The study of soil volatile organic compounds (VOC's) under annual and perennial cropping systems

Tables of soil data collected for IUK-133537
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Materials and methods

Soils and allied matrices

Three soil samples and one litter sample were collected from broad-leaved forests and previously cropped land, not currently in production (Table 1).

Table 1. Matrices with high VOC release potential used for optimising VOC collection and analysis procedures.

Matrix (Soil type)	Dominant vegetation	pH	Basal respiration rate (µg CO_2-C g^{-1} soil h^{-1})
Soil (Podzol)	Mixed forest, herbaceous understory	4.7	7.97
Soil (Gleyic brown earth)	Deciduous forest, herbaceous understory	6.4	3.17
Soil (Brown earth)	Indigenous herbaceous (weed) spp.	6.1	0.45
Leaf litter	Deciduous tree spp.	7.7	20.84

These soils were chosen because in comparison with soils from cropped land under production, the greatest diversity and quantities of VOC emissions have been reported from minimally disturbed soils, forest soils and leaf litter (e.g. Leff and Fierer, 2008). For Objectives 2 and 3, soil samples from established soil management field trials were obtained from 0-20 cm depth (Table 2). Environmental protection legislation limits the quantities of organic matter from various sources that can be applied to land in different locations. The amounts of organic matters applied at Samundham and at Morley St Botolph represent the maximum permissible applications (RB209). The amounts of organic matters applied at Samundham and at Morley St Botolph represent the maximum legally permissible applications, in accordance with contemporary environmental protection legislation (DEFRA, 2010). In addition to the contrasting treatments within the experiments which represent space for time substitution, the trials were chosen because they exhibit considerable differences with respect to soil texture and cropping regimes, but are nonetheless typical for cropped soils in the UK.

Visible plant debris and soil macrofauna were removed by hand on receipt and samples were homogenised by sieving to 5.6 mm in the field moist state. Macrofauna was also removed from the leaf litter before it was chopped into ~5 mm pieces with scissors.

Table 2. Selected site, soil and management information for the soils tested for soil health.

Location	Saxmundham	Morley St. Botolph	East Malling
UK grid reference	TM 368637	TG 053002	TQ 707569
Latitude, longitude	52.220937, 1.466055	52.560502, 1.027499	51.286323, 0.447380
Soil Series	Hanslope	Ashley	Malling
Soil Association	Hanslope	Ashley	Malling
Soil type[a]	Calcaric Stagnic Cambisol	Endostagnic Luvisol	Endoleptic Luvisol
Texture[b]	Clay loam	Sandy loam	Sandy loam
Land use	Arable cropping	Arable cropping	Vineyard
Cropping system	Annual	Annual	Perennial
Cropping history	1965-2014 mixed rotation, since 2014: 2 years winter wheat, winter barley, winter wheat, winter oilseed rape.	Continuous winter wheat since 2008.	Ploughed 2014, vines interspersed with a mixed grass sward planted 2015.
Amendments	25 t ha^{-1} farmyard manure applied regularly since 1965.	35 t ha^{-1} greenwaste compost applied 2008-2011.	Winter-grown mustard cover crop, incorporated May 2018; vegetation free plots used as unamended controls.

[a](FAO, IUSS, 2015), [b](Avery, 1973)

Measurement of biological, chemical and physical indicators of soil health

Basal respiration rate and microbial biomass were measured as biological indicators of soil health. Basal respiration was quantified by titration as the amount of CO_2 released by 30 g dry weight equivalent soil adjusted to 60% water holding capacity during 3 days' incubation at 20 °C in a 250 mL microcosm (Isermeyer, 1952). Microbial biomass was estimated as the difference in the ninhydrin-reactive N content of 0.5 M K_2SO_4 extracts of chloroform-fumigated and unfumigated soil (Amato and Ladd, 1988; Vance et al., 1987). Chemical indicators of soil health comprised pH (1:2.5 w/v, water) (Rowell, 1994) and spectrophotometric determination of i) 0.5 M K_2SO_4-extractable nitrogen as ammonium (Anderson and Ingram, 1993), nitrate (Cataldo et al., 1975) and amino forms (Amato and Ladd, 1988), and ii) permanganate oxidisable organic matter (Weil et al., 2003; Culman et al., 2012a,b). All chemicals and reagents were obtained from either Fisher Scientific (Loughborough, Leicestershire, UK) or Sigma-Aldrich (Gillingham, Dorset, UK), as appropriate. Physical indications of soil health were represented by the moisture content of soil on collection, at field capacity (-10 kPa) and after air drying (-100,000 kPa) and assessments of hydraulic conductivity (i.e. infiltration rate) using mini disk tension infiltrometers (METER Group, Pullman, WA; Zhang, 1997). The severity of compaction in the topmost 20 cm was also assessed as the percentage of sampling points with penetration resistance values >2 MPa. Soil resistance to penetration was measured using a recording soil penetrometer (Solutions for Research Ltd., Silsoe, Bedfordshire, UK; Anderson et al., 1980) in conjunction with a hand-held soil moisture meter (Model MO750, Extech Instruments, Nashua, NH).

Data handling and statistics
Penetrometer resistance values (in MPa) were standardised to a soil moisture content of 15% (v/v) (Bussher et al., 1997). The percentage of data points in the topmost 20 cm with resistance values >2 MPa was calculated to indicate compaction severity in relation to root growth through soil, 2 MPa being the resistance value at which root growth through soil ceases (Bengough and Mullins, 1990). Selected biological and chemical indicators of soil health were integrated by calculating index values of soil biological health (Equation 1, after Haney et al., 2018):

$$\text{Index value} = (\text{Soil respiration} \div 10) \times (\text{Oxidisable C} \div 100) \times (\text{Extractable organic N} \div 10) \quad (1)$$

Soil respiration is the amount (mg kg^{-1} soil) of C lost as CO_2 in 24 hrs, oxidisable C is the amount of permanganate oxidisable C (mg kg^{-1} soil) and extractable organic N is the amount (mg kg^{-1}) of amino-N. The scaling factors are derived from the generic C-to-N ratio of 10-to-1 in soil. Single factor (one way) analysis of variance and principal component analysis were performed using Genstat (Edition 13, VSN International, Hemel Hempstead, Hertfordshire, UK).

Results

Objective 3
As expected, for many of the biological (Table 3), chemical (Table 4) and physical (Table 5) indicators of soil health there were statistically significant differences between amended and unamended soils at each site. The pattern of differences across sites is variable and reflects the contrasting soil textures, local climates and cropping regimes. Principal component analysis based on the correlation matrix to emphasise the inter-relationships between indicators reveal consistent differences between the samples (Fig. 2). Principal component 1, which accounted for 50.7% of the variation in the dataset, separated the data according to organic matter amendment and was influenced by microbial biomass and microbial activity (basal respiration rate) and the principal environmental controls thereof, namely soil moisture content, the amount of labile carbon (permanganate oxidisable C) and pH. Principal component 2 accounted for only 17.2% of the variation in the dataset and separated the data according to soil texture and allied physical and chemical parameters, with the influential parameters being the moisture content of dry soil, soil mineral nitrogen content and the amount of labile carbon.

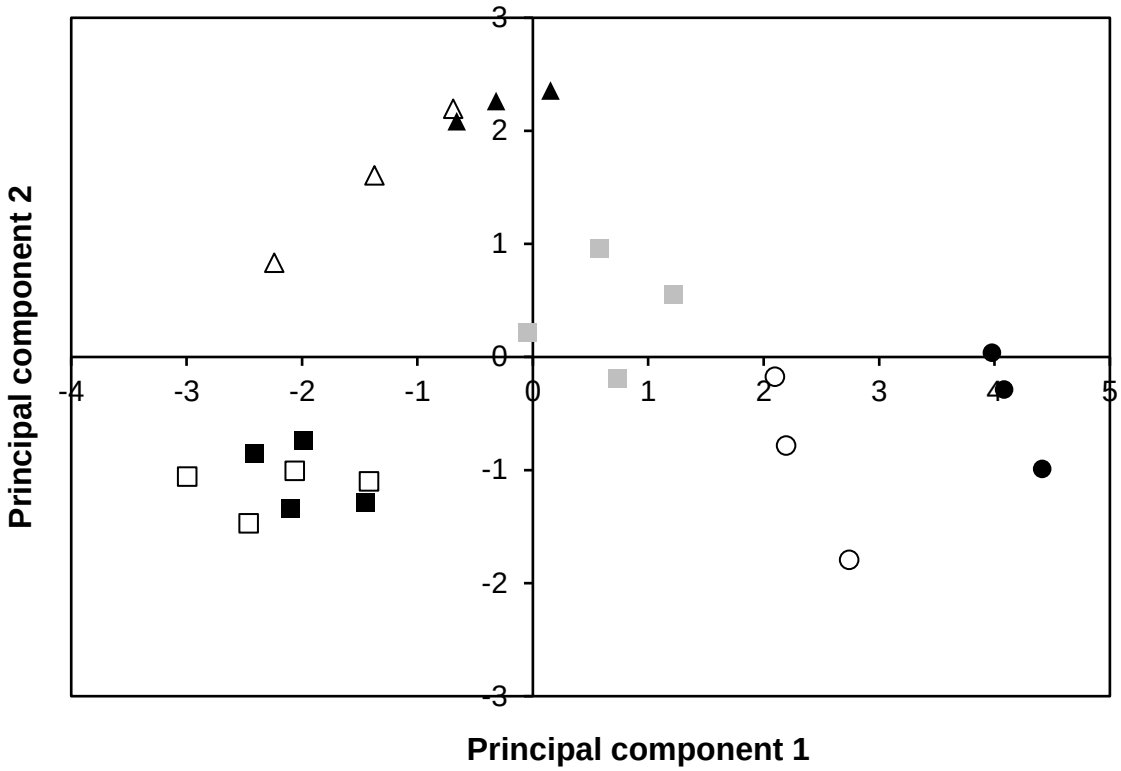

Figure 2. Principal component analysis biplot of sample scores for soil from unamended (open symbols) and amended (closed symbols), or grassed (▩) plots located at Saxmundham (●), Morley St Botolph (▲) and East Malling (■).

Table 3. Measured physical indicators of soil health.

Indicator	Functional relevance	Saxmundham		Morley St Botolph		East Malling			*P*
		Unamended	Amended	Unamended	Amended	Unamended	Amended	Permanent grass	
Penetrometer resistance >2 MPa (%)	Root development			3.7 (2.7)	9.6 (3.2)	67.6 (2.9)	39.7* (9.4)	67.6* (3.8)	<0.001
Hydraulic conductivity, 2 cm suction (cm h^{-1})	Drainage					2.2 (0.3)	2.0 (0.1)	2.3 (0.1)	0.642
Infiltration rate (cm h^{-1})	Drainage			4.8 (0.7)	10.4* (0.3)				<0.001
Moisture content (g kg^{-1})									
a) on collection	Water retention	121 (3.9)	133* (6.7)	45 (1.9)	48 (1.7)	105 (3.4)	139* (3.8)	**67*** (5.1)	<0.001
b) at field capacity, -10 kPa	Water retention	436 (1.6)	459* (10.9)	371 (6.6)	383 (2.7)	350 (4.1)	339 (1.7)	**435*** (4.9)	<0.001
c) in air dry soil, -100,000 kPa	Water retention	33.8 (2.3)	32.0 (1.7)	11.4 (0.2)	12.5 (0.1)	15.8 (0.2)	16.7 (0.2)	16.6 (0.2)	<0.001

Values are means, standard error in brackets, n = 3 for Saxmundham and Morley St Botolph and n = 4 for East Malling. * denotes a statistical difference at *P* <0.050 between unamended and amended plots within a site, according to Fisher's least significant difference test. For the permanent grass plots at East Malling only, * denotes a statistical difference at *P* <0.050 between unamended or amended plots; or if in bold type between unamended and amended plots.

Table 4. Measured chemical indicators of soil health.

Indicator	Functional relevance	Saxmundham		Morley St Botolph		East Malling			*P*
		Unamended	Amended	Unamended	Amended	Unamended	Amended	Permanent grass	
pH	Nutrient availability	8.23 (0.04)	8.03 (0.16)	7.13 (0.58)	7.50 (0.43)	6.29 (0.08)	6.58 (0.03)	6.67 (0.03)	<0.001
Extractable NH_4^+-N (mg kg^{-1})	Readily available nutrients	49.7 (0.6)	44.1* (1.1)	54.8 (2.7)	43.9* (1.7)	59.8 (2.7)	55.1 (1.6)	**48.4*** (0.4)	<0.001
Extractable NO_3^--N (mg kg^{-1})	Readily available nutrients	60.0 (5.4)	65.3 (3.9)	51.1 (3.0)	48.6 (1.0)	65.7 (4.2)	52.2* (3.0)	63.8* (3.9)	0.015
Extractable organic N, as R-NH_2 (mg kg^{-1})		11.6 (2.1)	12.0 (2.5)	19.0 (3.0)	22.3 (5.2)	20.6 (6.5)	23.4 (4.2)	16.9 (2.6)	0.372
Permanganate oxidisable C (mg kg^{-1})	Energy source for soil biota	415 (19.9)	680* (41.1)	506 (6.1)	510 (25.4)	407 (22.9)	332 (8.3)	442 (25.6)	<0.001

Values are means, standard error in brackets, n = 3 for Saxmundham and Morley St Botolph and n = 4 for East Malling. * denotes a statistical difference at *P* <0.050 between unamended and amended plots within a site, according to Fisher's least significant difference test. For the permanent grass plots at East Malling only, * denotes a statistical difference at *P* <0.050 between unamended or amended plots; or if in bold type between unamended and amended plots.

Table 5. Measured biological indicators of soil health.

Indicator	Functional relevance	Saxmundham		Morley St Botolph		East Malling			*P*
		Unamended	Amended	Unamended	Amended	Unamended	Amended	Permanent grass	
Basal respiration (mg CO_2-C kg^{-1} h^{-1})	General microbial activity	1.41 (0.08)	1.38 (0.09)	0.78 (0.06)	0.92 (0.09)	0.52 (0.06)	0.68 (0.05)	**1.07*** (0.13)	<0.001
Microbial biomass (mg NH_2-N kg^{-1})	Microbial community size	121 (5.8)	246* (8.1)	44 (4.2)	84* (0.8)	50 (2.7)	77* (6.7)	**151*** (11.6)	<0.001
Soil Biological Health Score		16.4 (3.6)	26.3 (4.5)	17.1 (3.3)	24.9 (6.4)	9.9 (2.8)	19.6 (4.4)	12.7 (2.4)	0.079

Values are means, standard error in brackets, n = 3 for Saxmundham and Morley St Botolph and n = 4 for East Malling. * denotes a statistical difference at *P* <0.050 between unamended and amended plots within a site, according to Fisher's least significant difference test. For the permanent grass plots at East Malling only, * denotes a statistical difference at *P* <0.050 between unamended or amended plots; or if in bold type between unamended and amended plots.

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