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Effect of open ditch draining on sediment and soil properties in cultivated areas in southeast Mexico

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Abstract

In the last 10 years in many parts of the coastal plain of Tabasco, SE-Mexico open ditch draining systems were installed. From April to October 2003 we investigated the effect of draining on sediment deposition on floodplain soils with agricultural and pasture use. Open ditch draining reduced the amount of sediment deposited on inundated soils. This was due to the fact that the number of inundations that occurred in the drained area was smaller than in natural areas. However, neither the amount of sediment deposited on the floodplain soils after a single inundation nor the nutrients or heavy metals (Zn, Pb) transported with the sediment deposited by a single inundation were influenced by the draining. The total amount of deposition in the drained areas varied from 94.2 to 123.5 t ha^{-1} (April to October) and did not show any significant differences between different land uses. In the natural area the deposition was significantly higher (242.6 t ha^{-1}). Organic matter, Ntot, Ptot and Zntot content of the new sediment did not differ between natural and drained sites. In none of the sediments Pb was detected. However, in the natural area organic matter, Ntot and Ptot content in topsoil increased significantly between April and October 2003 whereas in the drained areas only the Ptot content in topsoil increased. Eighty-five percent of the amount of organic matter and Ntot deposited on the topsoil of the natural area was lost probably by mineralization and lateral transport. The input of Zntot deposited with the sediment in all sites exceeded the trigger value of 1200 g ha $year^{-1}$ for critical load inputs in soils [Bundes-Bodenschutz- und Altlastenverordnung, 1999. http://www.fh-kehl.de/projekt_bodenschutz/bundesrecht/BodSchV.htm] due to extremely high quantity of sediment deposition.

Keywords: Draining; Sedimentation; Soil chemical properties; Heavy metals; Organic matter

1. Introduction

Increasing deforestation in tropical countries over the past 60 years has led to increasing soil erosion in mountain areas (Goodland, 1991). Land use changes have resulted in increasing flood frequency and severity (Tollan, 2002). In mountain areas in Mexico, such as in Chiapas, severe soil erosion occurs (Jara García, 2000; Ramirez Cruz, 2000). In Tabasco in the last 60 years forestland was reduced from 49.1% of the land surface to 13.6% (Palma López and Triano Sánchez, 2002). The eroded soil enters rivers and is transported over large distances. In plains areas such as in Tabasco, rivers deposit sediments on floodplains that are inundated several times per year in the rainy season. The soils in these areas are strongly influenced by the amount of sediment as well as nutrients and potentially toxic elements that are deposited with the sediments and accumulated over time (Chichester and Richardson, 1992). Agrochemicals as well as nutrients such as P, N and others applied in mountain areas of

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Chiapas and Tabasco are transported with eroded soil material. The use of agrochemicals often is associated with the input of heavy metals that also are transported to floodplains (Crane and MacDonald, 2003). Therefore, inundations of areas may have positive effects on soil fertility such as deposition of nutrients as well as negative effects such as deposition of potentially toxic elements.

In some regularly inundated areas of Tabasco the National Commission of Water (CNA) installed open ditch draining systems to control inundation and to improve the land for agricultural use. In drained areas the inundation rate decreases and, therefore, it is supposed that deposition of toxic elements also is reduced.

About 10 years ago a system of open ditch draining was installed throughout the Teapa region. The drained areas are presently used for agriculture or pastureland (INEGI, 2000). The areas left undrained are exclusively used for pastureland (INEGI, 2000). There is no information about the effects of draining systems on soil properties in these areas.

In this study we compared sediment, deposited in drained areas in three landuse types with sediment deposited in natural areas used as pasture. We included analyses of nutrient and heavy metal deposition to define the impact on soil chemical properties in the different areas.

2. Study area

The study area is located in the coastal plain (altitude less than 30 m asl) of Tabasco, SE Mexico. The area is part of the watershed of the Rio de la Sierra (INEGI, 2002) and is strongly influenced by inundations of the rivers Teapa and Puyacatengo (Fig. 1). It is characterised by warm and humid tropical climate with precipitation throughout the year. The average temperature is 25.4 °C and the mean precipitation 3862.5 mm. The maximal precipitation occurs in September with 600 mm, and the minimal precipitation in April with 150 mm (INEGI, 2000). The months of May to September are characterised by typical tropical rains with high intensities, the months between October and April are characterised by rainfalls with moderate intensities. The area influenced by inundations of the rivers Teapa and Puyacatengo has a size of about 120 km^2. In 1994, an open ditch draining system was installed in the northern part of the watershed, covering about 70% of the area. This area is used for banana plantations, rotation cropping or pasture; the natural areas exclusively for pasture.

In April 2003 we selected four study areas in drained (D) and undrained (U) land. We chose the three different typical land use forms in the drained areas: pasture (P), annual agricultural use (A), banana plantation (B) and in the undrained area pasture (P) due to the fact that this area was exclusively used as pasture. All study sites were located at an altitude of less than 30 m asl.

3. Materials and methods

3.1. Experimental design, sampling and analysis

The study took place from April to October 2003. This allowed us to study the area while under the influence of tropical rainfalls and moderate rains. In each study area we installed three replication plots at a distance of 20–50 m from the influencing river or drain. Each plot had a size of 100 m^2. At each study area we determined soil type from a soil profile (1 m deep, 1 m wide) applying the classification of FAO (1998).

At the start of the experiment we took three soil samples in each plot at three depths (0–5 cm, 5–10 cm, and 10–20 cm) (i.e. 27 samples per study area) to determine soil chemical and physical properties (texture, density, pH(KCl), CEC, organic matter content (OM), Ntot, Ptot, Pbtot and Zntot) (Table 1). We also determined infiltration rate with a double ring infiltrometer in three replications in each plot (Hartge and Horn, 1992). In October 2003 we repeated sampling and analysis at the depths of 0–5 and 5–10 cm in the same plots to determine changes in soil properties caused by sedimentation. In October we analysed selected soil chemical parameters that are supposed to be influenced by inundation processes in a short time study (OM, Ntot, Ptot, Zntot and Pbtot) (Walling et al., 1997).

In April 2003, in each plot we inserted two plastic tubs (0.90 m length, 0.60 m width, 0.50 m depth) to collect sediment load in case of inundation, i.e. six replications per study site. Immediately after each inundation, we collected sediment samples in the tubs. We analysed chemical and physical properties of the sediment collected (texture, density, pH(KCl), OM content, Ntot, Ptot, Zntot and Pbtot) (Table 1).

Furthermore, in April 2003 we inserted 18 sticks (0.50 m length) 1 m apart in each plot to measure the quantity of sediment that was deposited during inundation events. The sticks were marked 30 cm from the ground. After each inundation we measured the differences between the mark at the sticks and the soil surface. Based on these measurements we calculated the amount of sediment deposited.

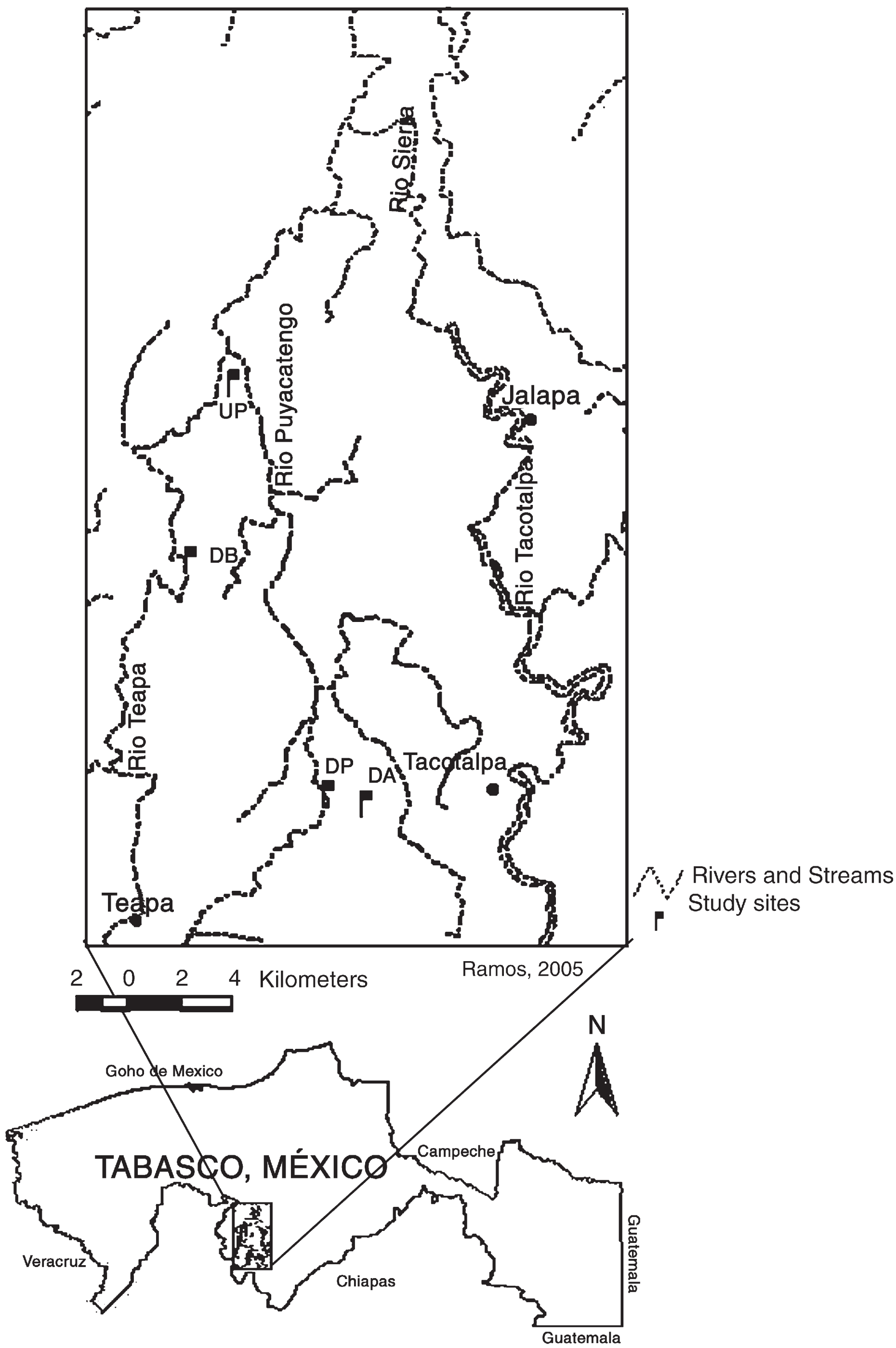

Fig. 1. Location of the study sites in Teapa, Tabasco (DA = drained agricultural land, DP = drained pasture land, DB = drained banana plantation, UP = undrained pasture land).

3.2. Data analysis and calculations

We used the K–S test to test for normality of the distribution. For normal distributed data we used ANOVA to estimate significant differences of soil properties between samples from before and after inundations (April and October). Furthermore, we used ANOVA followed by a Scheffé test to analyse

Table 1
Analysis of soil chemical and physical parameters (due to SEMARNAT, 2000)

Parameters	Methods of analysis
pH(KCl)	Determination in 1 m KCl
Ptot, Zntot, Pbtot	Extraction in HCl/HNO_3
Cation exchange capacity (CEC)	Exchange with Ag-tiurea
Organic matter	Walkley and Black
Ntot	Kjeldahl
Texture, density	Bouyoucos

differences in quantity and properties of the sediment deposited in the different study sites.

We calculated (i) sediment quantity (t ha^{-1}) based on the thickness of the sediment deposited and its density; (ii) nutrient deposition on the soil (t ha^{-1}) based on nutrient content in the sediment and sediment quantity; (iii) amount of nutrients (t ha^{-1}) based on nutrient content in the soil (0–5 cm depth) and soil density; (iv) nutrient net changes (t ha^{-1}) based on the difference of nutrient content before and after sedimentation; and (v) nutrient losses by the difference of nutrient deposition and nutrient net changes in the soil. Thus, we applied the following equations:

$$\text{Sediment deposited (t ha}^{-1}) = \text{differences between the mark of the stick} \times \text{and soil surface (cm)} \times \text{density of the deposited} \times \text{sediment (g cm}^{-3}) \times 100 \quad (1)$$

OM-, Ntot, Ptot and Zntot deposition during study time:

$$\text{OM deposited (t ha}^{-1}) = \sum \text{OM (g OM 100 g}^{-1}\text{ sediment deposited)} \times \text{sediment quantity (t ha}^{-1}) \times 10^{-2} \quad (2)$$

$$\text{Ntot deposited (t ha}^{-1}) = \sum \text{Ntot (g N 100 g}^{-1}\text{ sediment deposited)} \times \text{sediment quantity (t ha}^{-1}) \times 10^{-2} \quad (3)$$

$$\text{Ptot deposited (t ha}^{-1}) = \sum \text{Ptot (mg Ptot kg}^{-1}\text{ sediment deposited)} \times \text{sediment quantity (t ha}^{-1}) \times 10^{-6} \quad (4)$$

$$\text{Zntot deposited (t ha}^{-1}) = \sum \text{Zntot (mg kg}^{-1}\text{ sediment deposited)} \times \text{sediment quantity (t ha}^{-1}) \times 10^{-6} \quad (5)$$

OM-, Ntot and Ptot amount in the soil in 0–5 cm depth (t ha^{-1}):

$$\text{OM (t ha}^{-1}) = \text{g OM 100 g}^{-1}\text{ soil} \times 500\text{ m}^3 \times \text{density (g cm}^{-3}) \times 10^{-2} = 5\text{OM (g 100 g}^{-1}\text{ soil)} \times \text{density (g cm}^{-3}) \quad (6)$$

$$\text{Ntot (t ha}^{-1}) = \text{g Ntot 100 g}^{-1}\text{ soil} \times 500\text{ m}^3 \times \text{density (g cm}^{-3}) \times 10^{-2} = 5\text{Ntot (g 100 g}^{-1}\text{ soil)} \times \text{density (g cm}^{-3}) \quad (7)$$

$$\text{Ptot (t ha}^{-1}) = \text{mg Ptot kg}^{-1}\text{ soil} \times 500\text{ m}^{-3} \times \text{density (g cm}^{-3}) \times 10^{-6} = 5\text{Ptot (mg kg}^{-1}\text{ soil)} \times \text{density (g cm}^{-3}) \times 10^{-4} \quad (8)$$

OM-, Ntot and Ptot net change in the upper 5 cm of the soil from April to October (t ha^{-1}) (here shown an example for OM):

$$\text{OM net change (t ha}^{-1}) = \text{t OM ha}^{-1}\text{ in Oct.t OM ha}^{-1}\text{ in April} \quad (9)$$

OM, Ntot and Ptot losses from time of deposition until October (example for OM):

$$\text{OM loss (t ha}^{-1}) = \text{OM deposited in study period (t ha}^{-1}) - \text{OM net change (t ha}^{-1}). \quad (10)$$

4. Results

4.1. Inundations

During the period of investigation the undrained pasture site was inundated four times in the period between April and October, the drained banana plantation and agricultural land twice and the drained pasture land once (Table 2).

4.2. Soil characteristics

At all study sites soils were characterised by the influence of water. Eutric Gleysols were dominant in the drained agricultural land (DA) and eutric Fluvisols in the drained pastureland (DP). In the banana plantation (DB) stagnic Antrosols were found, due to the ridged

Table 2
Dates of inundation events in the four experimentation sites (–: no inundation)

Site	Dates of inundation in 2003			
Drained agricultural land (DA)	–	–	24/09	08/10
Drained pasture land (DP)	–	–	–	08/10
Drained banana plantation (DB)	–	–	24/09	08/10
Undrained pasture land (UP)	14/07	12/09	24/09	08/10

bed cultivation system. The undrained pastureland (UP) was characterised by gleyic Fluvisols.

Soil texture at the study sites varied from sandy loam (DA) to silt loam (DP, UP) and loam (DB). The infiltration rate ranged from 0.0007 to 0.0058 cm s^{-1} at all sites (Table 3). The soils at the sites DP, DB and UP were slightly basic with pH values between 6.94 and 7.82 whereas they were moderately acidic in the drained agriculture land (DA) with pH values of 5.4. At all sites the apparent density varied from 0.99 to 1.16 g cm^{-3}. Cation exchange capacity varied from 22.8 to 36.8 mmol g^{-1}.

4.3. Sedimentation

4.3.1. Quantity of sediment deposition and sediment properties

All data of sediment and soil properties are normally distributed. Therefore, we applied ANOVA to estimate significant differences.

At all study sites, the deposition of sediment showed a high variability in the quantity of sediment deposited (Table 4). There was also a big variation between the distinct inundation events. The first and the last inundations only occurred in the undrained pastureland (UP). Consequently, comparisons between the sediment deposited at the different sites are only possible for the September and October inundations. During the September inundation the quantity of sediment deposited was significantly higher in DA: (133.7 t ha^{-1}) and DB (111.0 t ha^{-1}) than in natural pastureland (UP) where soil losses of 33.2 t ha^{-1} were registered. However, the October inundation led to significant higher sediment deposition in the undrained area (UP: 52.8 t ha^{-1}) and the drained pasture land (DP: 103.4 t ha^{-1}) than in the other drained sites (DA: −39.5 t ha^{-1} and DB: 12.5 t ha^{-1}). The total amount of deposition varied from 94.2 (DA) to 123.5 t ha^{-1} (DB) during the study in the drained areas. During the study time there were significant differences between the quantities of the single depositions between all sites. In the natural area the deposition was significantly higher (242.6 t ha^{-1} in total) due to the fact that at this site four inundations occurred during the study time. Total sediment deposition during the study ranged from 94.2 t ha^{-1} in DA to 242.6 t ha^{-1} in UP which corresponds to a thickness of sediment deposition of 0.9 cm to 2.4 cm. The number of inundations affects this range.

Table 3
Soil properties of the four study sites (DA, DP, DB, UP) in three soil depths measured in April 2003 (*x*=mean, *s*=standard deviation)

Depth (cm)	pH(KCl)		CEC (mmol g^{-1})		Texture	Apparent density (g cm^{-3})		Infiltration (cm s^{-1})	
	x	*s*	*x*	*s*		*x*	*s*	*x*	*s*
Drained agricultural land (DA)									
0–5	5.41	0.07	33.95	1.83	Sandy loam	1.01	0.02	0.0038	0.0011
5–10	5.43	0.04	31.30	0.28	Sandy loam	1.12	0.04		
10–20	5.49	0.07	36.80	0.00	Loam	1.16	0.01		
Drained pasture land (DP)									
0–5	7.22	0.14	22.81	0.73	Silt loam	1.00	0.01	0.0007	0.0001
5–10	7.23	0.15	23.58	1.10	Silt loam	1.03	0.03		
10–20	6.94	0.15	23.43	0.15	Silt loam	1.07	0.02		
Drained banana cultivation (DB)									
0–5	7.75	0.06	29.03	0.73	Loam	1.14	0.04	0.0048	0.0018
5–10	7.79	0.04	28.77	0.37	Loam	1.15	0.04		
10–20	7.82	0.05	28.51	0.00	Loam	1.13	0.02		
Undrained pastureland (UP)									
0–5	6.96	0.16	29.29	0.37	Silt loam	0.99	0.03	0.0058	0.0027
5–10	7.24	0.09	28.25	0.07	Silt loam	1.05	0.01		
10–20	7.39	0.06	26.38	2.57	silt loam	1.05	0.03		

Table 4
Quantity (t ha^{-1}), apparent density (g cm^{-3}) and texture of sediment deposited on the floodplains after inundation (x = mean, s = standard deviation) (DA = drained agriculture land, DP = drained pasture land, DB = drained banana plantation, UP = undrained pastureland)

Site	Date	Sedimentation (t ha^{-1})		Apparent density (g cm^{-3})		Sand (%)		Silt (%)		Clay (%)		Texture
		x	s	x	s	x	s	x	s	x	s	
DA	12/9	133.7 b	139	0.90	0.10	69.2 c	3.2	18.7 a	1.2	12.1 a	3.4	Sandy loam
	13/10	−39.5 a	98	0.92	0.05	60.6 bc	1.4	25.6 b	0.9	13.8 b	1.4	Sandy loam
Sum (t ha^{-1})		94.2										
DP	13/10	103.4 b	185	0.81	0.01	15.2 a	2.8	30.4 b	2.8	54.4 c	6.3	Clay
Sum (t ha^{-1})		103.4										
DB	12/9	111.0 b	157	0.87	0.28	32.5 a	10.8	37.7 b	3.1	29.7 b	13.8	Loam
	13/10	12.5 a	105	0.81	0.24	47.8 b	21.8	13.6 a	1.1	38.6 c	12.6	Sandy clay
Sum (t ha^{-1})		123.5										
UP	14/7	80.8	84	1.04	0.10	89.6	1.6	6.8	1.6	3.6	0.1	Sand
	12/9	−33.2 a	80	0.78	0.02	50.1 b	5.2	30.4 b	3.5	19.5 b	6.5	Loam
	13/10	52.8 b	79	0.76	0.01	86.4 c	9.2	10.0 a	9.2	3.6 a	0.3	Loamy sand
	24/10	142.2	138	0.78	0.02	59.2	12.4	28.2	8.2	12.6	4.2	Sandy loam
Sum (t ha^{-1})		242.6										

Significant differences between sediment deposition on the different sites at a single inundation event ($p<0.05$): a<b<c.
Significant differences between sand, silt or clay content of the sediment deposited on the different sites at a single inundation event ($p<0.05$): a<b<c.

The sediment deposited at the DP, DB and UP sites was moderately basic, and the material deposited on DA moderately acidic, as was the case for the natural soils in the respective areas. Sediment texture as well as its OM, Ntot and Ptot differed significantly between some sites (Tables 4 and 5). The percent of the sand fraction was significantly higher in DA and UP than in the other two sites and consequently the percent of silt and clay significantly lower (Table 4). Furthermore, the OM, Ntot and Ptot content in the sediment deposited on the floodplains of DA and UP was significantly higher than at the other sites. The C/N ratio in all sediments varied between 7.3 and 13.2. No differences were found in the Zn content of the sediments deposited on the different sites (Table 5). Pb was not detected in any sediment sample (detection limit: 0.01 mg kg^{-1}). Density of the sediment did not differ significantly between sites or inundation events and varied between 0.76 and 1.04 g cm^{-3}. The number of inundations obviously did not effect properties of sediments deposited by a single inundation.

4.3.2. Net changes in soil chemical properties during study period

At all sites some soil chemical parameters changed significantly in the upper 5 cm of the soils between April and October 2003 (Table 6). In the undrained pasture (UP) OM, Ntot and Ptot increased significantly. As at the other sites, only Ptot significantly increased at UP (Table 6). The heterogeneity of the deposition was shown by a very high standard deviation. The content of Zntot did not change significantly in any site in the upper 10 cm of the soils.

Nutrient losses were highest in UP and lowest in DP and DB (Table 7). OM losses ranged from 0.75 t ha^{-1} in DP to 18.7 t ha^{-1} in UP, Ntot losses from 0.05 (in DP) to 1.21 t ha^{-1} (in UP) and Ptot losses from −0.02 (in DP) to 0.32 t ha^{-1} (in UP). At the sites DP and DB, where less nutrients had been deposited, soil nutrient losses were lower than at the other sites. Obviously net changes in chemical soil properties were higher in the undrained area due to an increased number of inundations.

5. Discussion

In the area with superficial draining the number of inundation events was significantly lower than in the undrained area. However, properties of sediments deposited by a single inundation event in the drained agricultural area did not differ significantly from those deposited in the undrained area. Therefore, we assume that open ditch draining did not show any significant effect on sediment properties. Furthermore, we did not observe any effect of the cultivation systems on sediment accumulation or deposition rate.

The OM content in sediments varied from 2.3 to 12.9 g 100 g^{-1}. Bogen (2004) described similar OM contents in sediments of the Atna Catchment, Norway. The highest organic OM contents as well as the highest Ntot

Table 5
Chemical properties of sediments deposited on the floodplain after the single inundations and calculated total amount (Sum, t ha^{-1}) of elements deposited in study time (x = mean, s = standard deviation; OM = organic matter); significant differences between pH, OM, Ntot, Ptot or Zntot content in the sediment deposited on the different sites at a single inundation event ($p < 0.05$): a < b < c; ab = a and b

Site	Date	pH(KCl)		OM (g 100 g^{-1})		Ntot (g 100 g^{-1})		C/N		Ptot (mg kg^{-1})		Zntot (mg kg^{-1})	
		x	s	x	s	x	s	x	s	x	s	x	s
DA	12/9	6.6 a	0.2	12.9 b	3.9	0.61 b	0.2	12.3	1.6	1750 b	218	105.2	12.0
	13/10	6.4 a	0.2	10.0 b	2.6	0.55 b	0.1	11.4	1.1	1708	231	84.3	16.9
Sum (t ha^{-1})				13.3		0.6				0.30		0.01	
DP	13/10	7.5 b	0.2	3.3 a	0.4	0.19 a	0.0	9.4	1.1	800	43	77.3	2.0
Sum (t ha^{-1})				3.3		0.2				0.08		0.01	
DB	12/9	7.6 b	0.1	2.3 a	0.8	0.10 a	0.0	13.2	8.8	831 a	26.5	129.4	12.5
	13/10	7.8 b	0.1	2.8 a	0.2	0.17 a	0.0	8.0	0.4	900	100	85.7	18.0
Sum (t ha^{-1})				2.5		0.14				0.10		0.02	
UP	14/7	6.8	0.2	11.7	2.7	0.74	0.2	9.1	0.7	1425	198	108.2	1.4
	12/9	7.1 ab	0.5	9.2 b	1.9	0.61 b	0.1	8.8	0.5	1433 ab	138	100.5	4.4
	13/10	7.0 ab	0.3	7.7 b	0.7	0.52 b	0.1	7.3	0.3	2058	72	98.3	
	24/10	6.9	0.2	8.1	2.1	0.54	0.1	9.3	1.0	1658	177	94.7	
Sum (t ha^{-1})				21.9		1.4				0.41		0.02	

and Ptot contents were found in both soils and sediments of the drained agricultural land (DA) and of the undrained pastureland (UP). This may indicate that sediment is only transported over short distances. The pH values also coincide between soil and the sediment deposited at the various sites. The Ntot content of the sediments varied from 1900 to 6100 mg kg^{-1} (i.e. 0.19 to 0.61 g 100 g^{-1}) which was extremely high in comparison with sediments transported by other tropical rivers. In Australia, Ntot contents in some river sediments are 400–900 mg kg^{-1} (McArthur, 1991). The maximum Ntot content found in tropical rivers in Australia was 5800 mg kg^{-1} (Government of Western Australia, 2003). The high content of Ntot in the

Table 6
Changes in soil chemical parameters between April and October 2003 at the four study sites (x = mean, s = standard deviation, significant differences between April and October ($p < 0.05$: *, $p < 0.01$:**, $p < 0.001$: ***)

Depth (cm)	April		Oct.		April		Oct.		April		Oct.		April		Oct.	
	OM (g 100g^{-1})				Ntot (g 100 g^{-1})				P (mg kg^{-1})				Zn (mg kg^{-1})			
	x	s	x	s	x	s	x	s	x	s	x	s	x	s	x	s
Drained agricultural land (DA)																
0–5	6.77	1.52	7.73	3.92	0.40	0.06	0.34	0.05	1099	97	1425*	280	81.6	8.42	78.4	4.59
5–10	5.57	1.24	6.15	1.45	0.29	0.05	0.31	0.04	1108	186	1333	210	77.6	7.50	82.6	9.33
10–20	4.26	1.03			0.23	0.04			842	172						
Drained pasture land (DP)																
0–5	3.39	0.34	3.90	0.39	0.20	0.02	0.17	0.02	829	46	1030***	63	111.5	6.16	99.4	5.58
5–10	3.25	0.27	3.30	0.24	0.21	0.02	0.15	0.02	838	37	1061**	141	98.5	5.38	101.0	6.98
10–20	3.01	0.23			0.19	0.01			912	114						
Drained banana cultivation (DB)																
0–5	2.91	0.36	2.72	0.24	0.16	0.03	0.17	0.02	803	57	1010*	78	120.4	9.17	120.4	12.67
5–10	2.61	0.12	3.26	1.25	0.14	0.01	0.15	0.02	790	45	1021*	152	112.6	6.67	110.1	8.35
10–20	2.25	0.28			0.13	0.01			838	109						
Undrained pastureland (UP)																
0–5	4.70	0.24	5.33**	0.30	0.25	0.02	0.29**	0.01	1025	71	1210**	41	119.5	4.69	122.0	3.37
5–10	3.61	0.31	4.00	0.56	0.21	0.01	0.22	0.03	964	87	1171**	64	152.1	50.3	118.7	3.91
10–20	2.86	0.42			0.18	0.02			912	109						

Table 7
OM, Ntot and Ptot deposition by sediments (s) (t ha^{-1}), net change (c) of OM, Ntot, and Ptot content in the soil (t ha^{-1}) from April to October and OM, Ntot and Ptot losses after deposition (l) (t ha^{-1}) (calculated by Eqs. (2)–(10) in data analysis); significant changes in upper 5 cm of the soil: *$p<0.05$, **$p<0.01$, ***$p<0.001$

Site	OM-s	OM-c	OM-l	Ntot-s	Ntot-c	Ntot-l	Ptot-s	Ptot-c	Ptot-l
DA	13.3	4.85	8.45	0.60	0.31	0.29	0.30	0.17*	0.13
DP	3.30	2.55	0.75	0.20	0.15	0.05	0.08	0.10***	−0.02
DB	2.50	0.90	1.60	0.14	0.06	0.08	0.10	0.12*	0.02
UP	21.9	3.20**	18.7	1.40	0.19**	1.21	0.41	0.09**	0.32

sediments in the study area is probably due to the fact that the soils in the area also have a high to very high Ntot content (Secretaría de Medio Ambiente y Recursos Naturales, 2000). The Ptot content of the sediments varied from 800 mg kg^{-1} to 2058 mg kg^{-1}. This total P content in sediments is comparable with the Ptot contents found in other studies of river sediments in rural, but not industrialized catchments in the world (Walling et al., 1997; Olley and Caitcheon, 2000; Winter et al., 2001; Owens and Walling, 2002).

The Zn content in sediments ranged from 77.3 to 129.4 mg kg^{-1}. The Zn content in all sediments was below the trigger value of 200 mg kg^{-1} as defined by ANZECC and ARMACANZ (2000). The authors defined this trigger value as the maximal tolerable Zn content in sediment in freshwater. Rosales-Hoz and Carranza-Edwards (1998) and Bilos et al. (1998) reported similar Zn contents in sediments of the Coatzacozlcos River in Veracruz and Río de la Plata Estuary, Argentina. Zn contents in soils were below the trigger value of the Bundes-Bodenschutz- und Altlastenverordnung (1999) that defines the maximum tolerable value for Zn in agricultural used soils. The Zn contents of the study sites showed the same ranges as reported from soils in the area of the Coatzacozlcos River in Veracruz (Rosales-Hoz and Carranza-Edwards, 1998). However, considering the Zn load that is deposited with the sediments on the soils of all sites the trigger value of 1200 g ha $year^{-1}$ (Bundes-Bodenschutz- und Altlastenverordnung, 1999) which defines maximal tolerable Zn inputs in soil is strongly exceeded due to the high quantity of sediment deposited.

The losses of OM and Ntot that occur after deposition with the sediments can be explained by lateral fluxes, leaching, plant uptake and gaseous emission. We did not estimate the processes of OM, N and P losses in this study. However, we try to distinguish the reasons of the losses taking results of other studies into consideration.

Especially in tropical regions, decomposition and mineralization rates are described to be highly dependant on organic material quality, especially its C/N ratio (Alvarez-Sanchez and Harmon, 2003; Geissen and Morales Guzman, 2005). Due to the fact that the C/N ratio of the sediment in the study area was very low (7.3–13.2, Table 5) decomposition and mineralization rate should be high. Feller et al. (2001) described C mineralization in tropical pasture soils to range from 3.3 t C ha^{-1} $year^{-1}$ to 13.9 t C ha^{-1} $year^{-1}$ These authors described that mineralization increased with increasing C content of the soils. In our study, we estimated OM losses of 0.75 t ha^{-1} in DP and 1.6 t ha^{-1} in DB in 6 months, i.e. Corg. losses of 0.75 t ha^{-1} $year^{-1}$ in DP and 1.6 t ha^{-1} $year^{-1}$ in DB. According to Feller et al. (2001), these losses may be mainly explained by soil respiration and gaseous emission of CO_2. In the same sites we determined N losses in DP and DB of 50 to 80 kg ha^{-1} in 6 months. Walker et al. (2002) and Hefting et al. (2003) found gaseous N losses of 24–30 kg ha^{-1} $year^{-1}$ in riparian wetlands. According to their results, we assume that 20–30% of the N losses in DB and DP can be explained by gaseous N emission. Furthermore, plant uptake of N can be assumed to be 30–70 kg ha^{-1} $year^{-1}$ (Lohse and Matson, 2005). These processes may explain the main part of the N losses in these two study sites. However, in DA and UP we estimated N losses of 290 and 1210 kg ha^{-1} in 6 months and OM losses of 8450 kg ha^{-1} (DA) and 18700 kg ha^{-1} (UP). These losses cannot completely be explained by plant uptake or gaseous emission. The climatic conditions of the study area, which is characterized by annual rainfalls of nearly 4000 mm and superficial water flow of 20–30% (INEGI, 2002), i.e. 800–1000 mm annual superficial water flow, indicate severe lateral element transport by water. We assume that an important reason for the N and OM losses in these sites were lateral flux. Leaching may not be an important factor because we did not find increase in Ntot or OM in lower soil layers. Furthermore, in the main part of the year soils are saturated with water and very low vertical transport takes place.

Lateral transport is also thought to be the principal reason for P losses due to the fact that reducing conditions lead to P mobilization (Brümmer et al., 1971; Chacon et al., 2005). This process can also explain the increase of Ptot in DP, where the net change of Ptot in the soil was 0.02 t P ha^{-1} higher that its quantity deposited with the sediment.

6. Conclusion

The area with open ditch draining was less affected by inundation events than the natural area. Properties of the sediments deposited by a single inundation event were not influenced by the draining system. Open ditch draining in the study area combines the positive effects of reduction of inundation events with the limitation of Zn deposition on the floodplains. Furthermore, there is sufficient natural fertilizing (organic matter, nitrogen and phosphorus deposition on the soils of the floodplains) for nutrient needs in the floodplain soils caused by sedimentation after inundations. Therefore, we conclude that open ditch draining in similar areas can be recommended.

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