Atti Soc. tosc. Sci. nat., Mem., Serie A, 112 (2007)
pagg. 79-83, figg. 5, tab. 1

D.A. DAVIDSON (*), G. DERCON (*), I.A. SIMPSON (*),
K. DALSGAARD (**), T. SPEK (***), D.A. PLANT (****)

THE IDENTIFICATION AND SIGNIFICANCE OF INPUTS TO ANTHROSOLS IN NORTH-WEST EUROPE

Abstract - In recent years there has been a renewed interest in soils which are the result of past land management practices involving substantial additions of mineral and organic matter. However, there is still a substantial lack of detailed information on their formation. Anthrosols are distinguished by the presence of a deep top horizon and such soils were investigated at sites in Scotland, Denmark and The Netherlands. Field data and samples were collected from eight sites under arable cultivation, meadowland and woodland. Particle size distribution, pH, loss on ignition, ECEC, base saturation and total P were measured. Carbonaceous particles were identified through micromorphological analysis and the determination of O:C ratios using an electron microprobe. Despite the use of different inputs in recent centuries and different current land management, the resultant anthropogenic soils are remarkably similar in field and analytical properties. Nevertheless, subtle changes in particle size can be explained by parent material influences, material imported by farmers and by inputs by other processes such as by wind. The results from microprobe analysis demonstrate the importance of carbonaceous particles in storing phosphorus. Thus the inherent fertility of these Anthrosols can be explained in part by the application of carbonised material in the past.

Key words - Anthrosol, chemical analyses, physical analyses, Scotland, The Netherlands, Denmark.

Riassunto - *Identificazione e significato degli apporti agli antrosuoli in Europa nord-occidentale*. Recentemente si è manifestato un rinnovato interesse per i suoli originati da pratiche agricole del passato che abbiano implicato aggiunte notevoli di materia minerale ed organica. Tuttavia vi è ancora una notevole mancanza di informazioni dettagliate sulla loro formazione. Antrosuoli caratterizzati dalla presenza di uno spesso orizzonte superficiale sono stati studiati in Scozia, Danimarca e Paesi Bassi, raccogliendo dati di campagna e campioni in otto località, sotto campi arati, prato e bosco. Sono state effettuate analisi granulometriche, misure di pH, perdita alla combustione, ECEC, saturazione in basi e P totale. Le particelle carbonatiche sono state identificate per mezzo di analisi micromorfologiche e attraverso la determinazione del rapporto O:C con microsonda elettronica. Si è osservato che i suoli antropogenici sono notevolmente simili sia sul campo che dal punto di vista analitico, quantunque vi siano stati differenti apporti nei secoli recenti ed indipendentemente dalle pratiche agricole attuali. Tuttavia vi sono lievi variazioni nella granulometria che possono essere imputate all'influenza della materia prima, al materiale introdotto dagli agricoltori e ad apporti derivanti da altri processi, ad esempio il vento. I risultati delle analisi alla microsonda dimostrano l'importanza delle particelle carbonatiche nell'immagazzinamento del fosforo. La caratteristica fertilità di questi Antrosuoli può essere spiegata in parte dall'aggiunta nel passato di materiale carbonizzato.

Parole chiave – Antrosuoli, analisi chimiche, analisi fisiche, Scozia, Paesi Bassi, Danimarca.

INTRODUCTION

The last decade has seen a growing and renewed interest regarding anthropogenic soils which owe their dominant characteristics to past land management practices. These soils, besides being of particular pedological interest, are also of high archaeological significance given the high density of sites which frequently occurs on them. According to the World Reference Base for Soil Resources, anthrosols are distinguished by an uppermost horizon of at least 50 cm which has been substantially modified by human activity (Bridges *et al.*, 1998). Integral to their formation was the addition of substantial manure and/or waste materials such as organic matter from cut turves (plaggen), forest litter, bracken, seaweed, manure from byres, waste materials from houses, and calcareous beach sand. A plaggic horizon is formed by the addition of turves whilst terric horizons result from the addition of mineral material. Early research on plaggen soils was done by Pape (1970) for the Netherlands and Conry (1974) for Ireland. In Scotland Davidson *et al.* (1998) and Carter (2001) investigated such deepened soils using micromorphology. Simpson (1997) and Simpson *et al.* (1998, 1999) integrated micromorphology with other techniques including the identification of biomarkers. In Denmark research on soil history has been discussed by Gormsen (1991), Stoklund (1999) and Dalsgaard *et al.* (2000). In The Netherlands, Spek (1992) and Smeerdijk *et al.* (1995) combined soil profile analysis, micromorphology and detailed investigation of landscape history with a similar approach in Belgium being adopted by Langohr (2001). The recent rise in research related to anthropogenic soils can be attributed to the realisation that such soils contain unique evidence regarding past use of soils. Furthermore, the need to formulate soil protection strategies as specified by the Commission of the European Communities (2002) is requiring member States to identify «valued» soils; it can be argued that

(*) School of Biological and Environmental Sciences, University of Stirling, Stirling, FK9 4LA, Scotland, United Kingdom.
(**) Department of Earth Science, University of Aarhus, C.F. Møllers Allé Building 120, Aarhus C, DK-8000, Denmark.
(***) Department of Landscape & Heritage, National Service for Archaeological Heritage in The Netherlands, PO Box 1600, Amersfoort, NL-3800 BP, The Netherlands.
(****) Department of Earth Sciences, University of Manchester, Oxford Road, Manchester, M13 9PL, United Kingdom.

anthropogenic soils are of distinctive character meriting protection. Questions related to their sustainable use can only be addressed once there is a fuller understanding of their nature and formation. This study addresses these issues through the analysis of anthropogenic soils at three sites in Scotland, Denmark and The Netherlands, all on sandy parent material.

MATERIALS AND METHODS

Study areas

The first study area is near Nairn in north-east Scotland (57° 34' North, 4° 53' West). Nairn is built on fluvioglacial terraces along the river Nairn. The Soil Survey of Scotland (1974) mapped freely drained Iron Podzols with a deepened phase in the southern outskirts of the town. A topsoil depth of 60-80 cm was confirmed by augering. For the parishes Moy and Dyke close to Nairn, the Old Statistical Account of Scotland (Sinclair, 1791-1799) describes the use of turf sods and additions of sand to dung by farmers. Donaldson (1794) refers in the General View of the Agriculture of the County of Nairn to the use of sand as litter in sheep stables, which is put afterwards on the dung-hill. However, when these practices began is uncertain. The period of maximum activity leading to the deepening of these soils was likely to be in the 18th and early 19th Century (Mairi Stewart, pers. comm., 2002). Rebuilding of turf walls in Nairn produced much waste material which would have been spread onto local fields. In addition, local farmers used seaweed until the Second World War (Joanne Thomas, pers. comm., 2002). Most of the anthrosol is under arable cultivation. However, deciduous tree plantations and fields under long term grass are also present. Three well drained representative soil profiles were selected in the area of anthrosols near to Nairn *viz* arable land, meadow land and woodland.

The second study area is located at Epse (52° 14' North, 6° 13' East) in the East of the Netherlands, close to the city of Deventer. Epse, a small rural village on the banks of one of the tributaries of the river IJssel, is characterised by the presence of several mixed farms which date back to the High Medieval period (11th-13th century). It is a coversand landscape on which dark brown plaggic anthropogenic soils have formed (The Soil Survey of the Netherlands (1979). Tillage of the original soil began during the 11th-13th centuries whilst intensive plaggen manuring started probably c. 16th century (Domhof, 1953; Slicher van Bath, 1957; Bieleman, 1992; Groenewoudt *et al.*, 1998). Possible sources would have been sods from nearby heath and meadow land. A study site was selected on a farm called «De Olthof» («the Old Manor») and three profiles were located on a well drained coversand ridge under three different land uses – arable land, meadow and a deciduous tree plantation.

The third study area is located in the South West of Ulfborg, Jutland, Denmark though the two profiles were some distance apart (c. 14 km). The first profile at Staby is located along a fjord just a few kilometres from the present coastline (56° 16' North, 8° 15' East). Remnants of Viking age (9-11th Century) houses were found and anthrosols with a topsoil depth of around 80 cm overlie these remnants (Dalsgaard *et al.*, 2000). The parent material is well-sorted sand of marine or lacustrine origin. Seaweed and turves from meadow land were mixed with cattle manure for application to the land. High quality meadows are close to the site. One profile from arable land near the Viking settlement was selected. The second Danish site is in a Norwegian spruce plantation called Stråsø, underlain by fluvioglacial sands and named after a farm dating to before 1435 AD (56° 15' North, 8° 28' East). Cultivation started at this site around 1300 BC and farmers used sods from Calluna heathlands mixed with manure (Dalsgaard *et al.*, 2000). Anthrosols under the plantation are shallow and one profile was selected from the plantation on the former cultivated fields of the old Straasø farm.

Laboratory analysis

Soil sampling was at 5-10 cm depth increments with some variation according to depth and horizon. Particle size distribution was determined by laser diffraction. Standard soil analysis for pH (H_2O, 1:2.5), loss on ignition (425 °C), ECEC (KCl 1 M extraction), base saturation (KCl 1 M extraction) and total P of the fine earth fraction, < 100 μm, (sodium hydroxide fusion method, Smith *et al.*, 1982) were done. In Scotland and Denmark, additional samples were taken from areas which had been potentially used by local farmers as sources of materials. Central to the study was comparison of particle size distributions of the anthropogenic horizons with those of the underlying parent material as well as with other possible source materials. Of particular interest in the study was investigation of the fertility of the anthrosols. It was expected that this would be closely related to the availability of P. Thus for a trial study, a soil thin section was prepared from the Nairn anthrosol for microprobe analysis of P distribution. This was undertaken in the Department of Earth Sciences, University of Manchester using a Cameca SX100 electron probe.

RESULTS AND DISCUSSION

A summary of the analytical results is given in Table 1. The high sand content is to be expected given the nature of the parent material at all the sites: the texture of the anthropedogenic horizons is generally loamy sand and the texture of the underlying parent material is generally slightly coarser than the upper horizons. Of note also from Table 1 is the high mean total phosphorus value though much variability is evident. The mean depth of the anthropogenic horizons is 0.85 m with a maximum of 1.35 m recorded for the Epse, pasture site and a minimum of 0.25 m for the Stråsø spruce site.

Particle size distributions as indicators of anthropogenic inputs

Particle size distributions of the upper anthropedogenic horizons can be contrasted with the parent material in order to identify if there has been addition of material

Tab. 1 - Summary of analytical properties for the sites in Scotland, Denmark and the Netherlands.

	Mean	Std deviation
Clay (< 2 μm) %	3	1
Silt (2-20 μm) %	15	5
Fine sand (20-200 μm) %	57	8
Coarse sand (200-2000 μm) %	25	10
Loss-on-ignition %	3.7	1.5
ECEC cmol/kg soil, fine earth	3.4	1.3
Total P mg/kg soil, fine earth	706	271
Base saturation %	71	31
pH	5.0	0.7

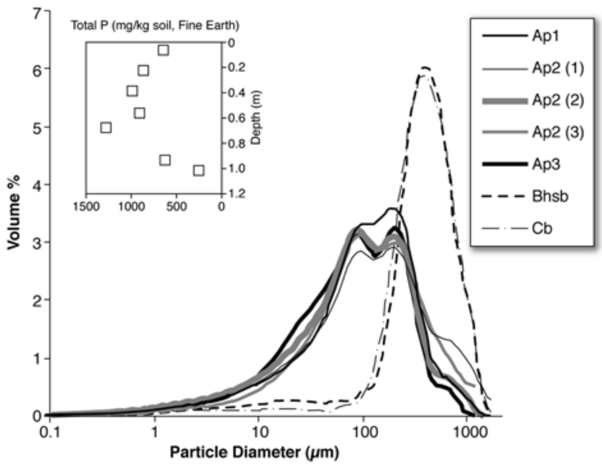

Fig. 1 - Particle size distributions for the site at Nairn (Scotland) under pasture.

with contrasting particle size distribution. The striking result from Nairn is the contrast in particle size bimodal distributions for the A and the lower horizons (Fig. 1). This provides strong evidence for the import of finer mineral material. The bimodal distribution can be explained by mineral input. The first maximum on the left of the bimodal distribution of the anthropogenic horizons can be attributed to additional inputs by farmers. There is historical evidence for the use of turf sods for house construction in Nairn (M. Stewart, pers comm.); such walls had limited life-spans and thus there had to be the ultimate disposal of the material onto local fields, probably in association with other urban waste. Another possibility is that this peak indicates the addition of pure sand. Donaldson (1794) comments that farmers in the area used sand for spreading in byres, a process also observed in the Netherlands (Pape, 1970). The second peak from the left coincides with the modal particle size class for local beach sand. There are several mechanisms by which beach sand could have become incorporated into these old cultivated soils. Beach sand may have been applied directly as was done in Ireland (Conry *et al.*, 1999). Alternatively, the sand may have been first mixed with dung before field application, a previous practice in local parishes (Sinclair, 1791-1799; Donaldson, 1794). A certain amount of beach sand could also have been added when seaweed was applied. In addition, it is likely that aeolian deposition resulted in the addition of silt and fine sand; «sand storms» are well documented for the Nairn area and continue today.

In contrast to the Nairn site, peaks in the particle size distribution curves for the Danish profile (Staby) are virtually identical to the parent material (Fig. 2). With increasing depth the particle size distribution becomes more narrow and similar to the underlying parent material. The topsoil of this Danish anthrosol has a greater amount of silt and fine sand than the underlying parent material. This is probably related to mineral input from the addition of turves from local marshy meadows close to the Staby site. On the Stråsø site the increased clay and silt fraction can be explained by fine dust captured by the Mor-layer (O horizon) from heather which is afterwards transported to the farm together with the sods. Dalsgaard *et al.* (2001) measured the captured fine sediment of less than 64 μm in the Mor-layer (O horizon) from the Straasø area. Based on these measurements and historical information on the use of the sods from the heathland, it is estimated that most of the increase in the fraction of less than 63 μm can be attributed to this process (Gormsen, 1991; Dalsgaard *et al.*, 2000). However, there may also have been greater use of turf and associated fine sediment from nearby meadowland.

The particle size distribution of the samples from the profile under arable land at Epse shows a similar decrease in sand around 200 μm and increases in fine sand, silt and clay (Fig. 3). Again the increase in fine sand and silt can be attributed to the use local turf from meadowland. Historical documents show that the use of meadow turves was quite common in the 16th and 17th centuries whilst in the 18th and 19th centuries it was strictly forbidden because of the damaging effect on the grassland. After that farmers changed mainly to heathland turves. This historical process is clearly reflected in the particle size distributions of the Ap4 (high content of fine sand and silt, meadow turves) and the Ap3-Ap2-Ap1 (lower content of fine sand and silt, heathland turves). The increase in fine sand is more marked than for the Danish site, perhaps explained by the use of sand on the floors of byres (Pape, 1970) in a similar way to the Nairn site.

Phosphorus distribution as determined from microprobe analysis

High levels of total phosphorus are characteristic of anthrosols, especially if a plaggen formation process is involved. Figures 1, 2 and 3 illustrate the distribution of total phosphorus with depth; generally there is much uniformity and enhancement in the uppermost 80 cm followed by a decrease in the B and C horizons. Micro-

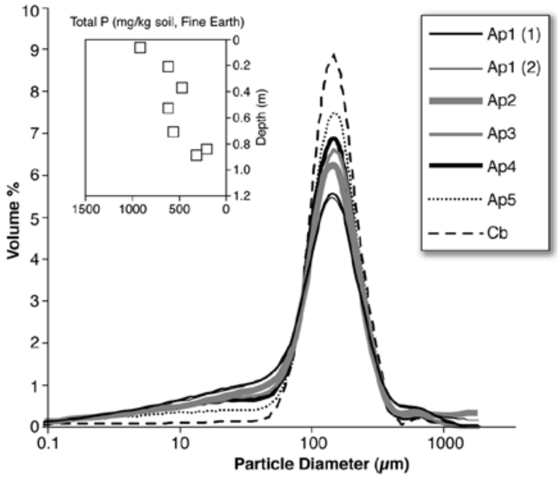

Fig. 2 - Particle size distributions for the site at Staby (Denmark) under arable.

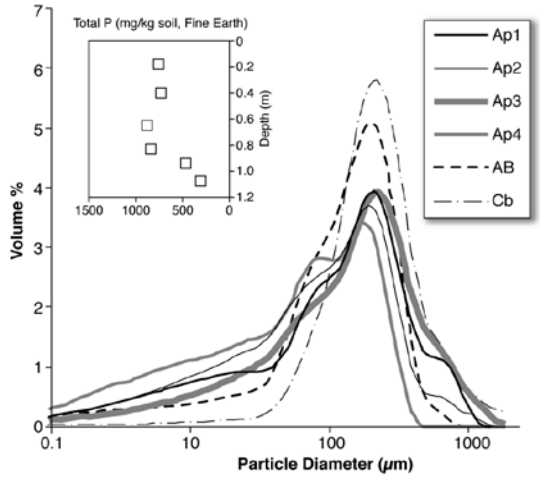

Fig. 3 - Particle size distributions for the site at Epse (the Netherlands) under arable.

morphology combined with microprobe analysis offers the opportunity to determine where the concentrations of phosphorus occur within the soil structure. The hypothesis was that this phosphorus would be associated with carbonised material. Black amorphous particles were first isolated through thresholding procedures within an image analysis system and sample results are illustrated in Figure 4. Determination of whether particles are pure carbonised material or mineral matter coated with organic material cannot be determined by conventional microscopy. Stoffyn-Egli *et al.* (1997) illustrate how determination of O:C ratios offers a way to distinguish between different types of black features and they proposed that O:C ratios between 0.05 and 0.1 are indicative of charcoal. Figure 4 illustrates the distribution of such carbonised particles and furthermore, those particles with a marked concentration of phosphorus are indicated. On the whole it seems that phosphorus concentrations are associated with larger fragments of charcoal though this is now always the case. Figure 5 illustrates at a more detailed scale the association of phosphorus with a large fragment of charcoal. Phosphorus is associated with the perimeter as well as with the internal voids of the charcoal. These illustrative results confirm the hypothesis that soil phosphorus in anthrosols is very much associated with carbonised material though further investigation of this is clearly required.

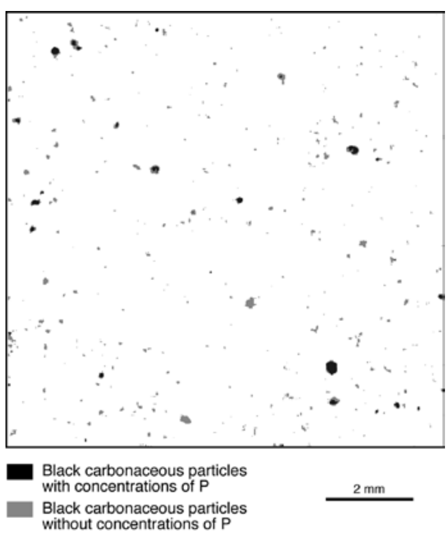

Fig. 4 - Distribution on a soil thin section of black carbonaceous particles and concentrations of phosphorus from electron microprobe analysis. The sample is from the Epse site (the Netherlands) on arable land at a depth of 63 cm.

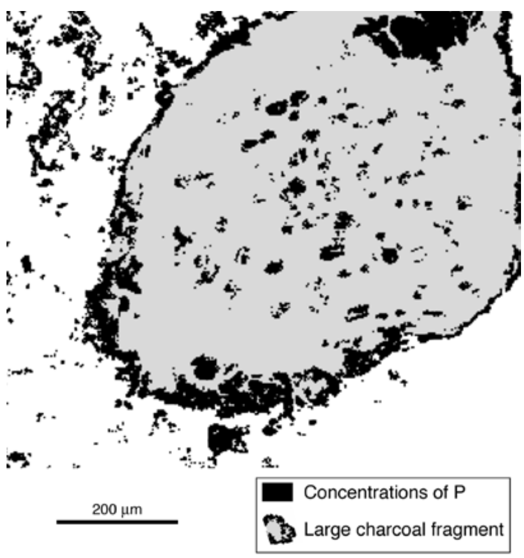

Fig. 5 - The association of phosphorus with a large fragment of charcoal. The sample is from the same context as in Figure 4.

CONCLUSIONS

This has been the first study to directly compare anthropogenic soils of north-west Europe. The key finding from this comparative study indicates that despite the use of different inputs in recent centuries and different current land management systems at the 3 study areas, the resultant anthropogenic soils are remarkably similar in field and analytical properties, such as particle size distribution, ECEC, loss on ignition and total P. Contrasts in particle size distributions between the anthropogenic horizons and the underlying parent material are used to identify input sources from turf. Despite inputs from aeolian inputs at the Scottish and Danish sites, it is likely that turf, often from areas of finer textured soils, provided the main source of mineral additions. Such material also contained domestic waste including carbonised material which continues to be of soil fertility value given its ability to store phosphorus.

ACKNOWLEDGEMENTS

This research is supported through a European Community Marie Curie Fellowship. The authors thank Mr Forbes at Nairn, Mr Jens Thorup Staby and Ulborg State Forest District, Denmark, Mrs Francoise Appels and Mr Michiel Bartels of the Archaeological Department of the Municipality of Deventer, and the Municipality of Deventer, the Netherlands for their kind hospitality and for allowing access to their land. Bill Jamieson produced the figures. Mairi Stewart and Joanne Thomas are thanked for their support for the Nairn study.

REFERENCES

Bieleman J., 1992. Geschiedenis van de landbouw in Nederland 1500-1950. Uitgeverij Boom, Meppel.

Bridges E.M., Batjes N.H., Nachtergaele F.O. (eds.), 1998. World reference base for soil resources: atlas. Acco, Leuven, Belgium.

Carter S., 2001. A reassessment of the origins of the St Andrews «garden soil». *Tayside and Fife Archaeological Journal* 7: 87-92.

Commission of the European Communities, 2002. Towards a thematic strategy for soil protection. COM(2002) 179.

Conry M.J., 1974. Plaggen soils. A review of man-made raised soils. *Soils & Fertilizers* 37 (11): 319-326.

Conry M.J., MacNaeidhe F., 1999. Comparative nutrient status of a peaty gleyed podzol and its plaggen counterpart on the Dingle peninsula in the south west of Ireland. *Eur. J. Agron.* 11: 85-90.

Dalsgaard K., Karlsen A.D., Larsen L., 2000. Bonden og agerjorden. In: Dalsgaard K., Eriksen P., Jensen J.V., Rømer J.R. (eds.), Mellem Hav og Hede - Landskab og bebyggelse i Ulfborg herred indtil 1700: 87-103. Universitetsforlag, Aarhus.

Dalsgaard K., Odgaard B.V., 2001. Dating sequences of buried horizons of podzols developed in wind-blown at Ulfborg, Western Jutland. *Quaternary Int.* 78: 53-60.

Davidson D.A., Carter S., 1998. Micromorphological evidence of past agricultural practices in cultivated soils: The impact of a traditional agricultural system on soils in Papa Stour, Shetland. *J. Archaeol. Sci.* 25: 827-838.

Domhof J., 1953. Strooiselwinning voor potstallen in verband met de profielopbouw van heide- en oude bouwlandgronden. *Boor en Spade* 6: 192-203.

Donaldson J., 1794. General View of the Agriculture of the County of Nairn, the eastern coast of Inverness-shire, and the parish of Dyke, and part of Edenkeillie, in the county of Elgin, and Forres. Board of Agriculture and Internal Improvement, B. Millan, London.

Driessen P.M., Dudal R., 1989. Lecture notes on the geography, formation, properties and use of the major soils of the world. Agricultural University Wageningen, Katholieke Universiteit Leuven, Wageningen, Leuven.

Gormsen G., 1991. Traditional heathland farming in Western Denmark. Reconstruction of an agricultural system from a peasant diary. *Ethnologia Scandinavica* 21: 105-125.

Groenewoudt B.J., Spek T., van de Velde H.M., van Amen I., Deeben J.H.C., van Smeerdijk D.G., 1998. Raalte-Jonge Raan: de geschiedenis van een Sallandse bouwlandkamp. Rapportage Archeologische Monumentenzorg 58, 173, Uitgave ROB, Amersfoort.

Langohr R., 2001. L'anthropisation du paysage pédologique agricole de la Belgique depuis le Néolithique ancien - Apports de l'archéopédologie. *Etude et Gestion des Sols* 8 (2): 103-118.

Pape J.C., 1970. Plaggen soils in the Netherlands. *Geoderma* 4 (3): 229-255.

Simpson I.A., 1997. Relict properties of anthropogenic deep top soils as indicators of infield management in Marwick, West Mainland, Orkney. *J. Archaeol. Sci.* 24: 365-380.

Simpson I.A., Dockrill S.J., Bull I.D., Evershed R.P., 1998. Early anthropogenic soil formation at Tofts Ness, Sanday, Orkney. *J. Archaeol. Sci.* 25: 729-746.

Simpson I.A., van Bergen P.F., Perret V., Elhmmali M., Roberts D.J., Evershed R.P., 1999. Lipid biomarkers of manuring practice in relict anthropogenic soils. *Holocene* 9 (2): 223-229.

Sinclair J. (ed.), 1791-1799. The Old Statistical Account of Scotland: Volume 12, pp 381 (Nairn), Volume 19, pp. 616 (Auldearn), Volume 20, pp. 192 (Moy and Dyke). E.P. Publishing, Wakefield, 1978.

Slicher van Bath B.H., 1957. Een samenleving onder spanning. Geschiedenis van het platteland in Overijssel. Uitgeverij Van Gorcum. Assen.

Smeerdijk D.G., Spek T., Kooistra M.J., 1995. Anthropogenic soil formation and agricultural history of the open fields of Valthe (Drenthe, The Netherlands) in medieval and Early Modern Times. Integration of palaeoecology, historical geography and soil science. In: Herngreen, G.F.W., van der Valk L. (eds.), Neogene and Quaternary geology of North-West Europe. *Mededelingen Rijks Geologische Dienst* 52: 451-479.

Smith B.F.L., Bain D.C., 1982. A sodium hydroxide fusion for the determination of total phosphate in soils. *Commun. Soil Sci. Plan.* 13: 185-190.

Soil survey of Scotland, 1974. 1:50.000 Soil map of Nairn & Cromerty (Sheet 84 and part Sheet 94). Aberdeen: Macaulay Institute for Soil Research.

Soil Survey of The Netherlands, 1979. Bodemkaart van Nederland, Schaal 1:50.000, Blad 33 Oost. Uitgave Stichting voor Bodemkartering, Wageningen.

Spek T., 1992. The age of plaggen soils. An evaluation of dating methods for plaggen soils in the Netherlands and Northern Germany. In: Verhoeve A., Vervloet J.A.J. (eds.), The transformation of the European rural landscape: Methodological issues and agrarian change: 72-91. National Fund for Scientific Research, Brussels.

Stoffyn-Egli P., Potter T.M., Leonard J.D., Pocklington, R., 1997. The identification of black carbon particles with analytical scanning electron microscope: methods and initial results. *Science Total Environm.* 198: 211-223.

Stoklund B., 1999. Turf manuring on the Danish island of Læsø. Geografisk Tidskrift. *Danish Journal of Geography*, Special Issue 1: 209-214.