

AMAZONIAN DARK EARTHS IN BOLIVIA? A SOIL STUDY OF ANTHROPOGENIC RING DITCHES NEAR BAURES (EASTERN LLANOS DE MOJOS)

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With 5 figures and 1 table

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Summary: Archaeological, pedological and ethnobotanical research of the last decades brought new insights on the view on human-environment interrelations in the Amazon. In this context, we analyse possible links between Amazonian Dark Earths (Terra Preta do Índio) traditionally known from the central Amazon of Brazil and pre-Colombian Earthworks (ring ditches) in the Llanos de Mojos of Bolivia. By doing so, we also discuss the local inhabitants' perception of soils and scrutinise the importance of soil fertility. Therefore, various methods such as interviews, field surveys, soil profile discussions and laboratory analyses were applied. Results show that soils tend to have particular characteristics at ring ditches in contrast to surrounding areas. The combination of distinctively elevated phosphorus values, darker soil colour and the occurrence of potsherds indicate the presence of the Amazonian Dark Earth type "Terra Mulata" at ring ditch sites. Interviews reveal that local farmers are aware of the increased soil fertility of "Tierras Negras" within ring ditches. Nevertheless, incentives for using those soils are low due to the limited land use pressure and generally more favourable reference soils in contrast to central Amazonian Ferralsols. We finally discuss integrative approaches covering aspects of both physical and social science as pursued within the presented work in context of the dichotomy between human and physical geography.

Zusammenfassung: Archäologische, bodenkundliche und ethnobotanische Forschungen der vergangenen Jahrzehnte brachten neue Anstöße zur Betrachtung der Mensch-Umweltbeziehung in Amazonien. In diesem Kontext untersuchen wir mögliche Zusammenhänge zwischen Terras Pretas do Índio (Amazonian Dark Earths), welche bislang vor allem im zentralen Amazonasbecken Brasiliens verortet werden, mit präkolumbianischen Erdwerken (Earthworks, Rundgrabenanlagen) der Llanos de Mojos Boliviens. Dabei berücksichtigen wir ebenfalls die Wahrnehmung von Böden durch die lokale Bevölkerung und den allgemeinen Stellenwert von Bodenfruchtbarkeit. Hierfür wurden unterschiedliche Methoden angewandt, welche Interviews und Feldbegehungen sowie Profilsprachen und Laboranalysen umfassen. Die Ergebnisse zeigen, dass die Böden an Rundgrabenanlagen bestimmte Eigenschaften im Vergleich zu Referenzflächen aufweisen. Die Kombination aus deutlich erhöhten Phosphorwerten, dunkler Oberbodenfarbe und der Präsenz von Tonscherben deutet auf den anthropogenen Schwarzerdetyp „Terra Mulata“. Interviews zeigen, dass die erhöhte Fruchtbarkeit der „Tierra Negra“ an den Rundgrabenanlagen durch die lokale Bevölkerung wahrgenommen wird. Jedoch sind Anreize zur besonderen Nutzung dieser Böden auf Grund des niedrigen Landnutzungsdrucks kaum vorhanden. Auch sind die Referenzböden im Vergleich zu den Ferralsolen von Zentralamazonien allgemein fruchtbarer. Integrative Ansätze, wie in dieser Studie verfolgt, werden abschließend im Kontext der Dichotomie zwischen Humangeographie und der Physischen Geographie diskutiert.

Keywords: Amazonian Dark Earths, Terra Preta, Earthworks, ring ditch, Llanos de Mojos, integrative geography

1 Research perspectives on human-environment interrelations in Amazon

The view of the Amazon as a sparsely populated and anthropogenic untouched region before the arrival of the Europeans is getting increasingly questioned by ongoing researches. Especially researches on Amazonian Dark Earths (Terras Pretas do Índio) and pre-Columbian Earthworks brought new insights on the historical dimension of human-environment interrelations in the Amazon. Amazonian Dark Earths (ADE) were already noticed by scien-

tists in the 19th century (e.g. ORTON 1870), pre-Colombian Earthworks in the early 20th century (e.g. NORDENSKIÖLD 1913). Nevertheless, those findings were rarely discussed more intensively for nearly a whole century. This changed during the last decades as ethnobotanical and archaeological studies revealed the complexity of indigenous resource management strategies (e.g. POSEY and BALÉE 1989), settlement patterns and the large-scale landscape alterations by pre-Columbian societies throughout the Amazon (e.g. HECKENBERGER et al. 2003; ERICKSON 2008). Consequently, also the idea of the Amazon as an eco-

logically disadvantaged region inhibiting the creation of complex societies (MEGGERS 1971; WEISCHET 1980) got more and more criticised.

This risen interest in revealing the human history from different perspectives by studying the pre-Columbian legacy was of course also coupled with an interest in revealing the future potential of agriculture in the tropics. Amazonian Dark Earths (ADE) show that many pre-Columbian societies achieved to increase soil fertility in the long run by applying special soil and fire management practices including the incorporation of charcoal and other organic materials (GLASER et al. 2001; NEVES et al. 2003). Descriptions of ADE characteristics and differentiations to other soil types are available on a large scale (e.g. FALCÃO et al. 2009; GLASER and BIRK 2012; REBELLATO et al. 2009). Also research on pre-Columbian Earthworks such as raised fields, anthropogenic mounds, causeways, ring ditches or canals exhibit that pre-Columbian agricultural practices and settlement structures of past societies strongly differ from the present time (e.g. ERICKSON 2008; LOMBARDO et al. 2011; PRÜMERS 2004; WALKER 2008).

While research on ADE focuses mainly on the inner Amazon of Brazil, research on Earthworks concentrates on the southern Amazonian periphery (Bolivian Llanos de Mojos, Brazilian Mato Grosso). These different geographical locations imply different ecological settings for instance regarding climate, soils and vegetation (SCHULTZ 2009). However, only few studies scrutinize these differences in relation to pre-Columbian agricultural practices or try to reveal possible links between Earthworks and ADE. One of the few who picked up the latter is WALKER (2011) who achieved to establish a link between Earthworks and the occurrence of ADE postulated by ERICKSON (2008).

Much work on ADE and Earthworks is dedicated to reveal past human-environment interrelations, potentials for modern agriculture or the carbon sequestration potential of ADE farming. However, comparably few studies such as GERMAN (2003) scrutinize the importance of ADE and Earthworks for the livelihood of actual inhabitants. Therefore, this work puts an emphasis on revealing the relevance of (anthropogenic) soils for local smallholder farmers and their soil knowledge. Furthermore, possibilities and problems of integrating their soil knowledge into pedological research are evaluated. These tasks will support our main objective of figuring out the possible existence of anthropogenic soils, their characteristics and the interference on actual land use patterns at ring ditch sites in the eastern Llanos de Mojos of

lowland Bolivia. Finally, our approach of regarding land-use from both natural and social science perspective will be discussed in reference to the divide between physical and human geography.

2 Research area

The Llanos de Mojos (= Mojos) are savannas lying in between of the Andes in the west, the Brazilian Shield in the east and the central Amazon in the north. Our research area, the municipality of Baures and Huacaraje (province of Iténez), is located in the eastern part of Mojos (Fig. 1). This region can be described as typical for the Llanos de Mojos due to the flat topography of only some metres difference in elevation. Seasonally inundated bajíos (pampas) make up more than 80 percent (DENEVAN 2003, 239) of the area. Only few areas, mostly actual river levees and remnants of former levees are not subject to seasonally inundations due to their upper position and therefore called alturas. Most of the inundated bajíos are characterised by herbaceous vegetation while higher alturas exhibit dense tropical forests (NAVARRO and MALDONADO 2002). Many isolated altura fragments are mentioned as (forest) islands or islas (del bosque) (LANGSTROTH 1996). Besides vegetation also soils differ between Cambisols/Luvisols at alturas and clayey soils (Gleysols/Planosols) with low infiltration rates at bajíos (GEROLD 2008). Contemporary land use correlates to this ecological setting as pampas are mainly used for cattle ranching while alturas are used for agriculture and settlements.

Baures was chosen as research area due to the known presence of archaeological relicts such as ring ditches, fish weirs and causeways indicating the large scale of anthropogenic landscape alterations before the arrival of the European conquerors (ERICKSON 2008). Not only anthropogenic landscape relicts indicate that the natural ecosystem of Mojos was strongly transformed by historical and recent human activities, also non-forested inundated lowlands, constituting major parts of Mojos, might be a result of anthropogenic burning activities by pre-Columbian societies (ibid). Nevertheless we will focus on the alturas as ring ditches can be commonly found there.

Ring ditch perimeters vary between 300 and 5400 metres while depths and wideness account for several metres (ERICKSON 2010). Historical expedition documents and excavations indicate that they were used as former settlement areas and might have served for defensive purposes in combination with palisades (ibid). Population densities were generally

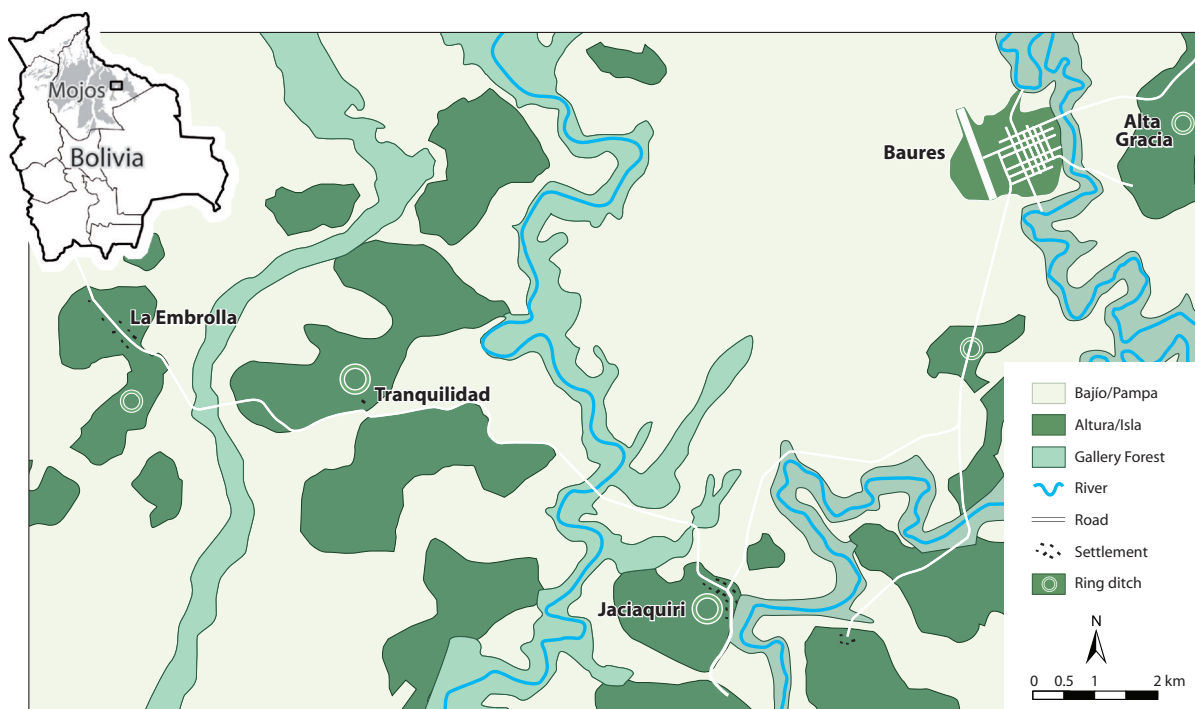


Fig. 1: Location of research areas

high before the arrival of the first Jesuit missionaries in the 17th century (ROBISON et al. 2000; WALKER and CORDERO 2004). Introduced diseases, slavery and displacements of the former inhabitants led to the abandonment of many areas.

Today many ring ditches cannot be perceived from the air as they are covered by dense forest vegetation. Several of those forests are characterised by an abundance of wild cacao (*Theobroma cacao*), a legacy which might be attributed to Jesuits missions during the 18th century (JORDÁ 2003). Some ditches are actually used for shifting cultivation such as the intensively cultivated ring ditch of Jaciaquiri (Fig. 1). Actual land use and economic activities in Mojos are generally limited to extensive cattle-ranching organised in big estancias, small-scale slash and burn agriculture and collection of wild cacao. The province of Iténez can be additionally characterised by its difficult access, its remote position and an extremely sparse population density (0.52 inhabitants per km², CONSULTADORES GALINDO 2003, 6). Most of the young population migrates to the bigger cities of Trinidad and Santa Cruz de la Sierra in search of educational and economic perspectives (DURÁN 2009). This massive migration often interrupts the social networks of remaining families resulting in a further destabilisation of rural areas (NEUBURGER 2007). Recent support by the government and NGOs is limited; most can

be accounted to the recent establishment of a TCO (Tierra Comunitaria de Origen) in a formerly uninhabited remote area of Baures. Our research focuses on the villages of Jaciaquiri (40 households) and La Embrolla (15 households). The former was officially founded more than a century ago at the location of a former estancia while the latter exists only for about 50 years. For analysing ring ditches we focussed on Jaciaquiri, the forest of Tranquilidad and Alta Gracia.

3 Applied methods

Methods from both natural and social sciences were applied to get a broader understanding on the interrelation between land management strategies and soil characteristics. About 50 soil profiles were gathered with a soil auger to get an overview on the interrelationship between ecological factors, soil characteristics and human use. All profiles were discussed according to the FAO guideline for soil description (FAO 2006a), the taxonomy was assigned to the World Reference Base for soil resources (FAO 2006b). Afterwards, 16 representative top soil samples were taken from a depth of 0–15 cm for more detailed laboratory analyses and interpreted according to Landon (1991). Thereby, emphasis was put on comparing different ecological settings, land use

and positions in respect to ring ditches. Each sample consisted of approximately 15 subsamples randomly taken at a representative and homogenous area of approximately 20 x 20 metres. Three ring ditch sites are represented by soil samples taken within the ditches and references taken outside the respective ditch. In the case of Jaciaquiri and Alta Gracia test areas were chosen according to the agricultural management stage for collecting comparable data (Tab. 1).

All 16 laboratory samples were analysed at the CIAT (Centro de Investigación Agrícola Tropical) in Santa Cruz de la Sierra and analysed for pH (1:5 KCl, 1:5 H₂O), electric conductivity, effective CEC, base saturation, Ca, Mg, Na, K, Al, P (Olsen modified), N (Kjeldahl), soil organic matter (Walkley-Black modified by Metson) and texture. Three top soil samples were additionally analysed at the BoWaSan (Boden Wasser Schutz) to reveal influences of past soil managements and chemical characteristics of ring ditches more profoundly. An emphasis was put on analysing macro- and micronutrients at different stages of availability beside basic parameters such as pH (KCl, H₂O), soil organic matter (SOM), C/N, potential/actual CEC, and base saturation. Analyses were carried out according ÖNORM (2004) and HUSZ (2001). The same samples were analysed at the Faculty of Geoscience and Geography (University of Göttingen) in relation to labile and stable carbon fractions for analysing the possible influence of organic material combustion by former inhabitants. Therefore, two methods are used, an extraction procedures with Na₂S₂O₈ after HELFRICH et al. (2007) and measurements with the RC-412 Carbon Determinator (Leco).

Soil colour was determined as an important factor for identifying Amazonian Dark Earths (KÄMPF et al. 2003; REBELLATO et al. 2009). Therefore, top soil colours of 81 additional samples were estimated using a Munsell colour chart at the forest ring ditch La Tranquilidad. Samples were collected at a depth of 15 cm using plastic bags, positions were chosen randomly along a given path and marked on a GPS device. Colours were assigned after collecting samples, bag numbers were assigned randomly to avoid subjective colour estimations due to the sample position.

Social science methods included expert interviews with political decision makers and representatives of NGOs. Structured interviews (n=55) were carried out at a household level in the villages of Jaciaquiri and La Embrolla. The questionnaire focussed on family sizes, agricultural activities and additional income sources. A mix of existing methods in the field of Ethnopedology (ODWATER and MARTIN 2003) was used to reveal local knowledge on agriculture and soils. Unstructured field surveys were conducted with several farmers to get an understanding of their view on agricultural practices. Further group discussions and participatory mapping exercises were held with approximately 15 participants at the village of Jaciaquiri regarding land use, social and economic settings, agriculture and soil knowledge. Detailed semi-structured interviews were conducted with 16 farmers to gather information about agricultural practices, local soil taxonomy, crop plants and soil management. Nine soil samples were discussed separately with 16 farmers. Samples were collected according to soil differentiations mentioned by farmers at field surveys and revealed by own soil surveys.

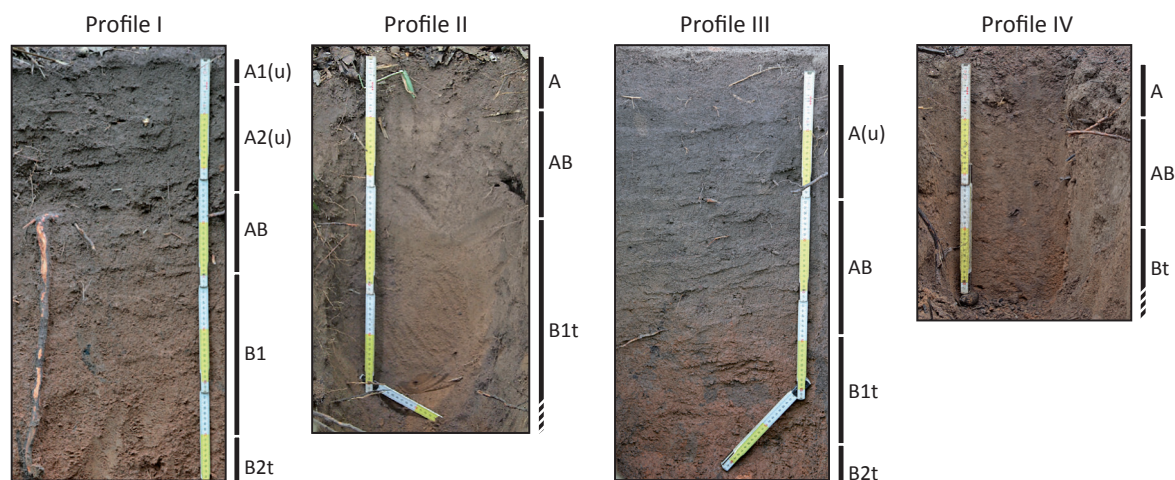
4 Results

4.1 Soil properties at ring ditch sites

Profile excavations carried out in the research area revealed the strong influence of few metres difference in altitude for soils. At bajios Planosols and Histosols were prominent while Fluvisols and Plinthosols dominated near rivers. As agriculture and ring ditches are concentrated at alturas we will focus on the soils there. Profile discussions (Fig. 2) clearly demonstrate strong chemical weathering processes such as clay displacement typical for altura soils in our research area. With increasing depth profiles show an increase of clay content, decrease of pH and more intense colour. Due to the subsurface accumulation of low activity clays, low CEC and high base saturation those soils can be viewed as be-

Tab. 1: Overview on collected soil samples

Soil sample type and locations	Purpose	Number
Soil auger profiles in whole research area	Gaining an overview	n=54
Top soil samples at Tranquilidad round ditch	Colour measurements	n=81
Soil profile samples at representative areas	Laboratory analyses	n=16
Soil samples representing local soil taxonomy and soil diversity	Discussion with farmers	n=9



Profile I – Tierra Negra site under forest vegetation

Location: Tranquilidad inside ring ditch; Land use: Forest, wild cacao collection

Hor.	Depth	Colour	Texture	Bulk Density	pH*	Soil structure	Roots	Org. matter (%)
A1(u)	5 cm	7.5YR 3/2	SL	intermediate	5.8	single grain/granular	common	2-4
A2(u)	25 cm	5YR 3.5/3	SL	intermediate	5.4	single grain/granular	few-common	1-2
AB	40 cm	5YR 4/4	SL	intermediate	5.4	single grain/coherent	few	0.6-1
B1	70 cm	5YR 4/6	SC	intermediate	4.8	single grain/coherent	very few	0.9-1.5
B2t	95 cm	5YR 5/8	SCL	intermediate	4.7	single grain/coherent	very few	0.3-0.6
B3t	110+ cm	5YR 5/8	SCL	intermediate	4.6	coherent/single grain	very few	0.3-0.6

Profile II – Non-Tierra Negra site under forest vegetation

Location: Tranquilidad outside ring ditch; Land use: Forest, wild cacao collection

Hor.	Depth	Colour	Texture	Bulk Density	pH*	Soil structure	Roots	Org. matter (%)
A	10 cm	7.5YR 3.5/3	SL	intermediate	5.3	single grain/granular	common	1-2
AB	30 cm	7.5YR 4/3	SCL	intermediate	-	single grain/granular	few	0.6-1
B1t	70+ cm	5YR 5/6	SCL	intermediate	-	single grain/coherent	very few	0.3-0.6
B2t	90+ cm	multiple	CL	firm-very firm	4.2	coherent/single grain	very few	< 0.3

Profile III – Cultivated Tierra Negra site

Location: Jaciaquiri inside ring ditch; Land use: Agriculture (maize)

Hor.	Depth	Colour	Texture	Bulk Density	pH*	Soil structure	Roots	Org. matter (%)
A(u)	25 cm	7.5YR 3/2	SL	loose-interm.	6.8	single grain/granular	common	2-4
AB	50 cm	5 YR 4/4	SCL	loose-interm.	6.3	single grain/coherent	few	0.9-1.5
B1t	70 cm	5 YR 4/6	SCL	intermediate	6.0	coherent/single grain	very few	0.9-1.5
B2t	100+ cm	5 YR 5/6	CL	intermediate	5.2	coherent	none	0.3-0.6

Profile IV – Cultivated Non-Tierra Negra site

Location: La Embrolla, small ring ditch further away; Land use: Agriculture (maize)

Hor.	Depth	Colour	Texture	Bulk Density	pH*	Soil structure	Roots	Org. matter (%)
A	10 cm	7.5YR 4/3	SL	loose-interm.	5.8	single grain/granular	common	0.6-1
AB	30 cm	5YR 4/4	SCL	loose-interm.	4.4	single grain/coherent	few	0.6-1
Bt	45+ cm	5YR 4.5/6	SCL	intermediate	4.5	coherent/single grain	very few	0.4-0.6

*) pH 1:5 H₂O

Fig. 2: Typical soil profiles of altura locations in the research area, all profiles belonging to the WRB class of Lixisols

longing to the WRB class of Lixisols (FAO 2006b). Profiles I and II represent typical altura sites under forest vegetation while profiles III and IV represent altura sites under agricultural use. Profiles I and III were excavated inside ring ditches, profiles II and IV outside.

Assessing the influence of pre-Columbian soil management within agricultural fields is generally difficult due to the influence of recent land use. Therefore, we conducted our first soil profile analyses at the less “disturbed” ring ditch site in the Tranquilidad forest. The different top soil characteristics of profiles excavated within and without the ring ditch are remarkable. Inside, a notable dark top soil horizon reaches a depth of 25 cm. Within this prominent top soil potsherds and charcoal fragments can be found. In contrast, most top soils outside the ring ditch exhibit a much lighter top soil colour and shallower depths (Fig. 2 Profile I–II, Fig. 3). Also vegetation differs inside the ring ditch due to the prominence of *Theobroma cacao* and more clear undergrowth vegetation. Profile III is characteristic for areas within the ring ditch of Jaciaquiri due to the profound and dark coloured top soil horizon. The transition to the sub soil is less prominent compared to Tranquilidad due to the influence of recent agriculture. Potsherds can be found easily also within this ring ditch indicating the influence of past inhabitants. PH values are higher than at the Tranquilidad forest ring ditch due to the effect of burning and decreased litter decomposition. Soil auger analyses showed that top soil colours at the whole Isla of Jaciaquiri are generally dark (mostly Munsell 7.5YR 3/2). In contrast, most other Islands such as La Embrolla exhibit lighter (Munsell 7.5YR 4/3 to 7.5YR 4/4) and less profound top soils (profile IV) as already revealed at the profile outside of the Tranquilidad ring ditch (profile II).

As suspected, laboratory analyses reveal a general low sorption capacity of altura soils due to the sandy structure and the assumed dominance of dioctahedral clay minerals (such as Kaolinit) offering only few nutrient reserves. Nevertheless, some characteristics can be distinguished in line with the soil profile findings (Fig. 4). The difference of P is remarkable at all three test sites as values are even more than three times higher inside ring ditches and strongly indicates long-term anthropogenic influences. In contrast, many other nutrient values increase only moderately within ring ditches which can be partly attributed to the influence of recent land management. The effect of recent slashing and burning of former fallows is clearly visible as alkaline ashes temporarily increase

pH levels at those sites. Interestingly, all Jaciaquiri samples show higher SOM and N values compared to La Embrolla despite comparable management strategies. However, analysis of carbon fractions shows only small differences among the three samples. The stable fraction ranges from 17 to 23%. The generally lower nutrients values of the Tranquilidad profiles correlate with decreased pH values due to intense litter decomposition on forest soils. In contrast, regular burning at agricultural fields has a positive effect on pH values. More detailed soil analyses carried out by the BoWaSan in Vienna confirm the presented findings. Furthermore, no toxic Al- or Fe-levels could be detected and trace elements are available sufficiently at ring ditch sites except for Mo and Cu.

Summarising the above profile excavations and laboratory analyses indicate different soil characteristics within all three ring ditches observed. Potsherds found and the presence of the ring ditch show that past societies strongly modified their environment at these particular places. Therefore, it is likely that the increased soil fertility is of anthropogenic origin.

4.2 Land use and soil knowledge of local farmers

Most areas of Baures and Huacaraje are characterised by extensive cattle ranching driven by big estancias. However, smallholder farmers pursue different land use strategies as agricultural activities are concentrated on altura areas which are usually owned collectively by the respective village members. Household surveys show that slash and burn agriculture, the collection of wild grown cacao and occasional employments at nearby cattle ranches are the most important income sources. Cacao collection got increasingly relevant because of recently rising prices and poses the main source of monetary income of many households (44 out of 55 households collect, pre-process and sell cacao). Nearly all households interviewed pursue subsistence agriculture highlighting its importance. Many farmers of Jaciaquiri also sell harvests on the regional market in contrast to La Embrolla. Agricultural practices can be generally characterised as small scale rotational slash and burn, most work is performed manually. Average field sizes per household lie at 1.9 ha in Jaciaquiri and 1.6 ha La Embrolla. Fields are normally cultivated between 2 and 5 years and fallowed for at least 4–5 years. Incentives for more intensified cultivation do not exist due to the isolated location, long market distance and intensive emigration.

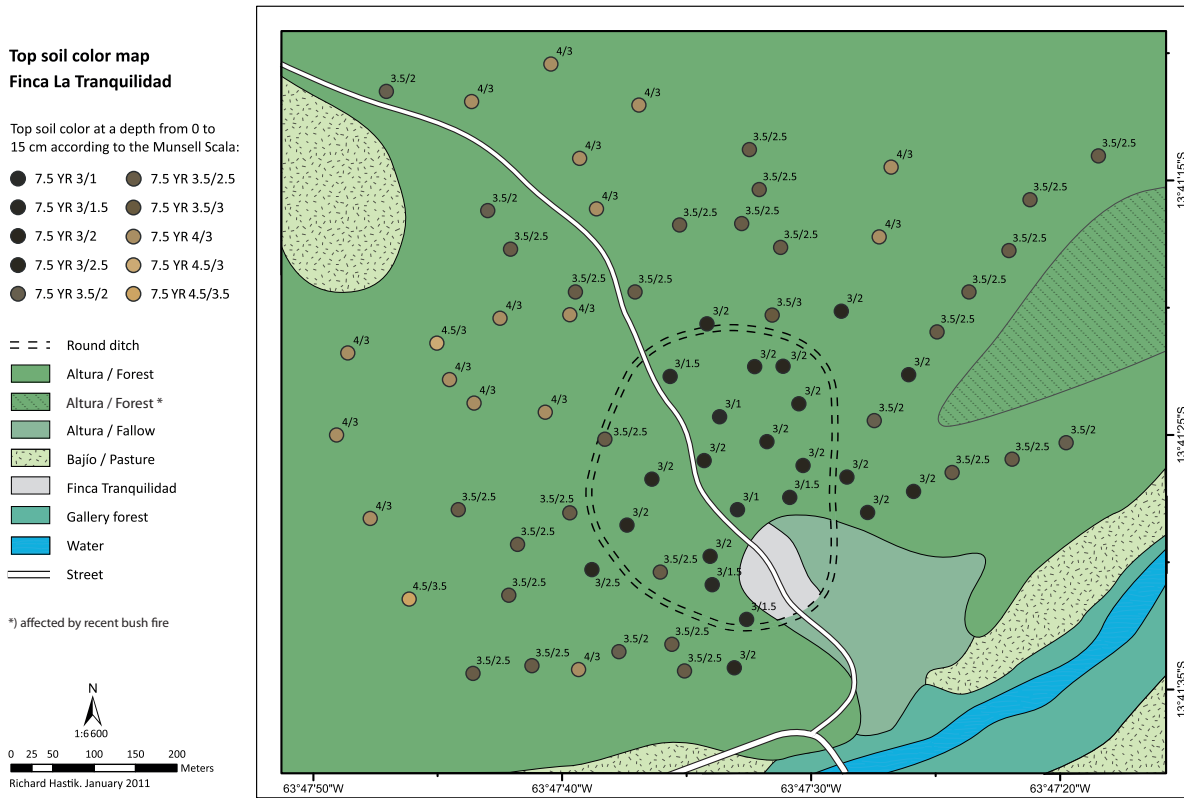


Fig. 3: Top soil colour map of forested ring ditch Tranquilidad (compiled by authors)

Therefore, only few land scarcities occur although most agricultural production is limited to the relatively small altura areas.

The weaker focus on agriculture in La Embrola can be attributed to the fact that many villagers work at the nearby Finca La Tranquilidad and to the longer existing settlement of Jaciaquiri. Nevertheless, the question arises whether also different soil characteristics have led to a more intense agriculture in Jaciaquiri. To settle this question we first scrutinize local soil knowledge in both villages and reveal soil properties at several altura sites afterwards.

Group discussions hold with villagers of Jaciaquiri show that many farmers recognize most fertile soils within the ring ditch. However, agricultural practices (e.g. crop selection) do not differ in respect to the location of the ring ditch in Jaciaquiri except for longer cultivation periods. Interestingly, nearly all parts of the Isla Jaciaquiri were mentioned as very fertile except for soils exhibiting ferralitic concretions (“cascajo”) and river levee soils. Further information on local soil knowledge was gained by conducting soil sample discussions. An overview on the four most relevant altura soil samples discussed with farmers is given in figure 5. The sample origi-

nating from the ring ditch Jaciaquiri (sample A) was mentioned as “tierra negra” by local farmers without knowing the sample origin. All farmers interviewed highlighted its high fertility and several even use this soil as ingredient for organic fertilizer. This soil is mentioned as suitable for the cultivation of many different crop types. However, farmers did not refer this soil type explicitly to the location of ring ditches as dark coloured soils seem to be common on several parts of Jaciaquiri. Sample B, originating from the south-western part of the Isla Jaciaquiri 800 metres from the ring ditch was also mentioned as fertile and also named as “tierra negra”, but with “cascajo” due to its ferralitic concretions. The dark colour of this soil sample is not distinguishable from sample A. Some farmers mentioned that the concretions do not have an effect while others reported faster soil desiccation making rice cultivation therefore more difficult. In contrast to the first samples most farmers could not give a typical name for sample C. Soil surveys showed that this soil can be commonly found at alturas when tierras negras are absent. Statements made by farmers varied, especially in context of crop suitability. Nevertheless, the looser structure and increased sand content was recognised by several farm-

Position	pH	Ca	Mg	Na	K	CEC	BS	P	SOM	N	El. C.	Sand	Silt	Clay
Jaciaquiri ring ditch, maize field*	8.0	4.8	1.2	0.09	0.41	6.5	100	42	2.9	0.20	178	57	36	7
Jaciaquiri ring ditch, fallow	6.6	3.7	0.8	0.08	0.17	4.9	97	20	3.4	0.17	55	68	19	13
Jaciaquiri near ring ditch (20m), platano field	7.1	3.1	0.7	0.08	0.21	4.1	100	20	2.9	0.16	55	58	25	17
Jaciaquiri 800m from ring ditch, maize field	6.8	2.3	0.7	0.05	0.05	3.2	97	3	2.2	0.13	36	56	29	15
Jaciaquiri 800m from ring d., recently burned**	7.6	3.0	0.8	0.08	0.16	4.0	100	5	2.6	0.15	85	58	30	12
Alta Gracia ring ditch, recently burned	7.8	6.8	1.8	0.08	0.23	8.9	100	42	2.9	0.20	131	61	26	13
Alta Gracia 80m from ring ditch, maize field	7.2	2.6	0.7	0.09	0.26	3.6	100	9	2.0	0.11	89	69	21	10
Tranquilidad ring ditch, forest	6.7	2.6	0.6	0.07	0.17	3.6	97	15	2.4	0.13	56	63	25	12
Tranquilidad 100m from ring ditch, forest	5.7	0.9	0.4	0.05	0.06	2.1	67	4	1.9	0.11	34	82	10	8
La Embrolla, recently burned	6.9	2.1	0.8	0.09	0.31	3.4	97	11	1.4	0.05	115	67	24	9
La Embrolla, maize field***	6.6	1.4	0.6	0.05	0.14	2.3	95	6	1.2	0.07	42	74	17	9
La Embrolla, fallow	5.9	1.1	0.4	0.05	0.07	1.9	87	3	1.6	0.09	45	74	16	10

pH (1:5 H₂O), Ca Mg Na K (cmol/kg), CEC (eff., cmol/kg), BS (%), P (mg/kg), SOM (%), N total (%), electric conductivity (1:5 $\mu\text{S cm}^{-1}$), texture (%)

* = Figure 2 Sample A, ** = Figure 2 Sample B, *** = Figure 2 Sample C

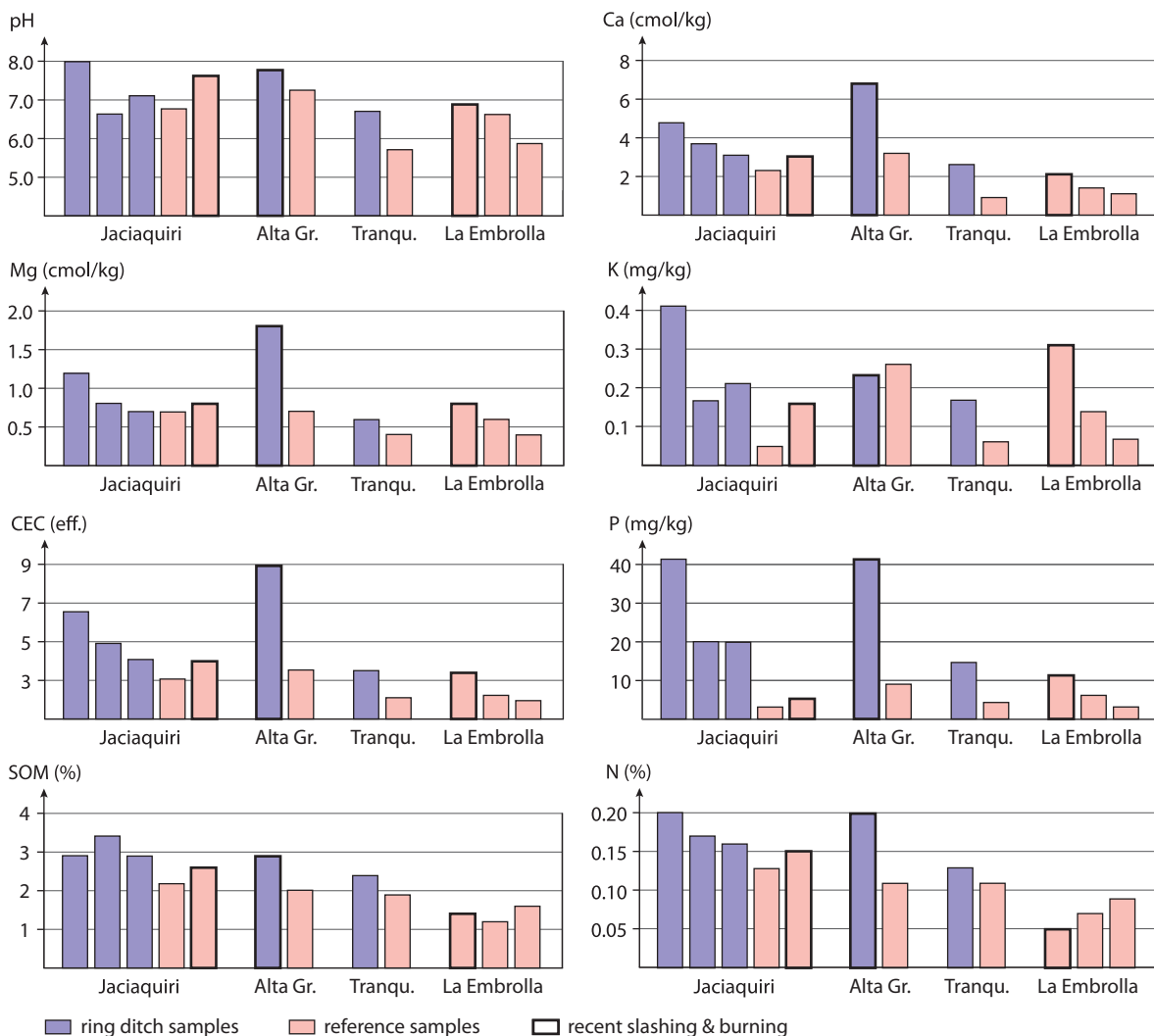


Fig. 4: Comparison of soil characteristics depending on ring ditch locations (CIAT Laboratory analysis)

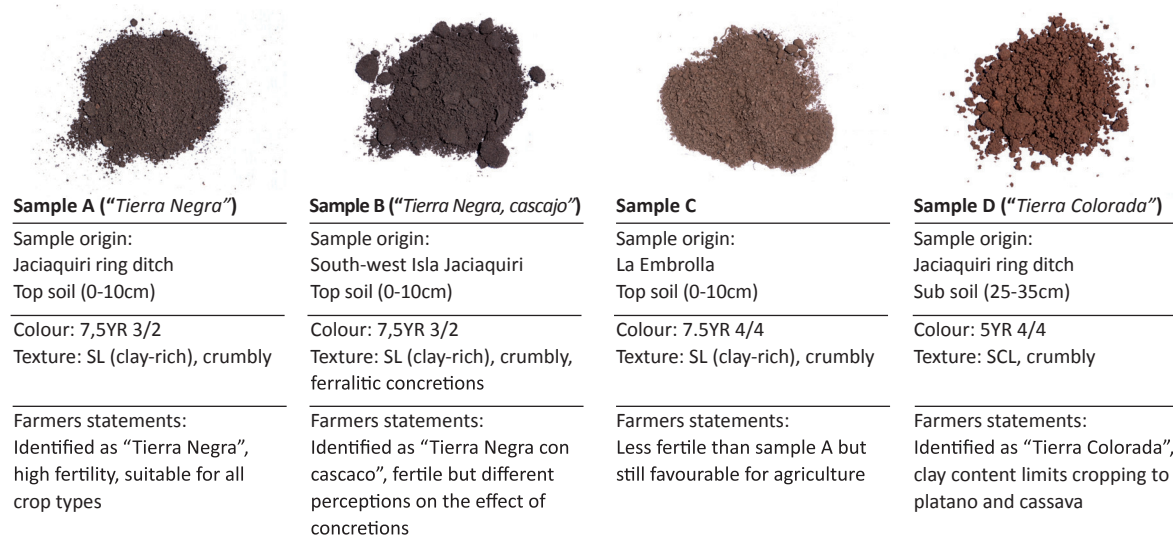


Fig. 5: Selection of altura soil samples discussed with farmers, all samples collected at maize fields

ers. In contrast to the first three samples "tierra colorada" was excavated at a deeper soil depth to inquire the recognition of the subsoil at altura sites. Many farmers recognised its high clay content resulting in a more difficult cultivation, which is mainly restricted to plantains and cassava. Interestingly, only one person mentioned that this sample originates from more profound depths showing that vertical delineation of soils applied by scientist has little relevance for local farmers.

Nevertheless, it was possible to get a broad overview on the local perception of different soils. No general differences could be revealed in between the villages of La Embrolla and Jaciaquiri as many statements varied depending on the social factors such as migration backgrounds or the farmers experience level in agriculture. It seems that both socioeconomic and ecologic factors led to a stronger focus on agriculture in Jaciaquiri. However, there are few incentives for intensive soil management strategies due to the moderate land use pressure caused by the long market distance, migration and other income sources besides traditional agriculture.

5 Discussion

Comparing tierras negras found in ring ditches with central Amazon ADEs is difficult due to the different reference soils in Mojos (Lixisols) and the central Amazon (Ferralsols). One of the most striking differences can be regarded in respect of pH levels. All reference samples collected at altura sites showed pH values above the central-Amazon

ADE average of 5.6 (H₂O) revealed by FALCÃO et al. (2009, 215). PH values within ring ditches even reach a slightly alkaline level. This can be attributed to the fact that the group of Acrisols and Lixisols are generally less acidic than background Ferralsols of the central Amazon (GEROLD 2008). Nevertheless, both Brazilian ADE and our ring ditch samples show an increased pH in contrast to the respective background soils. REBELLATO et al. (2009) mention soil colour, amount of pottery and phosphorus levels as most important factors for identifying the ADE types of terras pretas (TP) and terras mulatas (TM). In our case colours refer to TP but pottery quantity and phosphorus levels barely hit typical TP levels. Our samples are far away from central Amazon ADE phosphorus levels of more than 200 to 300 P mg/kg. However, focusing on relative values our results reflect the strong enrichment of P typical for ADE sites in contrast to reference soils exhibiting low values limiting agriculture (GLASER and BIRK 2012). Those strikingly increased P values strongly indicate past human influences which might be attributed to organic kitchen residues containing high proportions of fish (LEHMANN et al. 2003). Looking at the definition of ADE GLASER and BIRK (2012) also revealed multiple times enriched Ca, Mg, SOM and (slightly) increased amounts of K, Zn and Mg in contrast to surrounding soils. Most ADE provide typical CEC values of 13–25 cmol/kg contrasting surrounding soils having a low capacity to hold nutrients due to presence of kaolinite and quartz (ibid). Again, our results do not reach typical TP values but the variances in contrast to surrounding soils resemble to those observed in the central Amazon. The

local “tierra negra” prominent at ring ditches generally resembles more to TM except for their dark colour. Interestingly, dark coloured soils can be found throughout Jaciaquiri. However, they do not resemble to the values regarded within the ring (in particular P). Therefore, we do not associate those soils with ADE.

Our results correlate to the findings of WALKER (2011) who revealed the existence of TM in ring ditches of central Mojos. TM are believed to represent areas of former agricultural activities in contrast to the more prominent TP representing former settlement areas and horticultures (WOODS and McCANN 1999). Nevertheless, transitional TP/TM might exist punctually within ring ditches at the location of the former settlements. The decreased population density after the arrival of Europeans, introduced tools such as metal axes and a shift in land use strategies resulted in changing agricultural practices (DENEVAN 2003). Thus, TM are a product of formerly practiced long term mulching and frequent burning agriculture differing from today practiced long fallow shifting system (WOODS and McCANN 1999). As ring ditches are occurring commonly in Mojos it is likely that ADE (TM) are a widespread phenomenon for those parts of the southern Amazon periphery. Thus, TM can be generally regarded as a further result of the interrelation between former societies in Mojos and their local geo-ecological setting as revealed by LOMBARDO et al. (2012). However, incentives for using ADE seem to be less strong than in central Amazon due to the more favourable ecological setting, migration and the risen importance of wild cacao. The recently constructed soccer field inside the ring ditch Jaciaquiri can be regarded as an example for changing priorities and consequently arising trade-off decisions. Incentives for land use strategies change over time depending on particular technological, political, social, economic and ecological influences. These changes occur in mutual feedback loops. Socio-economic crisis and knowledge losses are consequently intertwined with environmental crisis, e.g. at the time when the Europeans arrived.

Evaluating the importance of anthropogenic soils for actual inhabitants was quite intricate due to the less prominent differences between anthropogenic soils and reference soils in contrast to the central Amazon. Therefore, specific crop preferences as stated by GERMAN (2003) could not be revealed for tierras negras. Moreover, it was generally difficult to communicate soil relevant questions without visual aids. For instance, it was difficult to communicate and question the idea of plants indicating a certain soil quality to

farmers as done within other studies (e.g. BARRIOS et al. 1994). Knowledge is passed on from generation to generation mostly by working on the field as no agricultural school exists in the research region. The importance of education for reflecting and verbalising this knowledge is mentioned by BIRMINGHAM (2003, 489). As a result, “*tacit knowledge*” (GIDDENS 1984) or “*performative knowledge*” (MINGERS 2008) is mostly accessible via observing actions performed. Underlying concepts are often hidden and require a time intensive cultural examination (DION 2010, 307).

Nevertheless, local knowledge can be seen as essential in the interface of managing sustainable agroecosystems, biodiversity and ecosystem function (ALTIERI 2004). Based on three studies in Latin America, also BARRIOS and TREJO (2003) emphasize the advances of combining both local and scientific knowledge for developing sustainable soil management strategies and consensus building. Examples of homegarden management in the Austrian Alps (VOGL-LUKASSER and VOGL 2004) and farming practices in Hungary (ENGEL-DI MAURO 2003) highlight that these approaches are definitely not limited towards the global south or “traditional” societies. Strategies focussed on the conversion of implicit to explicit soil knowledge in our research area could “stimulate the development of reflective routines” and “creating opportunities for (group) discussion” as proposed by STUIVER et al. (2004, 106). In contrast to conventional agriculture farmers should become self-aware “knowing agents” in the context of sustainable agroecosystem management (MORGAN and MURDOCH 2000). However, this might be hindered by the devaluation of local knowledge by many smallholder farmers themselves in contrast to scientific “standards”. The mentioned depreciation contrasts to the ongoing emancipation of many indigenous groups and highlights the importance of power and politics on the valorisation of local knowledge (BRIGGS and SHARP 2004). Links can be made to the divergent discourses at a global level between the promotion of “indigenous” movements for forest protection and critically observed slash and burn agriculture in context of forest destruction and carbon emissions (WEITZENEGGER 1992; WORLD BANK 2008, see also for the context of the Rio Negro region in Brazil NEUBURGER 2008). Also in Baures “indigenous” movements get strong support by NGOs while smallholder farmers are little regarded. Therefore, we suggest that both the process of knowledge valorisation and issues related to tacit knowledge have to be discussed more intensively in the context of development strategies and participatory approaches.

6 Conclusions and outlook

Studying soil management by applying methods from both physical and human geography helped us to scrutinize the interrelation between environmental and sociocultural changes in Mojos. The presented research objects of anthropogenic soils and local environmental knowledge overcome the dichotomy of “nature” and “culture” as often discussed in the context of integrative geography (e.g. GEBHARDT et al. 2007; WARDENGA and WEICHHART 2006). This view opens a wide research field in the intersection between social sciences (human geography) and physical sciences (physical geography) complementary to traditional, disciplinary bound science (HOLLING et al. 1998). Nevertheless, most efforts of German-speaking geographers on integrative research remained on a theoretical or philosophical level. By scrutinizing the concept of Social Ecology in the context of a Bolivian community RINGHOFER (2010) nicely illustrates how integrative theories can be transferred into empirical research. Plenty further concepts exist at the intersection of integrative science and integrative geography (such as Political Ecology, Environmental Social Science, Sustainability Science, Human Natural Systems Research) reflecting the ongoing discussions of the last decades. These discussions also reflect the claim for an integrative background theory as communication basis between geographers. In respect to our experiences, we raise the question whether it is reasonable to search for this integrative background theory if we regard geography as a discipline inherent of multiple paradigms (WEICHHART 2000, 2006). We rather support von GROOTE et al.’s (2011, 18) demand towards “dynamic, flexible swimmers” as communicators rather than a static bridge between the disciplines of human and physical geography. The actual system of research funding and evaluation is in disfavour of research on reflecting integrative research approaches (WEICHHART 2012). Therefore, we propose that future research on integrative geography should focus more on empirical and methodological problems. Our experiences within the presented work confirm that small to medium scale projects are an ideal setting for finding a common language within geographers and reflecting theoretical approaches.

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