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Table of Contents

Page

A geodatabase of the soil cultural heritage of Italy

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Abstract

Soils can possess heritage characteristics and can be classified according to their "cultural value". The methodology used to evaluate and group pedosites of Italy, and the software developed to collect such information and create a specific geodatabase, are presented in this paper as an example for use in other countries. A map and a geodatabase storing 726 pedosites of Italy was created. Soil profiles as cultural heritage were: i) paleosols, ii) soils from the archaeological and paleontological sites, iii) soil displaying natural or anthropic processes and benchmarks of classifications. Pedosites as soilscapes were: i) cultural landscapes; ii) soilscapes determining the amenity of a panorama; iii) soilscapes in fragile environmental balance; iv) soilscapes that contribute to the maintenance of particular ecosystems. The criteria for the evaluation of pedosites and the suggestions for their protection were indicated as following: i) area and ii) type of scientific interest, iii) state of conservation, iv) type and v) intensity of risk, vi) level of knowledge, vii) geological age, viii) protection and ix) proposed protection, x) accessibility, xi) visibility, xii) exposure, xiii) observability. The geodatabase can be used at different scales, from the national to the local level.

Key Words

Pedosite, geosite, paleosol, land planning, soil awareness, Mediterranean

Introduction

The geosite concept (that is a geological site having scientific, historic and cultural heritage interest) has been internationally acknowledged (Todorov and Wimbledon 2004). The Council of Europe committee of ministers, in the Recommendation Rec (2004) on conservation of the geological heritage and areas of special geological interest (Adopted by the Committee of Ministers on 5 May 2004 at the 883rd meeting of the Ministers' Deputies) recommends that governments of member states identify in their territories areas of special geological interest, the preservation and management of which may contribute to the protection and enrichment of national and European geological heritage. At the same time, it was suggested to develop national strategies and guidelines for the protection and management of areas of special geological interest, embodying the principles of inventory development, site classification, database development, site condition monitoring and tourist and visitor management, to ensure sustainable use of areas of geological interest through appropriate management. As a role, databases of geosites take into account a few of the most important paleosols, but other kinds of soils displaying cultural heritage still lack of a specific interest. More recently, there has been a trend towards the evaluation of some hitherto inadequately recognised soil functions (such as its role as guardian of biodiversity, safe keeper of many archeological, paleotechnological and paleontological treasures) of values which are not immediately or easily quantified in monetary terms (Yaalon and Arnold 2000). The doors have thus been opened to the idea of taking into account a whole series of, broadly speaking, cultural aspects linked to the knowledge accumulated on a pedological site. This information may be connected to that site or be functionally dependent upon it, to the extent that the soil can be considered to all effects and purposes - including legal aspects – as having a "cultural heritage". While it is true that all soils "narrate" the events which have taken place on a territory, and therefore possess a certain cultural value, some can nevertheless claim superiority over the others, either because of the quantity of information preserved or else because of the quality or importance of this data.

Although there is still a lack of widespread systematic work in Italy, an increasing number of pedologists have substantially amplified their sensibility towards the cultural values of the soil. Over the years, some basic concepts have been developed, which permitted to consider new categories of pedosites, besides paleosols (Costantini 1999). Work has been carried out at both a local scale (Arnoldus-Huyzenveld and Gisotti 1999) and a regional scale (Brenna and Rasio 1999; Costantini *et al.* 2007). The idea of collecting pedosites of Italy was born during the second international symposium on the conservation of our cultural heritage, held in Rome in 1996. A pedosite was defined there as a georeferenced soil having cultural heritage, that is, a soil exposure or a soilscape where an extraordinary cultural interest has been recognized (Costantini 1999). In fact, a pedosite can take the form of an exposure or a trait of land, as soil possesses

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both a vertical dimension – the profile – and a horizontal dimension – the soilscape. The actual collection of the pedosites started in the year 1999, as a side-activity of the national project dealing with the creation of a soil database of Italy and it is still in progress. The purpose of this work is to describe the methodology used to evaluate and group pedosites of Italy, and the software developed to collect such information and create a specific geodatabase. In addition, the map of pedosites having national interest is reported.

Methods

The collaboration of many soil surveyors made the census possible. The information was seldom published, so it was necessary to interview the surveyor to collect it. Paleosols are exceptions, as many published studies could be considered, giving the possibility to better assess the relative scientific relevance of the pedosites. The pedologists who signalled the pedosites also furnished an empirical evaluation of their value, which was maintained as either local or regional area of interest. The classification of national or international pedosites was obtained with a uniform and original method.

Soil profiles as pedosites

Soil profiles as pedosites were the followings:
i) Paleosols. Dated paleosols were considered particularly important, in that they can be used as stratigraphic markers and thus give more accuracy to the mapping of Quaternary formations. ii) Soils from the archeological and paleontological sites. Pedosites of this category were only signalled when there was a clear recognition of the input provided by pedological studies in understanding the environmental processes which exerted an influence on ancient human settlements. iii) Soils displaying at best natural and anthropic processes. Included in this group were the soils representing the main taxonomic units of the pedological classification, as well as the benchmark profiles of the main types of Italian soil.

Soilscapes as pedosites

Soilscapes declared as pedosites included:
i) Soils characterising a precise and important cultural landscape. The characteristics of the soil, its fertility and the agricultural landscape are factors which interact to form a characteristic “whole” or “unit”. ii) Soils as panoramic beauty. These soils were acknowledged as contributing to the amenity and attractiveness of a landscape through their colour. iii) Soils occurring in fragile environmental balance. iv) Soils that support fragile ecosystems, like soils related to specific biotopes, in particular, some wetlands.

Criteria for the evaluation of pedosites

The classification of the pedosite value followed the specifications of the pedosite category.
i) Level of interest (importance). The pedosites were classified of international, national, regional and local interest. ii) Types of scientific interest. Every pedosite was specified up to five types of interest. iii) State of conservation. iv) Type of risk to lose natural/cultural heritage. v) Degree of risk to lose natural/cultural heritage. vi) Level of knowledge. The cultural value of a pedosite took into account the quantity and quality of the studies carried out on it. vii) Geological age. In this section the estimated age of the pedosite was reported, when possible and relevant. Eight classes were considered: Holocene, late, middle and early Pleistocene, Pliocene, Miocene, ages prior to these. viii) Protection. A pedosite belonging to a protected area was considered particularly worthy, not only because its conservation was deemed easier, but above all because its potential scientific, didactic, and touristic values were enhanced. ix) Proposed protection, or “measures”. x) Accessibility. xi) Visibility. xii) Exposure. xiii) Observability.

The geodatabase

An original geodatabase was created to store the pedosites. Since pedosites could be either soil profiles or soilscapes, every record of the new geodatabase referred to a point or an areal location (polygon). Therefore, every soil profile was located with its point coordinates, while a soilscape was formed by one or more polygons. The database created runs with the software Access® (versions 2000 and followings) and its tables were structured so as to be easily imported into national and international Geosites databases. Data can be entered by means of a form with combo box menus. The software permits to store photographs and to print the form of the pedosite. The main tables are: “t_pedosites”, “bibliography” and “Soil_region”. The fields of the table t_pedosites are those described in the paragraphs above, plus the identification codes, the local name of the soil, site indications (nation, region, province, place), pedosite surveyor, soil classification,

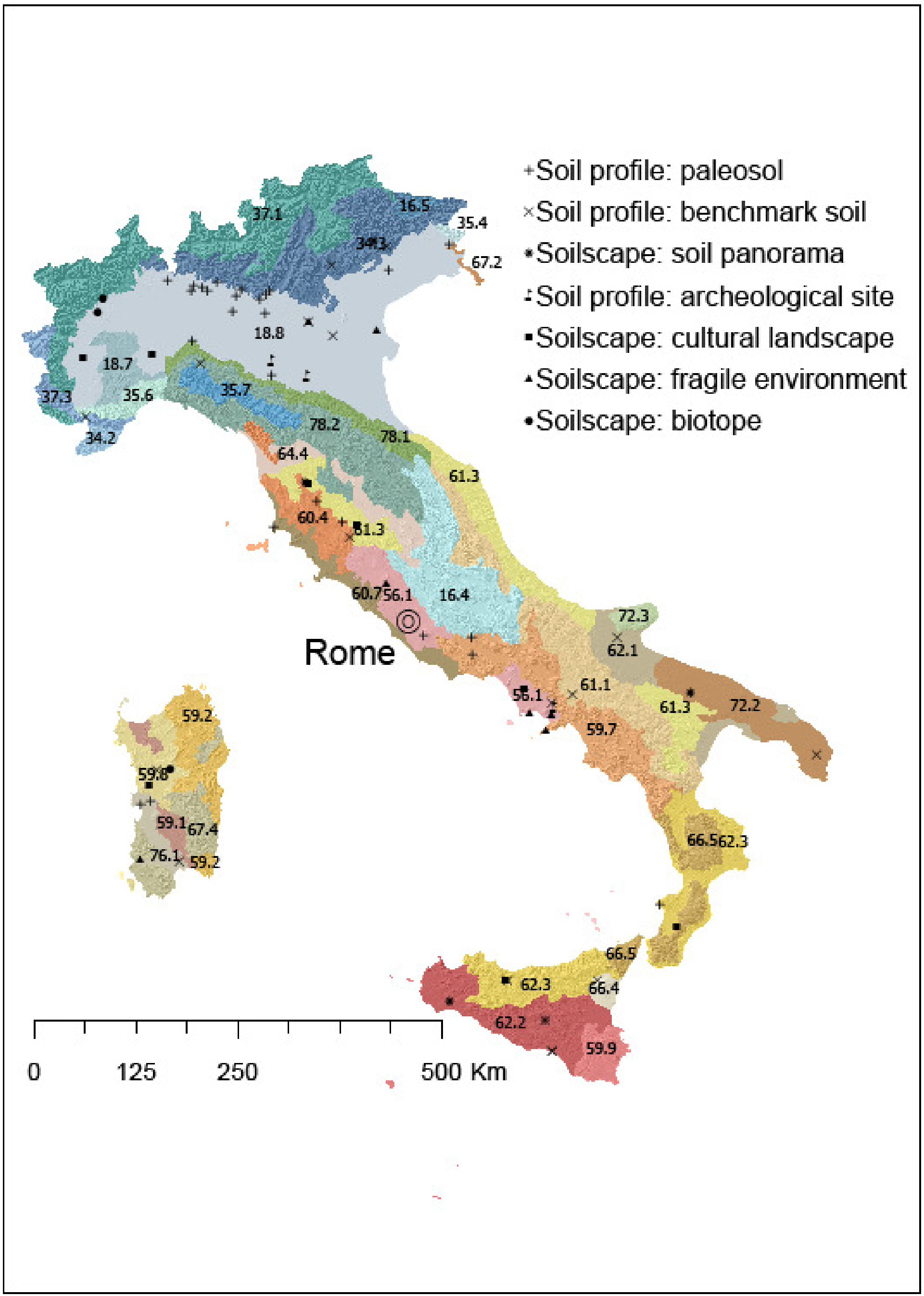

Figure 1. Map of the national pedosites and soil regions of Italy.

according to either Soil Taxonomy (Soil Survey Staff 1999) or World Reference Base for Soil Resources (IUSS-ISRIC-FAO-ISSDS 1998), geological formation, and a note with a free wide description of the pedosite. The fields of the table bibliography are those which can be retrieved from a standard bibliographic citation. The fields of the table "Soil_region" are the same of the European database (Finke *et al.* 1998). The geographic information of pedosites instead is stored in the tables: "l_pedosites_gdb" and "p_pedosites_gdb". All the geographic information can be read through the software ArcGIS (versions 8.x and followings).

Results

The geodatabase stores at present 726 pedosites. The majority of them are paleosols (598) followed by pedosites showing natural or anthropic processes (benchmarks, 58), and cultural landscapes (36 pedosites). There are some 107 pedosites with national degree of interest, 228 regional, and 391 with local interest. The few pedosites acknowledged at international level were joined to national ones. The conservation state of pedosites is good for 72%. There are some 79 pedosite at risk of loss of cultural heritage, especially because of anthropic risk (89%). The geodatabase links the database with the map of the Italian soil regions, allowing the viewer to query the pedosites for any typological criterion and soil region attribute. The map depicts the state of the art about the most important pedosite heritage of Italy, that is pedosites of national and international interest, which are only the 14.7 % of the total. Hence the criteria adopted for their selection seem to have been sufficiently severe. Most pedosites belong to the profile category (83 pedosites). As expected, the majority of them (61) are paleosols, 19 are profiles showing natural and anthropic processes, and 3 are archeological sites. There are 24 soilscape pedosites: 9 cultural landscapes, 7 soilscape have delicate balance, 4 soilscape have scenic value and other 4 are biotopes.

Conclusion

The current national geodatabase is certainly not exhaustive and affected by an uneven density of soil studies; however, it provides an initial indication of the quantity, quality, distribution and diversity of the pedosites in Italy. The geodatabase, freely available on demand from the authors, was build up so to help a soil scientist to recognize and evaluate the cultural value of a soil, and it can be used at different scales, from the local to the national and continental. The most detailed information, in particular, can be of particular interest for land planners, especially in the delineation of protected areas such as Geoparks and in the singling out of hot spots. This is a kind of information which is neither provided nor easily obtainable from a soil maps. Finally, most relevant pedosites of Italy can be overlaid on GoogleEarth, by downloading the file “peodosites_it.kml” from http://www.soilmaps.it/download/dt-Soilsites_of_Italy_26.kml. It seems possible and indeed desirable for further work to be carried out elsewhere, especially in countries where soils possessing cultural heritage are threatened by urbanization, using the same or similar principles and methodologies, so as to complete a list of soils having cultural heritage at the continental and, in perspective, at the global scale.

References

Arnoldus-Huyzenveld A, Gisotti G (1999) The planosols of the “old dunes” of Castel Porziano (Rome): A rare soil type for Italy and Europe. *Mem. Descr. Carta Geol. d’It.*, Ist. Pol. Zecca dello Stato, Roma, **LIV**, 193-197.

Brenna S, Rasio R (1999) Enhancing the naturalistics functions of soils: some cases in the Lombardy region. *Mem. Descr. Carta Geol. d’It.*, Ist. Pol. Zecca dello Stato, Roma, **LIV**, 181-185.

Costantini EAC (1999) The recognition of soils as part of our cultural heritage. *Mem. Descr. Carta Geol. d’It.*, Ist. Pol. Zecca dello Stato, Roma, **LIV**, 175-180.

Costantini EAC, Malucelli F, Brenna S, Rocca A (2007) Using Existing Soil Databases to Consider Paleosols in Land Planning. The Case Study of the Lombardy Region (Northern Italy). *Quaternary International*. **162-163**, 166-171.

Finke P, Hartwich R, Dudal R, Ibanez J, Jamagna M, King D, Montanarella L, Yassoglu Y (1998) Georeferenced soil database of Europe. Manual of procedures. Version 1.0. EUR 18092 EN: pp. 184.

IUSS-ISRIC-FAO-ISSDS (1998) World Reference Base for Soil Resources. World Soil Resources Reports 84, FAO, Rome, pp. 88.

Soil Survey Staff (1999) Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys. 2nd ed. USDA-NRCS Agric. Handb. 436. U.S. Gov. Print. Office, Washington, DC.

Todorov T, Wimbledon WAP (2004) Geological heritage conservation on international, regional, national and local levels. *Polish Geological Institute Special Papers* **13**, 9-12.

Yaalon DH, Arnold RW (2000) Attitudes toward soils and their societal relevance: Then and now. *Soil Science* **165**, 5-12.

A history of rhizosphere research – roots to a solution

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Abstract

The availability and accessibility of water and nutrients to plants, and the interactions of roots with soil, continue to be subjects of active research. Hiltner's insight that there was a volume of soil, the rhizosphere, over which the roots had influence, and in which a range of processes occurred, was a major advance in thinking. Soil science, though, took some time to incorporate this notion into its mainstream thinking. Nutrient and water availability to plants was defined throughout the early 1900s in equilibrium terms; for nutrients with chemical extractants, and for water by the equilibrium concepts of field capacity and permanent wilting point. It was not until the mid 1950s that ideas of water and nutrient mobility superseded ideas of thermodynamics and equilibria with measurements of convective and diffusive movement of resources to roots demonstrating the size of the zone of root influence. The size of the rhizosphere differs spatially and temporally depending on the resource considered, with microorganisms experiencing strong gradients. For the future, while direct management of rhizosphere properties to enhance the efficiency of N fixation is already a reality, interventions that will improve the recovery of nutrients and other resources are still a major challenge.

Key Words

Root systems, microorganisms, rhizodeposits, aggregation, phytase, root elongation.

Introduction

The concept of the rhizosphere originated with Hiltner's (1904) field and pot studies of the effects of green manuring with legumes on soil fertility. He determined that, to explain his observations, there must be a series of processes occurring at the root/soil interface. Among the processes occurring, it was clear that: i) a volume of soil existed that was shared by roots and bacteria; ii) exuded materials from the roots of different legumes attracted different organisms than roots of non-legumes; and iii) each legume species attracted organisms that had a specific benefit for that species. His main insight from these observations was that there was a volume of soil, the rhizosphere, over which the roots had influence and that this soil volume was also shared by bacteria. Apart from a few soil microbiologists, though, soil scientists in general took some time to incorporate this concept into their mainstream thinking.

As Gregory (2006) relates, the role of roots in determining plant accessibility to water and nutrients received little attention throughout the early 1900s when availability of nutrients to plants was defined by use of chemical extractants and that of water was similarly defined by the equilibrium concepts of field capacity and permanent wilting point. It was not until the mid 1950s that ideas of water and nutrient mobility superseded those of equilibria and thermodynamics. For nutrients, the change of thinking came in a ground-breaking paper by Bray (1954) in which he introduced the concept that nutrient mobility was central to soil-plant relations, and demonstrated that mobile nutrients such as nitrate moved to roots from large distances whereas adsorbed nutrients such as phosphate moved only short distances. The corollary of this was that the zones of competition for nutrients by roots differed depending upon the mobility of the nutrient. This change of thinking about the availability of nutrients to plants was paralleled by similar developments regarding the movement of water towards roots (Gardner 1960).

Besides a few contributions to mainly biological journals, neither roots nor the rhizosphere impinged on the soil science literature as topics of major importance until the latter part of the 1900s. Gregory (2006) showed in a survey of the major soil science journals at five-year intervals from 1950 onwards that roots or the rhizosphere featured in only a very small number of papers until about 1990. The major soil science journals still carry few such papers (Soil Biology and Biochemistry excepted) and Plant and Soil has emerged as the journal carrying the most papers on the plant/soil interface, with substantial coverage also in New Phytologist.

Recent understanding of the rhizosphere

The rhizosphere is a "zone of soil surrounding the root which is affected by it" (Darrah 1993) but its size differs spatially and temporally depending on the factor considered, ranging from a fraction of a mm for microbial populations and immobile nutrients to tens of mm for mobile nutrients and water to several tens of mm for volatile compounds and gases released from roots. This means that the interface between the root and the soil is complex, frequently an ill-defined boundary, and heterogeneous in space and time. Compounds released from roots into the soil change its chemical and physical properties, and stimulate the growth of various organisms. Rhizodeposits of various exudates, sloughed cells and decaying roots provide an important substrate for the soil microbial community and there is a complex interplay between this community and the quantity and type of compounds released (Marschner and Baumann 2003). There is increasing evidence that microorganisms (particularly rhizobia) can alter processes within plant roots especially those related to root hair and lateral root development (e.g. Mathesius 2008). Much research has now demonstrated that other compounds released from roots may act as messengers that communicate and initiate root-root, root-microbe, and root-faunal interactions (Walker *et al*. 2003). Root-microbe and root-insect interactions can be either positive (symbiotic) to the plant (e.g. via associations with mycorrhizal fungi and N-fixing bacteria) or negative to the plant (e.g. interactions with parasitic plants, pathogenic microbes and herbivorous insects).

Chemical changes in the rhizosphere of plants have been widely reported (see Hinsinger *et al.* 2009 for a review), though their quantitative significance for crops is still a matter of debate. Depletion of nutrients such as N, P and K close to roots is widespread, while others such as Ca, Mg and S may accumulate depending on soil solution concentrations, plant demand and transpiration rate. In addition to changes in ionic concentrations of nutrients, there are four other major root-induced changes to the chemical environment of the rhizosphere mediated through alterations of: i) pH; ii) reduction/oxidation conditions; iii) complexation of metals; and iv) enzyme activities. In particular, the release of organic anions such as malate and citrate by roots can offset the toxic effects of aluminium as well as acting to solubilise P (Kirk *et al*. 1999; Ryan *et al*. 2009)

Physical changes in the rhizosphere have been much less studied than biological or chemical changes, despite their potential consequences for the movement of water and solutes. The release of root mucilage may change the water relations of the rhizosphere. For example, Read *et al*. (2003) showed that the addition of the surfactant component of mucilage can alter the relationship between water content and soil matric potential (the moisture characteristic curve) making the soil drier at a given value of matric potential, especially at high matric potentials. Whalley *et al*. (2005) also found that rhizosphere soil of maize and barley tended to be drier at a given matric potential than bulk soil but suggested that differences in wetting angle and pore connectivity were the likely explanation for these differences. The development of water-stable aggregates is an important process in the genesis of soils because it strongly influences a range of soil characteristics including aeration, infiltration and erodability. Plant roots play a major role in this process. Their influence comes about indirectly through the release of carbon compounds which provide a substrate for microbes (Young and Crawford 2004), and directly through: (i) wetting and drying phenomena; (ii) the accumulation in some soils of inorganic chemicals at the root surface that act as cementing agents; (iii) the release of organic compounds that promote aggregation of particles; and (iv) the structural support of undecayed, senescent roots which act like steel rods in reinforced concrete.

The future – solutions to crop production constraints

With the development of new imaging techniques, genetic manipulation of roots and the development of process-based models, the future for rhizosphere exploration appears bright and will, in time, lead to practical ways of controlling performance in the field. Three areas that where progress is starting include:

Utilisation of genes to modify root surface properties

Near isogenic lines are already available to study aspects of root growth such as the effect of dwarfing and semi-dwarfing genes on root growth (e.g.Wojciechowski *et al*. 2009) and transgenic plants able to excrete specific enzymes will open up aspects that are currently difficult to explore. For example, George *et al.* (2009) demonstrated that for tobacco plants transformed to exude phytase, the presence of rhizosphere microorganisms reduced the dependence of the plants for extracellular secretion of phytase from roots when grown in a P-deficient soil. However, the expression of phytase in transgenic plants had little or no impact on the microbial community structure as compared to control plant lines, whereas soil treatments, such as addition of inorganic P, had large effects. The results demonstrated that soil microorganisms are explicitly involved in the availability of P to plants but that the microbial community in the rhizosphere appears to be resistant to single-gene changes in plants designed to alter rhizosphere biochemistry and nutrient cycling.

Managing rhizosphere biophysics

Soil strength at the root apex affects both the pressure that a root must exert to penetrate the soil and the degree of colonisation by soil microorganisms (Hinsinger *et al*. 2009). Mucilage and root cap cells lubricate the passage of the root through soil (Iijima *et al*. 2004) but the ability of some roots to continue growth at strengths that inhibit shoot growth and/or root growth in other species is an important property that might be amenable to genetic manipulation. For example, Clark *et al*. (2000) used wax layers to screen the differential ability of six rice genotypes to penetrate strong soils and found substantial differences in the number of axes penetrating the layer. Further research is necessary to determine the genetic factors influencing both the production of lubricants and the underlying factors influencing root growth in hard soils.

Quantification of complex, interacting processes using mathematical models

Many studies of rhizosphere processes have indicated the presence or absence of a process in particular circumstances but many processes may operate in parallel. For example, plant P acquisition from a soil with low plant available P may depend on production of root hairs, degree of mycorrhizal infection and efficacy of the fungus, changes in soil pH, release of organic anions, changes in redox potential, release of enzymes etc. These processes often interact and measuring them in experimental systems is difficult although their end result can be determined. Mathematical models can assist in assessing the contribution that each process makes to the final result and in indicating which processes are important in various circumstances. In upland rice, for example, modelling demonstrated that the measured P uptake of the plants was a consequence of P solubilization by organic anions principally through the chelation of metal ions that would otherwise have immobilized P or through the formation of soluble citrate-metal-P complexes or both, whereas displacement of P from adsorption sites was unimportant (Kirk *et al*. 1999).

References

Bray RH (1954) A nutrient mobility concept of soil-plant relationships. *Soil Science* **78,** 9-22.

Clark LJ, Aphalé SL, Barraclough PB (2000) Screening the ability of rice roots to overcome the mechanical impedance of wax layers: importance of test conditions and measurement criteria. *Plant and Soil* **219,** 187-196.

Darrah PR (1993) The rhizosphere and plant nutrition: a quantitative approach. *Plant and Soil* **155/156,** 3-22.

Gardner WR (1960) Dynamic aspects of water availability to plants. *Soil Science* **89,** 63-73.

George TS, Richardson AE, Li SS, Gregory PJ, Daniell TJ (2009) Extracellular release of a heterologous phytase from roots of transgenic plants: does manipulation of rhizosphere biochemistry impact microbial community structure? FEMS (in press)

Gregory PJ (2006) Roots, rhizosphere and soil: the route to a better understanding of soil science? *European Journal of Soil Science* **57,** 2-12.

Hiltner L (1904) Über neuere Erfahrungen und Probleme auf dem Gebiete der Bodenbakteriologie unter besonderer Berücksichtigung der Gründüngung und Brache. *Arbeiten der Deutschen Landwirtschaftlichen Gesellschaft* **98,** 59-78.

Hinsinger P, Bengough AG, Vetterlein D, Young IM (2009) Rhizosphere: biophysics, biogeochemistry and ecological relevance. *Plant and Soil* **321,** 117-152.

Iijima M, Higuchi T, Barlow PW (2004) Contribution of root cap mucilage and presence of an intact root cap in maize *(Zea mays*) to the reduction of soil mechanical impedance. *Annals of Botany* **94,** 473-477.

Kirk GJD, Santos EE, Santos MB (1999) Phosphate solubilization by organic anion excretion from rice growing in aerobic soil: rates of excretion and decomposition, effects on rhizosphere pH and effects on phosphate solubility and uptake. *New Phytologist* 142, 185-200.

Marschner P, Baumann K (2003) Changes in bacterial community structure induced by mycorrhizal colonisation in split-root maize. *Plant and Soil* **251,** 279-289.

Mathesius U (2008) Auxin: at the root of nodule development? *Functional Plant Biology* **35,** 651-668.

Read DB, Bengough AG, Gregory PJ, Crawford JW, Robinson D, Scrimgeour CM, Young IM, Zhang K, Zhang X (2003) Plant roots release phospholipid surfactants that modify the physical and chemical properties of soil. *New Phytologist* **157,** 315-326.

Walker TS, Bais HP, Grotewold E, Vivanco JM (2003) Root exudation and rhizosphere biology. *Plant Physiology* **132,** 44-51.

Whalley WR, Riseley B, Leeds-Harrison PB, Bird NRA, Leech PK, Adderley WP (2005) Structural differences between bulk and rhizosphere soil. *European Journal of Soil Science* **56,** 353-360.

Wojciechowski T, Gooding MJ, Ramsay L, Gregory PJ (2009) The effects of dwarfing alleles on seedling root growth of wheat. *Journal of Experimental Botany* **60,** 2565-2573.

Young IM, Crawford JW (2004) Interactions and self-organization in the soil-microbe complex. *Science* 304, 1634-1637.

Historical approach of the role of earthworms and termites in soil functioning

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Introduction

Recent developments of agriculture towards practices sustaining both agronomic and environmental ecosystems services raised the interest of land users, politicians and scientists for soil biological activity. Soil organisms are seen as a resource in agroeocystems. Among them, soil engineers, such as earthworms and termites, are of prime importance as they regulate soil processes, i.e., the activity of microorganisms through a modification of soil structure and availability of nutrients (Lavelle, 2002). Although earthworms and termites are now seen as emblematic soil animals, this has been quite different during history. This paper aims to describe the development of scientific knowledge regarding the effect of earthworms and termites on soil functioning.

Key Words

History of soil science, soil organisms, soil engineers, Antiquity, Darwin.

Historical reputation of earthworms

This part is mainly based on the syntheses by Brown et al. (2003); Feller et al. (2003); Bouché (2003); Blanchart et al. (2005). Earthworms were already well known organisms during the Greek and Egyptian antiquity. Aristotle called them "the intestines of soil" probably because they were able to dig and move in the soil while digesting it. In Egypt they were seen as important elements of soil fertility along the Nile and Cleopatra made them sacred, prohibiting farmers from killing them (Minnich 1977; Kevan 1985). Between Antiquity and the end of the 19th Century, only limited information is available on earthworms (Agricola 1549, cited by Kevan 1985). Most of this time, earthworms were considered as harmful organisms that had to be eliminated (White 1789; Rozier 1805; Chateauneuf 1844; Walton 1928). Only Rozier (1805) recognizes some beneficial effects especially as medicines and White (1779) described earthworms as beneficial for soil fertility. From a taxonomical point of view, earthworms were mixed with all worms and it is only in 1800 and the classification by Lamarck that Annelids were separated from other worms.

The first papers by the famous English naturalist Darwin (1838; 1840 and 1844) on earthworms and his book published in 1881 considerably modified the perception by humans of earthworms. In 1881, about 20 years after the publication of « On the origin of species » and six months before dying, Charles Darwin, published his last book. Though his last book was as successful as his main publication, it was nonetheless characterized by a subject considered by scientists to be of small importance at that time, which probably increased its literary success. This book, which actually dealt with earthworms, was entitled "The formation of vegetable mould through the action of worms with some observations on their habits". This subject, which was a highly surprising one for this great naturalist, would however, change our perception of nature and favor the development of disciplines like pedology and soil biology. In his last book, Darwin explains and describes (with data to prove it) how "worms" affect soil formation and alteration processes, soil horizon differentiation and formation of "vegetal mould", soil fertility, the erosion-sedimentation cycle, and the burial of archeological remains. This book has changed the way earthworms are considered. Darwin's book confirmed White's statements, and must be considered a turning point in history regarding work on earthworms and the perception of their importance. Nevertheless many scientists were quick to criticize Darwin's conclusions and promptly began research to disprove them. One of them was the famous German soil physicist E. Wollny, whose results (1890) finally proved Darwin was correct.

In the same time, the Danish forester P.E. Müller (1878) also gave earthworms a great importance in soil fertility and humus formation. The role of earthworms on soil functioning only began to be considered in other parts of the world after the 1930's. This delay may be explained by the important development of chemistry in agriculture, following Liebig's work (1840). Since then, and with the specialization of scientists, thousands of papers have been published on earthworms. Most of them confirm Darwin's conclusions and theories.

Historical reputation of termites

This part is mainly based on the syntheses (only usable by French-speaking scientists) by Duboisset (2003) and Duboisset and Seignobos (2005). The first descriptions of termites and termite-mounds in Africa and Asia were given by explorers, in the 17th and 18th Centuries (Bosman 1705; Adanson 1757; Köenig 1779, Smeathman 1781). Explorers were impressed by the size and complexity of (fungus-growing) termite-mounds. In 1802, Golbery compared termite-mounds with Egyptian pyramids: "They erect monuments so phenomenal, so firmly built, that, compared with the extreme smallness of the insect (…), they appear more marvelous than the most considerable buildings of human industry". Numerous descriptions of these mounds were given later (Mattei 1890; Decorse 1906; Schweinfurth 1975). At the same time, termite societies were also described. The existence of castes (i.e., king, queen, workers and soldiers) was observed by some explorers (Golbery 1802; Mattei 1890). The most impressive to European explorers was the huge numbers and the omnipresence of termites (Livingstone and Livingstone 1866). Their voracity was also an important criterion that makes termites emblematic animals of the exotic universe. Golbery (1802) wrote: "They wolf down and reduce to an extremely fine powder, the hugest trees". Livingstone and Livingstone (1866) related how their blankets were eaten in one night. Bosman (1705) probably mistook termites for carnivorous ants: "During the night, they came to some of my living sheep and gnawed them so as in the morning, we found only carcasses".

In the first explorer stories, termites were thus seen as one of the main scourge of the Tropics.
The first scientific studies occurred in the 18th Century and focused on three aspects of termites: taxonomical classification, biology (mounds and societies), and importance of damage. Smeathman, in 1781, seems to be the first seeing a positive effect in termite activity as they recycle decomposable matter: "They are in one sense most pernicious, they are in the other most useful"; "There are not probably in all nature, animals of more importance". But this beneficial effect will be overshadowed up to the mid-20th century by the search for means to eradicate termites. The economical development of European colonies was strongly disrupted by termites and their damage to seed stocks, wood buildings, railway line, telegraph posts.

As a consequence, the role of termites in ecosystem and soil functioning was not studied before the beginning of the 20th Century, with the exception of the paper by Drummond in 1886. Drummond compared termites (in the tropics) to earthworms (in temperate regions). According to him, these insects maintain the functioning of ecosystems and the fertility of soil: "The ground is literally living with them". Other scientists, such as Cameron (1905) were dubious regarding the beneficial effects of termites on fertility, estimating that termites immobilize nutritive elements. Hegh (1922), in a very complete synthesis, estimated that "The soil of Africa is in reality a vast termite-mound". The study of Holdaway (1933), which seems to be the first quantitative study of the effect of termites, gives the composition of the mounds of *Eutermes exitiosus* in Australia. Adamson in 1943 (like McGregor in 1950) recognized that "an adequate understanding of the influence of termite on soil fertility is obviously impossible at present". In the1950s, termites are still seen as harmful (Harris, 1949) or beneficial (Grassé 1950) insects. After 1950, termites would be studied by different scientific disciplines: damage, societies, biogeography, pedology. The first studies on soil transport and soil feature formation by soil-feeding termites were done by Boyer (1973), Nye (1955), Stoops (1964), and synthesised by Bachelier (1978). From 1970, many studies are realized regarding the importance of termites in the functioning of ecosystems, with different syntheses being published (Lee and Wood 1971; Wood 1976; Lal 1987; Black and Okwakol 1997)

Conclusion

Nowadays, termites, like earthworms, are seen as very important soil organisms: they act as soil engineers and actively participate to soil and ecosystem functioning (Lavelle *et al.* 1992; Bignell and Eggleton 2000).

References

Adamson AM (1943) Termites and the fertility of soils. *Trop. Agr. Trin.* **20,** 107-112.

Adanson (1757) 'Histoire naturelle du Sénégal. Coquillages, avec la relation abrégée d'un voyage fait en ce pays, pendant les années 1749, 50, 51, 52 et 53'. (Bauche : C.J.B., Paris).

Agricola (=Bauer) G (1549) De Animantabus Subterraneis Liber. Basileae «(=Basel). Frobenium et Epicopium. 79+(8)+(18)+(3)+(1) pp. [Autre édition 1558 : De Ortu et Causis Subterraneorum]. (cité par Kevan, 1985).

Bachelier G (1978) 'La faune des sols, son écologie et son action'. Inititations-Documentations Techniques, 38, ORSTOM.

Bignell DE, Eggleton P (2000) Termites in ecosystems. In ‘Termites : evolution, sociality, symbioses, ecology’ (Eds T Abe, DE Bignell, M Higashi) pp. 363-387. (Kluwer Academic Publishers : Netherlands).

Black HIJ, Okwakol MJN (1997) Agricultural intensification, soil biodiversity and agroecosystem function in the tropics : the role of termites. *Applied Soil Ecology* **6**, 37-53.

Bosman W (1705) Voyage de Guinée contenant une description nouvelle et très exacte de cette côte où l'on livre et où l'on traffique de l'or, les dents d'éléphants et les esclaves, Autrecht.

Bouché MB (2003) Vers de terre, de Darwin à nos jours. Un révélateur heuristique. Académie des Sciences et lettres de Montpellier. Séance du 02/06/2003, Conférence n°3826. Montpellier, France.

Boyer P (1973) Les différents aspects de l’action de certains Bellicositermes sur l’évolution des sols des savanes oubanguiennes (République Centrafricaine). Annales des Sciences Naturelles. Zoologie et Biologie animale. Masson éd. (Paris).

Brown GG, Feller C, Blanchart E, Deleporte P, Chernyanskii SS (2004) With Darwin, earthworms turn intelligent and become human friends. *Pedobiologia* **47,** 924-933.

Cameron M (1905) *Proceed. Rhodesia Scient. Assoc.* **IV**, 58-61.

Chateauneuf M de (1844) La nouvelle maison rustique, encyclopédie-manuel de toutes les sciences et de tous les arts, dont un habitant de la campagne, propriétaire, fermier, cultivateur, peut tirer parti, soit pour son utilité, soit pour son agrément. Tome 2, 3e édition, Lebailly, Paris.

Darwin Ch (1838) On the formation of mould. Proceedings of the Geological Society of London 2, pp. 574-576.

Darwin Ch (1840) On the formation of mould. Transactions of the Geological Society of London II, Series 5 (III), pp. 505-509.

Darwin Ch (1844) On the origin of mould. Gardener’s Chronicle and Agricultural Gazette 14.

Darwin Ch (1881) The formation of vegetable mould through the action of worms with some observations on their habits. John Murray ed., London.

Decorse J (1906) Du Congo au Lac Tchad : la brousse telle qu'elle est, les gens tels qu'ils sont : carnet de route. Impr. Asselin et Houzeau, Paris.

Drummond H (1886) On the termite as the tropical analogue of the earthworm. *Proc. Roy. Soc. Edinburgh* **13**, 137-146.

Duboisset A (2003) L'importance agricole des termitières épigées dans le nord du Cameroun. L'exemple des nids de *Macrotermes subhyalinus* et d'*Odontotermes magdalenae*. Doctorat de Sciences et Techniques de l'Environnement, Université Paris XII.

Duboisset A, Seignobos C (2005) Petite histoire des connaissances acquises sur les termites et leur rôle agroécologique. *Etude et Gestion des Sols* **12,** 153-164.

Feller C, Brown GG, Blanchart E, Deleporte P, Chernyanskii SS (2003) Charles Darwin, earthworms and the natural sciences: various lessons from past to future. *Agriculture, Ecosystems and Environment* **99,** 29-49.

Garnier-Sillam E (1987) Biologie et rôle des termites dans les processus d'humification des sols forestiers du Congo. Thèse de l’Université Paris XII, Créteil.

Golbery SMX (1802) Fragments d'un voyage en Afrique, fait en 1785, 1786 et 1787 dans les contrées Occidentales de ce continent entre le Cap Blanc des Barbades... et le Cap de Palmes. Tome II. Treuttel et Würtz Libraires, Strasbourg, 512 p.

Grassé P (1950) Termites et sols tropicaux. Revue Int. Bot. Appl.et Agric. Trop. (337-338): 549-554.

Harris WV (1949) Quelques aspects agricoles du problème des termites en Afrique orientale. *Revue Int. Bot. Appl.et Agric. Trop.* **323,** 506-513.

Hegh E (1922) Les termites. Partie générale : Description, distribution géographique, classification, biologie, vie sociale, alimentation, construction, rapports avec le monde extérieur. Imp. Industr. Finan., Bruxelles.

Holdaway FG (1933) The composition of the differents regions of mounds of Eutermes exitiosus Hill. *Austr. J. Counc. Sci. Indust. Res.* **6,** 160-165.

Kevan DK McE (1985) Soil zoology, then and now – mostly then. *Quaestiones Entomologicae* **21,** 371.7-472.

Koënig JG (1779) Naturgeshichte der sog. Weissen Ameisen. Beschr. Der Berliner, Gesellschaft naturforsch.

Freunde, IV.

Lamarck J-B de (1800) Discours d'ouverture de l'an VIII, réédité dans *Bull. Sci. Fr. Belg.* (1906), **40,** 459-482.

Lal R (1987) Termites. In 'Tropical ecology and physical edaphology'. (Ed R Lal) pp. 337-422. (Wiley and Sons: New York).

Lavelle P, Blanchart E, Martin A, Spain AV, Martin S (1992) Impact of soil fauna on the properties of soils in the humid tropics. *Soil Science Society of America*, Special Publication **29,** 157-185.

Lavelle P (2002) Functional domains in soils. *Ecological Research* **17,** 441-450.

Lee KE, Wood TG (1971) 'Termites and Soils'. (Academic Press: London and New York).

Liebig J von (1840) Die Chemie in ihrer Andwendung auf Agrikultur und Physiologie. Vieweg u.S., Braunschweig.

Livingstone C, Livingstone D (1866) Exploration du Zambeze et de ses affluents et découverte des lacs Chiroua et Niassa, 1858-1864. Trad. H. Loreau, Paris.

Mattei C (1890) Bas-Niger, Bénoué, Dahomey. Imp. Vallier et Baratier frères, Grenoble.

Mc Grégor WD (1950) Termites, soil and vegetation. *Forestry abstract* **12,** 3-8.

Minnich J (1977) 'The Earthworm Book: How To Raise And Use Earthworms for Your Farm and Garden'. (Rodale Press: Bethlehem).

Müller PE (1878) Studier over Skovjord. I. Om Bøgemuld od Bøgermor påa sand og Ler. *Tidsskrift for Skovbrug* **3,** 1-124.

Nye PH (1955) Some soil forming in the humid tropics. IV The action of the soil fauna. *Journal of Soil Science* **6,** 73-83.

Roose E (1976) Contribution à l'étude de l'influence de la mésofaune sur la pédogénèse actuelle en milieu tropical, Rapport ORSTOM, Adiopodoumé.

Rozier J-BF dit l'Abbé (1796) 'Cours complet d'agriculture théorique, pratique, économique et de médicine rurale et vétérinaire. 12 Vols.'. (Rue et Hôtel Serpente: Paris).

Schweinfurth G (1875) Au coeur de l'Afrique, 1868-1871. Voyage et découvertes dans les régions inexplorées de l'Afrique Centrale. Tome I. Ouvrage traduit des éditions Anglaises et Allemandes par H. Loreau, Paris.

Smeathman H (1781) Some account of the termites which are found in Afrika and other hot climates. *Phil. Trans. R. Soc. Lond.* **LXXI**, 189-192.

Stoops G (1964) Application of some pedological methods to the analysis of termite mounds. In 'Etude sur les termites africains', Coll. Int. UNESCO, Univ. Lovanium (Leopoldville), Masson éd. (Paris), 379-398.

White G (1789) The natural history of Selborne. Benjamin White, London.

Wollny E (1890) Untersuchungen über die beeinflussung der ackerkrume durch die thätigkeit der regenwurmer. *Forschungen Geb. Agricultur Physik* **13**, 381-395.

Wood TG (1976) The role of Termite in decomposition processes. In 'The role of terrestrial and aquatic organisms in decomposition process' (Eds JM Anderson, A Macfadyen) pp. 145-1681. (7th Symposium of the British Ecology: Society, Oxford).

Micromorphological evidence for the use of urban waste as a soil fertiliser in and near to historic Scottish towns

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Abstract

This paper presents micromorphological evidence for the addition of urban waste to soils in and near to three historic Scottish towns; Lauder, Pittenweem and Wigtown. Waste deposited within historic town cores included human and animal excreta, kitchen refuse, building materials, industrial wastes and fuel residues. Similar types of waste are also evident in nearby agricultural land. Mechanisms of waste disposal are likely to have included direct application and midden spreading within town cores and dunghill redistribution to the hinterland. It is proposed that urban waste was deliberately used as a fertiliser to enhance soil quality within and near to historic Scottish towns, thus increasing agricultural sustainability.

Key Words

Waste disposal, urban refuse, soil micromorphology, Anthrosols, soil modification, fertiliser.

Introduction

Prior to sedentarisation, the settlement of nomadic people in a permanent place of habitation, waste disposal was not a problem given the transient nature of hunter-gatherer subsistence (Rathje and Murphy 2001). However, residents in the first permanently settled communities until today have been faced with the problem of what, where and how to dispose of their waste. In contrast to modern perceptions, waste in the past was seen as a resource rather than a burden, and was routinely used in soil enhancement strategies. As far back as 2300 years ago people were applying household rubbish to cultivated terraces on Pseira Island, Crete (Bull *et al.* 2001). Similarly, the formation of Amazonian Dark Earth is testament to long-standing pre-Colombian practises of soil enhancement through application of domestic refuse (Sombroek *et al.* 2002, Woods and McCann 1999).

Waste disposal in historic Scottish burghs (towns)

The use of rubbish as a fertiliser is not confined to ancient cultures; recent studies indicate this practice was a feature of many historic Scottish burghs. Davidson *et al.* (2006) attribute an area of deepened topsoil at the edge of Nairn, Nairnshire to sustained application of urban waste for the purpose of soil enhancement. Examination of a deepened phase revealed a maximum concentration of phosphorus in the Ap3 horizon supporting the theory of using urban waste as a fertiliser. In addition, both Davidson and Dercon *et al.* (2005) identify a significant quantity of finer material in the upper A horizon within the deepened sequence at Nairn, the presence of which is associated with mineral components of applied rubbish such as sand and ashes, used in byres to absorb fluid and stabilise dung, and turves used in building construction and repair. Deepened topsoil deposits have also been identified within the burgh core (urban centre) of many historic towns including St. Andrews, where the occurrence of ‘garden-soil’ deposits reflects a deliberate and sustained attempt at soil improvement for the purpose of urban cultivation (Cachart 2000; Carter 2001). As yet there have been no systematic attempts to characterise and compare soils modified through deposition of urban waste materials. This paper presents micromorphological evidence for the use of urban waste as a soil fertiliser in and near to three historic Scottish burghs, and discusses the wider implications of soil improvement within past urban environments.

Methods

Three historic Scottish burghs (historic towns) were chosen for investigation based upon differences in geography and past function; namely Lauder, Pittenweem and Wigtown. Functional zones were delineated within each burgh through spatial analysis of selected soil properties including topsoil depth (Golding and Davidson 2005) and elemental concentrations, in addition to historical research. Comparable areas are evident within all burghs including the ‘High Street’ (historic burgh core) and ‘Hinterland Near’ zones (Figure 1). The location and number of soil pits within each burgh was determined by patterns in soil variability. At least one soil pit was dug within each delineated zone, and additional soil pits were located in areas of high heterogeneity such as the burgh core.

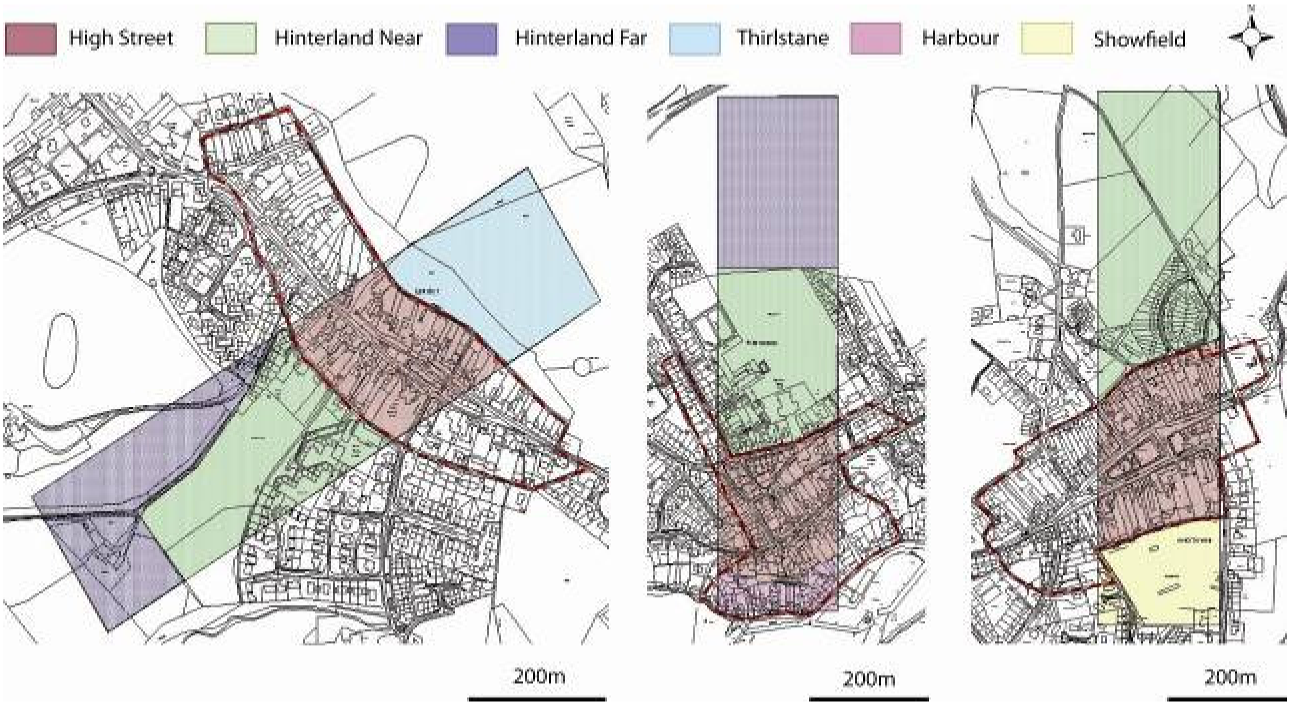

Figure 1. Delineation of zones at Lauder, Pittenweem and Wigtown (left to right). Red boundary delimits mid-late AD 19th century urban extent. Certain zones are specific to individual burghs, for example only Pittenweem has a Harbour zone.

In total 42 Kubiena tin samples were taken from exposed topsoils for micromorphological analysis. Thin sections were prepared from undisturbed soil samples at the Thin Section and Micromorphology Laboratory, University of Stirling (impregnation and processing procedures are outlined at http://www.thin.stir.ac.uk). Thin sections were examined using an Olympus BX 51 petrological microscope and described according to procedures outlined in Bullock *et al.* (1985) and Stoops (2003). A range of magnifications (x10-x400) and light sources (plane polarised, cross polarised and oblique incident light) were used. Semi-quantitative determinations of coarse mineral and organic features were made using a randomised grid system to enable statistical comparison of key anthropogenic inclusions (Figure 2). Precise details of the methodology used to semi-quantify coarse anthropogenic features are described in Golding (2008, 92-99).

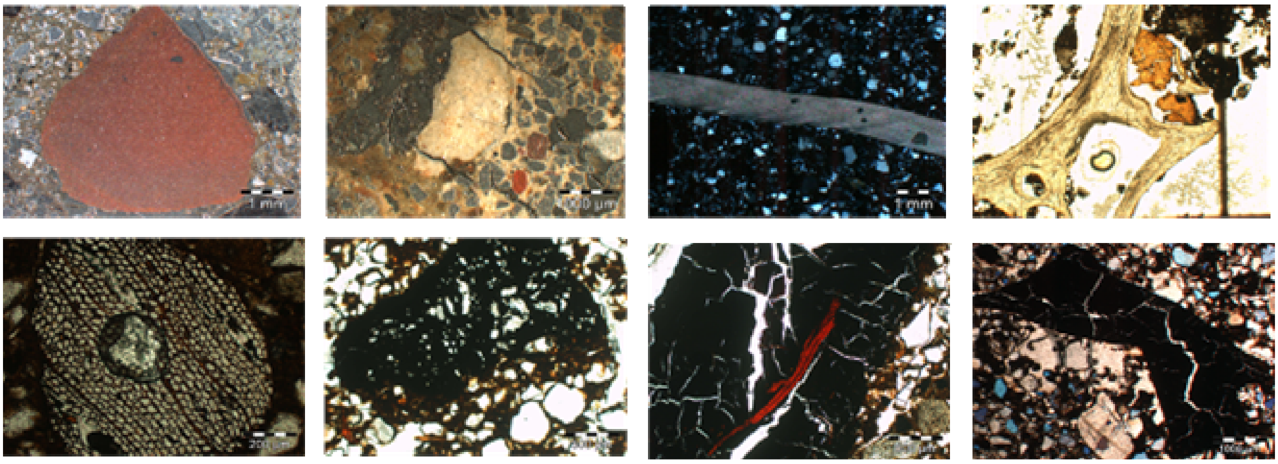

Figure 2. Example images of selected coarse mineral and organic features in thin section from Lauder, Pittenweem and Wigtown. First row: pottery, mortar, shell and bone. Second row: charcoal, fuel residue type 4, fuel residue type 3 and fuel residue type 1.

Results

A summary of key results emerging from micromorphological analyses is presented in table 1.

Table 1. Summary of trends in micromorphological characteristics of topsoils within three historic Scottish towns; Lauder, Pittenweem and Wigtown.

Soil Feature	Summary of Key Trends
Profile characteristics	Soils within all three burgh cores are characterised by hortic topsoil horizons. Soils within the immediate hinterland of Lauder exhibit hortic properties.
Coarse mineral material	Anthropogenic mineral material is most abundant and diverse in burgh cores. Anthropogenic mineral material is present within the wider hinterland at Lauder and Pittenweem. Shell inclusions are limited to Pittenweem and Wigtown. Abundances of shell, mortar and pottery differ between the High Street and Harbour areas within the burgh core at Pittenweem.
Fine mineral material	Soils within all three burgh cores are characterised by brown/dark brown, dotted fine mineral material.
Coarse organic material	Anthropogenic organic material is most abundant and diverse in burgh cores. Anthropogenic organic material is present within the wider hinterland at all three burghs. Differences in principal fuel residue types are apparent between towns. Abundances of certain fuel residues differ between the High Street and Harbour areas within the burgh core at Pittenweem.
Fine organic material	Amorphous red and yellow organic material is present within all three towns.
Pedofeatures	The nature and distribution of pedofeatures is site specific.
Structure	Soils within all three burgh cores are characterised by channel and chamber microstructures with vughy elements. There is no significant difference in coarse material arrangement, groundmass, Coarse:Fine (C:F) distribution or C:F ratio between towns.

Discussion

Waste disposal within burgh cores

Waste deposited within the burgh core at all three towns includes building materials, human and animal excreta, kitchen refuse, industrial wastes and fuel residues. Evidence for shell waste is limited to Pittenweem and Wigtown, reflecting their historic involvement in marine resource exploitation. In addition, differences in the abundance of key fuel residue types were identified between burgh cores, signifying variation in fuel resource utilisation and/or industrial processes between towns. Whilst there is strong evidence for sustained waste deposition within burgh cores, methods associated with waste disposal are less clear. It is suggested that domestic refuse associated with individual households and mixtures of straw, sand and dung from byres were applied to the backlands as a convenient source of fertiliser. Considering the diversity of materials in burgh core topsoils, it is also likely that middens comprising domestic and/or industrial wastes were periodically spread across back gardens.

Waste disposal within the burgh acres

Urban derived waste was deposited within the hinterland of Lauder, Pittenweem and Wigtown in areas corresponding to the burgh acres, agricultural land historically owned by the towns' burgesses. Despite similarities in the nature of waste deposited within burgh cores and burgh acres, anthropogenic inclusions are less diverse and fewer in number within burgh acres. Waste disposal processes are likely to have involved the transportation of dunghills, temporary stores of urban waste, from burgh cores to the burgh acres by means of horse and cart, and in some cases individual labour. In addition to soil improvement, application of urban waste to the burgh acres alleviated problems associated with dunghill accumulation such as the obstruction of thoroughfares in burgh cores. In agreement with Davidson *et al.* (2006) it seems that an early form of urban composting was practised within these towns, with dunghills acting as waste stores prior to redistribution on local soils.

Conclusions

This study has used micromorphological evidence to investigate the legacy of waste disposal on soils in and near to three historic Scottish towns. It is evident that urban refuse was applied to soils within burgh cores and burgh acres at Lauder, Pittenweem and Wigtown. Mechanisms involved in processes of waste disposal are likely to have included direct application, midden spreading and dunghill redistribution. It is proposed that urban waste was deliberately used as a fertiliser to enhance soil quality within both burgh cores and burgh acres, thus increasing agricultural sustainability. Improvement in the quality and yield of crops was central to meeting the consumption needs of an expanding urban population, yet not all residents had access to the burgh acres. Urban horticulture was an important strategy in enhancing the food security of poorer/lower-status residents, who were able to produce foodstuffs for their own consumption and fodder for livestock within back-gardens. Given current challenges associated with finding environmentally sustainable solutions to waste management and the growing importance of urban horticulture, particularly in developing countries, the significance of urban waste as a past soil improvement resource should not be overlooked.

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References

Bull ID, Betancourt PP and Evershed RP (2001) An organic geochemical investigation of the practise of manuring at a Minoan site on Pseira Island, Crete. *Geoarchaeology* **16**, 223-242.

Bullock P, Federoff N, Jongerius A, Stoops G and Tursina T (1985) 'Handbook for soil thin section description'. (Wolverhampton: Waine Research Publication).

Cachart R (2000) Excavations at 106-110 South Street, St Andrews *Tayside and Fife Archaeological Journal* **6,** 109-136.

Carter S (2001) A reassessment of the origins of the St. Andrews 'Garden Soil' *Tayside and Fife Archaeological Journal* **7,** 87-97.

Davidson DA, Dercon G, Stewart M and Watson F (2006) The legacy of past urban waste disposal on local soils *Journal of Archaeological Science*. **33**(6), 778-783.

Dercon G, Davidson DA, Dalsgaard K, Simpson IA, Spek T and Thomas J (2005) Formation of sandy anthropogenic soils in NW Europe. Identification of inputs based on particle size distribution *Catena* **59,** 341-356.

Golding KA (2008) The effect of waste disposal on soils in and around historic small towns. PhD thesis, University of Stirling.

Golding KA and Davidson DA (2005) The effect of past waste disposal on soils near to Scottish burghs. *SEESOIL, Journal of South East England Soils Discussion Groups* **16**, 28-36

Rathje WL and Murphy C (2001) 'Rubbish: The Archaeology of Garbage'. (Tucson: University of Arizona Press).

Sombroek W, Kern D, Rodrigues T, Cravo M, Jarabas T, Woods W and Glaser B (2002) Terra Preta and Terra Mulata: Pre-Columbian Amazonian kitchen middens and agricultural fields, their sustainability and replication. *17th WCSS Symposium* **18,** 1-9.

Stoops G (2003) 'Guidelines for analysis and description of soil and regolith in thin section'. (Soil Science Society of America, Inc.: Wisconsin).

Woods WI, McCann JM (1999) The anthropogenic origin and persistence of Amazonian Dark Earths. *The Yearbook of the Conference of Latin American geographers* **25,** 7-14.

Soil fertility management and its contribution to the formation of amazonian dark earths in urban homegardens, Santarém, Pará, Brazil

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Abstract

In order to understand how anthropogenic soils, Amazonian Dark Earths, may have been formed in the past, this study considered soil fertility management in 40 homegardens in the Amazonian city of Santarém, Pará, Brazil. We compared the soil chemistry of a soil conditioner created by the slow burning of organic household debris known as Terra Queimada (TQ) with adjacent non-TQ soil. We found that the TQ had significantly higher CEC, higher pH and was in general much more fertile than the adjacent soil. Although preliminary and small-scale, this study supports the hypothesis that ADEs were likely formed through cool, slow burning, and that this process can likely be recreated to help improve low-fertility soils in the Amazon region.

Key Words

Soil fertility management, anthropogenic soils, Amazonian Dark Earths, carbon.

Introduction

Amazonian Dark Earths (ADEs), also known as *Terra Preta* (*do Índio*) (Black Earth [of the Indians]) soils, are highly fertile organic-rich anthropogenic soils (‘Hortic Anthrosols’) found throughout the Amazon Basin in small patches ranging in size from about 2 to 300 ha (Sombroek 2002; Kern *et al*. 2003). Overall it is estimated that there are 6,000-18,000 km^2 (or 0.1%-0. 3% of 6 million km^2) ADE in the region, but the majority (80%) of ADE sites are very small (<2 ha) (Wood and McCann 1999; Kern *et al*. 2003; Sombroek *et al*. 2003). Organic waste of native Amazonians likely had a major influence in the high level of organic material typically found in ADEs (Wood and McCann 1999). Vegetative food remains such as those from manioc and fruit processing as well as animal residues such as bones, exo-skeletons and carapaces of armadillo, tortoise, crab and shells produce great quantities of organic residue that is not consumed but does remain in place (Wood and McCann 1999). These organic materials are responsible for the increase of a number of elements present in ADEs (Kern 2001). Pabst (1991), in studying ADEs in the region around Belterra, Pará, Brazil, confirmed that the humic fraction in ADEs is six times as stable as the humic fraction in Oxisol. The significant stability of the organic material of ADEs is why Amazonia’s native peasantry, the Caboclo people, consider ADEs the most fertile soil available in the region today, and actively seek it out for cultivation.

Research to date confirms that Amerindians are responsible for the formation of ADEs approximately 500 to 2,500 years ago. What is still not well understood is how ADEs were formed initially and how they might continue to be formed by residents of the region today. Strategies of soil management in urban homegardens today offer a window into ADE formation rooted in daily practice, which may, over time, result in ADEs. In many parts of the world, including the Brazilian Amazon, homegardens are small-scale agricultural production systems. They are multi-layered agroforestry systems for the production of food, fibers, medicinal plants and construction materials, most of it for subsistence (Kumar and Nair 2006. Much research in homegardens has been centered on the agrobiodiversity of homegardens and their role in conserving that diversity, but the soil management of these gardens has not been considered even though it is what is important in terms of ADE formation. In this context, research on homegardens has documented a soil management process locally known as *Terra Queimada* (TQ), or ‘burnt earth’ (WinklerPrins 2002; WinklerPrins and de Sousa 2005). This practice involves the sweeping of homegarden organic debris such as leaves, branches, seeds, peelings are other household residues such as fish or chicken bones to a remote area of the yard where everything is burned, using a slow and cool burning technique. This process creates TQ. The process of burning has two functions, 1) it gets rid of household garbage; and 2) creates a soil conditioner that is rich in organic materials and nutrients that is used to fertilize plants in homegardens. The basic objective of this research was to evaluate the changes in soil fertility as a result of the use of *Terra Queimada* (TQ), burned earth, in homegardens in the Municipality of Santarém, Pará, Brazil, considering that this process may serve as a possible modern-day ADE formation analog.

Materials and methods

This research was conducted in 40 homegardens in the Amazonian city of Santarém, Pará state, Brazil. In each homegarden two samples were taken in the TQ pile and two from an adjacent (non TQ) soil. Each sample was collected at 0-10 cm, 10-20 cm, and 20-30 cm depths. Samples were dried and passed through a 2 mm sieve. Chemical analysis was conducted to determine the values for pH$_{(H2O)}$ and pH$_{(KCl)}$ l, P, Ca^{2+}, Mg^{2+}, K^{+}, Al^{3+} and H^{+} +Al^{+++}. Also calculated was base saturation (BS), cation exchange capacity (CEC), and percentage of Al saturation (% m) (Embrapa 1997). Data were calculated and analyzed using descriptive statistics using the ASSISTAT 8.0 program.

Results and discussion

Soil acidity limits plant production indirectly by limiting available macro and micro-nutrients and the existence of some toxic elements such as Al and Mn. The acidity of the soil could be caused by the increase in concentration of CO_2, through rainfall or microorganism respiration, roots or the decomposition of organic material. The removal of the absorbed bases through cultivation and lixivation also work together and augment the acidity of the soil. All these factors that influence the acidity index of the soils could be present in the agricultural systems on ADE, some with different levels of intensity.

Table 1 demonstrates how the soil management process used in urban homegardens can produce a material rich in macro and micronutrients and is important for cultivated plants. The average pH $_{(H2O)}$ values encountered in the 0-10 and 10-20 cm soil layers in the TQ are extremely high and reveal a direct effect of burning and the production of pyrogenic charcoal and ashes, neutralizing the effects of Al^{+++} and also of H^{+}. The elevation of pH $_{(H2O)}$ directly reflects the decrease in exchangeable acids, demonstrating values of Al^{+++} between 0.12 and 0.14 cmol/kg, values considered extremely low. The values of pH $_{(H2O)}$ in TQ are higher than those of the non-TQ adjacent soils, and this impacts the values of the exchangeable acids (Al^{+++}) and potential acidity (H^{+} + Al^{+++}) demonstrating that TQ represent lower values of these variables.

Table 1. Average values of chemical attributes of TQ and adjacent non-TQ soils in the 40 homegardens sampled in the Municipality of Santarém, Pará, Brazil.

Soil Type	Depth	pH	pH	N	P	K+	Ca++	Mg++	Al+++	Al+H	Fe	Zn	Mn
	(cm)	H_2O	KCl	g/kg	mg/kg	-------------------cmol/kg-------------------					--------mg/kg--------		
Terra Queimada	0—10	6.4	5.9	1.0	460	0.59	4.34	0.83	0.12	0.86	112	26	32
Terra Queimada	10—20	6.6	5.9	0.9	366	0.40	3.56	0.70	0.14	1.44	137	21	25
Adjacent soil	0—10	5.9	4.6	0.5	72	0.07	0.81	0.08	0.44	2.59	184	4	5
Adjacent soil	10—20	5.5	4.3	0.4	54	0.06	0.62	0.06	0.54	2.71	203	2	3

In general Oxisols are extremely acid, with pH $_{(H2O)}$ values between 4.0 and 5.0 (Sombroek, 1966). Samples of Distrophic Yellow Latosols (Brazilian classification), collected at the Fazenda Aruanã, in the Municipality of Itacoatiara, Amazonas state, exhibit average pH values of 4.20 in the topsoil and 4.24 in samples from the subsoil (Falcão & Silva, 2004), the same was found by Moreira & Malavolta (2002), in the same type of soil under *cupuaçu* trees and manioc. Samples from Yellow-Red Ultisols collected at 0-20 cm, with an agroforestry systems in the Municipality of Manacapuru, demonstrate pH $_{(H2O)}$ values of about 4.5 (Falcão, 2001). Soils in our sample do not exhibit the low pH values typical of regional Oxisols, even though these are the underlying natural soils found in homegardens.

Parameters such as CEC and base saturation (BS) are all much higher in TQ than in adjacent soils (Table 1). These elevated levels of CEC are not just the result of a higher quantity of organic material, but also due to the existence of a higher density of charges available on the carbon (Sombroek *et al*., 1993; Liang *et al*. 2006). This property of organic carbon is specific to soil carbon with high amounts of pyrogenic charcoal, such as found in ADEs (Glaser *et al*. 2001; Cunha *et al*. 2007). The reasons for the higher efficiency of nutrient retention of pyrogenic carbon is because: (a) pyrogenic charcoal has a much higher specific surface than charcoal made under high burn conditions; (b) represents a much denser negative change per unit of the surface area, consequently a higher overall charge density (Liang *et al*. 2006). This elevated charge density can, in principal cause oxidation of the pyrogenic carbon itself or through the adsorption of non-pyrogenic charcoal (Lehmann *et al*. 2005). Both processes have been observed in ADEs (Liang *et al*. 2006). The chemical values presented in Table 1 for TQ demonstrate very similar characteristics to those found in ADEs, likely because of the cool, slow and repeat burning that occurs in the TQ piles in homegardens. The values of Ca, Mg, K e Al as well as the CEC and BS as shown in Table 1, demonstrate soil fertility parameters that are much higher in the TQ soil than in the adjacent non-TQ soil.

P is a nutrient that is very important for plant growth, given that many natural soils do not contain sufficient available phosphorus for high productivity. The total P contained in the earth's crust is approximately 0.12% and in soils it can vary from 0.02 to 0.5%, with an average of 0.05%. Sombroek (1966), while studying ADE profiles in the region around Belterra, Pará state, encountered elevated levels of total P_2O_5 in both the topsoil and the subsoil. He also observed that the highest values were encountered in ADEs, with a much clayier texture. In the current study we encountered values of available P that were much higher in the TQ. These results support the hypothesis that large quantities of animal bone were burned, resulting in a large amount of available P for plants. Potassium values were higher in TQ and much lower in adjacent soils. Another element that was much higher in TQ than in adjacent soils was Zn. Given the results of our study to date, we can conclude that present-day soils management in homegardens, particularly the creation of TQ, supports the hypothesis that this soil management practice was used by indigenous people to initially form ADEs.

Acknowledgements

We are immensely grateful to the Santarém householders who let us into their backyards and let us sample their soils, burn piles, and let us interview them. We also extend sincere gratitude to Sandoval Morais, Steve Aldrich, and Perpetuo Socorro de Sousa Oliveira for their important roles in making this research a reality.

References

Cunha TJF, Novotry EH, Madari BE, Melo VB, Martin-Neto L, Peixoto RT (2007) In 'Carbono pirogênico' (Eds WG Teixara *et al.*) (Manaus: Embrapa Amazônia Ocidental).

Falcão NPS, Carvalho EJM, Comerford N (2001) Avaliação da fertilidade de solos antropogênicos da Amazônia Central. In '*Congresso da Sociedade de Arqueologia Brasileira, XI.* Grupo de trabalho: Terras Pretas Arqueológicas na Amazônia' (Estado da Arte. Rio de Janeiro)

Falcão NPS, Comerford N, Lehmann J (2003) Determining nutrient bioavailability of Amazonian Dark Earth soils; methodological challenges. In 'Amazonian Dark Earths; Origins, Properties, Management' (Eds Lehmann J, Kern DC, Glaser B, Woods WI) pp. 255-270 (Kluwer Academic Publishers: Dordrecht).

Falcão NPS, Silva JRA (2004) Características de adsorção de fósforo em alguns solos da Amazônia Central. *Acta Amazônica* 34, 337-342.

Kern DC, Costa ML, Frazão FJL (2001) Evolution of the scientific knowledge regarding Black Earth soil in the Amazon. Terra Preta. Sympósiun, Benicássim, Spain, July 13-14.

Kern DC, D'Aquino G, Rodrigues TE, Frazão FJL, Sombroek W; Myers TP; Neves EG (2003) Distribution of Amazonian Dark Earths in the Brazilian Amazon. In 'Amazonian Dark Earths; Origins, Properties, Management' (Eds J Lehmann, Kern DC, Glaser B, Woods WI). pp. 51-75. (Kluwer Academic Publishers: Dordrecht).

Kumar BM, Nair PKR (2006) Tropical Homegardens: A Time-tested Example of Sustainable Agroforestry, Springer: Dordrecht.

Liang B, Lehmann J, Solomon D, Kinyangi J, Grossman J, O´Neill B, Skjemstad JO, Thies J, Luizão FJ, Petersen J, Neves EG (2006) Black carbon increases cation exchange capacity in soils. *Soil Science Society of America Journal* **70,** 1719-1730.

Pabst E (1991) Critérios de distinção entre Terra Preta e Latossolo na região de Belterra e os seus significados para a discussão pedogenética. *Boletim do Museu Paraense Emílio Goeldi, Série Antropologia* **7,** 5-19.

Sombroek WG (1966) Amazon Soils - A reconnaissance of the soils of the Brazilian Amazon region. Center for Agriculture Publications and Documentation Wageningen. PUDOC.

Sombroek WG, Ruivo ML, Fearnside PM, Glaser B, Lehmann J (2003) Amazonian Dark Earths as carbon stores and sinks. In 'Amazonian Dark Earths; Origins, Properties, Management' (Eds J Lehmann, DC Kern, B Glaser, WI Woods) pp. 125-139. (Kluwer Academic Publishers: Dordrecht).

WinklerPrins AMGA (2002) Linking the urban with the rural: House-lot gardens in Santarém, Pará, Brazil. *Urban Ecosystems* **6,** 43-65.

WinklerPrins AMGA, de Souza PS (2005) Surviving the city: Urban homegardens and the economy of affection in the Brazilian Amazon. *Journal of Latin American Geography* **4,** 107-126.

Woods WI, McCann JM (1999) The Anthropogenic Origin and Persistence of Amazonian Dark Earths. *Yearbook, Conference of Latin Americanist Geographers* **25,** 7-14.

Soil profiles: the more we see, the more we understand

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Abstract

The aesthetics of soils have fascinated soil scientists in all times. Since the late 1800s soil profile drawings, paintings and photographs have been depicted in hundreds of text books. The first soil profile depictions were simple diagrams illustrating different layers and soil processes. Photographs started to appear in textbooks at the end of the nineteenth century. In the 1950s, several books contained water paintings and from the 1970s onwards text books had colour photographs. Soil profile depictions were merely used to illustrate different orders in a classification system. Since the 1990s, efforts have been made to depict the soil profile in 3D. The depiction of soil profiles follows the understanding of the key properties and processes that have formed a soil.

Key Words

Soil profile, painting, soil science history, soil science literature.

Introduction

The first depictions of soil profiles were made long before soil science was established. In many national art galleries across the world, there are paintings of landscapes, usually from the seventeenth century onwards. They illustrate how artists viewed the landscape but also how the naturalists' view and the countryside has changed over time. Landscape painting was popular across Western Europe. Several authors have stated that the Dutch, for all intent and purposes, invented naturalistic landscape paintings in the seventeenth century. It was part of a comprehensive record in paint of their land, people and possessions.

Hans Jenny (1899-1992), best known for bringing together the factors of soil formation into an elegant formula (Jenny 1941), was a dedicated visitor of art galleries. To Jenny, soils were highly aesthetic; threatened soils deserved to be preserved for future generations – an idea that has spread to several countries including New Zealand and that was re-formulated by soil scientists in the USA in 2006 (Drohan and Farnham 2006). Some 40 years ago, Jenny (1968) wrote an article on the image of soil in landscape art from medieval times to the mid 1900s. In 19 paintings he discusses medieval rocks, Renaissance paintings, landscapes of the noble moods, trends towards naturalism, Mediterranean painters, red soils, and the abstract landscape. Jenny's article is a brief historic summary of the artists' views on soils and landscapes, and painters saw things that most other humans did not. In part, because they had never been there and thus it was new, and in part because the artist's ability to actually see and depict was better developed.

The main objective of this paper is to present a historic overview of soil profile depictions supplemented with some discussion on soil knowledge to put the depictions in context. Text books on soils, geology and natural resources from the late 1700s to the present were analysed. The depictions have been grouped chronologically and arbitrarily in periods based on the techniques by which the soil profiles are depicted.

Early depictions of the soil profile

One of the first clear depictions of a soil profile was made by the Dutch medical doctor, nature researcher, writer and poet J.F. le Francq van Berkhey (1729-1812) who wrote the *Natuurlijke historie van Holland* in 1771. Most things beneath the feet of the eighteenth century scientists were unknown, although there were various theories on stones in the soils (by chemical precipitation) or the formation of peat (by algae). Van Berkhey was one of the first to postulate that peat soils were formed from undecomposed plant material.

One of the first books in Britain that viewed soils from a geological point of view was written by J. Morton (1843). Morton wrote "The Nature and Property of Soils" in which discusses alluvial and diluvial soils – a distinction made between fine sediments deposited by water (alluvium), and coarse sediments deposited by floods (diluvium). To Morton soils and geology were one: "*The surface of the earth partakes of the nature and colour of the subsoil or rock on which it rests. The principal mineral of any district, is that of the geological formation under it*." (Morton 1843). The book contains a detailed description of the Whitfield farm (near Bristol, UK), including a map with a cross-section in colour. No horizons were depicted by Morton and the soil pattern at the map is based on the geological formations.

An often neglected book in soil science history epistels was written by the German F.A. Fallou (1794-1877) who had studied jurisprudence at the University of Leipzig (Germany). He worked as a land tax assessor (Asio 2005) and was interested in mineralogy. Fallou was never married. His love of nature turned his attention to soils - he studied soils as a hobby and published *Pedologie oder allgemeine und besondere Bodenkunde* (Fallou 1862). Just like Senft (1857) he attempted to treat the study of soils as an independent science, and soil as a separate topic from geology – ideas that are mostly attributed to V.V. Dokuchaev. Fallou distinguished between soils formed in-situ and "washed-in" or alluvial soils. He discussed the effect of relief on soil depth, and introduced new terms like pedology and soil quality. Both are still widely used but with a different meaning to different people. Fallou's book contains two maps with soil and geological layers and diagrams of four soil profiles taken near Colditz, between Leipzig and Dresden in Germany.

Russian work brought the study of soils out of the chaos and confusion of the geologic, chemical, and agronomic points of view and established it as independent science (Marbut 1936). This thinking was more or less established with *Ruskii Chernozem* (Dokuchaev 1883). Dokuchaev was a keen observer, travelled widely across the Russian Empire, collected data, and combined existing knowledge into a definition of soil as a natural body with a science on its own. He has been as important for the development of soil science as C. Lyell for geology, C. Darwin for biology and C. Linnaeus for botany.

Many of the study and text books on soil science contain diagrams and pen drawings of soil profiles to illustrate processes or the horizonation of a particular soil. Some have argued that the distinction of different horizons and its relation to soil genesis was an important conceptual finding in soil science, and these discoveries can be largely attributed to the Russian school. Diagrams were very popular in soil science texts to explain the development of horizons, illuvial and eluvial processes, the formation of stone lines and many other soil processes and properties.

Paintings (1950s)

The technique of water and oil paintings for depicting soil profiles has been used in various books. W.L. Kubiëna (1950) wrote the first text book with a pan European view. For the soils of Europe, he introduced a key to classify the soils analogue to the existing keys for classifying flora and fauna. Firstly, the soils of Europe are grouped into 4 zones: Central and Northern Europe, Southern Europe, Alpine soils, and sub-aqueous or underwater soils. The colour of the topsoil is a diagnostic criterion, followed by free $CaCO_3$ content, and then parent material. Following this key, Kubiëna distinguished 173 soil formations (great soil groups) for the whole of Europe. The book contains water paintings of 47 of these soil formations. Although colour pictures were not uncommon in books in the 1950s (the first colour photographs were already made in the 1860s), Kubiëna preferred such paintings because "*..die Zeichnung das Wesentliche besser hervorheben kann*."

The German soil scientist E. Mückenhausen (1907-2005) published in 1957 *Die Wichtigsten Boden der Bundesrepublik Deutschland*. It contains water paintings of 60 soil profiles and although colour photography was reasonably well-developed in the 1950s, Mückenhausen just like Kubiëna, preferred painting. In his view photographs were often falsely coloured, particularly in dry soils and when a flash light was used (Mückenhausen 1957). Water paintings allowed for more freedom to depict the soil profile and details and specific attributes of an individual soil type could better highlighted. Mückenhausen admitted that the paintings were not always a true reflection of the soil, but merely a true representation of a particular type; in his view that was allowed: "*Das alles verstößt nicht gegen die Natur, hilfst aber, das Natürliche klarer verständlich zu machen*.".

Colour photographs (1960-present)

From the 1960s onwards soil science text books were published with colour photographs. Apparently, the technique of obtaining good pictures as well as reproducing them sharply, in true colour and at reasonable cost was overcome. An example from the Netherlands is shown in Fig. 18. De Bakker and Edelman-Vlam published in the mid-1960s soil profiles and their description in magazines for professional land developers. These profiles were compiled in the 1970s and published in a book (de Bakker and Edelman-Vlam 1976). It is a series of 32 common soils in the Netherlands including landscape pictures, laboratory data and razorblade sharp pictures of the soil profiles. The pictures have been taken in a studio from monoliths or lacquer profiles.

A number of books with colour pictures of the soils of the world have also been published. One of the first was a global atlas of soil profiles based on a French soil classification system (Duchaufour 1976). For each soil group (e.g. *Sols isohumiques et vertisols*) there are colour pictures of typical profiles with approximately equivalent classification in FAO-UNESCO and USDA Soil Taxonomy. The pictures are from all over the world.

The soil profile in 3D (1990s and the future)

The increased computer power and micro-computers that became available in the early 1990s made it possible to depict the soil profile in 3D. There were 3D drawings and diagrams from soil profiles made in the past in relation to the smallest unit that can be recognised on the land scale as a “soil”, and it was used in the Australian land system mapping developed in the 1950s (Gibbons 1993). In the 1990s, it was possible to depict soils in three dimensions. This had direct applications for the prediction of soil compaction and shear strength or the movement of water and solutes but it also used to study horizons, pores, soil-landscape relations, modelling erosion and 3D GIS cartography-based on soil horizons.

Conclusions

The old landscape painters saw things that most other humans failed to see. They painted soil features that we now recognise as podzols (e.g. Jan van Goyen), paleosols (e.g. Jacob van Ruysdael), Oxisols (e.g. Paul Gauguin), or Vertisols (e.g. George Lambert). Many of these landscapes and soils have now disappeared under tarmac or through the expansion of agriculture and urbanisation. At the time they were painted these soils had no name, no description and soil science had yet to be invented. Yet we can now look at these early soil depictions and note that there is an element of great aesthetics. Perhaps, there was the hidden but apparent invitation to study what was seen. It is impossible to ascertain, but the arts may have opened the eyes for the science to follow – that link may have to be re-established.

References

Asio VB (2005) Comments on "Historical development of soil and weathering profile concepts from Europe to the United States of America". *Soil Science Society of America Journal* **69**, 571-572.

de Bakker H, Edelman-Vlam AW (1976) 'De Nederlandse Bodem in Kleur.' (StiBoKa - PUDOC: Wageningen).

Dokuchaev VV (1883) 'Russian Chernozem. Selected works of V.V. Dokuchaev. Volume I (translated in 1967).' (Israel Program for Scientific Translations: Jerusalem).

Drohan PJ, Farnham TJ (2006) Protecting life's foundation: A proposal for recognizing rare and threatened soils. *Soil Science Society of America Journal* **70**, 2086-2096.

Duchaufour P (1976) 'Atlas Ecologique des Sol du Monde.' (Masson: Paris).

Fallou FA (1862) 'Pedologie oder Allgemeine und Besondere Bodenkunde.' (Schönfeld Buchhandlung: Dresden).

Gibbons FR (1993) Soil mapping in Australia. In 'Soils: an Australian Viewpoint' pp. 267-276. (CSIRO Division of Soils: Melbourne).

Jenny H (1941) 'Factors of soil formation. A system of quantitative pedology.' (McGraw-Hill: New York).

Jenny H (1968) The image of soil in landscape art, old and new. In 'Organic matter and soil fertility' pp. 947-979. (North-Holland Publishing Company: Amsterdam).

Kubiëna WL (1950) 'Bestimmungsbuch und Systematik der Böden Europas.' (Ferdinand Enke Verlag: Stuttgart).

Marbut CF (1936) Introduction. In 'Pedology'. (Ed JS Joffe) pp. vii-xiii. (Rutgers University Press: New Brunswick).

Morton J (1843) 'The Nature and Property of Soils; their Connexion with the Geological Formation on which They Rest.' (James Ridgway: London).

Mückenhausen E (1957) 'Die wichtigsten Böden der Bundesrepublik Deutschland.' (Verlag Kommentator: Frankfurt am Main).

Senft F (1857) 'Lehrbuch der forstlichen Geognosie, Bodenkunde und Chemie.' (Manke: Jena).

The historical legacy of Anthrosols at Sandhavn, south Greenland

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Abstract

The impact of European settlement and farming on the landscape of southwest Greenland has been considered in many landscape and archaeological studies, however the nature and extent of soil modification associated with European land management has yet to be determined. This paper explores the historical legacy of Anthrosols at a large Norse farm site in south Greenland. Changes in land management, resource exploitation and site formation are examined, and the notion of soils based evidence for cultural interaction is explored.

Key Words

Anthrosols, Norse, Homefield, manuring, irrigation, Inuit, Greenland.

Introduction

Modification of the landscape through implementation of historic European farming practises is observable at a regional scale and at the individual farm level in southwest Greenland. The landscape across both the Norse Eastern and Western Settlement areas is characterised by a scattered settlement distribution reflecting the importation of a pastoral farming economy by European settlers in the 11th century AD (Arneborg 2005). In particular there is a distinct correlation between farm location and areas of high quality pasture in inner-fjord areas (McGovern 1980a, 1980b). Although all farms were engaged in pastoral agriculture, farms in more peripheral and/or marginal locations specialised in additional modes of subsistence. Interior farms were positioned to exploit migratory caribou, similarly coastal farms specialised in marine resource extraction (Berglund 1986). The settlement pattern of Norse farms was dictated by a European model of subsistence which extended to the spatial organisation of land at the individual farm level. Farmland was divided and utilised according to the infield-outfield system. The infield, also referred to as the homefield, was located near to the farmstead and was used to grow fodder for overwintering cattle. The outfield was used to graze cattle during the summer, and sheep and goats all year.

Farming in Greenland differed from mainland Europe in that it was based exclusively on livestock, however comparable management strategies to ensure maximum growth yields are apparent. The use of irrigation networks to supply the homefield with a regulated water supply has been identified at several Norse sites including Igaliku and Quassiarsuk (Arneborg 2005). This strategy enabled maximisation of fodder crop yields and led to increased growth security in more marginal years through offsetting growing season soil moisture deficits (Adderley and Simpson 2006). In contrast irrigation in mainland Europe was used as a mechanism to increase grain production. The establishment of shielings (small seasonal farms) is an additional example of European resource management in southwest Greenland. Within the Eastern Settlement hay making shielings are restricted to marginal resource areas. In addition, there is a close association between milking shielings and areas of medium quality pasture with limited opportunities for grazing (Albrethsen 1991). The impact of European settlement and farming on the landscape of southwest Greenland has been considered in many landscape and archaeological studies, however the nature and extent of soil modification associated with European land management has yet to be determined. This paper explores the historical legacy of Anthrosols at a large Norse farm site in south Greenland. Changes in land management, resource exploitation and site formation are examined, and the notion of soils based evidence for cultural interaction is explored.

Field Investigations

The site of Sandhavn (59°59'N, 44°46'W) is located on the south coast of Greenland 3.5km WNW of Herjolfsnæs. Sandhavn functioned as a large Norse farm and is thought to have been an important international trading post for Norwegian merchants. Inuit ruins have also been identified at Sandhavn including a dwelling, 'Inuit Structure 6', which is located within the Norse homefield. Charcoal from Inuit Structure 6 has been ^{14}C dated to the 13-14th centuries AD (Raahauge *et al.* 2003) raising the possibility that Norse and Inuit groups were co-existent at this site.

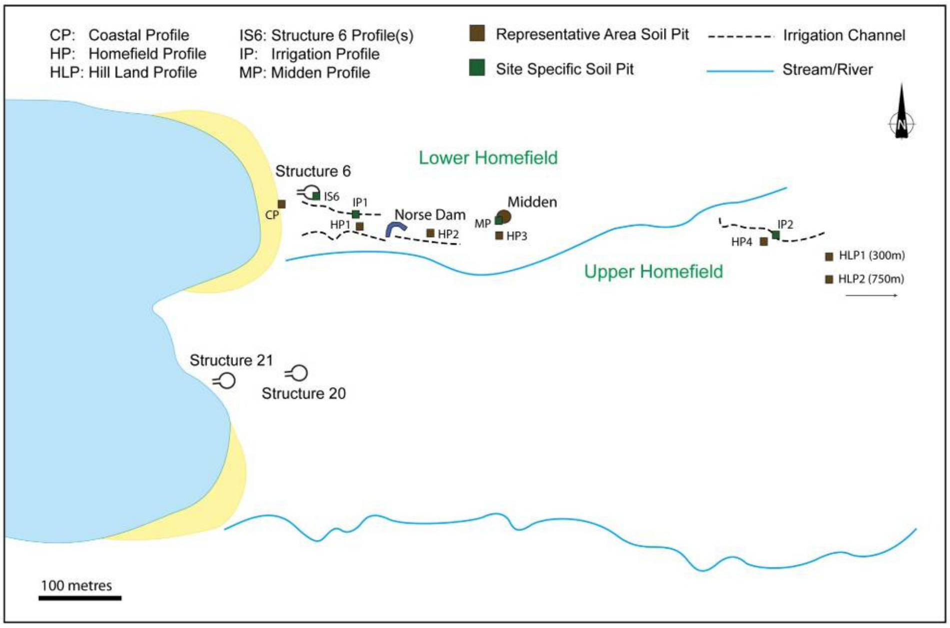

Figure 1. Location of site features and soil pits investigated at Sandhavn (Image geo-corrected in ArcGIS © ESRI 2006).

The first stage of fieldwork at Sandhavn involved locating and recording important landscape features such as Norse structures, Inuit dwelling remains, irrigation channels, and Norse 'upper' and 'lower' homefield areas. Subsequently seven representative area soil pits were dug along an east-west transect traversing the lower and upper Norse homefield to determine changes in landscape utilisation across space and in time. Site specific soil pits were located according to additional features of interest including Inuit winter dwelling 'Structure 6', a Norse midden, an irrigation channel in the lower homefield and an irrigation channel in the upper homefield (Figure 1). Exposed profile faces were recorded according to standard procedures (Hodgson 1976) and the presence of exotic inclusions such as charcoal and bone were noted. In total 38 charcoal samples were extracted for radiocarbon dating and 27 Kubiena tin samples were taken for thin section manufacture and micromorphological analysis.

Results

The existence of a fossil soil buried beneath anthropogenic deposits is noted within all soil profiles in the homefield. The fossil soil comprises dark brown/dark yellowish brown freely draining sand, which is overlain by a black/dark brown organic sandy loam horizon typically no deeper than 5cm. In some cases dark greyish brown sand is present above the latter horizon ranging in depth from 2cm (HP4) to 11cm (HP2). The distinctive black/dark brown organic sandy loam horizon is representative of the original land surface prior to Norse occupation. Charcoal (willow) obtained from this horizon has been ^{14}C dated to cal AD 1040-1230 (2σ) indicating Norse settlement in the 11th century AD.

Norse homefield

Differences in soil characteristics between the lower and upper homefield areas are identified (Figure 2). Soils within the lower homefield contain dark brown sandy loam/sandy silt loam topsoil varying in depth from 8 to 18cm. In comparison soils within the upper homefield contain three phases of dark brown organic loam, interspersed with thin bands of dark brown sand. The organic loam horizons are wavy and range in depth from 5cm to 10cm, whereas the brown sand layers are typically smooth and no deeper than 3cm. Differing manuring regimes may account for variation in soil characteristics between the lower and upper homefield areas. Charcoal obtained from topsoils within the lower homefield has been dated to 1030-1220 cal AD (HP3) and 1280-1400 cal AD (HP1) (2σ). These dates suggest sustained manuring of the lower homefield throughout the duration of Norse occupation, although the possibility of discontinuity in the onset of manuring across the lower homefield cannot be disregarded. In comparison results of ^{14}C dating on birch charcoal obtained from successive deposits within the upper homefield indicate three discrete phases of manuring activity: 1) 11th to late 13th century AD; 2) 13th century AD; 3) 13th to 14th century AD.

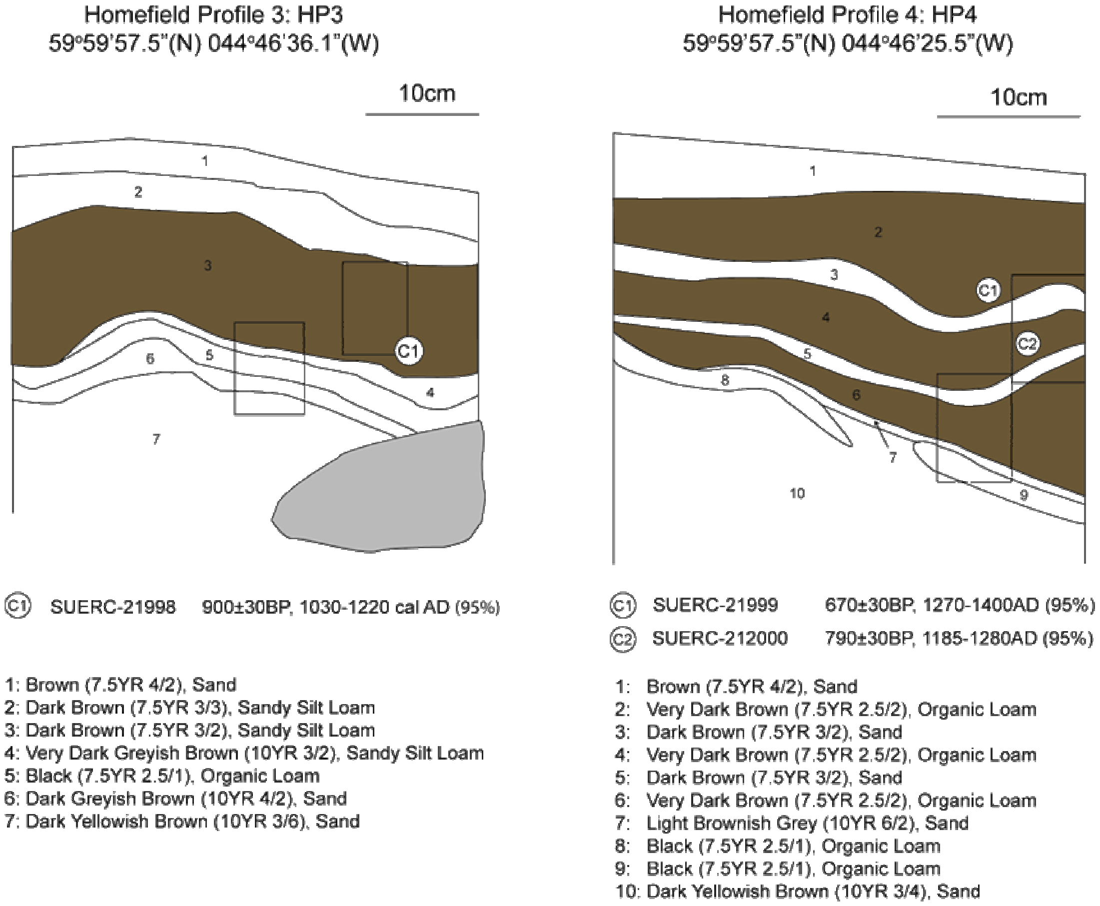

Figure 2. Profile description of Homefield Profile 3: HP3 (Lower homefield) and Homefield Profile 4: HP4 (Upper homefield).

Irrigation channels

A contrast in soil characteristics and channel morphology is noted between irrigation channel soil profiles in the lower (IP1) and upper homefield (IP2). It is proposed that manure/midden material was used to line and consolidate irrigation channels in the lower homefield. This would account for the markedly different colour and texture of the channel lining compared to surrounding soil horizons (Figure 3). Charcoal obtained from the channel lining has been ^{14}C dated to cal AD 1260-1390 (2σ), although it is possible that construction and use of irrigation channels at Sandhavn dates to an earlier period, especially if more recent charcoal became incorporated into the channel lining through replacement/repair. Surface irrigation within the lower homefield would have promoted higher crop yields in addition to growth security in more marginal years by offsetting growing season soil moisture deficits (Adderley and Simpson 2006). The irrigation channel investigated within the upper homefield appears to have been lined with small stones rather than manure/midden type material. Variation in channel morphology between the lower and upper homefield may reflect differences in when these irrigation channels were constructed and/or utilised.

Inuit structure 6

Profile descriptions of two cross sections through Inuit structure 6 are summarised in Golding *et al.* (2009). It is suggested that manure/midden material may have been used as a construction material accounting for the differing colour and texture of organic loam layers compared to adjacent sand horizons. The use of manure/midden material in dwelling construction is logical given its physical and thermal properties. Charcoal from the wall packing (context 9) and occupation surface of structure 6 date to cal AD 1220-1295 (2σ). It is possible that the Inuit were using Norse midden material in dwelling construction implying some element of mutual cooperation between the two groups. Alternatively it can be argued that Inuit Structure 6 predates Norse occupation at Sandhavn, and that the brown organic layers are formed through subsequent application of manure/midden to the lower homefield in which this structure is located. It is expected that subsequent micromorphological analyses will resolve this issue.

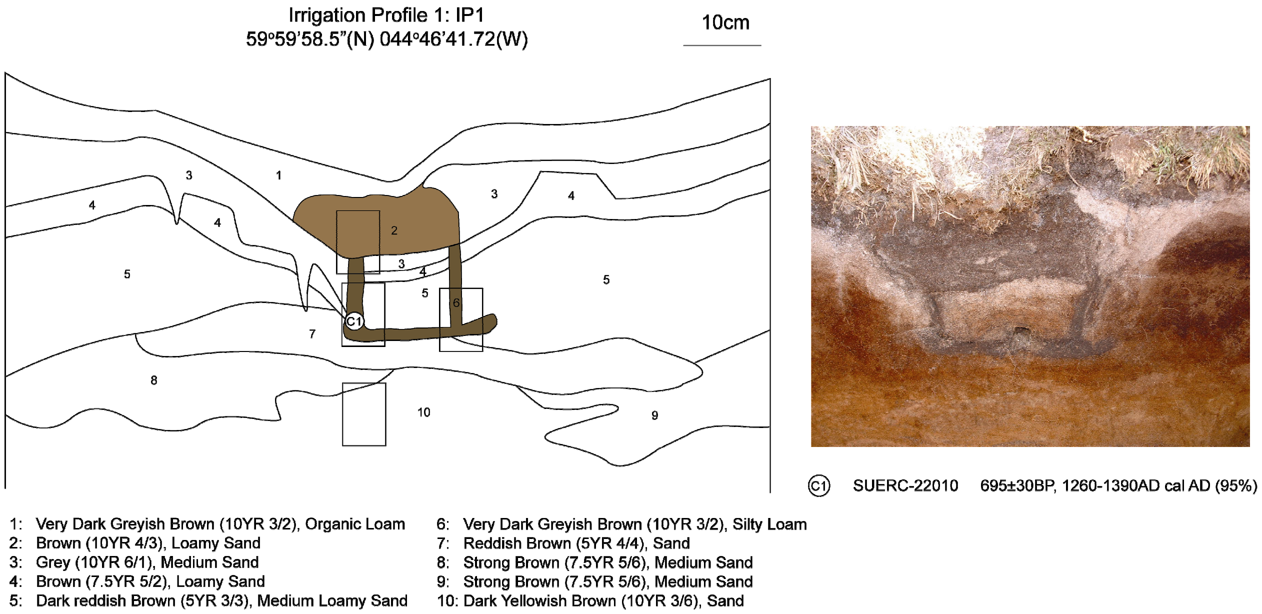

Figure 3. Profile description of Irrigation Profile 1 (IP1) (Lower homefield).

Conclusions and future work

Results of field investigations of Anthrosols at Sandhavn reveal complex landscape management practises associated with the Norse farm. It is apparent that soil improvement within the homefield and utilisation of irrigation channels were important strategies in maximising resource yield. The possibility of contact between Norse and Inuit groups at Sandhavn remains unresolved. It is expected that micromorphological analysis in association with quantitative chemical investigation of key anthropogenic features (SEM EDX) will prove vital in resolving whether the Inuit were utilising Norse midden/manure resources.

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References

Albrethsen SE (1991) Saeters in the Norse Eastern Settlement of Østerbygden in Southwest Greenland. *Acta Borealia* 1, 15-28.

Arneborg J (2005) Greenland irrigation systems on a West Nordic background. An overview of the evidence of irrigation systems in Norse Greenland c.980-1450AD. *Památky Archeologickė-Supplementum 17*, *Ruralia V*, 137-145.

Adderley PA and Simpson IA (2006) Soils and palaeo-climate based evidence for irrigation requirements in Norse Greenland. *Journal of Archaeological Science* 33, 1666-1679.

Berglund J (1986) The Decline of the Norse Settlements in Greenland. *Arctic Anthropology* 23, 109-135.

Golding KA, Simpson A, Schofield JE and McMullen AJ (2009) Field-based geoarchaeological investigations at Sandhavn, south Greenland. *Antiquity.* 83, www.antiquity.ac.uk/projgall/golding/

Hodgson JM (1976) 'Soil Survey Field Handbook: Describing and Sampling Soil Profiles, Technical monograph no. 5'. (Soil Survey of England and Wales: Harpenden).

McGovern TH (1980a) Site catchment and maritime adaptation in Norse Greenland. *Anthropology UCLA* 10, 193-209.

McGovern TH (1980b) Cows, harp seals, and churchbells: Adaptation and extinction in Norse Greenland. *Human Ecology* 8, 245-275.

Raahauge K, Hoegh-Knudsen P, Gulløv HC, Mohl J, Krause C and Møller NA (2003) *Tidlig* Thulekultur I Sydgrønland (Early Thule Culture in South Greenland) Rapport om undersøgelserne I Nanortalik Kommune, sommeren 2002, Feltrapport 9. SILA Nationalmuseets Center for Grønlandsforskning, Copenhagen.