3 Characterisation of soils

Variability of relief and soils in Leyte is high and both exercise an important influence on plant growth. LANGENBERGER (2003) described relief-dependency of natural vegetation in the research area. This chapter will give an insight in main soil forming processes as caused by climate and relief. Assets and constraints of soils at different sites will be discussed to better understand growth conditions for plants in agroforestry systems.

3.1 Profile descriptions

Samples were collected from soil profiles in 2004 at Cienda site and in 2005 on the paired plots (s. chapter 4, also for land use history). One soil profile per paired plot site was excavated, while on the new Cienda plot three profiles were installed. The nearest meteorological station for long-term data is PAGASA-ViSCA. Soil climate for all profiles is isohyperthermic (mean annual soil temperature ≥ 22°C with seasonal amplitude in 50cm depth ≤ 6°C) and udic (not dry in any part for longer than 90 cumulative days in normal years). All sites are situated in formerly forested areas, which have been used for agriculture during the last decades. None of the sites is still covered by the original vegetation, which was evergreen rainforest.

All analysis were carried out in duplicate in the following laboratories:

pH, bulk density and P_{Bray} were analysed at Dept. of Agriculture and Soil Sciences, Leyte State University;

Texture at Dept. of Soil Sciences, Hohenheim;

C, N, Fe, Mn and Al at Landesanstalt für Landwirtschaftliche Chemie, Hohenheim;

CEC and part of C_{org}/N_T at Dept. of Plant Nutrition and Soil Sciences, University of Halle.

Ecological evaluation followed the procedures and calculations described by JAHN, BLUME & ASIO (2003). These include aggregate stability as estimated on the basis of structure and pH; permeability (K_{sat}) derived from texture and bulk density and erodibility read from a nomograph of texture, organic matter, structure and K_{sat}. Erodibility covers only the soil-related component of erosion. For estimates of erosion (e.g. after Wischmeier), rainfall intensity, soil cover and slope need to be considered. Air capacity was evaluated after AG BODENKUNDE (1982).

3.1.1 Haplic Cambisol, Cienda PN1

PN1, 2 and 3 are on the same site, 1 located on the upper middle slope position, 2 at the lower middle slope and PN3 at the footslope on a natural terrace. Land-use and present vegetation: Coconut, secondary forest, bush fallow. Scarce undergrowth, low creeping grass and ferns, some *Pueraria*.
Weather: Sampling follows a rainy night after 4 weeks dry period.

Profile #	1
Date of description	040427
Location	Cienda, Gabas
Elevation [m asl]	130
Coordinate N	10° 43' 54.6"
Coordinate E	124° 48' 45.2"
Major landform	High-gradient hill
Profile position	Middle slope
Slope form	Slightly concave
Slope gradient [%]	50
Orientation	W
Parent material	Andesitic
Gen. observations	Young colluvial soil

Horizon	Depth [cm]	Tex-ture	Matrix colour	Struc-ture	Voids (n, Ø)	Roots >2mm/dm^2	Boun-dary	Observations[41]
Ah	0-6	CL	10YR 3/2	GR	C-M; M-C	>50	CS	Worm casts, *Cocos* roots
AB	6-12	CL	10YR 3/3	GR	C-M; M-C	>50	GW	*Cocos* roots
Bw1	12-32	CL	10YR 4/3	SB	M; FF	11-20	DI	Mottles (rust), charcoal
Bw2	32-62	C	10YR 4/3	SA	C-(M); F-M	6-10	CI	Charcoal
ICw	62-(100)	C	10YR 5/4	SG	F; V	6-10		Saprolite

41Ah and AB differ mainly in colour, AB and Bv1 in structure, Bv2 and ICv in material and texture.

Horizon	Depth	Rocks	∑ Sand	∑ Silt	Clay	Bulk density
	cm	%	% of fine earth			g/cm^3
Ah	0-6	1	26.9	37.8	35.3	0.72
AB	6-12	2	24.5	36.3	39.2	1.05
Bw1	12-32	3-5	24.7	36.0	39.3	1.11
Bw2	32-62	5	22.2	33.1	44.7	1.17
ICw	62-(100)	5	25.7	28.1	46.2	1.14

Horizon	pH $CaCl_2$	pH KCl	C_{org}	N_T	C/N	$P_{Bray\ II}$	P_{Truog}	CEC	Ca	Mg	K	Na	S	BS
	0.01M	1M	%			mg/kg		$cmol_c$/kg fine earth						%
Ah	5.69	5.14	4.65	0.41	11.4	0.98	15.7	48.66	13.83	6.41	2.55	0.22	23.01	47
AB	5.10	4.50	1.74	0.18	9.8	0.26	-	45.20	10.60	5.49	2.02	0.35	18.46	41
Bw1	4.94	4.24	1.97	0.19	10.2	0.45	6.0	43.68	10.74	5.29	1.40	0.37	17.81	41
Bw2	5.16	4.37	1.50	0.15	9.9	0.18	7.0	45.36	12.40	5.73	0.81	0.49	19.43	43
ICw	5.18	4.09	0.45	0.05	8.4	25.33	37.6	39.69	13.35	4.59	0.16	0.92	19.02	48

Horizon	Fe_o	Fe_d	Al_o	Al_d	Mn_o	Mn_d
	[g/kg]					
Ah	2.85	20.09	1.85	2.01	1.17	1.45
AB	3.05	22.38	2.30	2.55	1.05	1.47
Bw1	3.38	22.66	2.07	2.40	1.16	1.43
Bw2	3.45	21.63	2.06	2.14	1.08	1.31
ICw	1.69	11.76	2.03	1.30	0.67	0.78

Ecological evaluation

Soil depth and rootability:
Mechanical depth: >100cm. Physiological depth: Deep due to the soft bedrock.
Rootability is very good in Ah and AB (low bulk density, few stones, granular structure), good-moderate in B (subangular structure), moderate in Bv (subangular-angular structure) and poor in the cemented C horizon.
Effective rooting space (ERS) 100cm.

Air and water budget [%]	Total pore volume	Air capacity	Av. field capacity	Field capacity
Ah: CL; 8%OM; BD $0.72 g/cm^3$	69	17 (high)	27	52
AB: CL; 3.0%OM; BD $1.05 g/cm^3$	62	16 (high)	24	47
Bw1: CL; 3.4%OM; BD $1.11 g/cm^3$	56	11 (medium)	22	46
Bw2: C; 2.6%OM; BD $1.17 g/cm^3$	61	6 (low)	16	55
ICw: C; 0.78%OM; BD $1.14 g/cm^3$	53	6 (low)	11	47

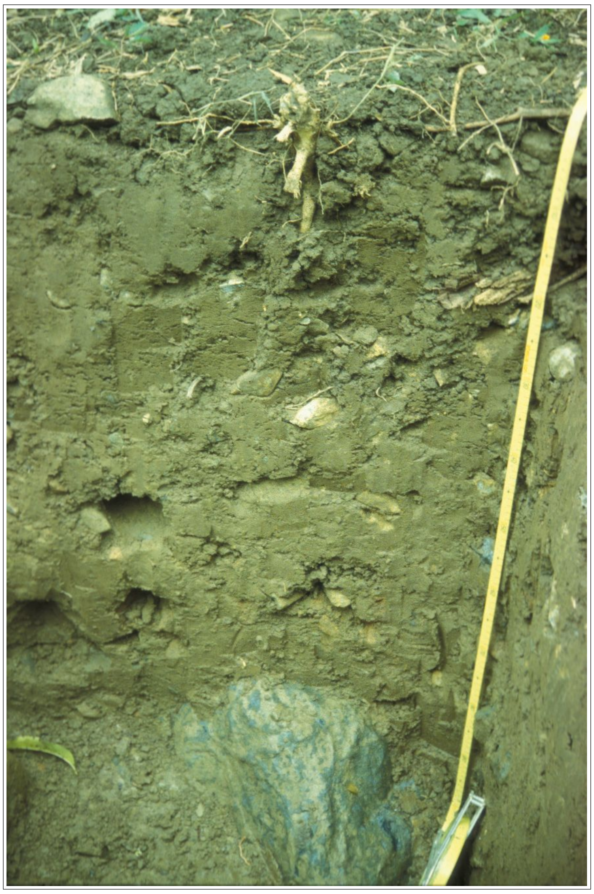
Nutrient status (considering rocks, bulk density, thickness of horizons and effective rooting space):
CEC ($cmol_c$/kg clay) is moderately high for all horizons.
S value: High: 182.,76 mol_c/m^2 ERS
N supply: High: N_T 1.42 kg/m^2 ERS
P supply: Low: 10.62g/m^2 ERS

Erodibility (8% OM; CL; Aggregate stability high; K_{sat} very high): Very low.

3.1.2 Haplic Cambisol, Cienda PN2

PN1, 2 and 3 are on the same site, 1 located on the upper middle slope position, 2 at the lower middle slope and PN3 at the bottom on a natural terrace.
Land-use and present vegetation: Coconut, banana. Relatively open canopy. Pioneers: Low creeping grass, ferns, kudzu. Weather: 90% overcast.

Profile #	2
Date of description	040427
Location	Gabas, Sitio Cienda
Elevation [m asl]	120
Coordinate N	10° 43' 55.3"
Coordinate E	124° 48' 43.7"
Major landform	High-gradient hill
Profile position	Middle slope
Slope form	Slightly concave
Slope gradient [%]	40
Orientation	W
Parent material	Volcanic
General observations	Colluvial



Horizon	Depth [cm]	Tex-ture	Matrix colour	Struc-ture	Voids (n, Ø)	Roots >2mm/dm²	Boun-dary	Observations
Of	1-0	Thin fragmentary litter layer; topsoil with less litter, roots, fauna than PN1.						
Ah	0-5	CL	10YR 3/3	GR	M; F-M	11-20	GS	Charcoal
AB	5-14	CL	10YR 4/3	SB	F-C; F-M	6-10	DS	Few mottles (rust), little charcoal
Bw	14-39	C	10YR 3/4-4/4	AB	F; V	1-5	DW	Little charcoal
BC	39-(100)	C	10YR 4/4	AB	F;V	1-5		Mottles (rust)

Horizon	Depth	Rocks	∑ Sand	∑ Silt	Clay	Bulk density
	cm	%	% of fine earth			g/cm^3
Ah	0-5	5	28.5	33.8	37.7	1.16
AB	5-14	2	27.4	33.7	38.9	1.26
Bw	14-39	10	23.9	29.7	46.4	1.33
BC	39-(100)	50	20.9	28.9	50.2	1.35

Horizon	pH $CaCl_2$	PH KCl	C_{org}	N_T	C/N	$P_{Bray\ II}$	P_{Truog}	CEC	Ca	Mg	K	Na	S	BS
	0.01M	1M	%			mg/kg		cmol$_c$/kg fine earth						%
Ah	5.30	4.89	3.13	0.34	9.2	0.70	4.7	39.27	10.49	5.39	0.5	0.17	16.54	42
AB	5.06	4.54	1.77	0.20	8.8	0.25	4.2	37.90	9.63	4.35	0.32	0.16	14.46	38
B_T	5.07	4.49	0.97	0.12	8.3	0.18	5.3	38.13	10.18	3.93	0.25	0.29	14.65	38
BC	5.14	4.45	0.74	0.09	8.6	0.11	7.7	38.82	10.80	3.90	0.11	0.46	15.27	39

Horizon	Fe_o	Fe_d	Al_o	Al_d	Mn_o	Mn_d
	[g/kg]					
Ah	4.06	29.61	1.55	2.97	1.72	1.54
AB	3.66	33.20	1.66	3.40	1.60	1.79
Bw	2.74	34.20	1.82	3.75	1.36	1.68
BC	2.01	35.78	1.63	3.88	0.94	1.35

Ecological evaluation

Soil depth and rootability:
Mechanical and physiological depth: 100cm.
Rootability: Ah good, AB moderate (due to structure), Bv moderate-poor and BC poor (due to angular-blocky structure and 50% rocks in BC).
Effective rooting space 100cm.

Air and water budget [%]	Total pore volume	Air capacity	Av. field capacity	Field capacity
Ah: CL; 5.4%OM; BD 1.16g/cm^3	63	12 (medium)	25	51
AB: CL; 3.1%OM; BD 1.26g/cm^3	56	11 (medium)	22	46
Bw: C; 1.7%OM; BD 1.33g/cm^3	51	4 (low)	10	48
BC: C; 1.3%OM; BD 1.35g/cm^3	51	4 (low)	10	48

Nutrient status (considering rocks, bulk density, thickness of horizons and effective rooting space):
CEC (cmol$_c$/kg clay) is moderately high for all horizons except BC (moderate).
S value: High: 100.15 mol$_c$/m^2 ERS
N supply: High: N_T 1.11kg/m^2 ERS
P supply: Very low: 0.167g/m^2 ERS

Erodibility (5.4% OM; CL; Aggregate stability moderate; K_{sat} high): Low.

3.1.3 Stagnic Luvisol, Cienda PN3

PN1, 2 and 3 are on the same site, 1 located on the upper middle slope position, 2 at the lower middle slope and PN3 at the bottom on a natural terrace.
Land-use and present vegetation: Open area, approx. 20% canopy cover. Coconut, previously annuals. *Imperata* and ferns in drier, yellow-flowering Asteraceae in wet parts. Crop residues. Weather: 50% overcast, changing.

Profile #	3
Date of description	040427
Location	Gabas, Sitio Cienda
Elevation [m asl]	102
Coordinate N	10° 43' 54.3"
Coordinate E	124° 48' 41.7"
Major landform	High-gradient hill
Profile position	Bottom
Slope form	Terraced
Slope gradient [%]	2
Orientation	W
Parent material	Volcanic

Horizon	Depth [cm]	Tex-ture	Matrix colour	Struc-ture	Voids (n, Ø)	Roots >2mm/dm^2	Boun-dary	Observations
Ah	0-5	C	10YR 3/3-4/3	GR	C-M; F; P	20-50	GS	
AB	5-14	C	10YR 3/ 4	SB	C; FF; P	11-20	GS	
Stagnic B_T1	14-49	HC	10YR 4/4	AB	C-F; FF; P	1-5	DI	Stagnic, Mn concretions
Stagnic B_T2	49-(100)	HC	10YR 4/6	AB	C; FF; P	1-5		Stagnic, 20% Mn, larger than in B_T1

Horizon	Depth	Rocks	∑ Sand	∑ Silt	Clay	Bulk density
	cm	%	% of fine earth			g/cm^3
Ah	0-5	1	21.4	33.0	45.6	0.89
AB	5-14	5	19.7	31.6	48.7	1.04
B_T1	14-49	15	12.2	21.0	66.8	1.19
B_T2	49-(100)	15	10.2	16.7	73.1	1.17

Horizon	pH $CaCl_2$	PH KCl	C_{org}	N_T	C/N	$P_{Bray\ II}$	P_{Truog}	CEC	Ca	Mg	K	Na	S	BS
	0.01M	1M	%			mg/kg		cmol$_c$/kg fine earth						%
Ah	4.52	4.23	3.97	0.34	11.7	0.73	12.0	38.30	5.30	4.76	0.31	0.11	10.47	27
AB	4.28	4.05	2.30	0.22	10.4	0.33	6.8	32.72	4.29	3.45	0.14	0.14	8.03	25
B_T1	4.45	4.13	1.00	0.11	9.4	0.07	3.9	35.58	5.77	2.77	0.04	0.24	8.82	25
B_T2	4.80	4.52	0.51	0.05	9.6	0.03	8.2	37.14	6.74	3.46	0.04	0.26	10.52	28

Horizon	Fe_o	Fe_d	Al_o	Al_d	Mn_o	Mn_d
	[g/kg]					
Ah	3.38	49.46	2.20	6.54	2.44	2.97
AB	3.69	50.30	2.07	6.50	2.47	2.98
B_T1	2.18	58.25	1.85	7.67	2.08	3.65
B_T2	1.35	68.93	1.53	8.29	1.30	2.40

Ecological evaluation

Soil depth and rootability:
Mechanical and physiological depth: Deep (100cm).
Rootability: Ah good (low bulk density, granular structure), AB good-moderate (subangular structure), B_T1, B_T2 moderate-poor (high clay contents, bulk density, stagnic). Presence of very few trees in this part of the plot may indicate problems for deep-rooting plants.
Effective rooting space (ERS): 100cm.

Air and water budget [%]	Total pore volume	Air capacity	Av. field capacity	Field capacity
Ah: C; 6.8%OM; BD 0.89g/cm^3	73	10 (medium)	25	63
AB: C; 4.0%OM; BD 1.04g/cm^3	73	10 (medium)	22	63
B_T1: HC; 1.7%OM; BD 1.19g/cm^3	57	6 (low)	13	51
B_T2: HC; 0.9%OM; BD 1.17g/cm^3	53	6 (low)	11	47

Nutrient status (considering rocks, bulk density, thickness of horizons and effective rooting space):
CEC (cmol$_c$/kg clay) is moderately high for all horizons.
S value: High: 83.89 mol$_c$/m^2 ERS
N supply: High: N_T 0.99kg/m^2 ERS
P supply: Very low: 0.105g/m^2 ERS

Erodibility (6.8% OM; C; Aggregate stability moderate; K_{sat} high): Very low.

3.1.4 Dystric[42] *Nitisol,* Cienda *(Rainforestation demo plot)*

Land-use and present vegetation: Rainforestation, densely (2 x 1m) planted in 1994, average height of trees 2004 approximately 8m. Scarce undergrowth: Poaceae in openings; pineapple. Plot size 1ha.
Reference plot: Grass and *Pueraria* 40cm, bush 1m, coconut 8x8m.
Weather: Overcast, no rain.

Profile #	4
Date of description	040512
Location	Gabas, Sitio Cienda
Elevation [m asl]	80
Coordinate N	10° 43' 41.7"
Coordinate E	124° 48' 38.6"
Major landform	High-gradient hill
Profile position	Lower part of Plateau
Slope form	-
Slope gradient [%]	3-5
Orientation	-
Parent material	Volcanic

Horizon	Depth [cm]	Tex-ture	Matrix colour	Struc-ture	Voids (n, Ø)	Roots >2mm/dm^2	Boun-dary	Observations
Ah	0-8	HC	7.5YR3/3	GR-SB	M; FF	11-20	D, S	
AB	8-27	HC	7.5YR3/4	SB	M; V	6-10	D, S	
Bw	27-73	HC	7.5YR4/4	SA	M; V	6-10	D, S	Mn concretions
B_T	73-(100)	HC	7.5YR4/4	SA	M; V	1-5		Mn concretions (Ø > in Bw)

Horizon	Depth	Rocks	∑ Sand	∑ Silt	Clay	Bulk density
	cm	%	% of fine earth			g/cm^3
Ah	0-8	-	12.0	23.8	64.2	0.98
AB	8-27	-	9.4	21.0	69.5	1.15
Bw	27-73	-	7.2	24.6	68.2	1.11
B_T	73-(100)	-	5.6	14.2	80.2	1.05

42 Formally, this soil would match the category hyperdystric, as BS < 50% between 20-100cm and <20% in some parts of the profile.

Horizon	pH $CaCl_2$	pH KCl	C_{org}	N_T	C/N	$P_{Bray II}$	P_{Truog}	CEC	Ca	Mg	K	Na	Al	S	Al-S[43]	BS
	0.01M	1M	%			mg/kg		cmol$_c$/kg fine earth							%	
Ah	4.33	4.20	2.77	0.27	10.2	1.44	9.8	32.25	3.40	3.42	0.17	0.10	0.52	7.09	7	22
AB	4.03	3.90	1.53	0.16	9.8	0.17	11.5	28.12	1.43	1.32	0.03	0.09	1.56	2.87	39	10
Bw	4.08	3.85	0.85	0.09	9.0	0.18	-	35.45	1.81	1.26	0.02	0.13	1.89	3.22	37	9
B_T	4.04	3.84	0.67	0.07	9.1	0.18	4.4	31.22	1.56	1.20	0.04	0.14	2.11	2.94	42	9

Horizon	Fe_o	Fe_d	Al_o	Al_d	Mn_o	Mn_d
	[g/kg]					
Ah	3.60	49.49	2.12	6.98	2.64	2.56
AB	2.86	50.95	1.88	6.87	2.41	2.83
Bw	1.54	51.15	1.76	6.93	1.27	1.94
B_T	1.06	50.04	1.78	6.68	0.88	1.41

Ecological evaluation

Soil depth and rootability:
Mechanical and physiological depth: Deep (100cm).
Rootability: Due to low pH and high Al-saturation, high clay contents and blocky structure restricted below Ah.
Effective rooting space (ERS): 100cm.

Air and water budget [%]	Total pore volume	Air capacity	Av. field capacity	Field capacity
Ah: HC; 4.8%OM; BD 0.98g/cm^3	73	10 (medium)	25	63
AB: HC; 2.6%OM; BD 1.15g/cm^3	61	6 (low)	16	55
Bw: HC; 1.5%OM; BD 1.11g/cm^3	57	6(low)	13	51
B_T: HC; 1.2%OM; BD 1.05g/cm^3	63	9 (medium)	16	54

Nutrient status (considering rocks, bulk density, thickness of horizons and effective rooting space):
CEC (cmol$_c$/kg clay) is moderately high for all horizons.
S value: Moderate: 33.88 mol$_c$/m^2 ERS
N supply: High: N_T 1.25kg/m^2 ERS
P supply: Very low: 0.292g/m^2 ERS

Erodibility (4.8% OM; HC; Aggregate stability moderate; K_{sat} high): Very low.

43 Al^{3+} saturation as percentage of (S-value + Al)

3.1.5 Chromic *Cambisol, LSU*

Land-use and present vegetation: Rainforestation, 15-20m height. Plot size approx. 2ha.
Reference plots:
a.) Adjacent, but less steep plot recently planted to abaca, yams and sweet potato. Well maintained, bare soil, where not covered by sweet potato.
b.) Pasture (grass 40cm, ferns, kudzú) in approx. 70m distance, same exposition and slope.
Weather: Overcast, 30h after long heavy rain, 12h after less intense rainfall.

Profile #	5
Date of description	050318
Location	LSU
Elevation [m asl]	Approx. 120
Coordinate N	10° 44' 50.2"
Coordinate E	124° 48' 14.8"
Major landform	High-gradient hill
Profile position	Middle slope, 80m below ridge
Slope form	Slightly convex
Slope gradient [%]	70
Orientation	SW
Parent material	Volcanic
General observations	Strong erosion in parts of the site (not sampled), observable from stones on top-soil and horizonation of auger cores.

Horizon	**Depth [cm]**	**Texture**	**Matrix colour**	**Structure**	**Roots >2mm/dm²**	**Boundary**	**Observations**
Of	3-0	Litter layer varying from 2-10cm thickness					
Ah	0-3	CL	7.5YR 3/3	GR	2	G, S	
AB	3-15	CL	7.5YR 4/4	GR- SB	15-20	G, W	5% rust
Chromic B_T	15-60	CL	7.5YR 4/6	SG- SB	1-2	G, S	Pseudo sand
C	60-(100)	SCL	10YR 5/3 (70%), 7.5YR 4/6 (30%)	SB	1		

Horizon	Depth	Rocks	∑ Sand	∑ Silt	Clay	Bulk density
	cm	%	% of fine earth			g/cm^3
Ah	0-3	< 5	31.9	36.9	31.2	0.95
AB	3-15	5	25.6	35.7	38.7	1.00
B_T	15-60	7	30.5	30.6	38.9	0.94
C	60-(100)	80	51.0	25.7	23.3	0.94

Horizon	pH $CaCl_2$	C_{org}	N_T	C/N	$P_{Bray\ II}$	CEC	Ca	Mg	K	Na	S	BS
	0.01M	%			mg/kg	$cmol_c$/kg fine earth						%
Ah	5.95	2.42	0.23	10.5	1.98	41.83	18.64	8.53	0.69	0.45	28.31	68
AB	4.65	1.24	0.13	9.6	0.41	39.89	9.74	8.25	0.11	0.38	18.49	46
B_T	4.85	0.69	0.07	9.6	0.18	42.05	7.74	9.97	0.07	0.34	18.12	43
C	4.70	0.31	0.03	9.0	0.89	51.61	11.90	16.83	0.07	0.35	29.14	56

Ecological evaluation

Soil depth and rootability:
Mechanical depth: 100cm, physiological depth 60cm due to (even though soft) rock contents in the C horizon.
Effective rooting space (ERS): 60cm.

Air and water budget [%]	Total pore volume	Air capacity	Av. field capacity	Field capacity
Ah: CL; 4.2%OM; BD 0.95g/cm^3	69	17 (high)	27	52
AB: CL; 2.1%OM; BD 1.00g/cm^3	62	16 (high)	24	47
B_T: CL; 1.2%OM; BD 0.94g/cm^3	59	15 (high)	23	45
C: SCL; 0.5%OM; BD 0.94g/cm^3	56	11 (medium)	24	45

Nutrient status (considering rocks, bulk density, thickness of horizons and effective rooting space):
CEC ($cmol_c$/kg clay) is high in Ah, moderately high in AB, B_T and moderate in the C horizon.
S value: mol_c/m^2 for ERS is 105.06 $cmol/m^2$ (high) assuming an effective rooting space of 60cm.
N supply: Moderately high: N_T 0.52kg/m^2 ERS
P supply: Very low: 0.17g/m^2 ERS

Erodibility (4.2% OM; CL; Aggregate stability moderate; K_{sat} very high): Low.

3.1.5.1 Ferri-stagnic Luvisol, Marcos

Land-use and present vegetation: Rainforestation, height 15m, few coconut. Undergrowth pineapple, some creeping grasses, 20cm. Plot size 0.3ha. Reference plots:
a.) Short grass 10cm, plot used for annuals and/or as pasture, probably burnt in previous years, stones outcropping.
b.) Gmelina plot of same size and age as rainforestation, height 20m, undergrowth 70-100cm, dominated by fern. Topsoil notably darker and wetter than under rainforestation.

Profile #	6
Date of description	050225
Location	Marcos
Elevation [m asl]	30
Coordinate N	10° 45' 55.3"
Coordinate E	124° 47' 26.0"
Major landform	High-gradient hill
Profile position	Middle slope
Slope form	Straight
Slope gradient [%]	60
Orientation	W
Parent material	Andesitic
General observations	Aquiferous horizons, spring/well nearby.

Horizon	Depth [cm]	Texture	Matrix colour	Structure	Roots >2mm/dm^2	Boundary	Observations
Of	2-0	Scarce, no cover. Very dry soil between pineapples.					
Ah	0-4	C	10YR 4/3	SB	80	GS	
Sw[44]	4-15	C	10YR 4/3	GR	50	GS	Cracks, Mn concretions <1mm, lateral water-flow
Ferric B_T-Sw	15-40	HC	10YR 5/6	SB	5-10	DW	20% rust, 10% Mn concretions, illuvial, hydromorphic
Stagnic Bw	40-65	CL	10YR 5/4	SG+MA	1	DW	Sandy andesitic material, 10% rust, 5% Mn concretions

44 Sw is used in the German classification for stagnic horizons, when stagnic properties are caused by infiltration or lateral flow, but not groundwater (gleyic properties).

Stagnic C	65-(100)	L	10YR 5/3	SG+MA	1		Strongly weathered, Mn <1mm

Horizon	Depth	Rocks	∑ Sand	∑ Silt	Clay	Bulk density
	cm	%	% of fine earth			g/cm^3
Ah	0-4	-	14.5	31.1	54.4	0.93
Sw	4-15	-	14.6	28.8	56.7	0.98
B_T - Sw	15-40	-	6.2	21.7	72.1	0.88
Bw	40-65	10	26.6	34.0	39.5	0.90
C	65-(100)	-	49.9	35.8	14.4	0.97

Horizon	pH $CaCl_2$	C_{org}	N_T	C/N	$P_{Bray II}$	CEC	Ca	Mg	K	Na	S	BS
	0.01M	%			mg/kg	$cmol_c$/kg fine earth						%
Ah	5.55	3.50	0.34	10.2	3.10	56.61	33.08	5.72	0.24	0.53	39.56	70
Sw	5.20	1.68	0.16	10.6	0.47	50.44	28.16	5.16	0.14	0.42	33.88	67
B_T - Sw	5.40	1.07	0.12	9.2	0.61	54.78	38.70	6.28	0.26	0.63	45.87	84
Bw	5.75	0.40	0.05	8.1	0.95	54.90	35.74	4.76	0.08	0.78	41.37	75
C	6.30	0.05	0.01	6.1	0.73[45]	33.65	22.05	2.45	0.05	0.54	25.09	75

Ecological evaluation

Soil depth and rootability:
Mechanical and physiological depth: 65cm, soft (andesitic) rock or cemented material in C horizon. Restricted rootability below B_T horizon because of lateral water flow and heavy texture (air budget).
Effective rooting space (ERS): 65cm.

Air and water budget [%]	Total pore volume	Air capacity	Av. field capacity	Field capacity
Ah: C; 6.0%OM; BD 0.93g/cm^3	73	10 (medium)	25	63
Sw: C; 2.9%OM; BD 0.98g/cm^3	67	9 (medium)	19	58
B_T-Sw: HC; 1.8%OM; BD 0.88g/cm^3	63	9 (medium)	16	54
Bw: CL; 0.7%OM; BD 0.90g/cm^3	56	14 (high)	22	42
C: L; 0.1%OM; BD 0.97g/cm^3	55	19 (v. high)	24	35

Nutrient status (considering rocks, bulk density, thickness of horizons and effective rooting space):
CEC ($cmol_c$/kg clay) is high throughout all horizons except C (moderate).
S value is 260.85 cmol/m^2 and thus very high, even when assuming an effective rooting space of only 65cm.
N supply: Moderately high: N_T 0.68kg/m^2 ERS
P supply: Very low: 0.491g/m^2 ERS, but moderate: 113.75g/m^2 ERS, if C is included to ERS.

Erodibility (6.0% OM; C; Aggregate stability moderate; K_{sat} intermediate): Very low.

45Additional samples (all in duplicate) nearby from the same depth gave 334.34mg/kg, 358.84mg/kg, 0.80mg/kg and 20.83mg/kg, respectively.

3.1.6 Ferri-chromic Luvisol, Pangasugan

Land-use and present vegetation: Rainforestation, height approx. 15m, mostly native species. Plot size 0.6ha.
Reference plot: Short-grass (10cm) pasture with single shrubs.
Weather: 25% clouds, no rain for > 48h.

Profile #	7
Date of description	050311
Location	Pangasugan
Elevation [m asl]	20
Coordinate N	10°45' 15.4"
Coordinate E	124° 47' 35.5"
Major landform	Medium-gradient hill
Profile position	Middle slope
Slope form	Straight
Slope gradient [%]	40
Orientation	WSW
Parent material (below 160cm)	Volcanic ashes and eroded material
General observations	Some horizons with 20% cutanic or redoximorphic features (MCP) on peds. Ah, AB formed by erosion (stone contents > than horizons below). Aquiferous horizons, spring nearby.

Horizon	**Depth [cm]**	**Texture**	**Matrix colour**	**Structure**	**Roots >2mm/dm²**	**Boundary**	**Observations**
Of	2-0	Leaf cover composed of native species.					
M1[46]	0-3	C	7.5YR 4/3	GR	>10	GS	Termites, ants. Boulders. Colluvial origin.
M2	3-30	HC	7.5YR 3/3	SB	7-10	CW	
Ferric, chromic Bts1	30-50	HC	5YR 4/6	AB	2	D	Few Mn concretions; strong red mottles. 20% of aggregates with greyish cover.
Ferric, chromic Bts2	50-(100)	HC	5YR 5/8	AB	1		

46 From the German classification: Colluvial mineral soil with organic matter contents similar to those of an Ah.

Horizon	Depth	Rocks	∑ Sand	∑ Silt	Clay	Bulk density
	cm	%	% of fine earth			g/cm^3
M1	0-3	10	16.6	28.7	54.7	0.73
M2	3-30	20	13.1	25.4	61.5	1.04
Bts1	30-50	-	7.1	19.1	73.8	0.96
Bts2	50-(100)	-	5.3	18.4	76.2	0.95

Horizon	pH $CaCl_2$	C_{org}	N_T	C/N	$P_{Bray\ II}$	CEC	Ca	Mg	K	Na	S	BS
	0.01M	%			mg/kg	$cmol_c$/kg fine earth						%
M1	5.35	3.26	0.28	11.7	1.40	35.76	7.86	7.79	0.45	0.62	16.72	47
M2	4.70	1.28	0.12	10.4	0.17	29.35	5.11	6.61	0.06	0.46	12.24	42
Bts1	4.30	0.87	0.09	9.4	0.20	28.56	3.82	4.65	0.05	0.29	8.81	31
Bts2	4.25	0.64	0.07	9.1	0.07	27.92	2.87	4.56	0.04	0.20	7.67	27

Ecological evaluation

Soil depth and rootability:
Mechanical depth: 100cm, physiological depth only to a limited extent below 30cm because of pH gradient and abrupt textural / structural change.
Still, effective rooting space was assumed 100cm.

Air and water budget [%]	Total pore volume	Air capacity	Av. field capacity	Field capacity
M1: C; 5.6%OM; BD $0.73g/cm^3$	73	10 (medium)	25	63
M2: HC; 2.2%OM; BD $1.04g/cm^3$	67	9 (medium)	19	58
Bts1: HC; 1.5%OM; BD $0.96g/cm^3$	63	9 (medium)	16	54
Bts2: HC; 1.1%OM; BD $0.95g/cm^3$	63	9 (medium)	16	54

Nutrient status (considering rocks, bulk density, thickness of horizons and effective rooting space):
CEC ($cmol_c$/kg clay) is moderate in all horizons.
S value is high (86.92 $cmol_c$ /m^2) for the entire to 100cm depth and moderate for the upper 3 horizons (48.57 $cmol_c$ /m^2) as ERS.
N supply: Moderately high: N_T 0.84kg/m^2 ERS
P supply: Very low: 0.139g/m^2 ERS

Erodibility (5.6% OM; C; Aggregate stability moderate; K_{sat} high): Very low.

3.1.7 Hypereutric Cambisol, stagnic properties, Maitum

Land-use and present vegetation: Rainforestation area naturally terraced by *Gmelina*. Plot size 0.5ha.
Reference plot: Pasture under common use; eroded, short grass 10cm, stone outcrops.
Weather: Rain during previous night.

Profile #	8
Date of description	050322
Location	Maitum
Elevation [m asl]	60
Coordinate N	10° 37' 23.5"
Coordinate E	124° 46' 23.8"
Major landform	Medium- to high-gradient hill
Profile position	Lower middle slope
Slope form	Concave
Slope gradient [%]	15-70 (25 at profile)
Orientation	NW
Parent material	Volcanic

Horizon	**Depth [cm]**	**Texture**	**Matrix colour**	**Structure**	**Roots >2mm/dm^2**	**Boundary**	**Observations**
Of	4-0	Thick *Gmelina* litter layer (up to 10cm).					
Ah	0-1	C	7.5YR 3/2	GR	n.d.	GS	
AB	1-15	C	7.5YR 3/2	SA	20	AB	10% orange
Stagnic Sw1[47]	15-60	C	s. observations	AB-MA	5	AB	50% grey, 35% orange, 15% stone
Sw2	60-(80)	HC (est.)	s. observations	AB-MA	n.d.		55% orange, 20% grey, 20% stone, 5% black

Explanations on colours:
'orange' = 10YR 6/8, sandy, weathered parent material with iron oxides
'grey' = 2.5Y 4/2, HC
'black' = illuvial humic substances, HC
'stone' = 10YR 8/2, weathered parent material, friable, no reaction with 10% HCl.

47 Sw is used in the German classification for stagnic horizons, when stagnic properties are caused by infiltration or lateral flow, but not groundwater (gleyic properties).

Horizon	Depth	Rocks	∑ Sand	∑ Silt	Clay	Bulk density
	cm	%	% of fine earth			g/cm^3
Ah	0-1	2	19.0	35.8	45.2	n.d.
AB	1-15	< 5	13.3	36.4	50.4	1.00
Sw1	15-60	15	24.3	31.8	43.9	0.98
Sw2	60-(80)	20	n.d.	n.d.	n.d.	n.d.

Horizon	pH $CaCl_2$	C_{org}	N_T	C/N	$P_{Bray\ II}$	CEC	Ca	Mg	K	Na	S	BS
	0.01M	%			mg/kg	$cmol_c$/kg fine earth						%
Ah	6.15	3.94	0.30	13.3	65.40	59.48	37.68	9.43	0.84	0.40	48.34	81
AB	5.60	1.78	0.13	13.8	7.98	53.44	33.63	9.12	0.20	0.44	43.39	81
Sw1	6.75	0.20	0.02	12.8	4.04	66.84	48.27	10.60	0.13	1.31	60.30	90

Ecological evaluation

Soil depth and rootability:
Mechanical and physiological depth 60cm. Rootability impeded by clayey and cemented material below 15cm.
Effective rooting space (ERS): 60cm.

Air and water budget [%]	Total pore volume	Air capacity	Av. field capacity	Field capacity
Ah: C; 6.8%OM; BD approx. $1g/cm^3$	73	10 (medium)	25	63
AB: C; 3.1%OM; BD $1.00g/cm^3$	67	9 (medium)	19	58
Sw1: C; 0.3%OM; BD $0.98g/cm^3$	59	9 (medium)	14	50

Nutrient status (considering rocks, bulk density, thickness of horizons and effective rooting space):
CEC ($cmol_c$/kg clay) is high in all horizons.
S value: Very high (293.7 $cmol_c$ / m^2 for 60cm ERS)
N supply: Moderate: N_T $0.26kg/m^2$ ERS
P supply: Very low: $3.207g/m^2$ ERS

Erodibility (6.8% OM; C; Aggregate stability high; K_{sat} intermediate): Low.

3.1.8 Stagnic Cambisol, Patag

Land-use and present vegetation: Rainforestation 10-15m height, sparse undergrowth. Plot size 1ha.
Reference plots:
Neighbouring *Gmelina* plot, 20m height, with some native species planted later and dense fern undergrowth.
Low grass, bush fallow, bare soil. Cleared 1-2 years ago for construction of transmission line.

Profile #	9
Date of description	050418
Location	Patag
Elevation [m asl]	40
Coordinate N	10°44' 10.5''
Coordinate E	124° 48' 15.5''
Major landform	High-gradient hill
Profile position	Middle slope
Slope form	Straight
Slope gradient [%]	75
Orientation	WNW
Parent material	Volcanic
General observations	Erosion visible on the surface; Ah eroded, profile truncated and new material deposited.

Horizon	**Depth [cm]**	**Tex-ture**	**Matrix colour**	**Struc-ture**	**Voids (n, Ø)**	**Roots > 2mm/dm²**	**Boundary**	**Observations**
Of	1-0	Thin fragmentary litter layer composed mainly of dipterocarp leaves.						
AB1	0-17	SiC	7.5YR 3/4	GR- SB	M; V	5	DS	Structure smeary under pressure. Grey eroded stones.
AB2	17-35	SiC	10YR 4/4	SB	M; F	2	DS	Grey eroded material.
Bw	35-70	C	10YR 4/6	SA	C; F	2	CW	Weathered material, outsides rusty. Mn concretions.
Bw	70-(100)	C	10YR 5/6	SB	F; nd	1		5% rust, Mn concretions <1mm.

Horizon	Depth	Rocks	∑ Sand	∑ Silt	Clay	Bulk density
	cm	%	% of fine earth			g/cm^3
AB1	0-17	<5	15.4	42.0	42.7	1.07
AB2	17-35	5	17.0	42.4	40.5	1.14
Bw	35-70	15	19.0	35.1	46.0	1.09
Bw	70-(100)	<5	12.2	38.5	49.3	0.98

Horizon	pH $CaCl_2$	C_{org}	N_T	C/N	$P_{Bray\ II}$	CEC	Ca	Mg	K	Na	S	BS
	0.01M	%			mg/kg	$cmol_c$/kg fine earth						%
AB1	4.43	1.53	0.14	10.9	0.36	37.07	10.01	7.33	0.07	0.30	17.72	48
AB2	5.20	0.93	0.10	9.7	0.30	41.44	13.53	8.45	0.05	0.31	22.34	54
Bw	5.61	0.52	0.06	8.4	0.15	45.53	18.94	9.33	0.05	0.46	28.78	63
Bw	4.94	0.44	0.05	8.4	0.29	47.98	21.38	10.68	0.05	0.65	32.76	68

Ecological evaluation

Soil depth and rootability:
Mechanical and physiological depth: 100cm. Rootability poor in stagnic horizons.
Effective rooting space (ERS): 100cm.

Air and water budget [%]	Total pore volume	Air capacity	Av. field capacity	Field capacity
AB1: SIC; 2.6%OM; BD $1.07g/cm^3$	66	8 (medium)	25	57
AB2: SiC; 1.6%OM; BD $1.14g/cm^3$	54	5 (low)	19	50
Bw: C; 0.9%OM; BD $1.09g/cm^3$	59	9 (medium)	14	50
Bw: C; 0.8%OM; BD $0.98g/cm^3$	59	9 (medium)	14	50

Nutrient status (considering rocks, bulk density, thickness of horizons and effective rooting space):
CEC ($cmol_c$/kg clay) is moderate from Ab to B_T and high in Bv.
S value amounts to 247.09 $cmol_c$ / m^2 for 100cm ERS (very high).
N supply: Moderate: N_T $0.78kg/m^2$ ERS
P supply: Very low: $0.249g/m^2$ ERS

Erodibility (2.6% OM; SiC; aggregate stability moderate; K_{sat} high): Low.

3.1.8.1 Calcari-Mollic Leptosol, Punta

Land-use and present vegetation: Rainforestation mixed with *Swietenia sp.* and *Gmelina sp*., 10-15 (20)m high. Plot size 5.4ha, sampled portion mainly consisting of native species. No undergrowth.
Reference plot: Reference 20m upslope, above a fertile plateau; not under agricultural use. *Cocos*, *Imperata* and ferns 30-40cm high. Has been burnt in the past.
Weather: Overcast and rainy after 3 dry weeks (soil extremely dry).

Profile #	10
Date of description	050524
Location	Punta
Elevation [m asl]	Approx. 80
Coordinate N	10° 37' 47.5"
Coordinate E	124° 46' 58.9"
Major landform	High-gradient hill
Profile position	Footslope-middle slope
Slope form	Concave
Slope gradient [%]	50 (upper part - 150)
Orientation	WNW
Parent material	Coralline limestone
General observations	Entire slope formed by landslide

Horizon	**Depth [cm]**	**Tex-ture**	**Matrix colour**	**Struc-ture**	**Voids (#, size)**	**Roots >2mm/dm^2**	**Boun-dary**	**Observations**
Of	2-0	Slowly decomposable litter of native species (in contrast to exotics farther downhill).						
Ap	0-6	HC	10YR4/2	GR, crusted	M; F	11-20	GS	Ants; channels by soil fauna at surface. Stones < in Ap.
Ap	6-20	HC	10YR4/2	GR, crusted	M; F	6-10	CS	Termites. Less and smaller stones than in Bv.
Bw	20-38	HC	s. below[1]		M; F	3-5	GW	Some stones covered with rust.
BC	38-47	HC	s. below[2]		C; V	1-2	AI	
C	47-(60)		10YR8/3	MA		-		

[1] Colour and structure: Matrix (45%) 10YR5/3, GR-SB; 35% 10YR7/6, GR cemented calcareous boulders; 20% 10YR3/2 AB, illuvial clay.
[2] Colour and structure: Matrix 10YR7/6 (70%); 20%10YR5/3; 10% 10YR3/2.

Horizon	Depth	Rocks	∑ Sand	∑ Silt	Clay	Bulk density
	cm	%	% of fine earth			g/cm^3
Ap	0-6	5	5.0	11.1	83.9	0.94
Ap	6-20	20	4.3	9.9	85.7	1.03
Bw	20-38	35	3.8	11.8	84.5	0.94
BC	38-47	40	2.6	16.9	80.5	n.d.
C	47-(60)	100	n.d.	n.d.	n.d.	n.d.

Hor.	pH $CaCl_2$	N_T	C_T	C_{org}	C_{carb}	X_{CO3}	$P_{Bray\ II}$	CEC	Ca	Mg	K	Na	S	BS
	0.01M	%					mg/kg	$cmol_c/kg$ fine earth						%
Ap	7.35	0.41	7.73	4.65	3.08	25.61	7.74	75.80	69.36	3.93	0.48	0.20	73.97	98
Ap	7.48	0.19	6.08	1.91	4.17	34.73	0.98	65.42	67.28	1.32	0.11	0.12	68.84	100
Bw	7.44	0.16	5.35	1.10	4.20	35.01	0.60	71.18	68.23	0.64	0.09	0.09	69.05	97
BC	7.49	0.09	7.67	1.14	6.53	54.36	0.81	36.69	45.16	0.36	0.04	0.05	45.62	100

Ecological evaluation

Soil depth and rootability:
Mechanical and physiological depth are 47cm. Rootability below 38cm strongly restricted by cemented material. Thus, effective rooting space was assumed to be only 38cm.

Air and water budget [%]	Total pore volume	Air capacity	Av. field capacity	Field capacity
Ap: HC; 8.0%OM; BD $0.94g/cm^3$	76	10 (medium)	28	66
Ap: HC; 3.3%OM; BD $1.03g/cm^3$	67	9 (medium)	19	58
Bw: HC; 1.9%OM; BD $0.94g/cm^3$	65	9 (medium)	18	56
BC: HC; 2.0%OM; BD ≈$1g/cm^3$	65	9 (medium)	18	56

Nutrient status (considering rocks, bulk density, thickness of horizons and effective rooting space):
CEC ($cmol_c$/kg clay) is high from Ah to Bv and moderate in BC.
S value over an ERS of 38cm is 200.05 $cmol_c$ / m^2, for 47cm ERS would be 224.69 $cmol_c$ / m^2 (both very high).
N supply: Moderately high: N_T 0.61kg/m^2 for 38cm ERS
P supply: Very low: 0.593g/m^2 for 38cm ERS

Erodibility (8.0% OM; HC; aggregate stability high; K_{sat} very high): Very low.

3.2 Synopsis and Discussion Soil Profiles

Profiles presented in the previous section will be discussed in the light of their parent material, soil forming processes and topography. Magnitudes of values for soil parameters will be compared to ranges given by other authors and methods will be discussed.

3.2.1 Parent Material

Leyte forest soils can be divided into two major groups with respect to parent material. These are volcanic rocks and calcareous sediments. Among the presented, only the Punta Leptosol developed on calcareous material, namely coralline / marly limestone. In the Maitum Cambisol, calcareous and igneous rocks coexist, possibly due to the influence of volcanic ashes as has been hypothesised for some Punta soils by Asio et al. (2006). Soils at all other sites were formed from basaltic volcanic rock, mainly Andesites and Saprolite.

In the landscape, calcareous terrain often appears more gentle than the rugged volcanic mountains. On the plot, outcrops can provide information on the parent material. Greyish, white and dark brown colours dominate the profile wall, while the volcanic soils tend towards yellow and reddish colours. Punta profile is shallow and its B horizon cemented showing massive structure. Texture is heavy clay (>80%) throughout the profile, in contrast to most volcanic soils, which have at least loamy topsoils. Organic matter contents do not differ significantly between Punta and any of the volcanic soils, nor do pore volumes. Bulk density is 0.94 to 1.03g cm^{-3}, which is less dense than what Asio et al. (2006) found for Punta limestone soils (1.25-1.51g cm^{-3}).

The most conspicuous chemical criterion to differentiate calcareous from volcanic soils is pH (fig. 30), which leads to a strongly acidic (red lines), a moderately acidic (yellow lines) group, Maitum and Punta categories.

For volcanic soils in Leyte, Zikeli (1998) measured pH-values between 4 and 5 which generally increased in C horizons. This was confirmed for all profiles with a C horizon within 100cm depth.

Maitum is a transition zone where coralline limestone, andesite and tuff have been superimposed as well as mixed. The lowest accessible layer in the Cambisol is volcanic material, but pH in the solum is clearly higher than for any volcanic soil. So are basic cations and CEC (see fig.33). This may be due to limestone or dissolved secondary lime. Strong differences in the profile with respect to texture occur mainly in the sand fraction. Clay contents are similar to a colluvial volcanic profile.

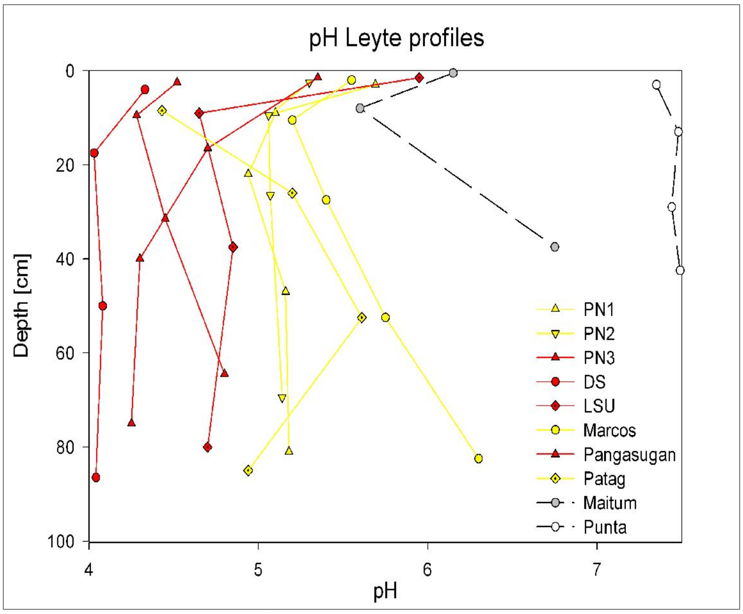


Figure 30: pH of profiles in Leyte

3.2.2 Formation of volcanic soils

Loss of bases, acidification and formation of Fe-oxides have been described as principal drivers for soil genesis on volcanic bedrock in Leyte (Asio 1996, Jahn & Asio 1998). Consequently, older and more weathered soils will be more acidic than young undeveloped stages. On the other hand, landslides as a natural phenomenon have always disturbed *in situ* soil development through truncation of upslope profiles or burying at the footslopes.
The studied volcanic soils can be categorised into two groups:
Yellowish soils of 10YR hue (Munsell soil colour charts), which are of colluvial nature and still in an early phase of development. Goethite is the predominant form of iron responsible for the yellow colour. Haplic Cambisol PN1, Haplic Cambisol PN2, Ferri-Stagnic Luvisol Marcos and the Stagnic Cambisol in Patag form part of this group.
Reddish (7.5 and 5YR) colours in soils are characteristic for hematite as dominant form of iron. The Stagnic Luvisol and Dystric Nitisol in Cienda, the Chromic Cambisol at LSU and Ferri-Chromic Luvisol Pangasugan are examples for this type of soils.
The differentiation of yellowish and reddish soils coincides with the grouping after pH (fig. 30). Reddish soils are the more acidic and the older ones. According to Asio (1994) red colours also indicate degradation, where the topsoil has been eroded.
Similar distinction has been made for Ferralsols, where the red soils are found on plateaus and yellow ones along the slopes (Schachtschabel et al. 1992). Mixed forms occur, where hematite has formed under warm and dry conditions during prehistoric times. As climatic conditions turned more humid, hematite was dissolved. Ferrihydrite and hematite could not be formed due to climate and organic matter, so that goethite dominates the upper part (Asio 1996). In the case of the Ferri-chromic Luvisol in Pangasugan, erosion has caused the subdivision into 5YR subsoil and superimposed 7.5YR material. Apart from hue, this leap can be observed in an abrupt decrease of sand and silt and increasing clay, and at the same time a drop in pH and base saturation.
Another factor that changes during ageing of volcanic soils, is bulk density. Supposing a chronosequence Andosol → Cambisol → Luvisol → Acrisol / Alisol, as suggested by Asio (1996), Andosols as starting point have extremely low bulk densities, which is one classification criterion. Zikeli (1998) found values as low as 0.34 - 0.6g cm^{-3} in Andosols at Mt. Pangasugan. Although significant differences in bulk density could not be observed among the studied soils with respect to age, the two eroded profiles, PN2 and Patag, were the only soils with BD >1 in the top horizon[48].

3.2.3 Topography

On volcanic grounds, mass fluxes along the slopes play an important role for arrested soil development. This will be illustrated for the example of Cienda profiles. Along the toposequence PN1-3 in Cienda, it is PN1 Cambisol, located on the upper middle slope, which shows the least developed solum with parent material present at 62cm depth. For PN2 Cambisol at the middle slope, the parent material rests below 100cm depth, but from 14 cm downwards rocks have been mixed with the solum through landslides. At PN3 (footslope), rocks still occur in the B horizon, but to less extent and generally smaller in size. Cienda demo plot on a plateau has not been affected by these movements and is deeply weathered with stone contents close to zero.
With respect to the topsoil, apart from landslides, man-made erosion has contributed its share to mass fluxes. Comparing topsoil colour as an indicator of humification, land use over the last decades is reflected. PN1 under secondary forest and PN3 at the footslope,

48 For Maitum, BD sampling of the top horizon was not possible due to only 1cm thickness.

where transported material accumulates, have 12 and 14cm of dark humic topsoil (Munsell value 3), while at PN2, in the middle of the slope and under banana for decades, thickness of dark humic horizons has not surpassed 5cm (fig.31). For PN2, lower contents in organic matter go hand in hand with lower aggregate stability and higher bulk density, reinforcing erodibility through reduced water infiltration. Soils on the slope are in arrested development through the repeated or continuous downhill transport of material and with the topsoil the most fertile portion of the soil is carried downhill and accumulated at the footslope.

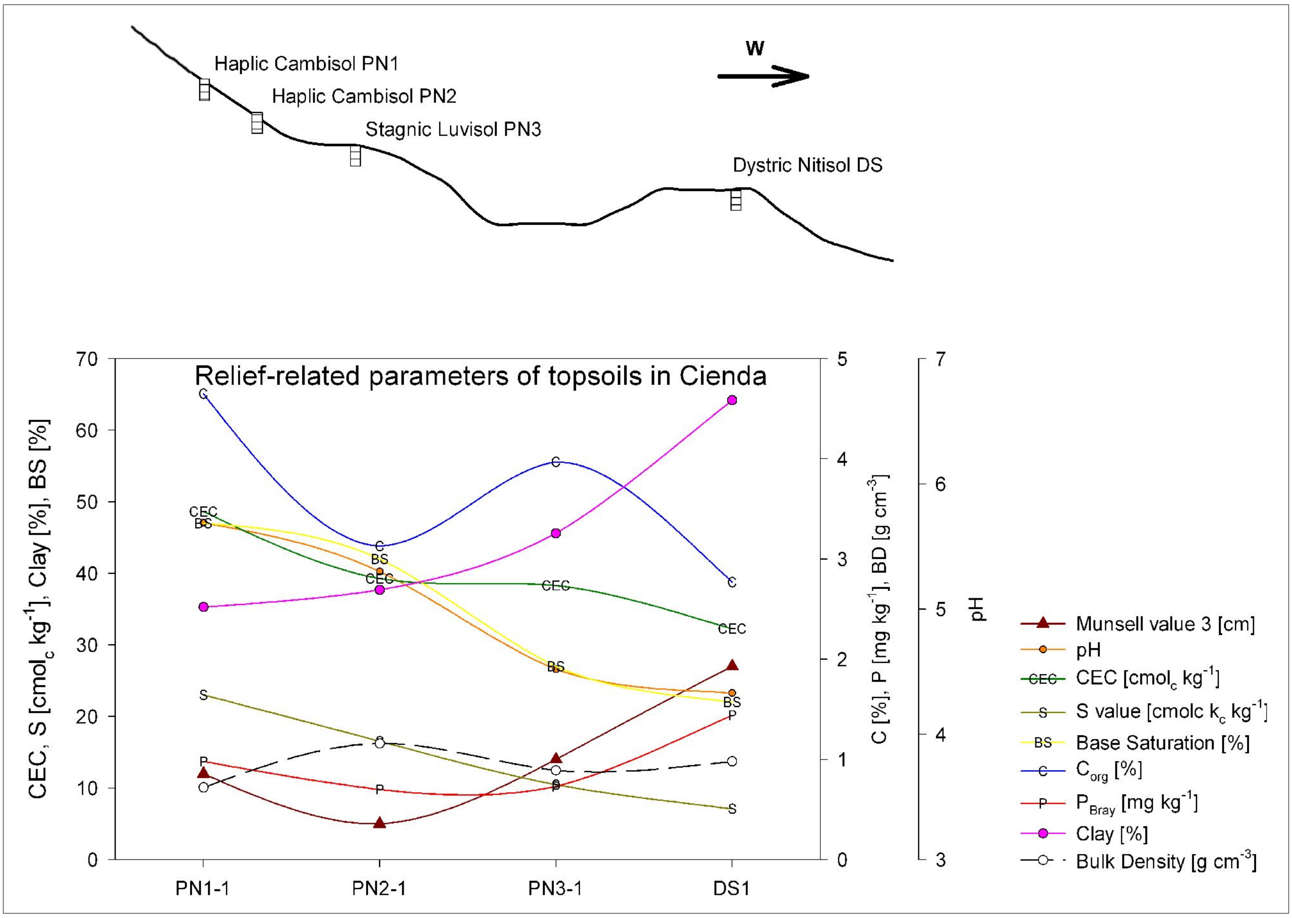
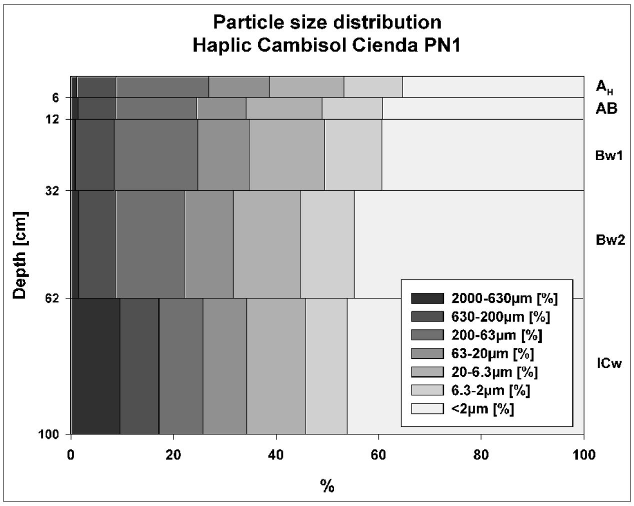


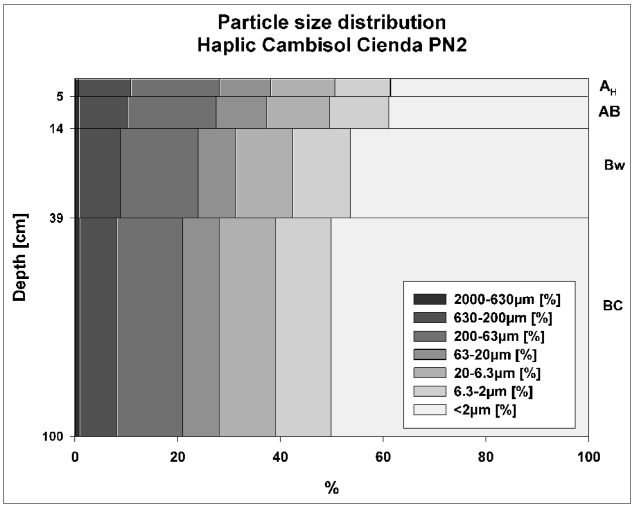
Figure 31: Topsoil contents of different parameters along a slope in Cienda. Munsell value 3 refers to thickness of humic horizons in [cm]

Contents of topsoil clay, Fe_D, $Al_{O/D}$, $Mn_{O/D}$ steadily increase downslope (fig.34), while parameters influenced by vegetation (C_{org}[49], P_{Bray}) first decrease from forest-like PN1 to banana PN2 and then increase again at PN3 (fig. 31). Contrarily to what was expected, topsoil silt as the most erodible textural fraction decreases downhill (fig.32).

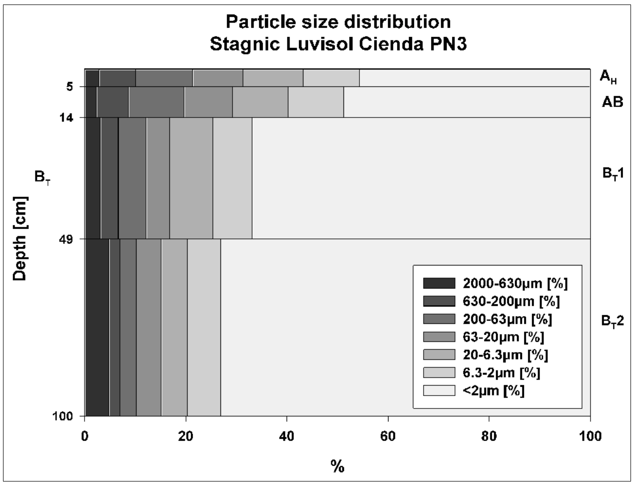
49 Section 4.2.1 will show, that C_{org} contents on a small scale are a function of vegetation rather than slope.



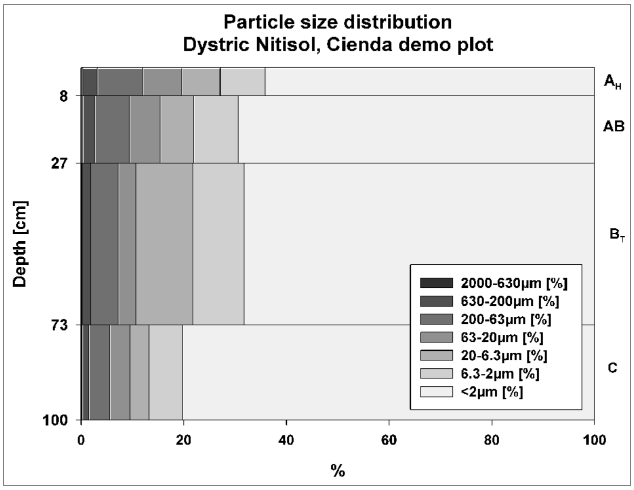
Haplic Cambisol PN1



Haplic Cambisol PN2



Stagnic Luvisol PN3

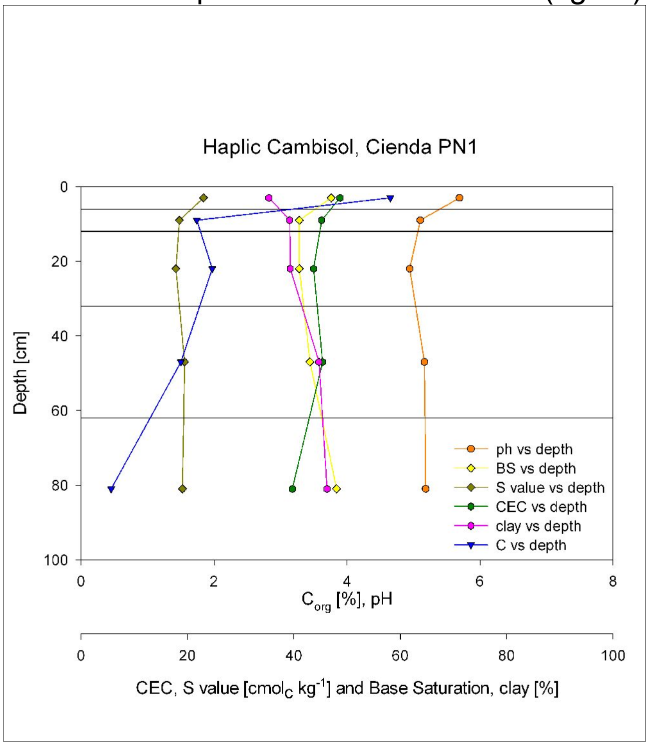


Dystric Nitisol DS

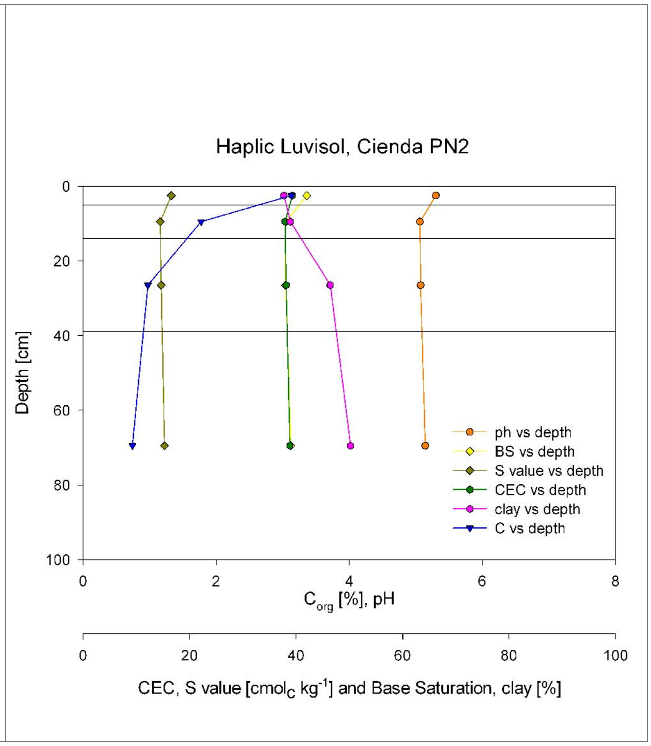
Figure 32: Soil texture of Cienda profiles

Subsurface water flow carries clay, basic cations and pedogenous oxides (Schachtschabel et al. 1992) and dissolved organic carbon (DOC). Zöfel (2004) found DOC contents of 183mgC kg^{-1} in a rainforestation soil at LSU equivalent to >300kg DOC ha^{-1}. Zech et al. (1997) state that DOC fluxes can amount to 5-60kg ha^{-1} a^{-1}. Even P, which is not leached in its inorganic form, can be easily displaced as P_{org}, especially in neutral hydrophobic dissolved organic matter fractions (Donald et al. 1993). Water flows on top of the clayey Bw layers (s. PN1 and 2) and gives PN3 its stagnic properties. This could be observed at PN3 during the rainy season 2006 even days after rainfall events and is also indicated by the presence of *Wedelia biflora*, which usually grows along creeks.

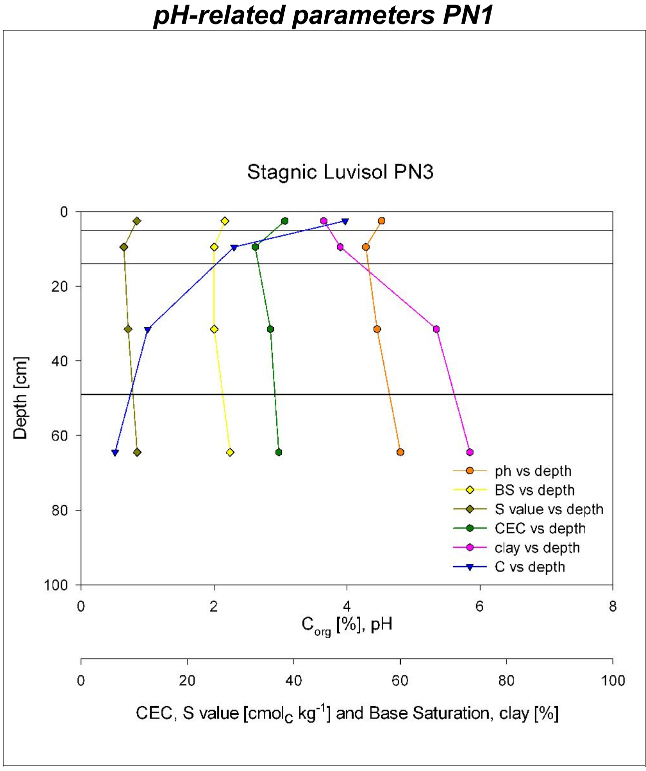
Illuvial processes concern vertical flows in profiles. *In situ* clay formation cannot be easily distinguished from clay illuviation, unless clear indicators like clay cutans or bleached horizons are observed. As mentioned, PN1 and PN2 are colluvial and disturbed, while PN3 has developed for a longer time. Clay formation and accumulation, loss of bases and decline of pH in Cienda are more advanced towards the deeper horizons in each profile and between profiles from PN1 to DS (fig.33).



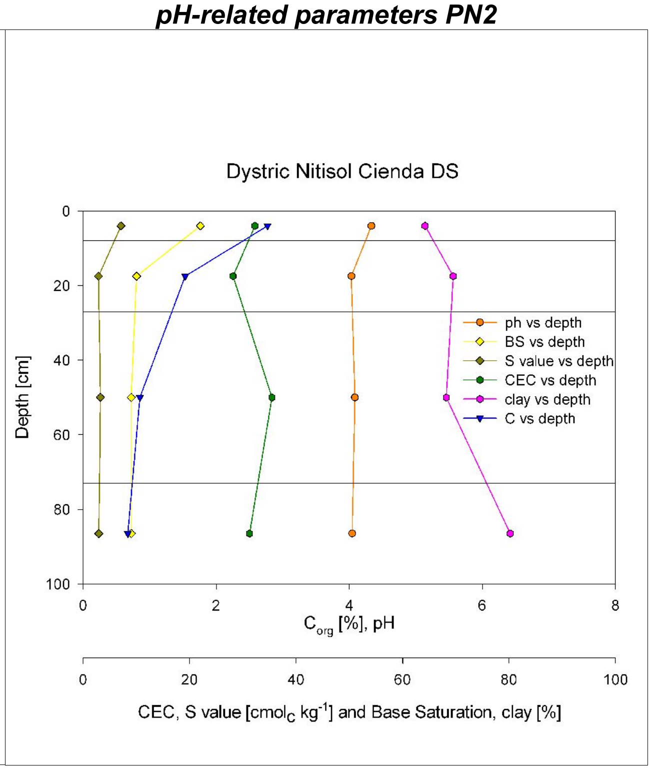
pH-related parameters PN1



pH-related parameters PN2



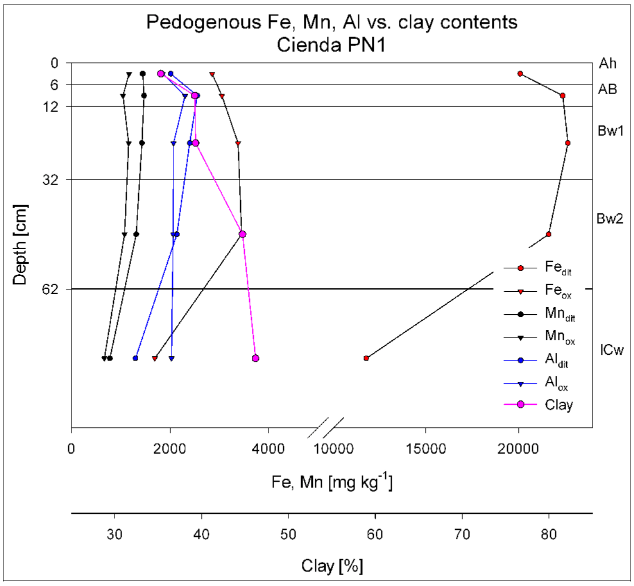
pH-related parameters PN3



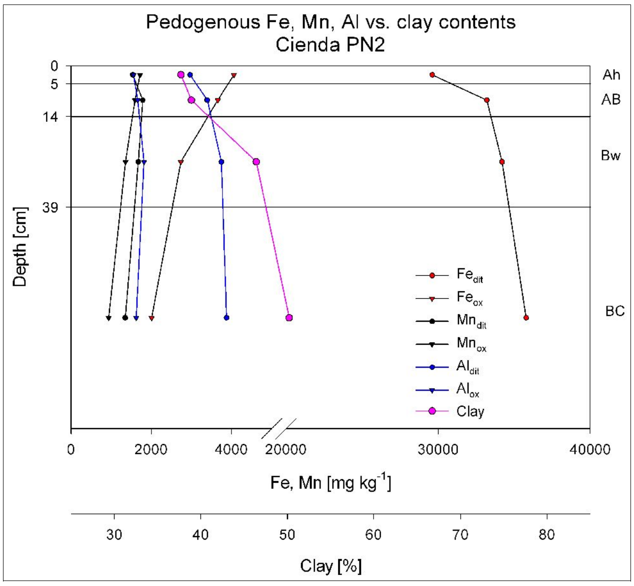
pH-related parameters DS

Figure 33: Depth functions of pH, CEC, S value, base saturation, organic carbon and clay contents in profiles along the toposequence PN1-3-DS at Cienda

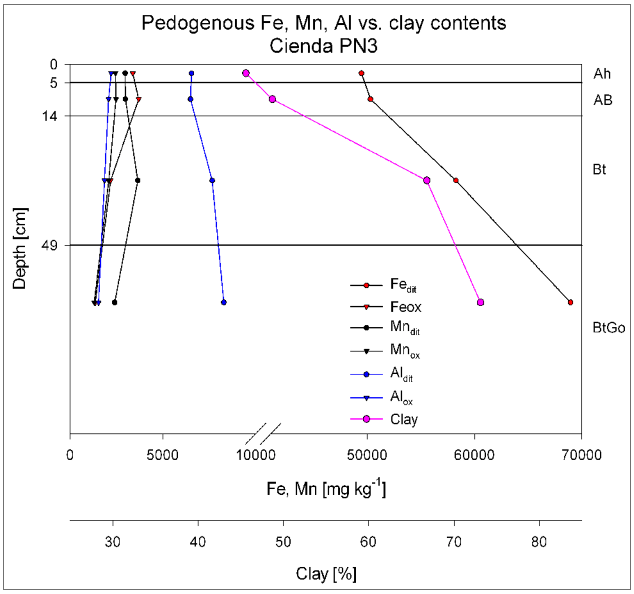
Like clay minerals, sesquioxides are formed during weathering and also accumulate due to downhill flow. Concentrations of mobile and crystalline forms of pedogenous oxides can provide information on the different processes. Oxalate extracts the mobile or 'active' fraction of Fe, Mn and Al oxides such as ferrihydrite, allophane or organo-complexes. Fe_O and Al_O represent the younger fractions, which have not yet formed crystalline bonds as is the case during clay formation. Dithionite-citrate extraction is employed to quantify crystalline pedogenic forms of Fe, Mn and Al. For Fe_D, this includes more stable oxides such as goethite, hematite and lepidokrokite, but not pyrogenic oxides like magnetite. Concentrations of Fe, Al and Mn extracted with oxalate and dithionite are shown in fig.34 in context with clay contents.



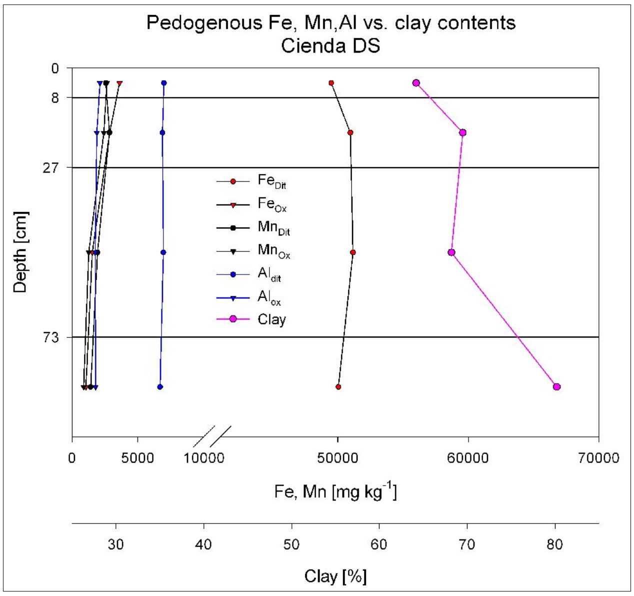
Fe Mn Al and Clay contents PN1



Fe Mn Al and Clay contents PN2



Fe Mn Al and Clay contents PN3



Fe Mn Al and Clay contents DS

Figure 34: Clay contents, oxalate- and dithionite-extractable fractions of Fe, Mn for Cienda profiles

Fe_D and Al_D follow almost identical trends throughout the Cienda profiles: Contents increase substantially from PN1 and PN2 to PN3 and DS, and in each profile concentrations shift downwards parallely to the formation of a B_T horizon. Elevated Fe_D and Mn_D contents often coincide with maxima of clay in B_T horizons (Schlichting et al. 1995). Parallel trends of clay contents and Fe_D as in PN2 and PN3 are interpreted as comigration and of dominating illuvial clay over *in situ* formation (Asio 1996)[50]. Mn_D accumulates in the B_T horizon of PN3. In DS, contents of Fe_D and Al_D are stable throughout the profile. Magnitudes in PN3 and DS are very similar to those found in a Baybay Alisol by Asio (1996) for Fe_D (5-6%) and Al_D (0.7-0.6%). For Mn, the range is from about 0.08 to 0.36%, beyond the 0.01-0.02% found by Asio (1996). Still, Mn might have been underestimated as soils were sieved to 2mm and concretions were not crushed.

In contrast to the dithionite-soluble fraction, translocation of Fe_O can extend even below a B_T. This could be observed in all Cienda profiles. Contents of Fe_O and Mn_O in the topsoil increase from PN1 to PN3, probably due to erosion, and decrease in the subsoils, due to illuviation and possibly due to crystallisation into more stable minerals like goethite for iron (Asio 1996). Al_O remains relatively stable over profiles and horizons with a slight decrease in subsoils.

Magnitudes for Fe_O and Al_O are around 0.1-0.4% and thus far below the 8%, that Zikeli (1998) found in Andosols at Mt. Pangasugan. None of the Cienda soils would meet the criteria of Andosols according to the WRB classification (Al_O + 0.5 Fe_O > 2%; FAO-ISSS-ISRIC 1999). All Cienda soils have already passed the Andosol stage in a topo- / chronosequence Andosol → Cambisol (PN1, 2) → Luvisol (PN3) → Acrisol / Alisol (Asio 1996).

Mn_O and Mn_D values are generally similar in magnitude (Schlichting et al. 1995), a typical Mn_O/Mn_D ratio in Cienda being around 80%. For Al and Fe, ratios differ considerably, decreasing along the sequence and downwards inside most profiles (tab.7). Generally, a low ratio of oxalate- to dithionite- extractable Fe and Al indicates higher shares of crystalline pedogenous oxides characteristic for more developed soils. Fe_O/Fe_D-ratios are around 0.1, higher than those found by Asio (1996), but different to ratios of 1 assumed by Schlichting et al. (1995) and found by Zöfel (2004) for LSU soils.

Table 7: Fe_O/Fe_D- and Al_O/Al_D-ratios in Cienda profiles.

PN1	Fe_O/Fe_D	Al_O/Al_D	PN2	Fe_O/Fe_D	Al_O/Al_D	PN3	Fe_O/Fe_D	Al_O/Al_D	DS	Fe_O/Fe_D	Al_O/Al_D
Ah	0.14	0.92	Ah	0.14	0.52	Ah	0.07	0.34	Ah	0.07	0.30
AB	0.14	0.90	AB	0.11	0.49	AB	0.07	0.32	AB	0.06	0.27
Bw1	0.15	0.86	Bw	0.08	0.48	B_T	0.04	0.24	Bw	0.03	0.25
Bw2	0.16	0.97	BC	0.06	0.42	B_T-Go	0.02	0.19	B_T	0.02	0.27
ICw	0.14	n.d.									

In summary, Fe, Mn and Al concentrations confirm, that PN3 and DS are advanced in development and that erosion and subsurface fluxes play an important role along slopes. Soil formation is most advanced in DS, the dystric Nitisol[51], which is deeply weathered, acidic, poor in bases and clayey in the subsoil.

50 The Cw horizon at PN1 mainly consists of parent material and is not taken into account.

51 Jahn & Asio (1998) classified a similar Baybay soil as Alisol. Nevertheless, Al-saturation for Cienda DS was <60% and a decrease of clay below 100cm was not assessed.

3.2.4 Single parameters compared across all study sites

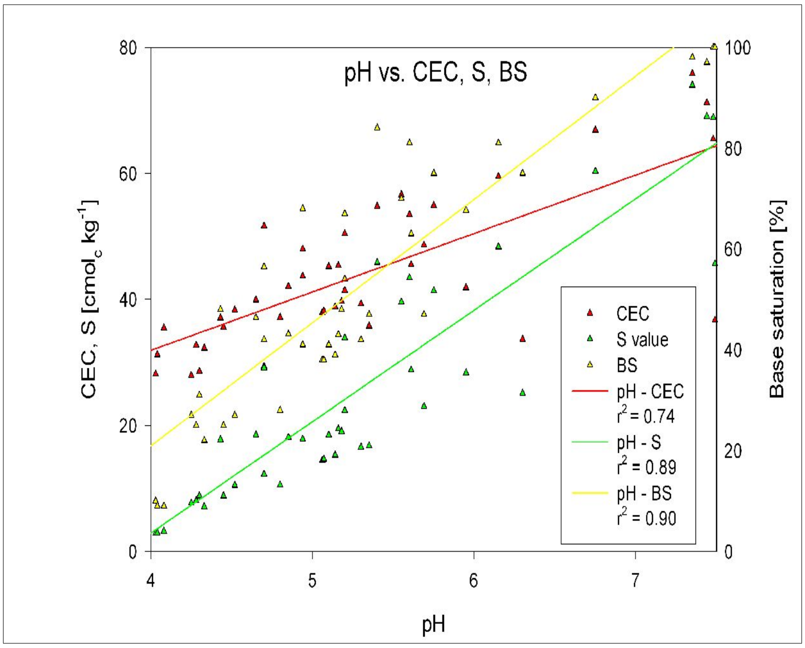


Figure 35: Correlations of pH with CEC, S-value and base saturation in Leyte soils

S-value and base saturation increase with pH across all soils. CEC and pH are also positively correlated for the studied soils (fig.35), but the correlation is less distinct. This can be explained from the influence of acidic humic substances, which are also connected with high CEC.

Clay contents *per se* allow a distinction of 10YR and 7.5YR groups again, with higher clay contents throughout the profiles and stronger increase in the B_T of the red group. However, LSU Cambisol and Marcos Luvisol (fig.36) are exceptions, which do not fit into the scheme. In the case of Marcos Luvisol high clay contents in the B_TSw may be a result of lateral water flow.

There is no clear relationship between clay contents and CEC ($r^2 = 0.09$), even if Ah and AB horizons, which are often low in clay but high in CEC and would distort any trend, are omitted (overall correlation $r^2 = -0.73$, but for individual profiles r^2 varies strongly).

CEC of fine earth shows (fig. 37a), that the more weathered reddish profiles are lower in CEC than the colluvial than the calcaric ones. As for clay, LSU and Marcos do not match the categories. Looking at CEC per kg clay (fig.37b), these two are very similar and form an extra group apart, which seems to originate from similar parent material.

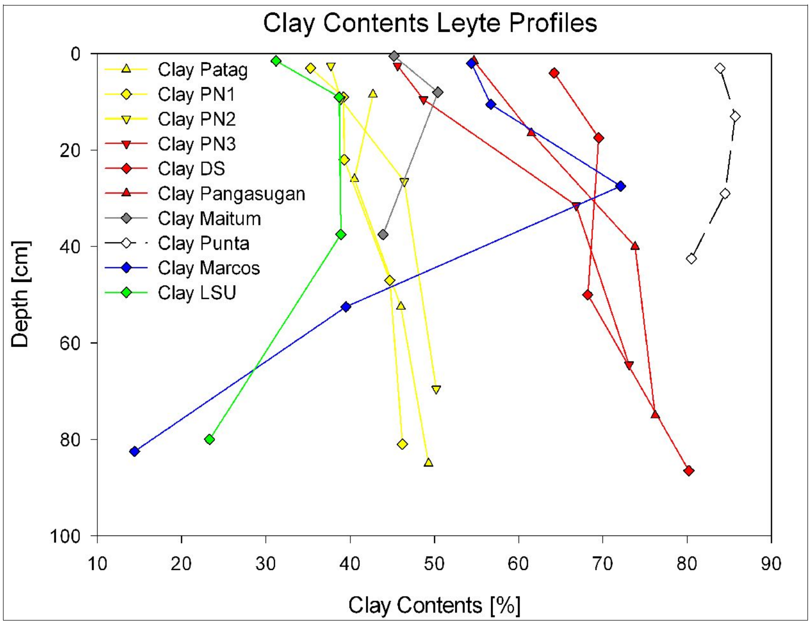
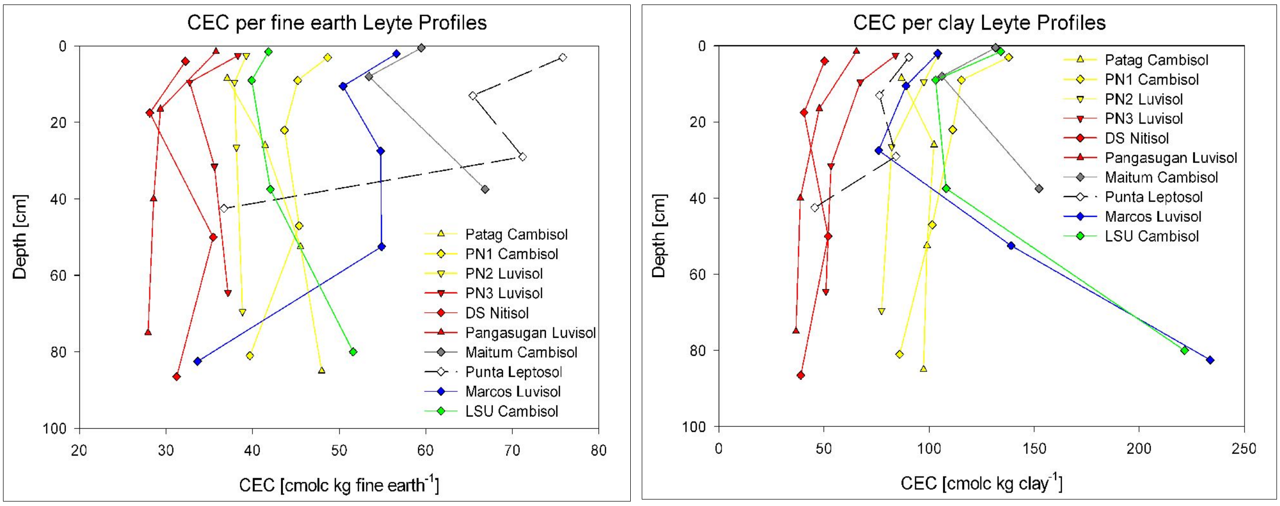


Figure 36: Clay contents and distribution in Leyte profiles



CEC per kg fine earth ***CEC per kg clay***

Figure 37: CEC per fine earth and per kg clay in Leyte profiles

On the other hand great differences exist with respect to present cation loads and base saturation: Ca/Mg-ratios in the LSU Cambisol decrease from about two to 0.7 towards the subsoil, while they increase from six to nine in Marcos Luvisol. Among the other volcanic profiles, Ca/Mg-ratio is around one to two, in Maitum about four and in Punta 18 (topsoil) to 125 in limestone (probably overestimated because of free $CaCO_3$ in the solum, s. Asio et al. 2006). Base saturation (fig.38) underlines this trend with Marcos Luvisol tending towards higher values and LSU among the colluvial soils. The striking difference in soil colour in Pangasugan ferri-chromic Cambisol is reflected (but not caused) by lower BS in the subsoil.

As for the data presented by Zikeli (1998) for Andosols, all CEC values are above 25cmol$_c$ kg^{-1} fine earth, but towards the upper end, the more developed volcanic soils analysed during this study reach about 55cmol$_c$ kg^{-1}. With respect to base saturation for the volcanic soils, DS Nitisol is similar to the Baybay Alisol studied by Asio (1996)[52] and Andosols in Zikeli (1998) are in the range of Marcos Luvisol. For most soils, BS increases towards the parent basaltic/calcareous material.

52 BS = 28 to 6% from top to bottom

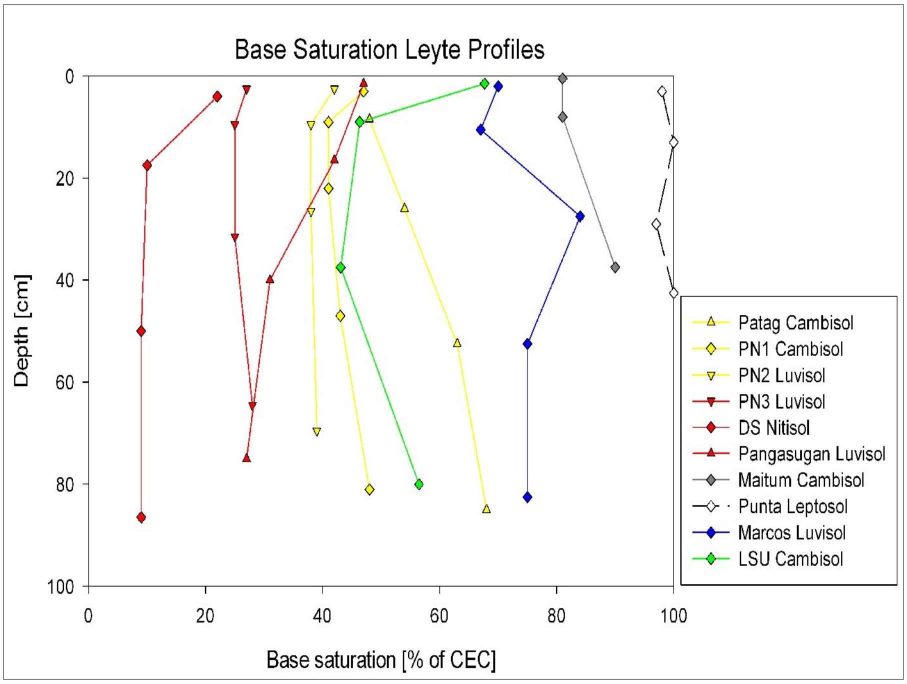


Figure 38: Base saturation of Leyte profiles

Not only for classification purposes (Alisol vs. Nitisol), it is of importance, that Al-saturation even in the most acidic DS Nitisol is below levels found by Asio (1996), where Al has by far the highest share among all cations. Due to pH clearly below 5, Al-toxicity may be problematic for plants.

Pagel et al. (1982) state that S-values alone do not provide too much information on a soil as long as the saturation of each basic cation is not calculated. High saturation of a cation implies high risk of leaching and also displacement of other cations from the exchange sites. Substitution of Mg and K through Ca certainly occurs in Marcos subsoils, Maitum and Punta. Constraints of soils due to low contents of cations will be discussed for each soil under 3.2.6.

Potassium contents are below 0.9cmol$_c$ kg^{-1} and K-saturation is below 2% (very low to medium for some topsoils) for all profiles except PN1 with high contents (2.55 to 0.8cmol$_c$ and 5.2 to 1.8% saturation from Ah to Bw2). Levels in Punta are clearly lower than those found by Asio et al. (2006) for the same site.

Sodium levels are all low (0.1-2% of CEC) and, especially in the topsoils, appear to be related to seawater spray, as they increase with vicinity to the sea and with W exposition.

Land use and present vegetation play a key role for soil organic matter (see Kellman 1970) and shall be discussed with more detail in chapters 4 and 5. In general, unfavourable conditions for decomposers, e.g. alkalinity and excessive drainage on limestone or free Al^{3+} ions (Veldkamp 1994) in strongly acidic soils, can lead to humus accumulation. For soils in Sumatra, v. Noordwijk et al. (1997) found that pH <5 and >6, dry or anaerobic conditions and high clay contents enhanced C_{org} levels. However, in this study correlation of pH and C_{org} was weak (r = 0.18) as pH is only one among several factors influencing C_{org} contents.

Mean topsoil C_{org} was 3.4%, ranging from 4.65% in Punta, where alkaline conditions hamper SOM decomposition (Asio et al. 2006), and the Haplic Cambisol under secondary forest in Cienda to 1.53% for the truncated profile in Patag. Clay contents exercise an indirect influence on decomposition of OM through the formation of organo-mineral complexes (Gaunt et al. 2000, Balesdent et al. 1996). Chenu et al. (in Rees et al. 2001) found, that organo-mineral aggregates in a French pine forest drastically decreased during cultivation of 35 years, leading to increased wettability of clay and thus to higher rates of erosion. In reverse, organic matter protected by minerals will become exposed to microbial attack once the aggregates are destroyed. The effect of erosion and accumulation at footslopes on C_{org} contents can be seen in fig.31. An impact of strongly acidic or alumic environments, that would protect SOM (Zikeli 1998) could not be deducted from the two sufficiently acidic examples (Pangasugan Cambisol, Cienda Nitisol). From Ah to the underlying horizons, C_{org} contents dropped to about 50% in all profiles except Patag and so did N_T. Subsoil contents of C_{org} were between 0.3 and 0.7% in all soils except Marcos (0.05%, C horizon) and Punta (C_{org} 1.14%, C_{Carb} 6.53%; C:N is higher than in the other horizons, which might imply an overestimation of C_{org}). This is close to results of Asio (1996).

Parallel trends can be seen for <u>N_T contents</u>: High values (0.41%) for PN1 and Punta, 0.23-0.34% for all other Ah and a leap from Ah to AB horizons. Subsoil N_T contents ranged from 0.01 to 0.07% for all profiles except PN1 and Punta (0.09%). This is in the range of N contents in Pangasugan Andosols studied by Zikeli (1998) for subsoils and about double of her topsoils. According to Pagel et al. (1982), 0.41% N_T is a maximum expected for soils of the Humid Tropics, while a mean would be around 0.16%. Pagel et al. (1982) state that Andosols are rich in nitrogen, and for the studied soils, atmospheric inputs and land use are supposed to have contributed additional N (Jahn 1998).

<u>Available phosphorus</u> is a limiting factor for many tropical soils. It is determined mainly by parent material and degree of weathering; at similar stages of development, acidic soils tend to be comparatively lower in available P than others (Pagel et al. 1982). In soils with low pH (<5), P is adsorbed by Fe, Al and clay minerals or fixed, either by Fe or Al ions. In calcareous soils P is fixed by Ca ions (forming apatites). Generally, P-sorption is more reversible and thus less problematic than fixation, which is typical for Andosols and Alisols in Leyte (Asio 1996).

An important share of available P is bound in organic molecules. While P_I is generally not leached in significant amounts, P_{org} has been found to be more susceptible than C and N (Schoenau & Bettany 1987 for a boreal soil). Goller et al. (2006) found that 2/3 of all P leached in an Ecuadorian montane forest was organic. Losses of P through erosion, leaching and slash and burn have been found to make up for 70-80% of total P losses including harvest in Indonesian timber plantations (Mackensen et al. 2003).

For AB and B horizons of the studied profiles, higher contents of available P with increasing pH could be observed in the pH - range 4 to 7 (fig.39). The maximum P contents of AB and B horizons (7.98 and 4.04mg kg^{-1}, encircled) were found in the Hypereutric Cambisol, Maitum, at pH 5.60 and 6.75).

All other P_{Bray} values >1mg kg^{-1} in fig.39 were measured in Ah and C horizons, with litter or rocks as sources. Generally, P_{Bray} decreases from the Ah horizon towards the AB and B and increases again where the parent material is not weathered strongly. An exception is Maitum, where all horizons show relatively high contents.

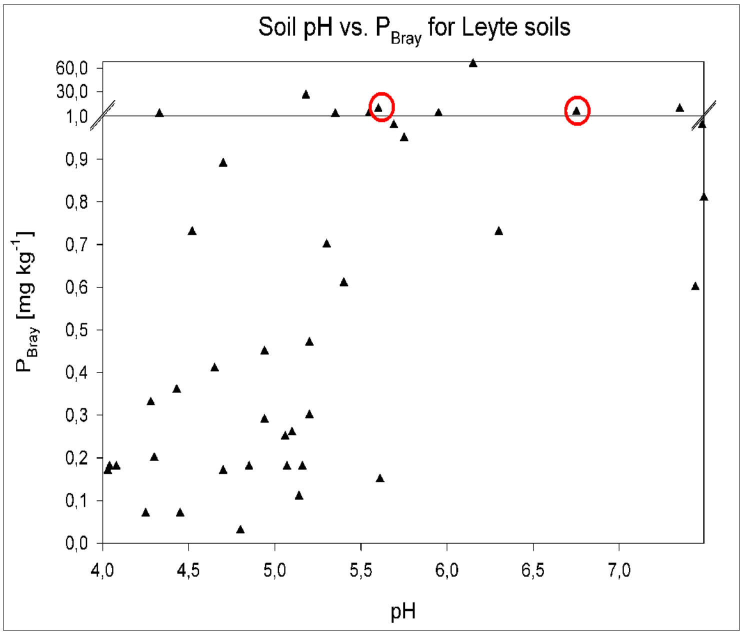


Figure 39: Available P (Bray II) of Leyte profiles, all horizons, plotted against pH

Extraordinarily high P_{Bray} contents were observed in samples from C horizons in the upslope profile PN1 in Cienda and in Marcos; these were 25 and >300mg kg^{-1}, respectively. Repeated sampling in Marcos revealed a high small-scale variability in 65-100cm depth, with P_{Bray} of 359, 334, 21 and 0.8mgP kg^{-1}. It seems that tree roots are able to penetrate the stagnic clayey (72%) B_TSw, tap the P resources and return them to the topsoil, which shows P_{Bray} values three times above those in the other volcanic soils. For PN1 Cambisol, DS Nitisol and LSU Cambisol, accumulation of P in the topsoil can be observed to some extent, too. This shows the importance of a close P-cycle to avoid that P is adsorbed and then fixed by minerals. Depending on vegetation, a large proportion of plant P can be supplied by organic P (Gaiser 1993). The proportion of P_{org} increases with weathering and SOM can contain 40-90% of total P in ferralitic soils of humid regions (Pagel et al. 1982). For Cienda profiles, P_{org}, calculated as difference of P_{Truog} in digested and non-digested samples was between 85 and 90% with exception to the C horizons of the PN1 Cambisol and the Cienda Nitisol. Zech et al. (1997) estimate, that 20-75% of P reserves in tropical soils are stored in topsoil SOM, 60-80% of them as P_{org}.

Generally all measured phosphorus contents save the mentioned exceptions are extremely low, about one tenth of what is considered an average level in soils of the Humid Tropics: Pagel et al. (1982) give typical values of 750mg kg^{-1} total P and 27mg kg^{-1} available P_{Bray}, which is 300% of the Maitum soil. For soils of Andosol chronosequences, contents <40mgP_{Bray} kg^{-1} and for calcaric soils <20mg kg^{-1} are considered low. For P extracted after Truog's method (0.002N H_2SO_4) <30mg kg^{-1} for soils rich in Fe and Al and <80mg kg^{-1} for calcareous soils have been defined as low (Pagel et al. 1982).

Zikeli (1998) found levels of available P_{Bray} of 0.4-1mg kg^{-1} and negative correlations to Fe and Al in Andosols between 350 and 550m asl on Mt. Pangasugan slopes; there were no clear tendencies of accumulation or depletion within the profiles. Asio (1996) determined P_{Bray} of two Alisols under forest in Baybay and measured 0.1 to 0.6 mgP kg^{-1} with maxima in Ah, B_T and BC horizons.

Asio et al. (2006) classified calcaric soils in Leyte as Calcaric Phaeozems (upper positions) and Calcaric Cambisols (middle and lower slope). They found, that solum thickness differed on a small scale and common limitations in nutrients were often aggravated through shallow rooting space.

In contrast, high levels of basic cations and moderate nitrogen supply were measured in Punta, the only serious constraint in nutrients being phosphorus, as in all former Leyte forest soils. Advantages for plant production due to favourable chemical properties are outweighed by the shallow effective rooting space and excessive drainage, which can lead to drought stress during periods of scarce rainfall. This fact, temporarily, and the high pH can be the causes for strong humus accumulation. Daub (2002) found biological activity of the mesofauna in Punta significantly higher than at LSU. Animals are able to evade into deeper soil layers during dry periods and are better adapted to higher pH than most bacteria. Microorganisms, which are responsible for the major part of decomposition, would be more affected by adverse environmental conditions.

3.2.5 Water Balance

Favourable water capacity as well as drainage have been observed for volcanic soils in Baybay (JAHN & ASIO 1998). Even during dry season (March 2005), water contents of soil samples from grassland[53] were still relatively high. On the other hand, water stress shown by rolled leaves was observed during dry season even for wild plants under closed canopy. In clayey soils, water contents may be relatively high but bound in fine pores and thus not available for plants.

In 2006, water contents (WC) and hydraulic or soil water potential (Ψ_H) measurements were conducted using Frequency Domain Reflectometry (FDR) sensors for WC and tensiometers for Ψ_H. Two permanent plots were installed in Cienda at middle and footslope position (next to profiles PN1 and 3). The first plot was under closed canopy and the second in open grassland (average height of vegetation 30cm). Sensors and tensiometers were installed on Feb 13th after four days of continuous rain, assuming that this represented a soil status of saturation. A few days with light rains later, the soil was assumed to be at field capacity and a second measurement was undertaken. The following readings were also event-specific during the transition from rainy into dry season.

A first test of FDR sensors in sandy soils of known gravimetric water contents showed, that deviation between sensors was considerable, especially towards the upper end of the scale, so that individual calibration was necessary. For each sensor, repeated readings in the same sample were reproducible and gave coefficients of variation between two and four percent. On the other hand, even laboratory calibrations with unstructured sandy soils seemed to produce artefacts, so it was decided to install the sensors directly in the respective soil layers and use parallel auger samples as control.

Correlations between gravimetric water contents (auger samples) and voltage read on FDR had to be determined for every individual FDR sensor. Data were not sufficient to develop meaningful regressions, so that only auger results were used for WC.

53 Determined for moisture correction factors of chemical soil analyses

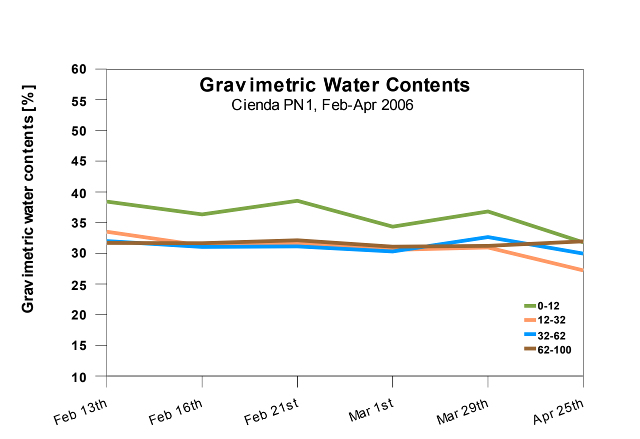


Figure 40: Gravimetric water contents at Cienda PN1 profile determined by auger method

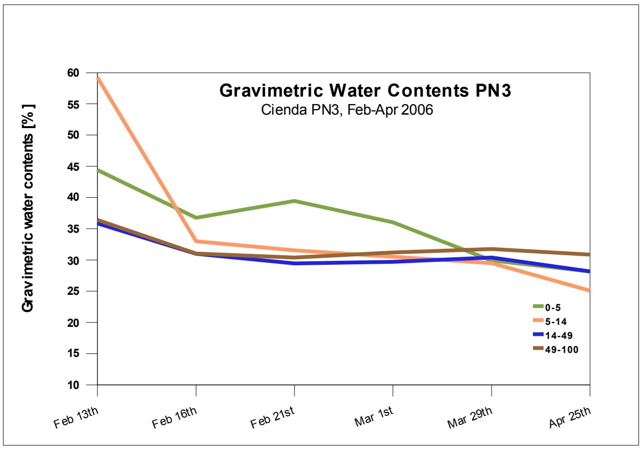


Figure 41: Gravimetric water contents at Cienda PN3 profile determined by auger method

Gravimetric water contents sampled by auger showed an overall decrease of soil water contents (fig.40 and 41). As expected, superficial horizons and PN3 profile were most affected by desiccation, whereas WC in the lower horizons of PN1 remained stable. At the peak and end of the dry season (April 25th), the upper two horizons at PN1 decreased more sharply and WC of Ah dropped below those of Bw2. At PN3, the WC of Ah and AB fell below those of B_T1 and 2 during the month of March.
Opposed to the decreasing water contents, matrix potential of the soils rose towards the end of the dry period (fig. 42 and 43).

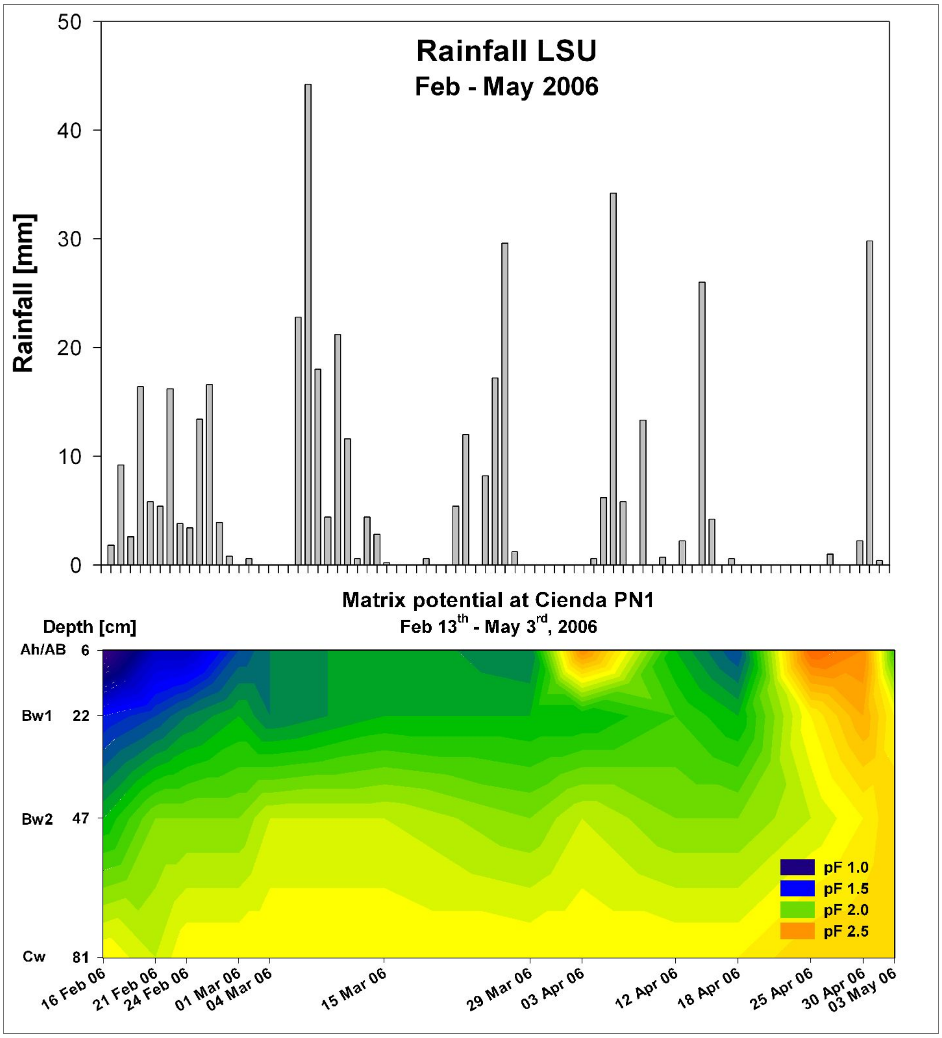


Figure 42: Isobares of pF in different soil depths of Cienda PN1 from Feb – May 2006 and rainfall at LSU during the same time; minor time lag between both sites possible

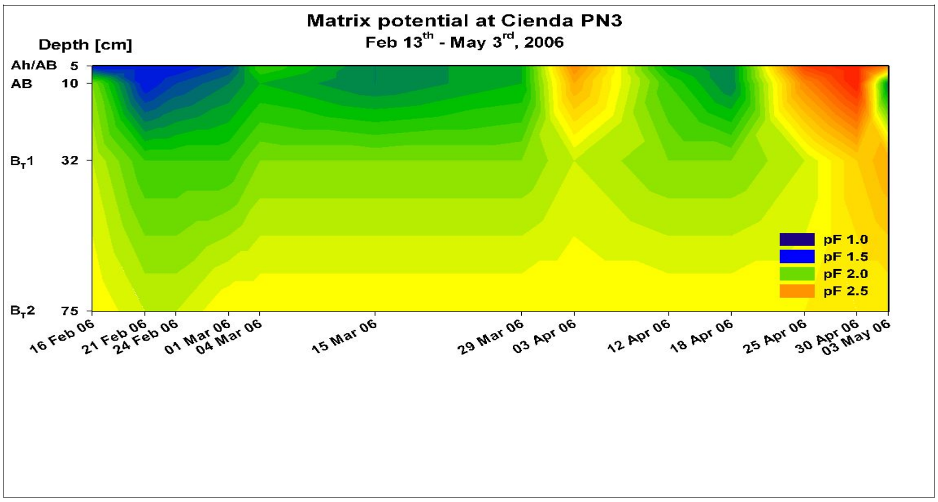


Figure 43: Isobares of pF in different soil depths of Cienda PN3 from Feb – May 2006

Tendencies are parallel in both plots, but although PN3 is fully exposed to sunlight and evaporation exceeds that at PN1, water reserves decrease earlier in the upslope position. The reason for this is better drainage of the andesitic subsoil compared to the stagnic B_T at PN3. With respect to plant water supply, the upper rooting zone will be replenished from lateral flow and capillary rise, which cannot be expected to the same degree at PN1.
The range of measured soil water potentials did not exceed pF -2.8 at any time, which would not constitute a limiting factor for plants yet[54]. During the peak of the dry season lower potentials were supposedly reached, but the range shown by tensiometers is limited to pF 2.8.
Comparing both methods under field conditions, soil water potential, even though osmotic and pressure potentials were not accounted for, gives a better insight of root water stress than water contents do. Curves relating pF to water contents should have been based on water removal under controlled pressures in the laboratory. For auger measurements, sufficient points over a broad range to plot a pF-WC curve were not available. Hydraulic conductivity of the saturated soil (K_{sat}), which is relevant for erodibility, was roughly estimated from literature (Jahn, Blume & Asio 2002; Schlichting et al. 1995). K_{sat} ranges between kf 4-5 (high to very high) for all horizons, which corresponds to 40-300cm/d. These estimates are based on texture and bulk density, which govern K_{sat}.

3.2.6 Ecological evaluation - summary

In a broader context, the most relevant constraints of Southeast Asian soils have been subsumed by Jahn (1998). Low base saturation ranks before low CEC, P retention and limited rooting space. For lowland soils stagnic properties also play an important role. Generally, soils in Leyte are geologically young, so that CEC has not been found to be a limitation for the studied sites. Low base saturation is problematic on the more acidic soils, but the most common problem is low plant-available phosphorus content.
All studied Leyte soils are characterised by moderate to high N supply. CEC is moderate to high and S value high to very high (except Cienda Nitisol, moderate). Available P contents are low, except in some C horizons. P retention is an important feature of Andosols, and during their development towards Cambisols, Luvi- and Acrisols, mainly sesquioxides and low activity two-lattice minerals like kaolinite are formed, which also retain P. Contents of exchangeable K are low for all soils except for PN1. As a heritage of their Andosol past, bulk density of the volcanic soils is generally low and pore volume is about 55-70%. Air capacity is low (<7%) for some clayey horizons, if estimated from texture and BD; in the field, often a sandy structure of aggregates was felt, which turned plastic under pressure. This indicates, that pore volume and infiltration are not a problem as long as the soils are not compacted. Pore volume of all horizons is very high. Available water capacity is 10-25%.
All profiles have been estimated to be of very low to low erodibility, which is owed to high infiltration rates (hydraulic conductivity of the saturated soil, K_{sat}, estimated from texture and bulk density) and SOM contents. In the field it becomes obvious, that steep slopes without sufficient soil cover and rain events of extreme erosivity cannot be compensated for by low soil erodibility (example PN2 Cambisol). Another source of underestimation may be the fact, that the nomograph for erodibility does not consider depth of the soil profile; once the soil is saturated, water will simply overflow, which can be observed on site after few days of constant rain. In practice, all studied soils which are not nearly level are in danger of being eroded, if not covered and managed properly.

54 Permanent Wilting Point (PWP) = pF 4.2. Plants can survive at pF 3.8, but not grow (Schlichting et al. 1995). These values were established for more drought-resistant plants (*Helianthus sp*. and *Pinus sp*.).

As erodibility concerns only the topsoil, it does not give any information about the risk of landslides, which are caused through sliding of a water-saturated soil on a plastic boundary layer of clay (Schachtschabel et al. 1992).
Evaluating each soil by constraints after Pagel et al. (1982) and Schlichting, Jahn & Asio (2003), plant production on PN1 Cambisol is only slightly limited by air capacity in the lower horizons and Na-saturation. PN1 is the only of all studied soils not deficient in K^+ and one out of two with reserves of available P in the lower horizons. As rootability is not restricted to a depth of 100cm, these P sources should be accessible at least for trees.
Due to erosion processes, PN2 Cambisol profile is more shallow, bulk density is higher than for the other profiles and air supply can be a problem for roots in lower horizons in addition to 50% rocks. P availability is low throughout the solum and so are K^+ and Na^+.
Stagnic properties in PN3 Luvisol are caused by an abrupt change of clay contents from 49 to 67% in 49cm depth and increasing bulk density. As a consequence and due to small pore size, the lower horizons have limited air capacity. Chemical limitations are low pH and deficiencies of available P, exchangeable Ca, K and Na.
Even more than the previous profile, DS is strongly acidic and aluminium toxicity may pose a problem in the future. Due to the low pH, contents of available P and all basic cations are also low. Heavy clay may cause problematically low air capacity, but in the field this did not seem to be a threat: Bulk density was not too high and this soil seemed to be an example of isovolumetric weathering (Asio 1996).
Horizons of LSU Cambisol are deficient in K and Na cations. S-value (at an average CEC) per m^2 is high even when the shallow rooting space (60cm) is considered. Available P contents are very low over the profile depth, but relatively high in the Ah horizons, as in DS Nitisol and Marcos, where reforestation is well established.
Characteristics of Marcos Luvisol depend very much on rootability, which may be species-specific. If roots are able to penetrate the B_TSw horizon, then air supply and even available P are minor problems. In the C horizon, 334mg kg^{-1} available P and, taking more samples nearby from the same depth, >300 to <1mgP_{Bray} kg^{-1} were found. The number of roots counted on the profile wall gave the impression, that the B_TSw is hardly rootable. On the other hand, P_{Bray} of the Ah was by far the highest of all volcanic soils, which leads to the conclusion that P is pumped up from the subsoil by trees. The profile shows extremely good Ca-supply and sufficient Mg (which may be displaced by the abundant Ca), so that base saturation is high, although exchangeable K and Na are deficient.
Effective rooting space in Pangasugan Luvisol may be mechanically restricted by an abrupt textural change, but as bulk density remains low, is not seen as a major constraint. The sudden drop of pH from M2 to $B_{TS}1$ may also reduce effective rooting space to some extent. Ca, K and Na contents are low and Ca concentrations are even less than Mg, as Ca is more easily leached under acidic conditions.
Patag Cambisol shows stagnic properties such as manganese concretions and rust, which point to a changing water regime. Air capacity may be problematic, but only in the AB2 horizon. C_{org} and N_T contents are the lowest of all profiles, but for N_T still moderate. P, K and Na are low as in most profiles.
Maitum Cambisol and Punta Leptosol both have structural limitations as their B and Sw horizons quickly turn from smeary-plastic (poor air supply) during rainy weather to extremely hard when dry. Moreover, rooting space of both profiles is shallow, which makes the overall nutrient supply problematic: Even though N_T in the Ah horizon is the highest of all profiles, Punta soil disposes of less than half of the nitrogen compared to Cienda dystric Nitisol on a square meter basis. The dominating Ca-saturation of exchange sites may displace the other basic cations. Overall P supply is very low for both profiles due to the shallow profiles and, in the case of Punta, pH. Kaiser et al. (in Rees et al. 2001)

underlined the relevance of nutrient losses through dissolved organic matter (DOM) in shallow calcareous soils in temperate regions. This is also true for tropical soils and especially affects P, which is leached as DOP.