observed in these figures, each transect has a different topography.

The topography of T-9 is shown in Figure 3-11. According to the figure, lowland area occupies almost 50% of transect line which is about 500m length.

Most area of lowland is left side of the river and there is Sawah, which was constructed in the year, 1999 by Sawah member in Biemso No.1. The topography of T-10 is shown in Fig. 3-14(1) and 3-14(2). As can be observed, the lowland area occupied about 50% of the transects' total length. However, because of the presence of some hilly places at the right side of the lowland, the area should actually be lesser. The distance from the left side of the fringe to the river is short while the slope from the hilly top of the transect to the fringe is steep.

T-10 in the Fig. 3-14(1) revealed that the slope at the left side of the valley is also very steep. Although the slope at the right side is shallower, the area constitute only about 10% of the total length of the transect. According to the 1/50,0000 scale map, T-3 is located on the same valley with T-10 in Biemso No.2. However, actual survey revealed that the hill of the Potorikurom extends longer than that shown on the map, which then separated, the two transects into two valleys.

The topographic characteristic of the Beimtetrete is presented in Fig. 3-15(1) and (2). Right side of the stream of T-11 is topographically unique as compared to the other transects not only because there is one river and one stream along the transect lines but also of the presence of a hill between these two water flow. Because of this geographical characteristic, a terrace is formed. On the other hand, the left side of the stream of T-11 does not have much lowland but mostly upland area and the field observation showed that its area is only about 10% of the total area of the transect.

3-3-2-2 Dynamics of land use along the transect lines

According to a previous survey (Asubonteng et al. 2001), the top and slopy area of the Potorikrom are mostly planted with perennial crops such as cocoa, oil palm, and citrus. However, the monitoring done revealed that land use was different in some places.

Along T-9, main land use of left side was maize cultivation while right side was fallow. Lowland was used mainly for rice cultivation, both upland rice and Sawah rice cultivation. From the top of the hill to the river in T-10 I Biemso No.2, the land along the transect was mostly used for the cultivation of annual crops and secondary forest partially covered the top area. The land along T-10 in Potrikrome showed almost the same trend. At the right side of the transect, land was used for fallow, maize and cocoyam, yam, land preparation, okra and flood plain rice from the top to the bottom of the valley in that order. At the left side area, however, there was a cocoa farm on the top of the valley. Annual crops were mainly cultivated at both top and bottom of the valley. On the other hand, the top and bottom areas of the land along left stream of T-11 was dominated by secondary forest. It is interesting to note that the lowest terrace is dominated by cocoa.

Along right stream of T-11, although two areas for cocoa and another large area of secondary forest dominated, the top of the hill was used for the cultivation of annual crops such as maize, cassava, cocoyam and plantain. Based on its topographical characteristic, it can be noted that the actual method of land cultivation is not suitable for the land shape.

The farmers use the slope of the hill to cultivate annual crops. This practice exposes and disturbs the soil and therefore, continually subjecting it to soil erosion. These farmers do not engage in any practical way to protect the land against this problem. At the same time, fallow system was shortened or less practiced because of the need to meet the demand for food of the rapidly increasing population. As a result, environmental degradation becomes a serious problem in the benchmark Biem watershed.

3-3-2-3 Dynamics of ground water level (GWL) along the transect of Biem River Side
Results of the monitoring of ground water level along each transect are shown in Figs 3-13---15. Generally speaking, GWL was high in lower place and low in higher place. Lower place in T-9, the place where P1, P2 and P3 or P5, P6 were, showed higher GWL. Among others, because of the concave shape, P10, P11 and P12 were also showing high GWL even though it was higher position. This may be because the hill in between river and the points of monitoring. This hill can be functioning as the barrier for the runoff or seepage water then water can be stored in the ground. On the other hand, GWL for P8 and P9 were not so high because these were on the riverbank. River itself functioned as drainage. GWL in T-10 in Biemso No.2 also had same dynamics as the T-9. From P1 to P5, and P14 to P16 had higher GWL among others. On the other hand, P9 did not show such high GWL. This was because the soil of P9 was so gravel even though upland rice was cultivated. The plant growth was not good because there was not enough water.

The results of T-10 in Potrikrom showed a little difference from T-9 and T-10 in Biemso No.2 (Fig. 3-13 and Fig 3-14(1) and (2)). Although the difference of relative height was about 4m, GWL in higher place such as P1, P2 and P7 were high. However P5 was the lowest place among others, GWL was not as high as P4 and P6. According to the field observation, very small stream was found on the bottom of valley where P5 was. However, GWL of P5 was not high, may be because the tube was installed by penetrating clay layer. Further discussion will come after soil analysis.

The results for the left side of the stream of T-11 were shown in Fig 3-13(2). According to the topographic characteristics, this transect is unique as compared to the other transects not only because there is one river and one stream along the transect lines but also of the presence of a hill between these two water flow. Because of this geographical characteristic, a terrace is formed and this affected to the GWL. P5 was where stream was flowing and P4 was lowest place in this terrace. The results of right stream of T-11 were shown in Fig 3-13(1). This figure showed interesting aspects that GWL was maintained high most point except P1. P1 was low GWL because of the Biem river as functioning for drainage. Whole area was used for mix cropping, upland rice and maize.

3-3-2-4 Soil Fertility of Sawah Developed in relation to
Topsoils were collected from various sawahs developed as shown in Fig. 3-16—3-19. Fertility characteristic were shown in Table 3-6---3-9. General soil fertility characteristics were similar to the resutls described in the previous section in the Table 3-4 and 3-5. However soil pH values showed the higher values in the older sawah plots, such as Danymae and Nicolas's sites than the younger sawah plots, such as Biemso No. 1. Although the electro-conductivity of the soil solutions was nott high, 0.03 – 0.13 mS/cm, this means the soils of sawahs developed in this project have to be monitored carefully to confirmed the sustainability of rice production.

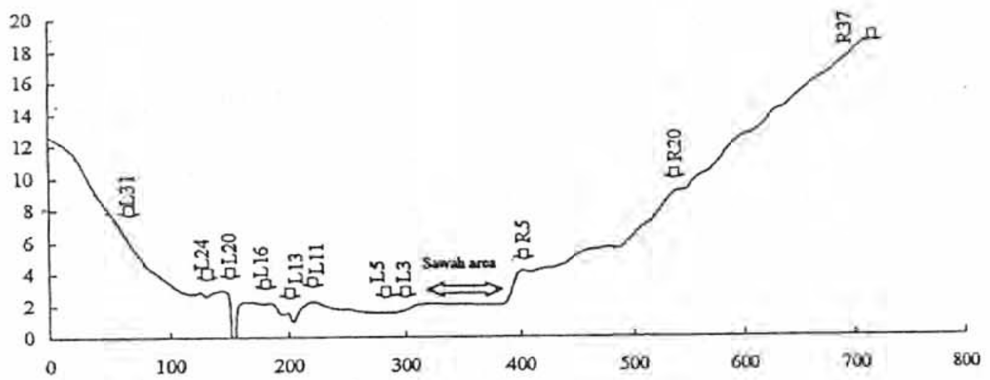


Fig. 3-16. Topographical information of transect line (T-9) in Biemso No.1

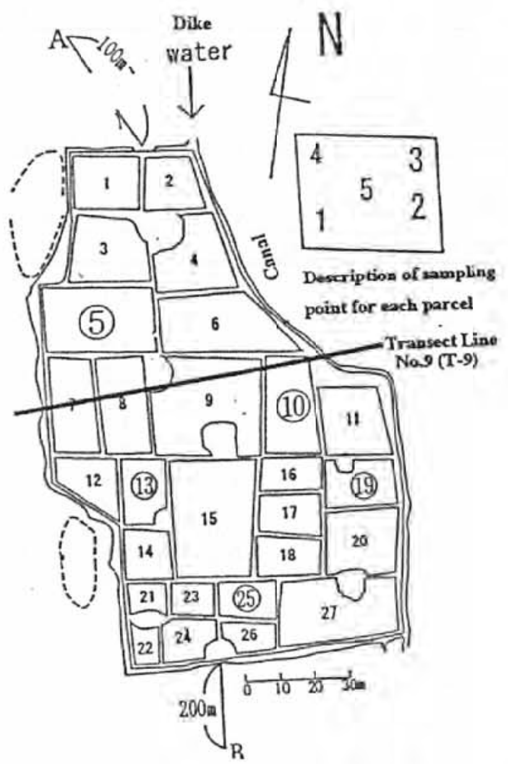


Fig. 3-17. Design of sawah and soil sampling points in Biemso No.1 (Constructed in 1999)

Table 3-6 Soil Chemical Characteristics of Transect Line(T-9)

Sample point	pH		T-C	T-N	Exch.cations (cmol(+)/kg)				
	H_2O	KCl	g/kg		Ca	Mg	K	Na	Sum
R37	7.0	6.4	23.3	2.3	1.41	2.14	0.02	0.03	3.6
R20	5.3	4.5	10.1	1.2	2.51	0.86	0.02	0.08	3.5
R5	5.9	5.3	14.0	1.5	3.77	1.51	0.04	0.05	5.4
L3	5.9	4.7	13.3	1.4	2.84	1.25	0.03	0.16	4.3
L5	5.6	4.4	13.2	1.5	2.75	1.26	0.02	0.11	4.1
L11	5.3	4.7	13.5	1.4	2.97	1.12	0.03	0.04	4.2
L13	4.8	4.0	9.2	1.1	1.12	0.31	0.02	0.13	1.6
L16	4.6	3.8	8.0	1.0	1.28	0.37	0.01	0.06	1.7
L20	6.2	5.4	12.8	1.3	3.87	1.15	0.04	0.04	5.1
L24	4.8	4.0	10.8	1.3	1.50	0.57	0.01	0.10	2.2
L31	5.1	4.0	9.6	1.0	1.70	0.77	0.04	0.06	2.6

Table 3-7 Soil Fertility Level of Sawah cinstructed inBiemsoNo.1

Sample point	pH		T-C	T-N	Exch.cations (cmol(+)/kg)				
	H2O	KCl	g/kg		Ca	Mg	K	Na	Sum
5-1	6.8	4.9	12.1	1.4	4.6	1.0	0.05	0.14	5.8
5-2	6.6	5.2	13.8	1.4	4.1	1.3	0.04	0.12	5.5
5-3	6.7	4.8	9.6	0.9	2.0	0.5	0.05	0.28	2.8
5-4	5.7	4.6	27.9	2.5	4.2	1.0	0.07	0.16	5.4
5-5	8.6	6.0	3.4	0.4	3.2	0.4	0.07	1.91	5.6
10-1	5.9	4.5	10.4	1.1	2.3	0.8	0.04	0.14	3.3
10-2	6.2	5.0	14.5	1.5	4.7	1.1	0.05	0.12	5.9
10-3	6.3	4.9	12.9	1.3	2.8	1.6	0.05	0.17	4.6
10-4	6.3	4.9	8.3	1.0	3.4	1.2	0.04	0.14	4.7
10-5	5.9	4.4	9.1	1.0	2.2	1.0	0.04	0.12	3.4
13-1	6.0	4.3	9.7	1.0	1.5	0.5	0.04	0.30	2.4
13-2	6.1	4.7	8.5	0.9	2.6	0.8	0.04	0.33	3.8
13-3	6.1	4.7	9.4	1.0	2.4	0.5	0.04	0.20	3.2
13-4	5.9	4.6	13.1	1.3	2.1	0.5	0.06	0.18	2.9
13-5	5.9	4.3	9.6	1.0	1.5	0.4	0.04	0.15	2.1
19-1	6.1	4.6	11.3	1.2	2.7	1.3	0.06	0.29	4.3
19-2	6.0	4.8	20.5	2.1	4.7	2.0	0.11	0.20	7.0
19-3	6.4	5.1	13.5	1.4	4.6	1.6	0.06	0.28	6.5
19-4	6.2	4.7	11.9	1.3	2.9	1.3	0.05	0.25	4.4
19-5	6.6	5.1	8.1	0.9	3.0	1.2	0.07	0.66	4.9
25-1	6.6	4.8	17.9	1.7	3.2	1.0	0.06	0.58	4.8
25-2	6.6	5.1	12.9	1.4	3.6	1.3	0.06	0.39	5.3
25-3	6.9	5.4	8.5	0.9	3.1	1.2	0.04	0.41	4.7
25-4	6.7	4.5	13.9	1.3	1.8	0.6	0.05	0.58	3.0
25-5	6.7	4.9	9.6	1.0	3.0	1.2	0.06	0.69	4.9
A	6.2	5.1	20.3	1.9	4.3	1.8	0.02	0.10	6.2
B	5.3	3.9	15.4	1.7	1.7	0.5	0.03	0.09	2.3

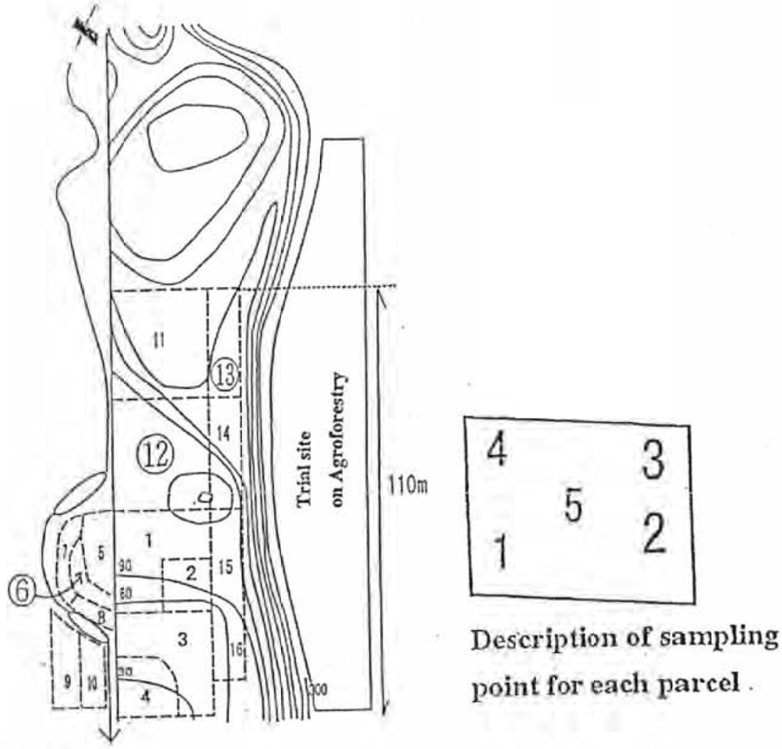


Fig. 3-18. Design of sawah and soil sampling points in Danyame site (Constructed between 1997 and 1998)

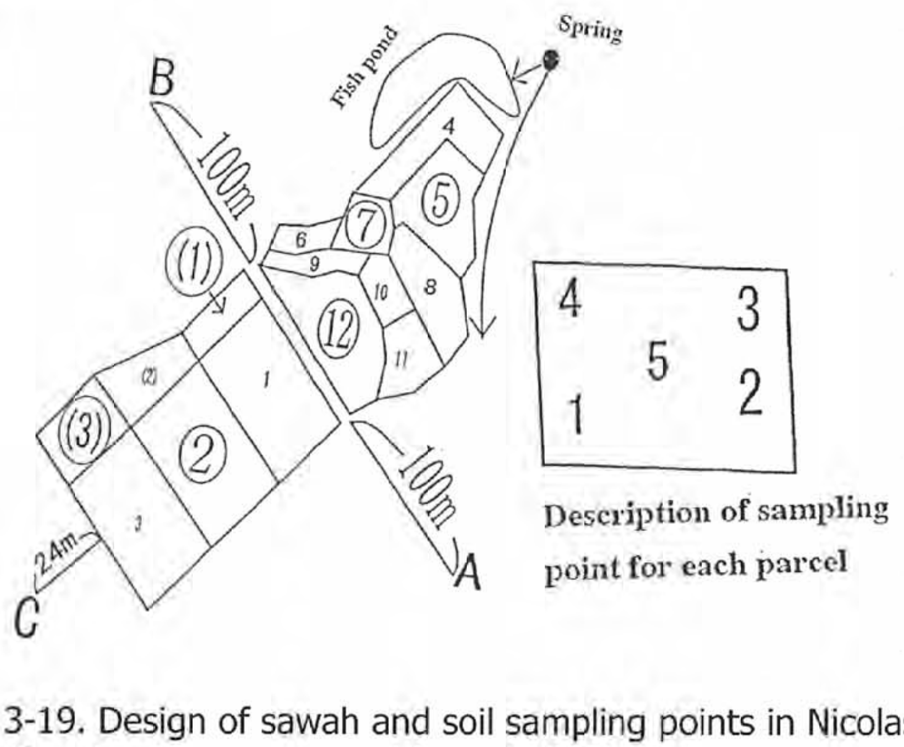


Fig. 3-19. Design of sawah and soil sampling points in Nicolas site (Constructed between 1997 and 1999)

Table 3-8 Soil Fertility Level of Sawah cinstructed in Danyame site

Sample point	pH		T-C	T-N	Exch.cations (cmol(+)/kg)				
	H_2O	KCl	g/kg		Ca	Mg	K	Na	Sum
6-1	6.7	5.4	8.8	0.9	10.0	2.5	0.13	0.08	12.7
6-2	6.8	5.8	13.9	1.4	8.7	2.4	0.15	0.06	11.3
6-3	6.8	5.6	11.0	1.1	9.2	2.6	0.10	0.27	12.2
12-1	7.3	6.2	11.2	1.2	8.9	2.1	0.08	0.06	11.2
12-2	7.1	6.0	12.1	1.3	6.9	1.1	0.05	0.05	8.1
12-3	7.6	6.4	8.5	0.8	8.9	2.2	0.09	0.05	11.2
12-4	7.6	6.3	10.3	1.1	9.1	1.9	0.06	0.05	11.1
12-5	7.4	6.3	10.3	1.0	10.9	2.5	0.10	0.05	13.5
13-1	7.9	6.9	17.6	1.6	7.5	1.9	0.08	0.05	9.5
13-2	7.4	6.4	13.9	1.3	9.4	2.4	0.13	0.06	12.0
13-3	7.4	6.0	11.4	1.0	7.3	1.8	0.08	0.07	9.3
13-4	7.4	6.2	12.8	1.3	7.8	2.6	0.10	0.04	10.5
13-5	7.7	6.5	23.7	2.3	7.2	1.4	0.04	0.06	8.7

Table 3-9 Soil Fertility Level of Sawah cinstructed in Nicolas site

Sample point	pH		T-C	T-N	Exch.cations (cmol(+)/kg)				
	H_2O	KCl	g/kg		Ca	Mg	K	Na	Sum
1-1	8.1	7.2	7.9	0.8	6.9	1.2	0.13	0.37	8.7
1-2	8.2	6.6	12.5	1.2	5.9	1.3	0.14	0.23	7.5
1-3	8.2	6.3	10.9	1.0	5.6	1.7	0.11	0.56	8.0
1-4	8.3	6.3	7.2	0.7	4.3	1.6	0.11	0.72	6.7
1-5	8.0	6.3	13.5	1.3	6.7	1.5	0.08	0.39	8.7
2-1	7.0	5.6	20.0	2.0	8.7	1.7	0.30	0.20	10.9
2-2	6.2	5.4	28.3	2.7	9.0	1.7	0.42	0.22	11.3
2-3	6.2	6.0	12.7	1.3	6.6	1.4	0.14	0.20	8.3
2-4	6.9	6.2	10.9	1.1	9.5	1.5	0.15	0.22	11.4
2-5	6.8	5.9	23.3	2.3	8.2	1.7	0.31	0.25	10.4
3-1	7.5	7.0	8.7	0.9	4.4	1.3	0.06	0.30	6.0
3-2	7.9	7.1	12.4	1.2	9.1	2.4	0.14	0.29	11.9
3-3	7.8	6.8	16.9	1.6	7.2	1.9	0.11	0.29	9.5
3-4	8.5	7.3	6.1	0.6	6.9	2.0	0.07	0.35	9.3
3-5	8.7	7.4	11.9	1.2	11.7	2.6	0.10	0.59	15.0
5-1	8.0	6.0	15.5	1.5	9.3	1.9	0.17	0.15	11.4
5-2	7.4	5.7	25.3	2.4	8.7	1.4	0.34	0.14	10.6
5-3	7.5	6.0	24.5	2.3	9.6	1.5	0.26	0.19	11.5
5-4	7.7	6.2	11.5	1.2	9.8	2.2	0.13	0.20	12.3
5-5	7.2	6.3	12.3	1.3	13.6	3.5	0.20	0.25	17.5
7-1	7.4	5.8	19.5	2.0	7.5	2.2	0.14	0.19	10.0
7-2	7.5	6.0	14.3	1.4	5.6	1.6	0.18	0.33	7.7
7-3	7.4	5.8	8.9	0.9	4.2	1.1	0.18	0.26	5.8
7-4	7.5	5.7	9.7	1.0	4.1	1.2	0.09	0.21	5.6
7-5	7.4	6.2	11.7	1.2	4.7	1.5	0.10	0.35	6.6
12-1	7.4	6.4	11.5	1.1	7.0	2.0	0.15	0.36	9.4
12-2	7.0	5.4	23.4	2.2	8.4	1.3	0.20	0.18	10.1
12-3	6.9	5.5	18.8	1.0	8.7	1.5	0.13	0.21	10.5
12-4	6.7	5.4	23.5	2.2	8.7	1.8	0.29	0.22	11.0
12-5	6.6	5.3	25.1	2.3	8.2	1.4	0.25	0.24	10.1
A	6.6	5.3	22.4	2.2	7.5	2.0	0.10	0.18	9.7
B	7.0	6.2	11.1	1.1	9.8	1.4	0.04	0.09	11.3
C	7.7	6.9	9.8	1.0	4.8	1.2	0.02	0.22	6.3

Another interesting character is the soils of termite mounds. As shown in the Fig.16, Fig. 3-17 and the Table 3-7, termite mounds distributed about 10 per ha in these lowland area. Sawah development destroyed parts of the termite mounds. The soils of termite mounds showed rich in exchangeable sodium and higher pH as shown in the sampling point 5-5 in the Table 3-7 (for the position, see Fig 3-17).

3-4 Guidelines for Sawah development at Dwinyan and Biem river watershed

3-4-1 Sawah Development at Dwinyan Watershed during 1997-1999

3- 4-1-1 Introduction of Sawah

As one part of this study project, 5 sawah sites had developed, i.e. Danyame or Gold valley (Ds or Gs), Potrikurom (Ps), Afreh's site (As), Rice valley or Anthony's site (Rs or Ans) and Nicolas site (Ns) as shown in the Fig. 10. The development had practically started in January, 1997 before the official project commencement. In 1997, the trial sawah development were carried out at 3 sites, i.e., Danyame (Ds), Potrikurom (Ps), Afreh's site (As) and in 1998, 2 new sites were, added, i.e., Rice valley or Anthony's site (Ans) and Nicolas site (Ns9) as shown in the Fig.10. Also 2 former sites developed, Danyame (Ds) and Potrikurom (Ps), have been extended in 1998. Sawah development during the project including pre- and post project time, 1997 – 2001, is sammarized in Table 3-10.

At the beginning of the development, the use of the machinery was limited. No heavy machinery were available in order to make the development way fit for local farmers condition. Because of this limitation, it seemed very unattainable to create such a rice field in local bush. However, through these practices of sawah development mainly by human labor power, sawah has been gradually formed and several manual technology fit for the local condition were also developed. As the result of the cultivation in 1997, the sawah produced the yield of 3.5 ton/ha rice. It was 4 times more than the yield of local rice cultivation.

But on the contrary, it was found that the development site should be very carefully selected mainly because of the water condition. Also, the development requires a lot of investment, especially at the first stage. In addition, the members of sawah cultivation association, which was formed to promote the extension of sawah development are fluid.

3-4-1-2 Sawah Site Selection

According to the result of preliminary land survey practiced from July to September in 1996, one catchment area in Mankranso district was selected for the main project site. Especially, among the area, two clusters of Adugyama and Potrikrom were determined as the first place proposed for the introduction of sawah construction. A schematic cross section of topography from ridge to ridge among the Potrikrom area is shown in Fig. 8 with the typical type of agricultural land use. Traditionallly the lowland is very freaquently used for the rice but in upland style cultivation. In case of sawah extension, this lowland area will the a main target.

3-4-1-3 Participant Recruitment

In order to recruit the participants to sawah activities, the briefing sessions were held at Adugyama and Potrikrom for two times in February and March 1996. In these sessions, the information of sawah activities was introduced to the people, especially to local rice farmers. The main points of explanation were what the sawah is, the merits, the construction methods and the cultivation methods of sawah rice. The explanation was carried out with using OHP and slides projectors. More than two hundred people enrolled for the session at Adugyama and one hundred in Potrikrom. In next stage of the recruitment, the explanation was carried out from house to house. Through this stage, the landlords who administer the lowland area and the rice farmers came to be main targets for the recruitment.

At the beginning of April 1997, two families (one in Adugyama and one in Potrikrom) agreed to participate in the sawah activities with using the lands they administer by themselves. In addition, the association of sawah cultivation was formed by 15 people in Adugyama to practice sawah activities using one members land. In 1998, construction sites were increased by two. But those new sites were developed by the same members of the association and so the number of participants did not increase.

3-4-1-4 Construction Process

From January to March in 1997, the preliminary land survey was conducted on the site proposed for the construction. The results are shown in Fig. 3-20 and 3-21. The broken lines show the proposed construction area and areas surrounded by the solid lines are actual sawah which were developed in 1997. Each construction process is explained in the following sub-sections.

The main feature of the method to practice the process was that, in this project, the use of machinery was minimized in consideration of the extension phase toward local residents. All processes have been practiced by making good use of man power. The machinery which have been used in practical processes were 2 Surveying instruments, 2 Power tillers, and 3 Small pumping machines.

i. Site clearing

The participants were asked to clear the proposed site. The site should be in the lowland, adjacent to the water resource. The size of the land to be cleared was always larger than the actual construction size. Because the dense weed always obstruct clear sight, since the survey can be done only in the cleared land (Photo.3-5).

ii. Surveying & Layout

In the cleared land, by using the surveying instrument (Photo. 3-6, 3-7), the area which is lower than the water resource nearby is firstly determined for the purpose of gaining the water for irrigating sawah by gravitation. Secondly, the area is classified into plots consisted of the land of a similar altitude. Each plot will be each sawah bed. The height difference in the same plot should be well arranged, within around 30cm. Because the soil moving in the process of leveling is the hardest work in the whole process of sawah activities, this arrangement is essential to reduce the expenditure, especially when constructing sawah without any heavy machinery. Also, moving thick layer of the surface soil when leveling results in the topsoil.

If the plot is arranged according to the altitude, the side of the plot will naturally come to a curve. The process of plowing and harrowing by the power tiller and transplanting, can be easily managed in the plot with the side of a straight line. Therefore, in the process of layout, although the altitude is most important factor to decide the plot shape, the shape of course is varies according to the surrounding.

iii. Preliminary Leveling

After the layout, tree trunks in the plot are pulled out and a protruding mounds or pits are leveled roughly.

iv. Bund construction

Along the line fixed by the layout, the bund surrounding the sawah bed was constructed. The height of the bond is around 50 cm. After mounding some soils, the bund was compacted to strengthen the structure.(Photo. 3-8)

v. Plowing & Harrowing

Each plot is ploughed and harrowed using power tiller before final leveling (Photo. 3-9).

vi. Leveling

After irrigating the ploughed field, the field will be leveled. Moving soils from higher place to lower place according to the condition of flooding water, the surface of the field should be flat. Whether the field flat or not affects the necessary water volume to irrigate the whole area of the field. The flatter the field was leveled, the necessary water volume comes to be smaller. In this project, it was found that even by the man power, the height difference among one sawah bed could be 3cm. Also the size of the sawah bed affects the leveling result. The bigger the size bed need more serious attention to this procedure.(Photo. 3-10, 11 and 12)

As shown in the Photo 13, leveling using tower tiller and wooden plank was the most efficient. The photo shows the leveling operation at the Biemso No. 1 site in 2000.

After all these stages of construction, then sawah rice transplanted. The harvest is done by the method of cutting straw together with the seeds.

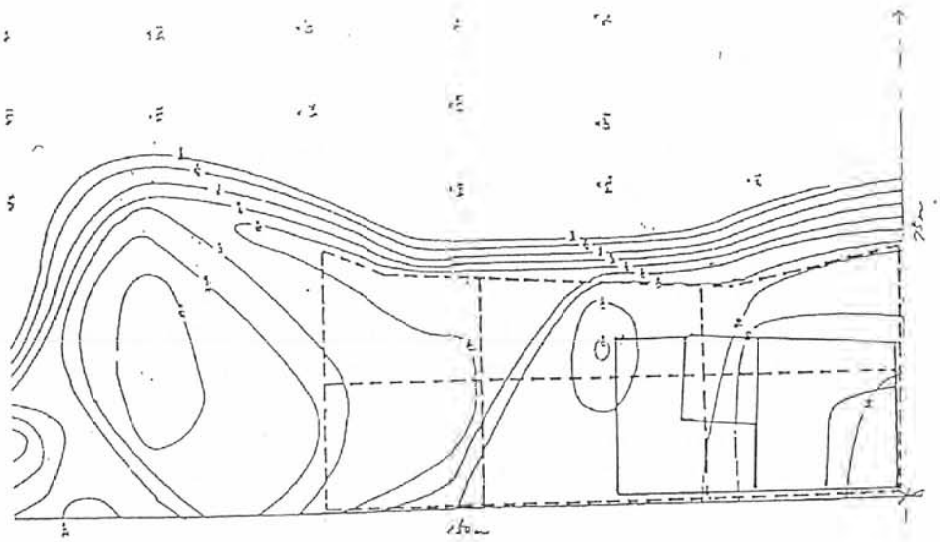


Fig. 3-20. Result of preliminary land survey at Danyame site. The broken lines show the proposed sawah construction area. The area surrounded by the solid lines were actually developed in 1997.

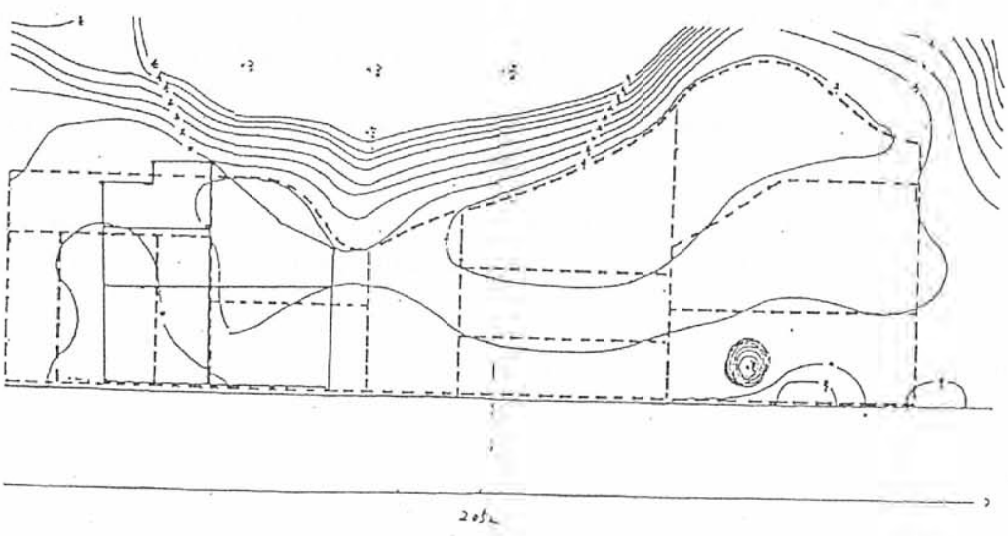


Fig. 3-21. Result of preliminary land survey at Potrikurom site. The broken lines show the proposed sawah construction area. The area surrounded by the solid lines were actually developed in 1997.

Photo. 3-5. Site clearing

Photo. 3-6. Survey

Photo. 3-7. Clearing for survey

Photo. 3-8. Bund compaction, Nicolas site

Photo. 3-9. Plowing and harrowing by the power tiller before leveling.

Photo. 3-10. Preliminary leveling including termite mound treatment, Danyame site

Photo. 3-11. Manual leveling, Biemso No.2

Photo. 3-12. Final leveling by manual

Photo. 3-13. Leveling using power tiller is very efficient

3-4-2 Sawah Development at Biem River Watershed during 1999-2001

3-4-2-1 Site selection

During the on-farm sawah trials in the Dwinyan river watershed of 3500ha, it became obvious that the flow of the stream was small. Although the peak flow during flooding reached 5 ton per sec during June, base flow was in a range of 50-300 liters per sec. During the dry spell period particularly, July and August, stream flow was close to negligible. In order to find the appropriate site for dyke to irrigate the sawah system, it was decided to expand the benchmark watershed to the neighboring Biem river, which is about 7000ha at the point of Biemso No 1 and No 1 villages. At first a general extensive survey from Mankranso where the total watershed area is about 50,000ha, to Nsutem village which is the 2km northeast from Asuadei, 5000ha as shown in the Fig. 3-22. Due to the fan-like shape and the existence of extensive mases and mountainous topography at the uppermost end of the Biem river, even at the Nsutem village area, stream flow was strong and constant even in August. Poor uppermost end, lower altitude, gentle slope and the arrow shape of the Dwinyan river watershed may be the cause of the low flows.

Field survey on 8 sites were made along the Biem river from Biemos No.1 to Nsutem as shown in the Fig.3-22, among which four sites were selected as possible trial site for dyke-canal irrigated sawah system. Major factors considered were the distance to neighboring village and the willingness of the population to respond to call for participation, clear and permanent river course, constant stream flow even in August or November/December, and relatively wide and very flat stretch of the valley bottom and also the existence of the narrow valley bottom which is good for dyke construction. Two sites near Mankranso were abandoned because of the possibility serious flooding problem over an area of 50,000ha. From Biemso No 1 and up to Nsutem, major parts of the valley bottom were considered good for the small dyke irrigation trial with the participatory and eco-technology approach. Finally Biemso No. 1 was selected as the trail site.

3-4-2-2 Participant Recruitment

As part of the recruitment exercise, briefing and explanation sessions were held at Biemso No.1 during March and April 1999. On 27th April, the project held the general explanation and discussion in the church building at Biemso No.1. By that time possible sawah group farmers were already created under the leadership of Mr. Osei Mensah. Apart from Ghanaian counterparts and Japanese experts, four members of Club-C of Adyujama also join to assist to understand the intention of our project.

About 50 men and women adult farmers and 100 children joined the session. Ghanaian counterparts explained the sawah principles to the participants using OHP. The session started at 5:30 and ended at 7:30 pm. The activities on forestry was finished earlier, the major focus was mainly on the participatory sawah development. Sawah, dyke, canal, bund construction, leveling, puddling, transplanting, and harvest were explained. It was further explained that, as a demonstration, the project would provide funds for the dyke and canal that year, and the participating farmers would construct the sawah themselves while the project staff provide the technical assistant.

Fig. 3-22. Dinyan watershed and Biem river watershed along the Biem river from Biemso No.1 to Nsutem.

During the discussion, major question from the participants were as follows:

- Is it really necessary to flood the soil for growing rice?
- Does the upland rice need submergence.
- Can the participant farmer sell the rice produced freely?
- Are there any possibilities that water borne diseases will increase because of project?
- Is bunding necessary for rice cultivation?
- Is it not preferable for the project to introduce bigger machines.
- What may happen to the sawah development in dry season when there no water?
- Is it easy to grow vegetable after rice in dry season?
- Is it possible to develop most of the valley bottom in the watershed in this area?
- There are many more farmers who want to participate apart from Mr. Osei 's sawah group. Don't you have any idea to form more farmer groups for others who wants to participate?
- The site that has been preliminary identified as the sawah development trials has limited number of landlords. Is it possible to start another sawah development trials in another site?
- Is it possible to get new good rice varieties?
- The power tillers will be supplied to the sawah group to rent. Can the machine be used freely by participant farmers?
- It seems that the leveling will be very hard work. Is it really necessary?
- How much yield increase in sawah compared to our traditional field?
- Are there any disadvantages in sawah technology?
- What kinds of help are Japanese going to give us?
- What kinds of advantages do you expect by transplanting? Is it really necessary?
- Are there any possibilities that by taking the water through the canal to this site, stop the river water supply to downstream for other users?
- Has this project some linkage with the district extension office?

3-4-2-3 The Initial Sawah group of farmers at Biemso No.1

The following were members of the sawah group at Biemso No.1 at the time the project started in May 1999. Due to various reasons described in Chapter 6 by Life Team, the number of the Sawah group was reduce to eight in the April 2000.

i. Mr. Osei Mensah, leader of the group, 54 years old, Ashanti farmer, has wife and seven children, a landed farmer, major activities farming as in 1998 were cocoa, plantain, maize, cocoyam, cassava, and yam. Major farming except for sawah rice in 1999, cocoa, maize, and plantain, He has experience in rice cultivation.

ii Mr. Frank Oteng, secretary and sub-leader, 35 years old, Ashanti farmer, has wife, nine children and mother in low, a landed farmer, major farming activities as in 1998 were plantain, cassava, cocoyam, and maize, in 1999 maize and okra cultivation. He has experience in rice cultivation. He resigned from the group in April 2000.

iii Mr. Antony Kwaku Duah, 33 years old, Ashanti farmer, has wife, mother, four sister, 8 children of sisters as dependants, landed farmer, major framing activities as in 1998 were maize, yam, plantain cultivation, and in 1999 only maize apart from sawah rice. He has experience in rice cultivation. He resigned from the group in March 2000.

iv Mr. Ata Poku Dickson, new sub-leader since April 2000, 31 years old, Ashanti farmer, has wife, mother and two sister as dependants landed farmer, major framings activities as in 1998 were maize, cassava, cocoyam cultivation, and in 1999 only maize apart from sawah rice. He has experience inn rice cultivation.

v Mrs. Akosua Konadu, 31 years old, Ashanti landed farmer, has husband, mother, ground mother, two sons, five sisters, two brothers as dependant, major framing activities in 1998 were maize, cassava, cocoyam, yam, and plantain cultivation, and in 1999 only maize apart from sawah rice. She has no experience in rice cultivation.

vi Mr. Kwabena larbi, 28 years old, tenant farmer from Eastern Region, single, father, has mother, two sister and two brother as dependants, major framing activities in 1998 were maize and cassava cultivation, and in 1999 only maize apart from sawah rice. He has no experience in rice cultivation.

vii Mr. Kofi Kyere, 28 years old, Ashanti tenant farmer and dressmaker, has wife, father, mother, tow sister and a brother has dependants, major framing activities in 1998 were maize and cassava cultivation, and in 1999 only maize apart from sawah rice. He has experience in rice cultivation.

viii Mr. Francis Yawdabanka, 26 years old, Ashanti tenant farmer and driver, single, has grandfather, two sisters, three brothers as dependants, major framing activities in 1998 were maize and cassava cultivation and in 1999 maize and onion apart from sawah rice. He has experience in rice cultivation. He resigned from the group in May 2000.

ix Mrs. Akosua Serwaa, 25 years old, Ashanti tenant farmer and dressmaker, has father-in-law, two bother, brother's wife as dependants, major farming activities in 1998 and 1999 were maize, cassava, cocoyam and plantain cultivation. He has no experience in rice cultivation. She resigned from the group in March 2000.

x Mr. Kwame Twaiah, 25 years old, Ashanti tenant farmer, wife and children are living in another village, major framing activity as in 1998 was rice. He has experience in rice cultivation. He resigned from the group in May 2000.

xi Mr. Kwaneba Owusu, 24 years old, Ashanti landed farmer, single, hasmother, two sisters, as dependants, major framing activities as in 1998 were maize and rice cultivation, and in 1999 only maize apart from sawah rice. He has experience in rice cultivation.

xii Ms. Ama Sewaa Mercy Opuku, 22 years old Ashanti trader, single, has mother, grandmother, five sisters, two brothers as dependants, no farming in 1998, no experience in rice cultivation. She has resigned from the group since March 2000.

xiii Mr. Edo Garbee, joined group in May 2000, 30 years old, Ashanti landed farmer, single, major farming activities as in 1999 were yam, plantain, cassava, cocoyam, palm tree cultivation, no experience in rice cultivation xiv Mr. Nnkruma Kwashi, 24 years old Ashanti landed farmer, has wife and family as dependants, major farming in 1999 were plantain, cocoyam, and maize cultivation, no experience in rice cultivation

3-4-2-4 Surveying and layout of Dyke, Canal, and Sawah

The process of selecting the site for the construction of a dyke started with a walk along the river to identify the most appropriate site (optimal cross section for dyke construction). This site should have steep(>10%) and stable slopes with river bed about 10m wide(Fig. 3-23A). With such a cross section cost of construction is relatively low even if it is a concrete type dyke. This type of cross section could not be found. The types found were having varying slopes (between 3% to 10%) with the riverbed also varying from 50 to 100meters(Fig. 3-23 B & C). With these cross sections, the cost of construction would be relatively expensive especially if it is by concrete because of the wide riverbed and also the extensive flood plains. The other envisaged problem was the possibility of the river changing course after the dyke has been built. Majorities of the cross sections found were the B type and these had unstable slopes with extensive flood plains.

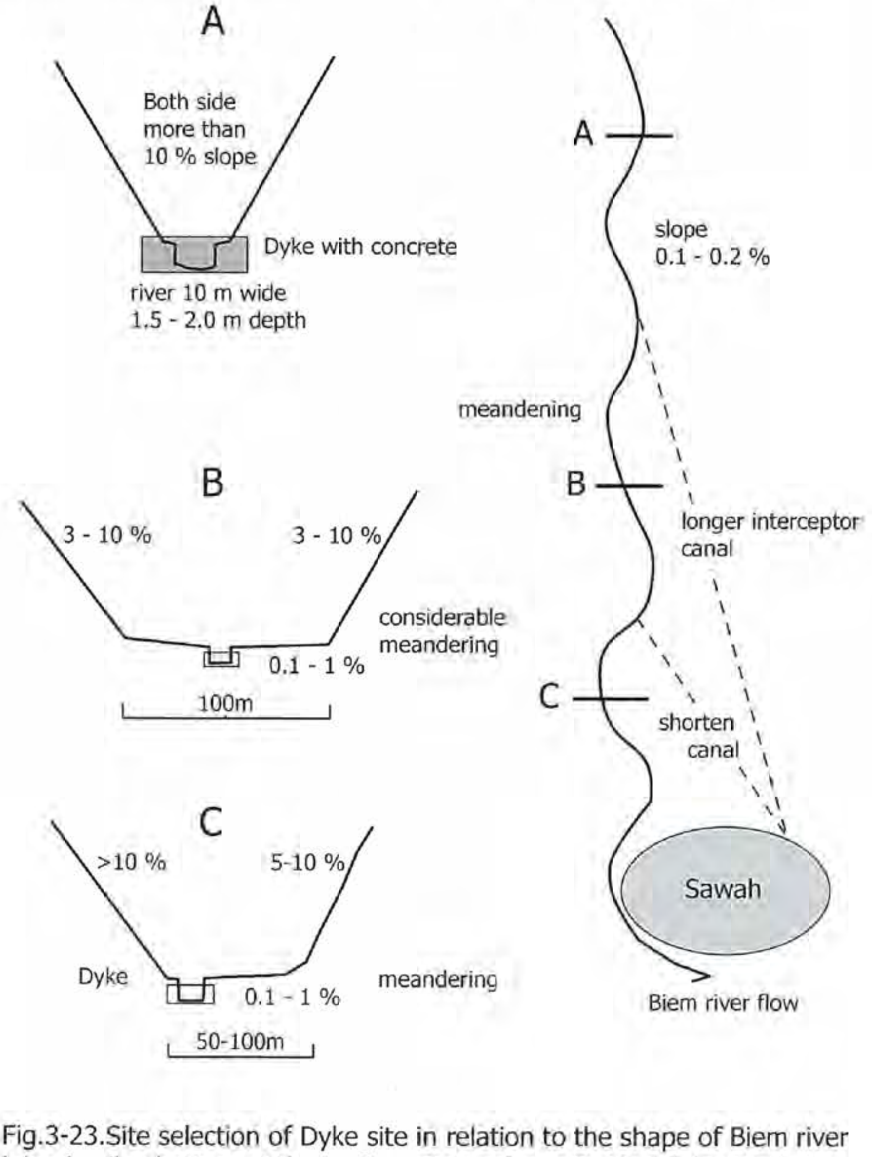


Fig.3-23.Site selection of Dyke site in relation to the shape of Biem river inland valley bottom at the project site : schematic Model description

Other considerations that was made during the selection of the site for the construction of the dyke is the relationship of the dyke, the canal and the sawah proper.

If the mean slope of the river is 0.15%, then water will flow from the river to the sawah plots when the slope of the canal between them is 0.1% and if the canal bed is lower than the river bed then water can flow even without a dyke. In the case of no dyke, however there will be the need to dig a deeper (>1.2m) and longer (>1.2km) canal as compared to the case when there is dyke which can raise the level of water to 1.2 meters. In the case of the former the additional work will require soil movement of 2700 tons, which will take about 1350 man-days and this could cost about 2,300 US dollars. In addition there could also be the possibility of the canal diverting the river course. In this case the management of the canal will be even more difficult.

In general, with the type A and C cross sections, it is better to construct a dyke since the cost of construction in the case of this project will not exceed 1000 US dollars per one unit, which can irrigate more than five hectares of sawah. Fig. 15 and 16 shows final layout of dyke, canal, and sawah. It was envisaged that this system in this particular area could develop 5 hectares of sawah. In terms of water availability by the construction of the dyke and assuming 50% efficiency of the system, more than 10 hectares of sawah could be realized if the water requirement of the sawah is less than 20mm per day.

3-4-2-5 Sawah Development during 1997 – 2001

Table 3-10 summarized the annual sawah development in square meter (m2) . Although these development themselves were the parts of trial and error of the joint study project with participant farmers groups, there are clear difference between groups. Biemso No 1 site shows the most promising results for rapid expansion of sawah. This is because of weir and canal systems which secure the irrigation water to sawah developed. Later we will discuss comparative evaluation of these sawah systems tesetd.

Table 3-10 Area of Sawah in Square Meter(m^2) Constructed during 1997-2001, The area includes bound and termite area. Parenthesis are estimation because of on-going development by new group by the end of August 2001

Village	Site	1997	1998	1999	2000	2001	Total
Adugyan:	Danyame(Gold valley)	1,610	1,490	-	-	-	3,100
	Afresh	830	-	-	-	-	830
	Nicolas	-	1,730	1,810	1,900	-	5,440
	Anthony	-	1,680	-	-	-	1,680
Potriklom:	Potriklom	2,650	3,780	-	-	-	6,430
Biemso No.1:	Sawah group A	-	-	13,270	5,000	-	18,270
	Sawah group B	-	-	-	-	(15,000)	(15,000)
Biemso No.2:	Sawah group A	-	-	-	6,100	-	6,100
	Sawah group B	-	-	-	-	(5,000)	(5,000)
Total		5,090	8,680	15,080	13,000	41,850	(61,850)

3-5 The Participatory Approach for Canal and Dyke Construction: Case study at Biemso No.1

3-5-1 Introduction

The inadequate water problem faced by Biemso No. 1 rice farmers necessitated the creation of a diversion dyke to channel water through a canal to the rice field. A temporary bamboo dyke supported by sand bags was constructed (Photyo 3-14, 15, and 16). However, water could flow temporary to the rice fields when there was general floods (Photo 3-17). The strong flood easily destroy the wooden and bamboo earth dyke (Photo 3-18 and 19). When the floods recede, water could only be channelled through the canal using pump pressure. After each high rain storm, the dyke could not also impound substantial quantity of water for pumping, expecially, when the rainfall is inadequate. Unfortunately, seepage losses were high. The seepage loss was created by the horizontal beams. The beams were used to stabilise the bamboo dyke. Thus, due to the inadequate water, only one rice with a ratoon crop could be harvested. This dampened the participatory spirit of the farmers. Farmers suggested a stronger dyke to meet their water requirements to be their highest priority if they want to continue the rice project. This will require little supplemental pumping to reduce the high fuel cost.

3-5-2 Selection of dyke type

An earth diversion dyke was selected. This was because farmers had made an effort in the previous year to construct one with local materials. The presence of different materials around Biemso No. 1 investigated: revealed that

i. There was some clay deposits close to the bridge along Adense road about one kilometre from the dyke site
ii. The river bed had sandy-clay layer followed by a uniform layer of sand-gravel mix.
iii. There were termite hills of uniform silty-lay texture scattered around the site.
iv. There is a U-shaped valley that could be used to impound substantial quantity of water.
v. The human resource (labour) for the construction of the dyke was available.

It was found necessary in consultation with the participating farmers that a gravity dam will suit their purpose. They proposed that if the water level drops during the major dry season, then they would rely on pumping system to supply water to the fields.

3-5-3 Principle of the dyke construction

The following principles were used:

(1) The velocity of water through a porous medium, especially, fine-grained materials such as clay, sand and sand-gravely mix materials, the seepage flow is laminar and follows the Darcy's formula:

V = KI

Where, V is seepage flow, K is hydraulic conductivity, I is hydraulic gradient.

The K value is of the order sand-gravel mix>sand>clay. An earth dyke with an alternating impermeable layer of clay sandy clay layers was selected.

(2) Silty-clay and sand-clay on compaction, attain high relative densities, subject to less cracking and acts as an impermeable layer (Antwi and Asiamah, 1996).
(3) The gravity dyke should satisfy strength requirements, stability to sliding and stability to overturning by horizontal forces of river. Reduced stability to sliding and overturning implies the dyke is no longer suitable for further operation. Secondly, there should be no deformations resulting from cracks and excessive seepage.

3-5-4 Materials

Thorough prospecting of materials within the vicinity of the Biem river was carried out. The properties of the soils and their distances from site were considered to reduce labour constraints. Fine, uniform grain of soils to be used as the body of the dam was investigated. The antiseepage element was considered from the point of availability, percolation properties, and homogeneity of the gain composition. The materials to be used were to satisfy low to average head of 2.5 metres. The following materials were used: clay, silty-clay, sandy clay, sand-gravel mix, sandbags. The clay and silty clay (termitaria) were transported to site (Photo 3-20 and 3-21). The sandy-clay and sand-gravel mix were excavated from river bed (Photo 3-22, 23, and 24) .

3-5-5 Site description

The river bed was augered to a depth of 0.7m to determine the materials that formed the river bed. A thin 0.1m was made up of sandy loam. This layer was cleared before the other layers to a depth of 0.7m was described. The 0.20m was sandy-clay followed by another layer of 0.3m of sand-gravel mix. The layer from 0.5 – 0.7m was a fine silty-clay sheet.

The bamboo dyke was strong with a lot of leaf litter and silt accumulation behind it. Seepage holes were observed along the wooden beams that ran parallel to the river course. The level of the bamboo mat was at the same level as the lower bank of the U-shaped valley. This was about 1.5m high compared to the deepest portion of the river bed. Three of such bamboo mesh was observed. Some sand bags were observed within the space between the bamboo mesh. Some of the sand bags had been cut open, others were rotten, while big spaces indicated mass movement of the sand bags downstream. Huge deposits of sand had been deposited just downstream of the river course.

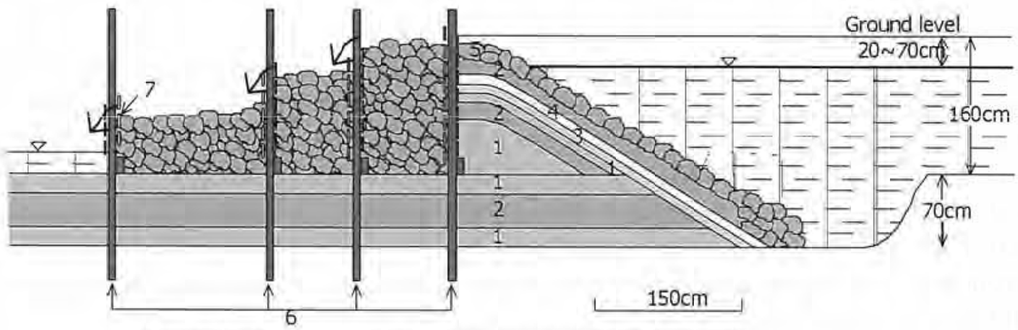
3-5-6 Method of laying the materials

3-5-6-1 Sealing the bamboo partition

Imported clay was puddle with the foot till it became very plastic. This was used to seal the pores within the first bamboo dyke, which receives the direct impact of the river force (Photo 3-25). This formed a plaster of about 0.05 – 0.10m thick. This technique is the same approach used by the local people in the construction of their mud structures, which have wooden stakes in them.

3-5-6-2 Laying the triangular base

The sandy-loam and debris within 4m from the first bamboo dyke was cleared. Sandy-clay soil from the riverbed was excavated from a distance of about 1.5m from the first bamboo dyke. This was heaped and compacted to form triangular shape to about 0.5m of the depth of the bamboo dyke(Fig 3-24). This formed the base for laying the other layers. The purpose of this layer is to allow any infiltrated water to seep through the base of the dyke in addition to the provision of stability to the dyke's base. This was covered initially with 0.2m sand-gravel mix from the riverbed. This material was sand-witched between the sand-clay sub-triangular layer and another 0.1m sandy-clay sheet. This idea is to allow infiltrated water to trickle back to the base of river.



1. - sandy clay
2. - sand and gravel mix
3. - clay sheet
4. - silty clay (termitaria)
5. - sand bags (sand and gravel mix)
6. - wood, 2x3 inches, 1.5~3.5m length
7. - bamboo slender plate

Fig. 3-24. Biemso No.1 Dyke, side view from the canal side.

3-5-6-3 Laying the triangular base

The semi-permeable layer consisted of 0.2m clay and 0.2m silty-clay sheets. They were puddle with the foot and plasted on the sandy-clay layer. The semi-permeable layers covered the base of the excavated portion to prevent unnecessary seepage through the base of the dyke. This was used to simulate the impermeable partition of steel or concrete proposed by the farmers. The local people use galvanised sheets as impermeable partition any time they dammed the river. The force of the river flow destroyed any earth dam constructed.

3-5-6-4 Dyke lining

The semi-permeable layer was covered with 0.2m of sand-gravel mixture. This layer was purposely to strengthen the surface of the semi-permeable layer and to prevent it from sliding and overturning. The dyke was then lined with sand bags (Photo 3-26). They acted like boulders to provide further stability to the slope, prevent excessive evaporation that will lead to deformations such as cracks and excessive seepage.

3-5-6-5 Spillway

The spillway construction in relation to the canal generated a lot of misunderstanding between farmers and scientists. Farmers decided on a spillway that was high enough to impound more water that can flow by gravity through their canal system to the rice fields. For purposes of dyke stability, scientists decided to lower the height by 0.3m compared to the lowest level of the riverbank. Adopting this technique implied that sand bags could be used to regulate the level of the dyke. This implied that the depth of the canal needed to be lowered from 0.2m – 0.4m at some sections.

Farmers insisted on their decision and the risks involved. It was generally agreed that the spillway was to be lowered to about 0.1m below the lowest part of the riverbank. This implied less work on the canal. The water on the spillway was channelled off using a cascade of sand bags placed within the old bamboo dykes. As at the end of August 2001 even in the second year, the spillway has worked in favour of the farmers (Fig 3-25 and Photo 3-27). Fig. 3-26 shows plain view and Fig 3-27 shows cross sections of A to E of Biemso No.1 Dyke.

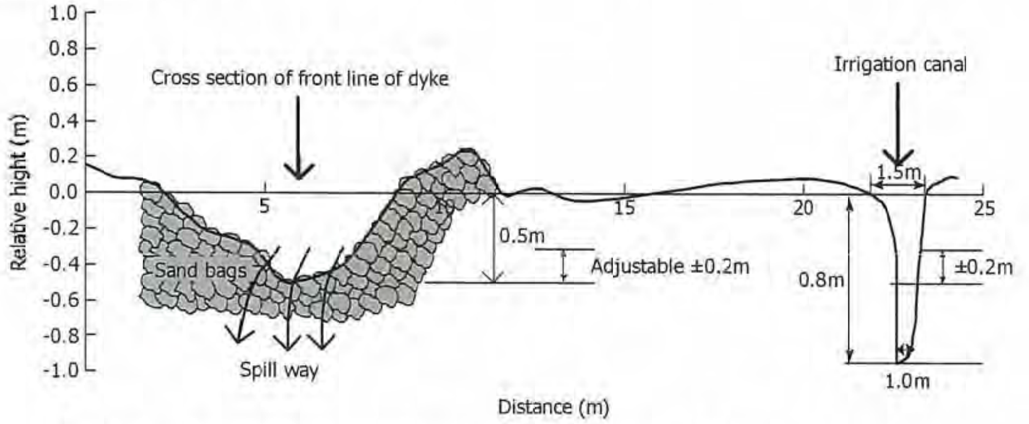


Fig. 3-25. Ajustable canal flow system using sand bags.

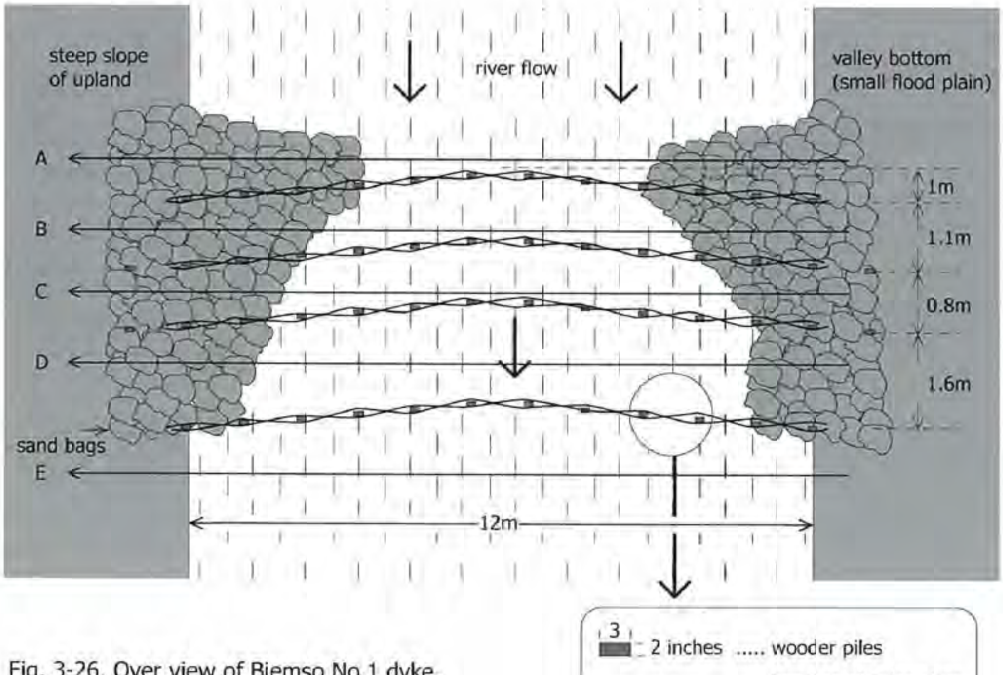


Fig. 3-26. Over view of Biemso No.1 dyke.

3-5-6-6 Dyke maintenance

Farmers were schooled on how to maintain the dam. They visited the dam at every rain event to observe any defects that is likely to threaten the annual lifespan of the dyke. They arranged displaced sandbags, replaced spoilt ones, and removed sandbags to lower the spillway to regulate water to the fields.

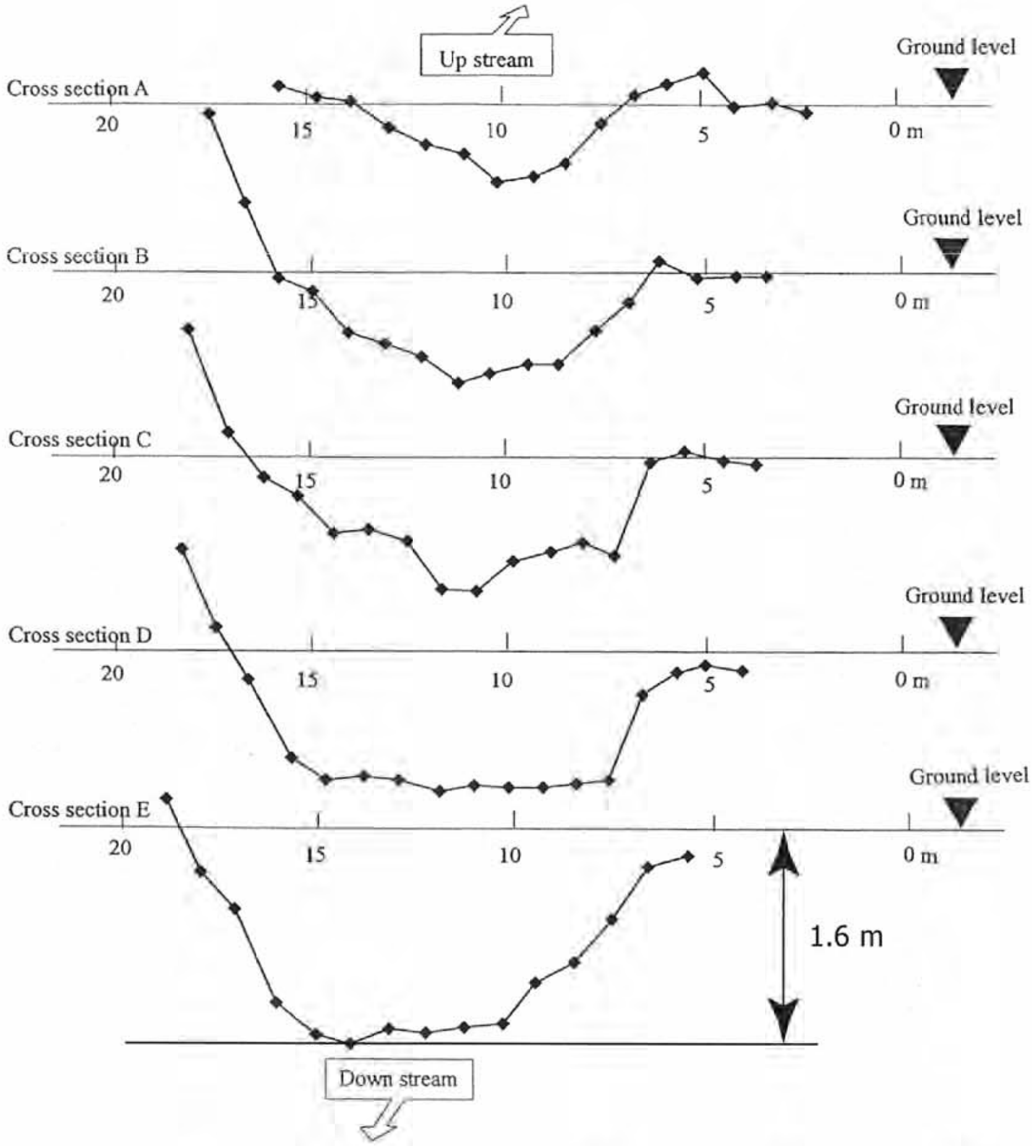


Fig. 3-27. Cross section of A to E of Biemso No.1 dyke. Cross section E shows the cross section of Biem river

Photo. 3-14. Bamboo and wodden dyke

Photo. 3-15. Dyke constraction with soil, wood and bamboo on May 1999

Photo. 3-16. Sand bag cover, May 1999

Photo. 3-17. Flooding over dyke

Photo. 3-18. After flooding

Photo. 3-19. Repairing to stop leakage of the dyke

Photo. 3-20. Clay and silty clay from termite mound

Photo. 3-21. Carrying clay and silty clay for creating impermeable layer on the front side of dyke

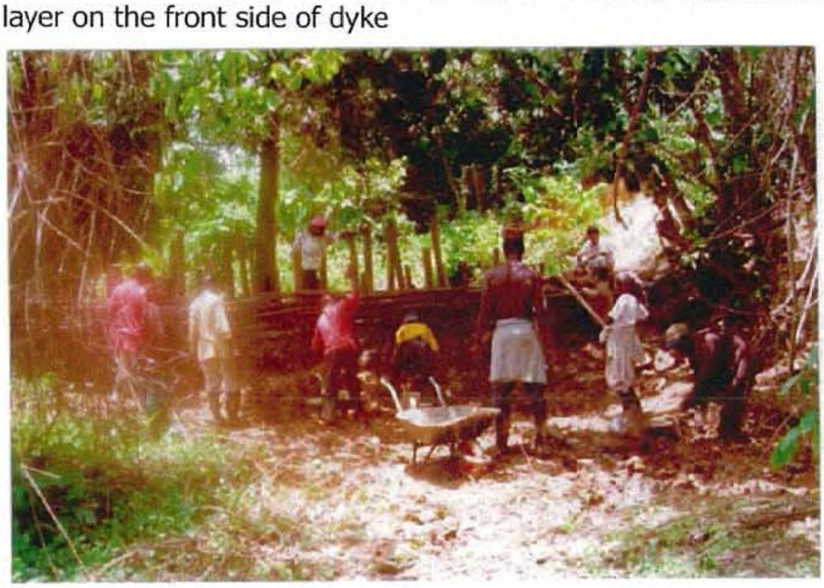


Photo. 3-22. Excavation of river bottom


Photo. 3-23. Excavation of river bottom and jute bags


Photo. 3-24. Sand bags contained the soils from river bottom


Photo. 3-25. Compaction to create impermeable layer on the front of dyke, March 2000

Photo. 3-26. Dyke was covered with sand bags after compaction of permeable layer

Photo. 3-27. Repaired dyke lift the river flow for canal irrigation. August 2000, evaluation survey.

3-5-7 Participatory Canal Construction

3-5-7-1 Introduction

The objective of the canal construction was to get water onto the sawah field. Meanwhile since it was the policy of the project to use the participatory approach, the project involved the owners of the sawah (farmers) from the very beginning. The sight for the canal was inspected with the farmers and where the canal was passing through a non participant's farm the participants were asked to negotiate for a compensation to be paid. After the land surface measurement (Photo 3-28) and design of the canal (Fig. 3-25 and 3-26, also see Fig.15 in page 27), the site was cleared and marked (Photo 3-29). The farmers started digging the canal from the side of the dyke (Photo 3-. Here they encountered a lot of problems whiles digging because they discovered stones and other materials which made it very difficult for them but with persrverance they were able to do it (Photo.3-32). After digging the canal the intake point was blocked with sand bags, which they had already prepared (Photo 3-33).

3-5-7-2 Canal Construction

After the identification of the dyke site, the possible route of the canal with 0.125% slope was decided, since mean river and valley bottom slope was 0.1-.2%. The construction of the canal with the length of 800m and mean depth of 75cm which started in April 2000,was completed in May 2000. The width of the canal from the dyke was 1.5m and as it approached the sawah became 1m. Total cost of canal digging was 300man-days, which was equivalent to 510dollars. Because of the first year demonstration, the project provided the cost of the first canal digging. During May 2000, just before starting the rice cultivation maintenance works were carried out on the canal by the farmers' sawah group. They cleared the debris and dug out a bit more deeply to clear siltation. These works for the canal improvement in 2000 were done by farmers themselves without any provision of payment of the labor cost from the project. Where necessary, hired labor cost was paid by the farmers' sawah group. The Fig. 3-28 shows the topographic height maps on the canal route, before the canal digging, after the first canal digging on May 1999, and after the first rice harvesting and second canal digging/smoothing on July 2000. Since the canal is not lined maintenance is very necessary. However, the quality of canal will improve year-by-year if proper maintenance is carried out.

3-5-7-3 Water flow from the Canal to the Sawah field

With the help of a current meter the flow of the canal was monitored. The results were summed up at the various days (Photo 3-34). The maximum flow of the canal measured with current meter was about $0.041m^3/s$. The discharges indicated that within the period of measurement, the canal could irrigate an area of 4.70 – 20.50ha (Table 3-11). Table 3-11 also shows the seepage amounts of spring water at the Nicolas' site (Fig. 10 and Fig.13)

The water intake rate of the canal was 20-40 liter per sec at 50m from the intake point. Although considerable leakage may be expected because of the no lining, permeable soil canal has advantage too. The 800meter canal also serves as an interception collector of water from the upland. Therefore the irrigation water at the rate of more than 10 liter per sec at the intake point between C5 and C4 for the sawah developed (Fig. 15 and Fig. 19 in pages 27 an 29 respectively).

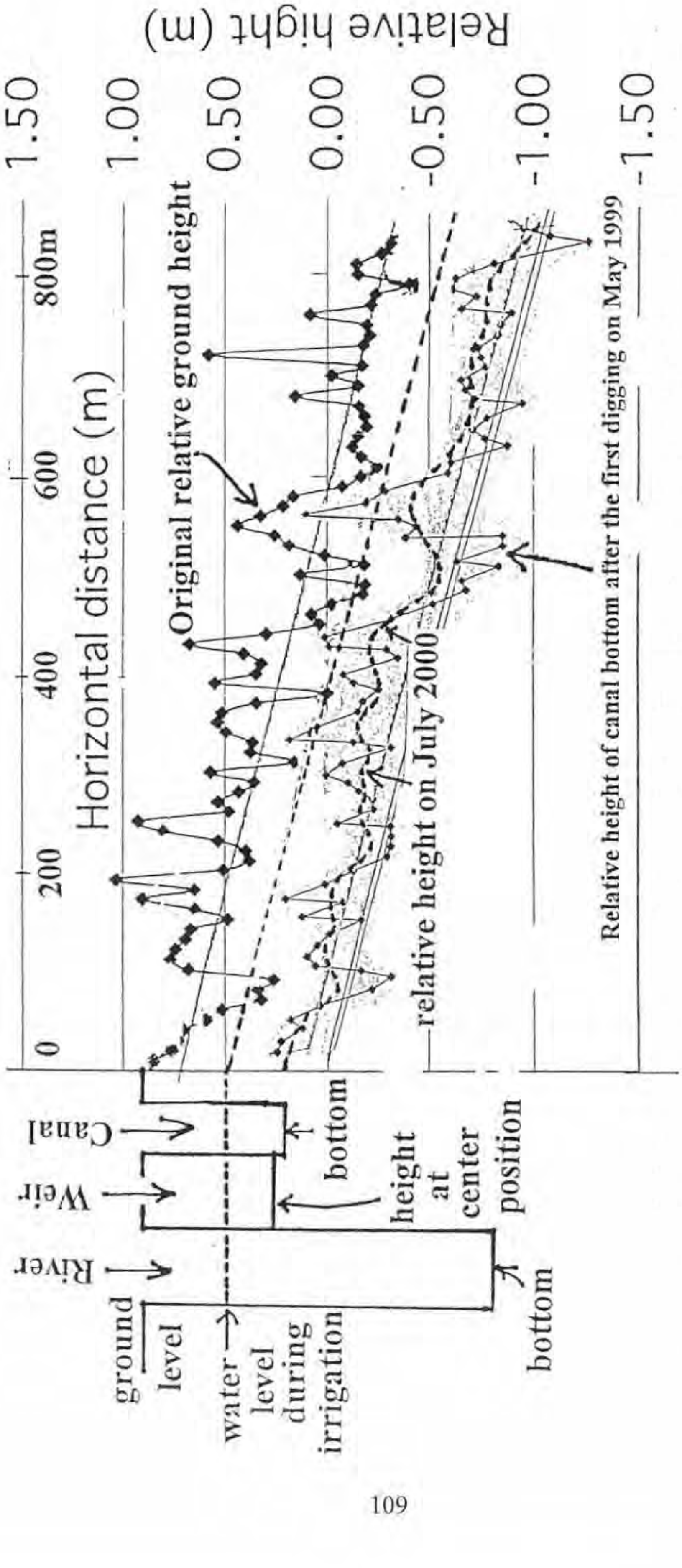


Fig. 3-28. Relation height of river, weir and canal

It is documented that about $1m^3/s$ discharge can irrigate an area of about 500ha of cultivated rice fields. Hence the Biemso No. 1 dyke has the capacity of irrigating an area of about 20.5ha. Meanwhile the area under rice cultivation at Beimso No. 1 was eabout 3.3 h/a by the end of August 2001 (Table 3-10).

Table. 3-11. Summary of discharge rates measure on the ammounts of irrigation water

Biemso No.1

Measurment date	Cross sectional Area (m2)	Speed (m/s)	Discharge (m^3/s)	Irrigable area (ha)
1996/6/25	0.37	0.11	0.041	20.5
1996/11/14	0.38	0.07	0.037	18.5
1996/11/17	0.36	0.07	0.025	12.4
1996/11/20	0.32	0.07	0.021	10.5
1996/12/5	0.28	0.06	0.017	8.3
1996/12/7	0.27	0.05	0.012	6.2
1996/12/14	0.25	0.04	0.009	4.7

Adugyama (Nicolas site of spring)

Measurment date	Cross sectional Area (m2)	Speed (m/s)	Discharge (m^3/s)	Irrigable area (ha)
1996/11/15	0.03	0.16	0.005	2.7
1996/11/27	0.03	0.04	0.001	0.6
1996/12/10	0.02	0.01	0.000	0.1

3-5-8 Cost estimation of Canal and Dyke Construction and Maintenance

Since the farmers constructed the dyke and canal all by themselves with little supervision, maintenance would not be a problem at all. Water impounded by the dyke can be used throughout the major and minor farming seasons. As at January 15, 2001, the canal has dried up, but there is still enough water stored by the dyke. The stored water could be used for vegetable farming, such as tomato, eggplant, cowpea, and pepper, after rice harvest for a supplemental income.

Fig. 3-26 shows the areal view (plan) of the dyke. Cross sections A, B, C and D has been presented in Fig. 27. Section E shows the immediate down stream cross section of the riverbed. Fig.3-24 shows the longitudinal section of the dyke. The head of the dyke can be adjusted using sandbags.

The flow into the canal at the intake can also be regulated using sand bags. In 2000 the farmers decided to increase the head of the dyke in order minimize the dept of the canal. Meanwhile, the higher the head of the dyke, the shallower the canal but the bigger the risk of destroying the canal during heavy floods. On the other hand the lower the head the deeper the canal will be and higher the labour cost, however the risk of destruction is low. The decision will have to be taken by the participating farmers themselves. The cost of labour and materials in the construction of the dyke per one unit that can irrigate 5ha of sawah was estimated to be 200 and 400 US dollars respectively. The cost of constructing 800meters canal to irrigate 5ha sawah was 1500 US dollars

The cost of additional work on canal was 200 US dollars, which is 20% of the original cost (or 300 US dollars). The estimate of labour cost for repairing the dyke two times will be 48 US dollars (ie 8man-days x 3days x two times x 6000Cedis). The material cost for repairing the dyke two times be 125 US dollars (ie cost 300jute and 300 plastic bags). Since the project provided the necessary materials, the decision by farmers group to choose the former was reasonable. However, since the canal management is not difficult, therefore constructing a deeper canal with lower head of the dyke year by year will be a reasonable process. Another factor which was considered is that the deeper the canal which will make the longer distance to the possible intake point to sawah.

3-5-9 Conclusion

Water availability to rice cultivation was the highest priority of Biemso No. 1 farmers under the Japan International Co-operation Agency (JICA) and Crop Research Institute (CRI) joint study on Integrated Watershed Management of Inland Valleys. The farmers made a bamboo dyke which collapsed at every heavy rain event. The Soil and Water Team held preliminary discussions with the farmers. It was agreed that a stronger dyke be constructed. The prospecting of materials for dyke construction was jointly made by the farmers and the scientific team. The old bamboo dyke was studied. The beams used to strengthen it accelerated canal seepage losses. The beams were cut and sandbags used to provide rigidity to the old dyke. Uniform sandy clay and sandy-gravel layers were used as the body of the dyke. Silt clay layer from termitaria was used as an impermeable layer. The uniform sandy clay and sandy-gravel mixture was excavated 1.5m from the upper reaches of the dyke. The heap was piled up in a triangular shape using farmer labour. Sandbags containing sand-gravel mix were used to line the dyke. This behaved like boulders to prevent the scouring of the dyke. This material has been deposited over time.

The excavation increased the volume of water in the reservoir. The base of this deposit was an impermeable clay layer. Using farmer labour, the diversion canal was surveyed. The canal has an average depth of 1.0m, bottom width of 0.8m, and top width of 1.5m in a trapezoidal shape. The slope of the canal from the intake point to the rice field was about 0.1-0.5%. Generally, there was relatively slope variations at varying points of the canal, however, this did not affect the flow adversely. The maximum intake from the canal was $0.041m^3/s$ with a capacity to irrigate 20 ha. The maintenance of the dyke is solely the responsibility of the farmers. Due to the backwater effect, the upper reaches of the river was permanently in flood. A wooden bridge was constructed for the farmers in the area.

Photo. 3-28. Survey on termite mound

Photo. 3-29. Clearing, demacation on the route of canal

Photo. 3-30. Canal constraction near dyke

Photo. 3-31. Canal constraction

Photo. 3-32. Canal constraction and compaction to prevent canal leakage

Photo. 3-33. Intake point of canal

Photo. 3-34.
Flow measurment
of canal

3-7 Design, construction, testing and Evaluation of various sawah systems

3-7-1 Various pilot sawah trials in the Project site

During the project period, 1997 to 2000, seven sawah demonstration sites were developed (Fig. 10). The total area developed during this period is presented in Table 3-10.

In April to June 1997, the first sawahs were constructed at Danyame valley(Ds), 0.16ha, Afreh's site(As), 0.08ha, and Potrikurom(Ps), 0.27ha. Immediately after the completion of sawah, rice was transplanted, which was harvested during October -November. The production and yield at the various sites are as follows:

Site	Production(kg)	Yield(t/ha)
Danyame	557	3.5
Afreh's	303	3.7
Potrikrom	1036	3.9

The farmers association for sawah development at Adujama villagewas called Club-C and was made up of 10 farmers, They were responsible for the development of Ds and As site. All the Club-C members were landed farmers.

During April to July 1998, the sawahs were expanded at Ds to 0.31ha (Photo 3-35), Anthony's site(Ans), 0.17ha, and Nicolas' site(Ns), 0.17ha and Ps to 0.64ha. The total area developed under sawah became 1.37ha, of which 0.64 ha was used for research purpose (agronomic rice trial) by Crops Team. Total area of sawah became 0.73ha, excluding Ps. Total paddy production was 2425kg and yield was 3.3t/ha. The Club-C was responsible for the development and rice cultivation at Ds, Ans, As, and Ns.

During April to August 1999, sawah development trials were expanded at the Biem river watershed. At Biemso No. 1 village, another new farmers association was formed, Sawah group with about ten landed farmers. Biemso sawah group developed 1.33ha of sawah as well as dyke and 800m of canal. Total paddy production was 5500kg, of which 430kg (5.5 tins = 275kg) of milled rice for landlord of the sawah and 100kg for family use. Mean yield was remarkable 4.5t/ha. The remaining, about 5000kg of paddy, was sold. The paddy was sold for 5million Cedis, which was equivalent to 1300 US dollars. This is equivalent to 1066$ per ha (Table 3 in page 21).

Adujama Club-C also expanded the sawah raea to 0.92ha (Photo 3-36), with paddy production of 4000kg, including 800kg of ratoon paddy. Mean yield increased to 4.3t/ha, including ratoon paddy. They sold the paddy for 5million Cedis, 1250 US dollars. This is equivalent to 1406$ per ha. The higher selling of the Club-C was based on the selection of good market price in December 1999. Relatively lower selling of Biemso sawah group was based on the poor market price it March, 2000.

During April to August 2000, one more Sawah group was formed at Biemos No. 2 village, and the group developed 0.62 ha of rain-fed type of sawah. Biesmo No. 1 sawah group also expanded their sawah to 1.80 ha during 2000 (Photo 3-37). The total rice production of Biemso No.1 sawah group was 5.7 ton in paddy and they sols it for 14.4million Cedis, which was equivalent to $2,057 (1US$ =7000 cedies at March 2001). Details economic evaluation was described in the section 6-8-4 of chapter 6.

Fig. 3-35. Gold valley on survey

Fig. 3-36. Sawah at Danyame (Gold) valley

Fig. 3-37. Pumping water at Gold valley

Fig. 3-38. Sawah at Rice valley

Fig. 3-39. Sawah and small pond at Biemso No.2

Fig. 3-40. Nicolas site with Club-C member

Fig. 3-41. Small pond constraction at the Nicolas site

Fig. 3-42. Potrikrom site

Fig. 3-43. Biemso sawah group farmers

3-7-2 Description of various sawah system trials

3-7-2-1 Rainfed type Sawah/ Drought prone Sawah: Danyame (Gold) valley (Ds), Anthony's Rice (Rs) valley, and Biemso No 2

Fig. 11 shows the sawah system at Ds. Fig. 10 shows location Photo. 3-35 and 3-36 shows the sawah at Danyame. This Danyame watershed is about 100ha. The main stream is very shallow and muddy, The stream dries during growing season. Main flow is from June to July and minor flow in September. During the flow period, from June and September, there are seepages from upland onto the sawah field. The sawahs suffer from some water shortage during dry months of the growing season. In that case rice have to be irrigated by pump from the small pond created in the river course (Photo. 3-37). Sometimes pond water also dries up during dry spell of August.

As seen in Fig. 11, the valley bottom slopes are 1-3%, (a mean of 2%). Mean sawah size was about 200m^2. For the leveling of mean sized of sawah, 200m^2, farmers have to move about 12.3m^3 of soil. For one hectare of sawah development, farmers have to move about 615m^3 of soil for leveling. The results of such calculations are shown in Table 3, assuming one side slope is 1%, the other slope is 3%. For the construction of the bund of size 0.4 x 0.4x 0.8m, about 400m^3 of soil have to moved. For the construction of two small pond, 53m3 of soil has to dug out per 0.33ha, for one hectare this will be 161m^3. Although it was not necessary, three termite mounds of about 0.30 ha were also removed. Mean size of the termite mound has a base diameter of 10m and height of 2m. The volume of such a termite mound can be 52m^3. The amount of soil moved to level the termite mound per ha was 477m^3 (ie. 53 x 3 x 3). If we assume three termite mounds per ha were leveled, total soil movement necessary to develop one ha of sawah was estimated to be about 1,333m^3 as shown in Table 4.

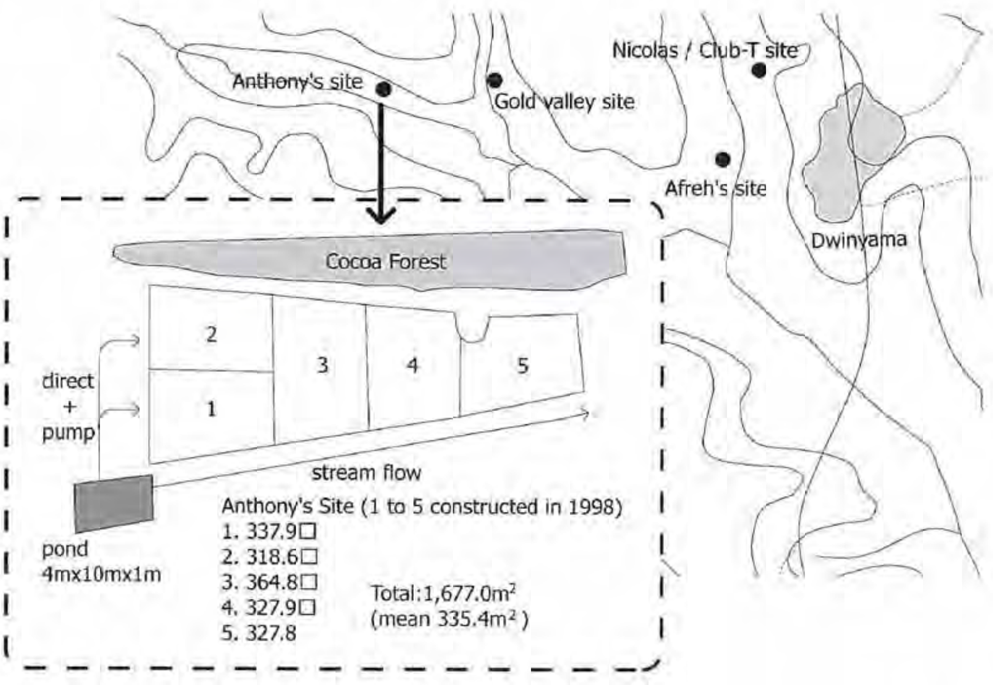


Fig. 3-29. Sawah system at Anthony's Site.

Fig 3-29 shows the sawah system at Rice valley or Anthony's site (Ans). The water condition is similar to that of Ds, which is also drought prone. Because the valley bottom slope is slightly lower, 1 -2%, than DS, mean plot size was about 335m^2. Soil movement necessary for the leveling was 573m^3 per ha and for bunding was 320 ton per ha. For the one small pond , total soil dugout was about 40 ton per 0.17ha, and for one hectare this will be 235 ton. Total soil movement was estimated to be about 1285m^3 per ha of sawah system, including 158m^3 of termite mounds leveling. Photo 3-38 shows the sawah at Rice valley.

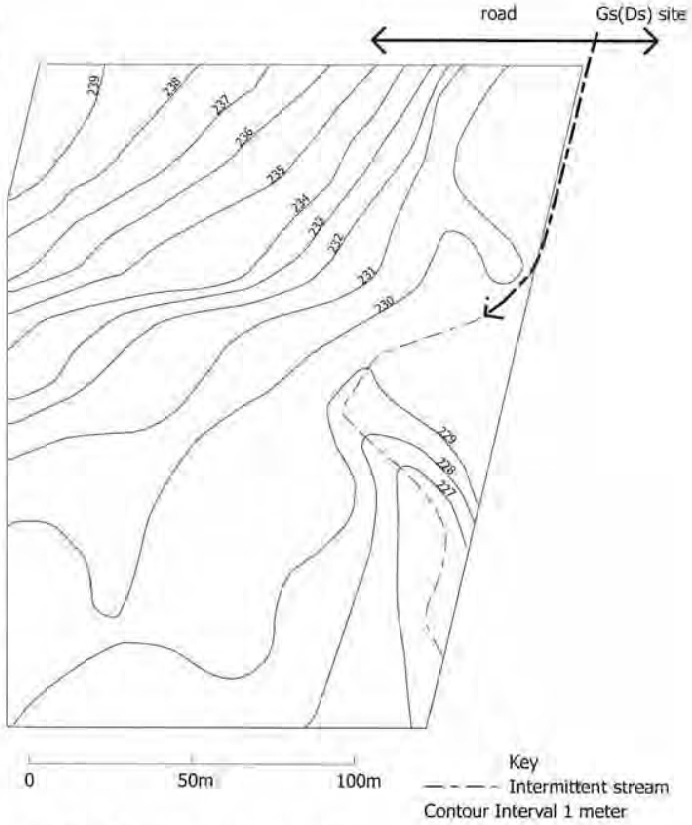


Fig. 3-30. Yakubu site, toposervey.

Because of drought prone nature of the area, relatively steep slope and land tenure problem, original sawah development plan at Yakubu's site was abandoned after brief top survey as shown in Fig. 3-30. The Yakubu's site is just under the site of Ds. Mr. Yakubu is a migrant farmer from the Tamale in the Northern Region. Therefore he could not get permission from his Ashanti landlord to develop the sawah.

In April 2000, another sawah group was formed at Biemso No. 2 as shown in Fig.10. This system is essentially the same as to the sawah system of Ans. By the end of August 0.61ha of sawah was developed. In the dry season, during December to April, farmers group planted pepper, tomato, and eggplant using the residual moisture in the soil. The Biemso No. 2 site has a special advantage in terms of high groundwater level in the dry season at the valley bottom. These characteristics have to be monitored carefully in the follow up of the project (Photo. 3-39).

3-7-2-2 Small pump irrigation sawah: Afreh's site

Fig. 12 shows the sawah system at Afreh's site (As) (location is shown in Fig. 10 in page 24). A road created by timber trucks which stretches from Adujama into the forest has creating permanent swampy area by partially damming the Dwinyan river near As. Small water pump, 60-100 liter per minute, was used for irrigation using the swamp water. Although the swamp water last up to December, the lifting of the water to about 2m and transporting it to a distance of 30-40m to the sawah, made irrigation efficiency very low. Furthermore, because of very sandy nature of the site and many pit that were filled as can be seen in the Fig.12, water permeability of plowed layer of the sawah was extremely high. Water requirement of the sawahs was higher than 5 cm per day. All these factors made the pump irrigation very poor at this site. One advantage at this site was that many farmers use this road and so it served as good demonstration for the farmers to see. Photo 4-3 shows heterogeneous rice growth at Afreh's site (see chapter 4).

Slopes of the sawah site were 3-5%, (mean 4%). Mean sawah size was $166m^2$ in our trial based on the participated farmers' work. The necessary soil movement for the leveling was $1067m^3$ and for bunding $420m^3$ per ha respectively. Two termite mounds were leveled which claimed soil movement of about $105m^3$ for 0.08ha, i.e. for one ha $1316m^3$. Total soil movement was estimated to about $1645m^3$ (Table 4 page 23), including $158m^3$ of three termite mounds levelling. If we try to remove all termite mounds that existed, a of mean about 10 per ha, additional $1158m^3$ termite soil have to be moved (although this was not necessary) per ha of sawah.

3-7-2-3 Spring water Sawah - Nicolas's site (Ns)

Fig. 13 shows the sawah system at Nicolas's (Ns) site (Fig. 10). Permanent spring source was available which is used by the people fordomestic purposes especially during the dry season. The spring is also for a fishpond owned by the Club-C leader. The spring may partly originate from Adujyama village or township,. The spring flow rate was estimated to be 2-5, (mean 3) liters per second, of which roughly half was used for the fishpond. Remaining 1.5 liter per second was used for the sawah. This amount of water makes about 1.5 ha of sawah irrigation. So far about 0.54ha of sawah was developed by the end of May 2000.

Slopes of the sawah site were 1-4%, (mean 2.5%). Mean sawah size was $276m^2$. Necessary soil movement was $867m^3$ for leveling and $336m^3$ for bunding. Total soil movement was about $1361m^3$ per ha (Table 3), including $158m^3$ of termite mounds levelling. Actually, two termite mounds were removed, which claimed the soil movement about $105m^3$ per 0.35ha, i.e., $300m^3$ per ha. However since it is not necessary to remove all termite mounds, we assumed three termite mounds would be levelled per ha. Although pond is not necessary for maintaining the water in this sawah, Club-C dug out two small ponds, to be used as fisf ponds with soil movement of $400m^3$(Photo. 3-40, 3-41).

3-7-2-4 Sawah with small canal and pump irrigation: Potrikurom site (Ps)

Fig. 14 shows the sawah system at Potrikurom site (Ps) (Fig. 10). Since the catchment area of the site is about 2,500ha, a second order valley, the flow of the central river is usually sustainable from June to November. Water to the sawah was made available through a diversion from the river upstream, and during dry spell dugouts were made in the river course for supplementary pumping. Pumping is also sometimes done directly from the stream when there is flow. Therefore, this sawah never suffers from shortage of water.
Rather, because of the nature of the topography, the extensive lowland and its nearness to the confluence of the two major streams (Fig.2), this sawah do sometimes suffer from flooding about 30-50cm 1-2 weeks during June. If rice plant is short, this flooding could damage the crop. Because of leaching, fertilizer efficiency will be very low. Because of slow flow even at the flooding, the damage of the bunds in the sawah is however negligible.

Slope of this site is about 0.2-1%, (mean 0.6%), and mean size of sawah was 531m2. Necessary soil movement was $287m^3$ for leveling and $267m^3$ for bunding. Although two small ponds os size , 2 x 4 x 1m was necessary, additional soil movement was only $16m^3$ per 0.64ha, i.e., $25m^3$ per ha. Small canal of size 0.6 x 0.6m and 150m long was constructed, with soil movement of about $36m^3$ per 0.64ha, or., $56m^3$ per ha. Total soil movement was therefore about $793m^3$ per ha of the development of the sawah, including $158m^3$ of termite mounds leveling (Table 4) (Photo. 3-42).

3-7-2-5 Dyke and canal irrigation sawah: Biemso No1.

Detail description of this system was described in the previous section. Fig. 15 shows the sawah system at B1s, Biemso No. 1 site which location is seen in Fig. 10. This system offer full irrigation to sawah, which compose dyke, canal and sawah.

The first dyke was construction by 20 farmers within a period of 12 hours in 10 May 1999. The dyke was mad of 60 wooden (locally available hard wood) piles of size 5 x 10cm and 1.5 to 3.5 m in length. These piles were pushed into riverbed up to 1m depth. The four lines of wooden sticks were roughly interconnected by slender and malleable bamboo plate. Central parts of the wooden sticks were fixed to each other using the 3.5m long wooden pile of the same size. The dbase of the was made up of laterite soil from nearby upland. Then 300 pieces of plastic bag containing about 30-40 kg of soil were piled. The spillway was covered with about 300 pieces of 8 x 21 x 42cm cement blocks. Total weight of the soil and cement blocks moved for the dyke was about 40 ton. The first dyke was destroyed during a strong flood during mid June. This was repaired inn August 14 using 150 jute bags by Biemso No. 1 sawah group farmers. On August 22, because of channeling, the dyke could not keep the water. Therefore another repair was done in August 24, using 300 jute bags. Although some leaking through the base was observed, the second repair work was more effective which kept the water allowed irrigation to be undertaken for the sawah up to the end of October. Soil movement for the construction and repair of the dyke amounted to $40m^3$. However to protect the leakage and channeling, original dyke width was expanded to about 1.5m, this increased the soil movement to about $60m^3$.

The 800m canal with the size of 1.5x1.0m and mean depth of 0.8m was constructed. Total soil movement for the construction of the canal was $800m^3$. In the following year the depth of the canal was improved up to a mean depth of about 1 m. Therefore ground total for the canal excavation was $1000m^3$. Slope of this site was 0.1-1%, (mean 0.5%) and mean size of sawah was $444m^2$. Necessary soil movement per ha was $213m^3$ for leveling and $273m^3$ for bunding. Total soil movement was $486m^3$ per ha. Since Biemso No.1 farmers developed 1.2 ha for the first year, actual soil movement was $587m^3$. The measured maximum water intake amount through the canal was about 40 liters per second. If we assume that water loss was about 50%, then the mean possible intake amount will be 20 liter per second. The potential irrigated area will therefore be about 5ha. Based on this potential, total soil movement per ha of the sawah system was $856m^3$, of which the breakdown will be $12m^3$ for dyke construction, $200m^3$ for canal excavation, $213m^3$ for leveling, $273m^3$ for bunding, and the termite mound leveling of $158m^3$ ds, respectively (Table 4). By the end of September 2000, total sawah area developed and cultivated sawah rice was 1.8ha (Photo. 3-43).

3-7-3 Comparative evaluation of various sawah systems tested

Table 2 to 5 summarizesd the various sawah systems tested in this study. Table 3-12 compared the sawah systems and its environmental fearture. The rainfed type of Danyame Valley (Ds), Rice Valley (Rs) and Biemso No.2 (B2s) needed considerably larger work for soil movement because of relatively steep slope of 1-4%. It seems slope difference between Potrikurom (Ps) and Biemso No.1 (B1s) and the Ds and Rs valley is negligible (1-3% to 0.1%). However, for sawah development, the difference was significant as necessary soil movement for the leveling was more than double. If all necessary components are included, such as bunding, pond digging, dyke construction, canal excavation, and the minimum treatment of the termite mounds, the amounts of total soil movement of each system, i.e. Gs, Rs, B2s as, Nicholas site (Ns), Ps and B1s are 1333, 999, 1132, 1132, 1645, 1012, 793 and 856m^3, respectively per ha of sawah system. The cost estimation for the sawah system development based on the soil movement (about 18,000 Cedis, which is equal to 3.0 dollars, per cubic meter on August 2000 at Kumasi) was as follows., i.e., 3999 dollars Gs, 2997 for Rs, 3396 for B2s, 4935 for As, 3036 for Ns, 2379 for Ps, and 2568 dollars for B1s, respectively. This is why the sawah development at Adugyama Rs was smaller in size and the area developed per year was smaller compared to the Potrikurom and Biemso No. 1 site.

Table 3-12 Various Sawah system and its environmental feature

(US$/ha)	Rainfed			Pump type	Spring type	Integrated type	Dyke canal type
	Ds	Rs	B2s	As	Ns	Ps	B1s
Occurrence of valley tpye	Many	Many	Many	Many	Few	Many	Many
Soil fertility	High	Medium	Low	Low	High	High	High
Drought problem	Severe	Severe	Severe	Severe	No	Sometimes	No
Flooding problem	No	No	?	No	Slightly (flush)	Smotimes (standing)	Slightly (standing)
Fuel cost for pump	High	High	High	Very high	Low/medium	Medium to high	Low
Operation of power tiller	Somewhat difficult	Easy but long distance	Easy	Somewhat difficult	Somewhat difficult	Easy	Seasy
Priority to Sustainable sawah development	Medium	Medium	Medium	Low	High	High	High

The drought prone nature of the rain-fed type sawah is another problem, which needs consideration. Even using excavated pond, water availability was small, therefore it was difficult to manage large sawah. Drought problem reduces the major advantage of sawah system, i.e. weed control by flooding water. Therefore, rice plant may suffer from both shortage of water and weed under drought condition. This is another reason why the Gs and Rs site can not be made into a larger sawah. Fuel cost for pumping from pond will be a consideration. Relatively steep slope made the operation of the power tiller somewhat difficult. The relatively long distance from the village to the sites of GS and RS as shown in Fig. 10 is another problem since power tiller and pump have to be carried to the site. Soil fertility is medium to high. Although, these kinds of valley bottoms are extensive (under surveying), their priority for sustainable sawah development will not be so high.

To get the irrigation water for the Afreh's site, 100% operation of pump is necessary. Because of sandy nature of soil, water requirement is very high. This makes fuel cost very high. Apart from the fuel cost, this site has the highest slopes among those tested. Therefore soil movement for the construction of sawah was the highest, 1645m^3 per ha although there was neither excavation of pond nor canal. Also soil fertility was poor. The site has since been abandoned (in year 2000) after three years of cultivation as shown in Table 3.

Nicolas's site is good due to a perennial spring supplying irrigation water. Although, slope is somewhat high and required soil movement is great, water management is the easiest among the sawahs tested and soil fertility is high. Potential area for irrigation will be about 1.5ha, since rice double cropping or ratoon harvest is easy, this kind of site should be surveyed. However the distribution of this kind of permanent spring is rare in the project site, maybe 2-3 sites for the 3500 ha of Dwinyama watershed and 6-10 sites (under surveying) for Biem river watershed, maximum sawah area based on the spring type will be less than 20 ha in the two watershed.

In terms of sawah development, Potrikrom site will be the easiest, since soil movement will be the minimal. Soil fertility is also high. A simple water using canal was enough, to supply irrigation water for the sawah. Supplementary irrigation from small pond is also available. The only problem of this site is flooding, which may continue for more than two weeks. This happened in June, 1998, one year among the four tested in this project. Transplanted young rice plant suffered considerably and fertilizers were flushed away. Since this kind of valley is wide spread in the valley bottom in this area, the priority for the development is very high.

Biemso No.1 system has the full facilities for irrigated sawah construction. Since the slope is minimum, levelling and bunding are the easiest among the sawah tested. The dyke was broken two times in the first year, June and August, 1999, but have been repaired and improved during March and April 2000 by the Biemso No.1 group of farmers, were in participatory manner with Ghanaian counterparts as described August 18, 2000 the newly repaired dyke has been working without any problem. As a result water availability expansion of sawah site was easy, the area of the sawah may reach about 2 ha by the end of August 2000. Since dyke and canal system are new for the farmers, the project has to carry out special on the job training for about one and half years. Once the participant farmers can master the basic eco-technology for the development and maintenance of the system, the expansion will be easier. The distribution of the valley bottom adopted to this system is widespread (under surveying), therefore, the sawah system also has high priority for the watershed development in this area.

Table 5 summarizes the economic parameters of various sawahs tested. Labour man-days for soil movement per ha were 2530, 2370, 1866, 2920, 2040, 1182 and 920 man-days per ha for Gs, Rs, B2s As, Ns, Ps and B1s respectively. These figures can be compared with the total soil movement as shown in Table.2. Since labour cost was about 2 dollars per man-day, estimated cost for the construction of the various sawahs were 5060, 4740, 3737, 5840, 4080, 2264, and 1840 dollars per ha for. Gs, Rs, B2s As, Ns, Ps and B1s, respectively. In addition to these labour cost, the costs of fuel for pump and power tiller for the development were estimated at 48,48, 57, 102, 38, 23 and 46 dollars per ha for Gs, Rs, B2s As, Ns, Ps and B1s respectively. In the case of B1s, materials for dyke construction were purchased. Total cost was about one million cedi, equivalent to 400 dollars for the dyke, which has a capacity to irrigate more than 5 ha. Therefore the cost per ha was 80 dollars. Total costs for the development of the various sawah systems were therefore 5100, 4800, 3800, 5900, 4100, 2400, and 2000 dollars per ha for Gs, Rs, B2s As, Ns, Ps and B1s, respectively.

Table 2 compared the cost estimated for the sawah development in dollars per ha both based on estimated man-day for the development (Masuda, 1999) and on the volume of soil movement. The mean cost including fuel and material was 4570, 3900, 3600, 5470, 3600, 2400, and 2350 dollars per ha for Gs, Rs, B2s As, Ns, Ps and B1s, respectively. If the cost of power tiller and pump are $3500 and $500, respectively, life span of the machines are five years, and the maintenance is 20% of the total machinery cost, then machinery cost per ha of sawah development will be $960. Therefore the grand total will be $5,650, $4,980, $4,680, $6,580, $4,680, $3,480 and $3,430 per ha for Gs, Rs, B2s As, Ns, Ps and B1s, respectively.

Agronomic rice farming practices was summarized in Table 5, too. The breakdown of the various agronomic practices was shown in Table 6. Since the participant farmers were all new in sawah based rice farming, these figures will be reduced. In addition these mandays work for the participant farmer is not real cost. These labor cost are not necessary to pay unless they hired the labor on behalf of their agronomic work.

Among the cost which farmers have to buy, fertilizer cost comes the first, then fuel cost comes the second. Total cost in dollars equivalent per ha was 87 for Ps site, the lowest, and 138 for As site, the highest. Although at the moment we can not estimate the cost of the maintenances for the pump and power tiller, those will be the most expensive. Tentatively we put the double price for each of the running cost. Total running cost can be estimated in the range of 174 to 276 dollars per ha per year.