



CHAPTER 28

Manure Analysis: A Strategy for Improved Nutrient Management and Sustainable Crop Production

Ken A. Smith and David R. Chadwick

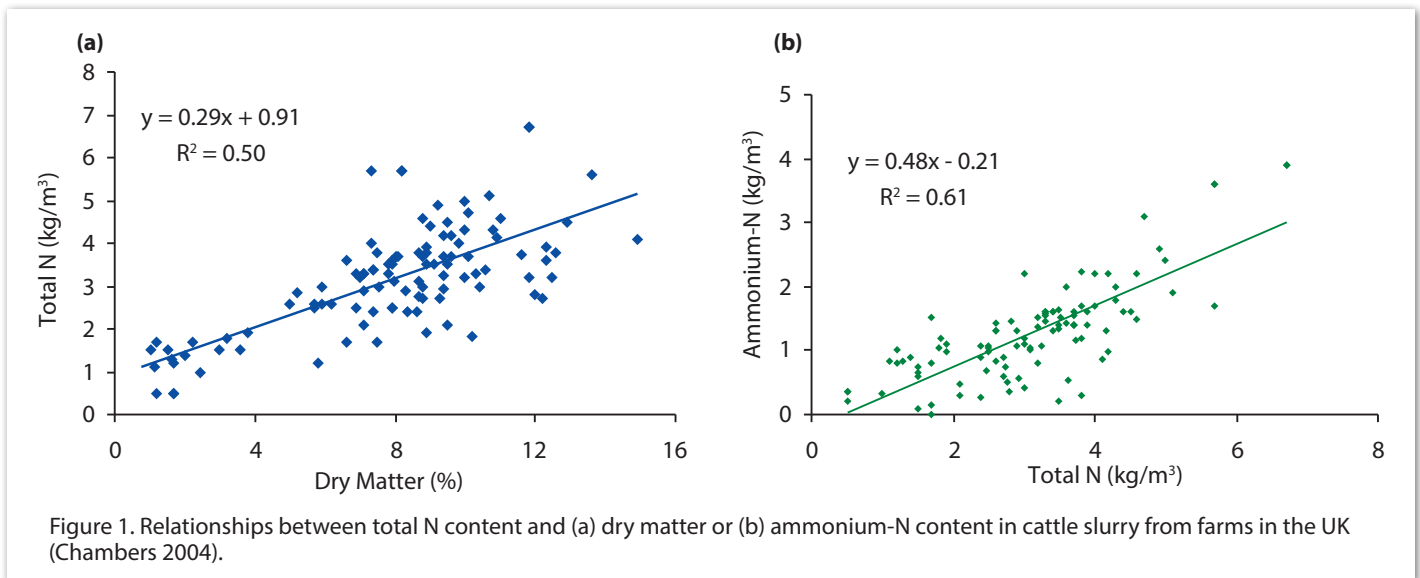
Livestock manures supply valuable plant nutrients and organic matter which can meet a substantial part of crop requirements for nutrients and maintain soil fertility. However, without careful management, manures represent a major potential source of environmental emissions, of both point source and diffuse water pollution (Lord et al. 1999; Chadwick and Chen 2003), and atmospheric emissions of ammonia (Misselbrook et al. 2010) and greenhouse gases (Defra 2007; Chadwick et al. 2011). Recent statistics of fertilizer practices in the United Kingdom (Defra 2010) suggest that farmers continue to assume only a modest nutrient contribution from manures when considering fertilizer inputs. No doubt, the growing intensification of livestock production and relatively low-cost chemical fertilizers have contributed to the perception of livestock manures as having modest value and, hence, a waste to be disposed of at least cost and inconvenience. Inadequate information on the nutrient value of manures for crops has also contributed to poor practices.

National advisory literature often publishes data on 'typical' manure nutrient contents (e.g. Defra Technical Bulletin,

RB209 in the UK; Anon. 2010). These data are means based on analyses of large numbers of samples, but the variability behind such estimates needs to be understood (Fig. 1). So, whilst cattle slurry at a typical 6% DM contains 2.6 kg/m³ N (21.7 lb/1000 gal), the range is considerable at 1–4 kg/m³ N (Fig. 1a); similarly, the content of ammonium-N, which averages 1.0 kg/m³ (8.3 lb/1000 gal) ranges from 0.1–2.0 kg/m³ (Fig. 1b) (Chambers 2004). Typical manure nutrient content data are, therefore, useful for strategic planning of manures and fertilizers on farms, but are not satisfactory for crop N recommendations. A shortfall in N supply will usually result in significant yield loss whilst over-supply of N can also cause yield loss (e.g. from crop lodging) and can be associated with crop quality problems, harvesting difficulties and increased risk of environmental emissions.

Manure analysis

Producers need to know the total N and inorganic N content of manure in order to estimate the rate of manure N applied, the potential loss following application, and the N



fertilizer replacement value (NFRV) of the manure. Current methods of laboratory analysis can be slow and expensive, and because of sampling difficulties, can give inconsistent results, especially for solid and semi-solid materials. In fact, manures are rarely analysed.

Rapid on-farm tests

It was hoped that the development of reliable, rapid on-farm techniques for the assessment of manure nutrients would lead to improved manure management. The best of these on-farm tests were reviewed in *Advanced Silage Corn Management* (Chadwick et al. 2004; see www.farmwest.com). These tests included the 'slurry hydrometer', test kits for analysis of the ammonium-N content of manures, potential in-line nutrient sensors on slurry tankers, and near infra-red spectroscopy (NIRS).

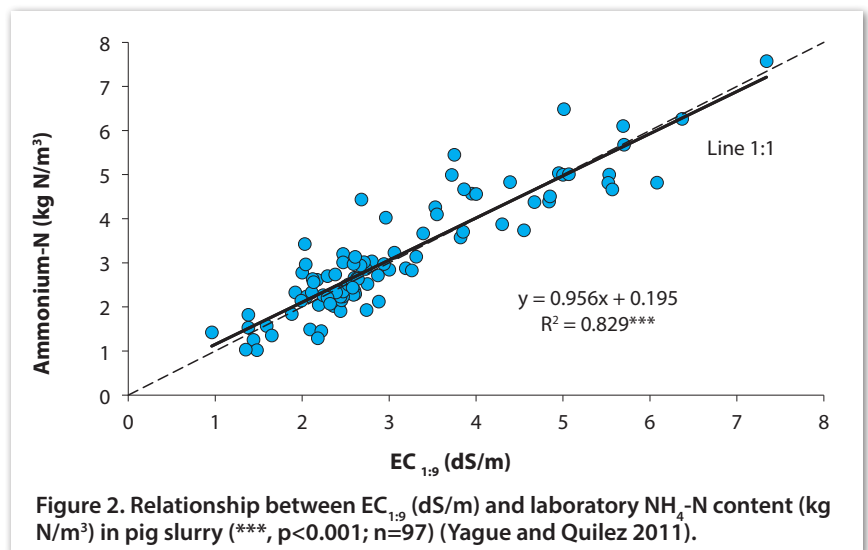
Rapid techniques have proven successful under practical farming conditions, with the robust construction, simple operation and accuracy of the slurry N meters (Agros and Quantofix) proving particularly suitable. The conductivity meter (EC), with its simple operation and instant read-out (for ammonium-N), was also popular with farmers. A recent review of on-farm "Quick Tests" reported similar results (Reeves 2006). Of the Quick Test methods, only the conductivity meter and NIRS have proven potential for adaptation for in-line testing. Despite their success in research and on-farm trials, uptake of these methods within practical farming operations is limited both in Europe and in North America. Uptake by farmers of the conductivity meter and DM measurements has been greater in Hokkaido, Japan, because the methods are linked to the 'AMAFE' decision support system for improved crop recommendations and

environmental benefit (Matsunaka et al. 2011).

Whilst there has been generally little advance since the review by Chadwick et al. (2004), Spanish workers have recently reported much improved performance of the conductivity meter measurement of $\text{NH}_4\text{-N}$ for pig slurry (Yagüe and Quilez 2011). The researchers reported that dilution of pig slurry by 1:9 (slurry:water) has produced better results with the conductivity meter than with the Quantofix N meter over a wider range of ammonium-N concentrations (1.0–7.6 kg N m^{-3}) (Fig. 2) and the method is being well received in NE Spain due to its low cost and ease of use (Rosa Yagüe, personal communication).

Manure analysis by near infrared spectroscopy

Near infrared spectroscopy (NIRS) is a technique involving measurement of the spectrum of infrared energy reflected from a sample illuminated by white light. The spectral properties of the sample are related to chemical composition and need to be calibrated against classical "wet chemistry" data in order to predict the composition of subsequent



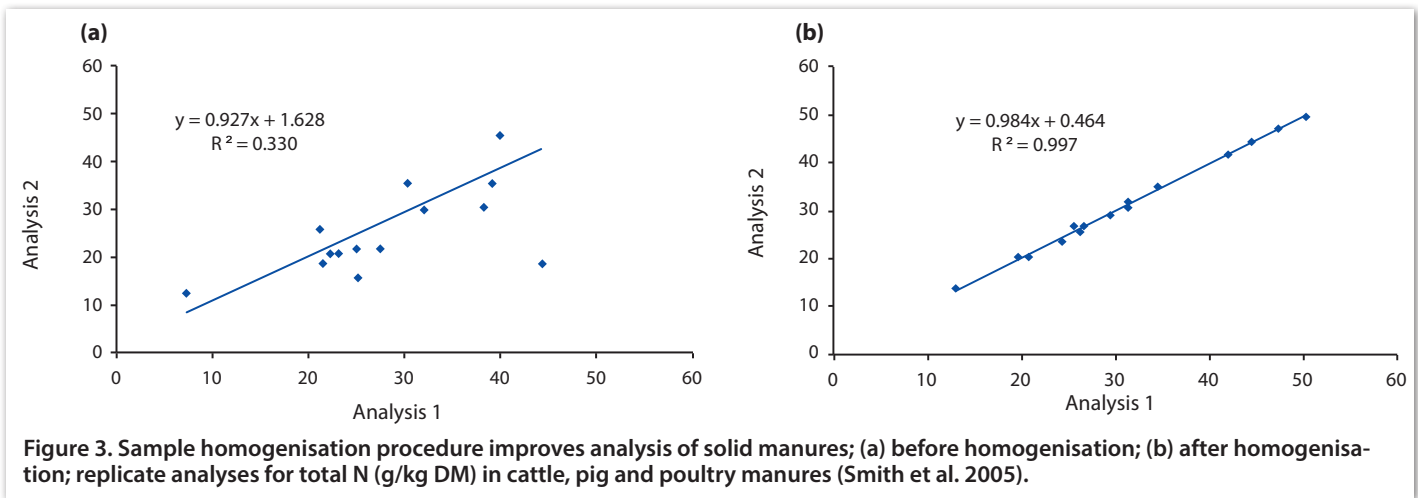


Figure 3. Sample homogenisation procedure improves analysis of solid manures; (a) before homogenisation; (b) after homogenisation; replicate analyses for total N (g/kg DM) in cattle, pig and poultry manures (Smith et al. 2005).

samples. NIRS has greatly improved precision and reliability in forage analysis and is now used routinely for the analysis of grain. NIRS methods have been developed for estimation of the nutrient content of manures, slurries and biosolids via multiple, rapid, scanning of fresh samples (Reeves and Van Kessel 2000; Smith et al. 2005).

Accurate calibration is dependent on reliable reference data, but routine wet analysis of manures had proven problematic due to the heterogeneous nature of manure samples. We developed a robust homogenisation technique for solid manures using a powerful homogeniser (FOSS 2096) following rapid freezing of the samples in liquid N (Smith et al. 2005). The success of this technique ensured the accurate reference calibration of the NIRS models, and demonstrated the potential for errors arising from conventional laboratory sub-sampling procedures used for solid manures (Fig. 3).

This technique would be too expensive to use on routine samples and can only be realistically used for the accurate calibration of a secondary rapid measurement technique. NIRS technology allows multiple rapid scans with spectral averaging covering more of the fresh sample than would normally be used for a 'wet' analysis, thereby further reducing error. Development of robust calibration models (for

dry matter, total N, $\text{NH}_4\text{-N}$, SO_3 , P_2O_5 , K_2O , MgO and pH) for cattle and pig manures (slurries and solid farmyard manures-FYM) and treated biosolids, required the collection of a large number of samples in order to cover the range of analyses, sample types and NIR spectral variability. Almost 2200 samples were collected from throughout the United Kingdom and Ireland. Following initial scanning, principal component analysis (PCA) was used to select a set of calibration samples (418 samples) that were representative of the spectral variability of the larger database. These samples were NIR scanned again in more detail (6x) and analysed by wet chemistry, following homogenisation. Final calibration models for DM and N content are shown in Figure 4.

The following guideline was proposed for describing the performance of calibration models for environmental samples, based on the r^2 (correlation coefficient) and RPD statistic (standard deviation of the analyte set divided by standard error of prediction): $r^2 > 0.95$, RPD > 4 — *excellent*; $r^2 = 0.9-0.95$, RPD 3–4 — *successful*; $r^2 = 0.8-0.9$, RPD 2.25–3 — *moderately successful*; $r^2 = 0.7-0.8$, RPD 1.75–2.25 — *moderately useful*; $r^2 < 0.7$, *useful for screening purposes* (Malley et al. 2005). The performance of the calibrations for conventional analysis of manure and biosolids samples was

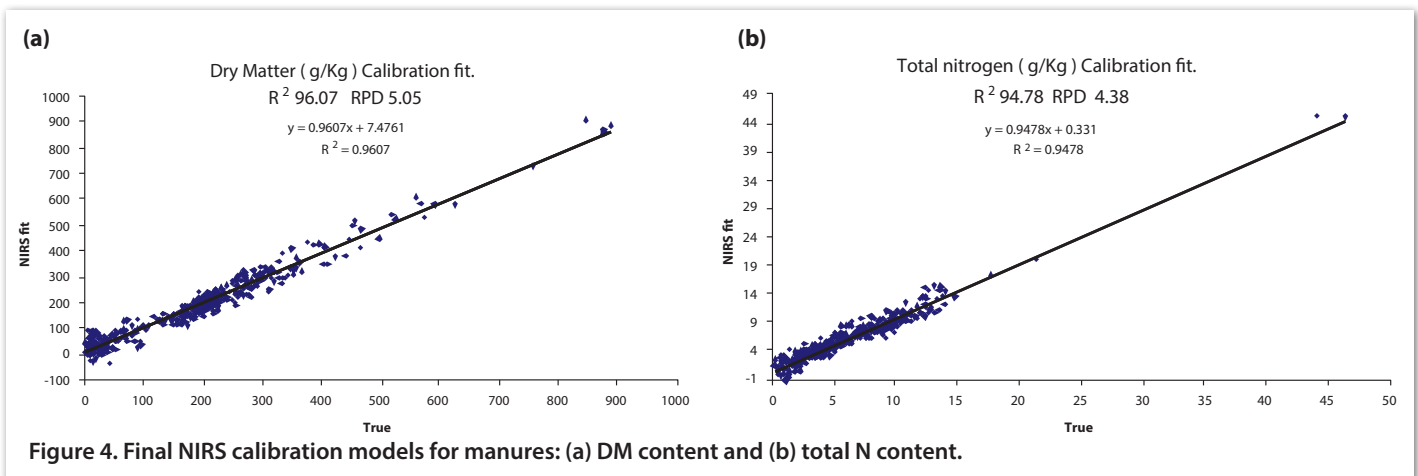


Figure 4. Final NIRS calibration models for manures: (a) DM content and (b) total N content.

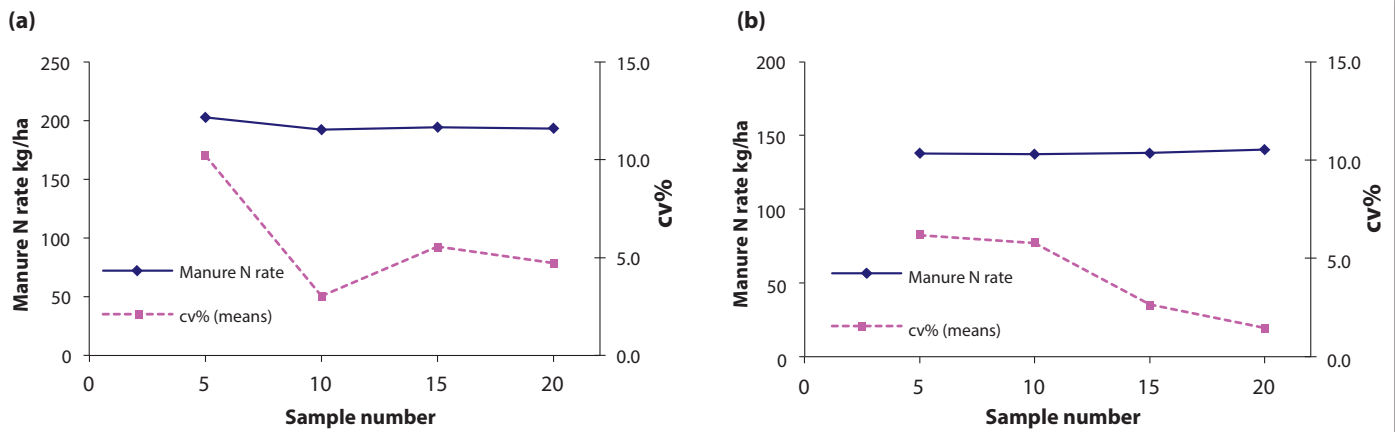


Figure 5. Impact of sampling strategy on calculated manure N application rate (kg/ha N at notional solid farmyard manure 20 T/ha (8.9 t/acre) application rate) and associated variability (cv%); (a) tidy 'A' shaped storage heap; (b) untidy storage heap.

as follows: *excellent* — DM, total N; *successful* — $\text{NH}_4\text{-N}$, P_2O_5 ; *moderately successful* — SO_3 ; *moderately useful* — K_2O , MgO .

Slurries, solid farmyard manure and biosolids samples from the NIR spectral database were also used to develop a calibration model for the estimation of N release from the organic N component of manure (N mineralisation). Data for the calibration model were derived from experiments with ryegrass grown in large pots (10 litre), in which we tracked the release of N from a range of manures applied to three different soil types (clay loam, sandy loam, loamy sand) in two experiments over a 3-year period (180 manures in total). The pots were set in plastic tunnels with overhead irrigation to ensure that moisture was not limiting and dry matter yield and N offtake were recorded for each cut of grass. Model correlations with a number of derived variables were good, and best with N recovery expressed as g N/t manure/day. Our conclusion was that a good estimate of potential manure N uptake over the season was

possible via the NIRS scanning procedure. However, N uptake was dominated by the mineral N content of the manures and, therefore, suggesting that further development of the NIRS calibration model for manure N release is needed to separate the impact of initial mineral (ammonium) N from the mineralisation of the organic N content of the manure.

The NIR calibration models were used to study the variability of nutrient content in a manure storage which was intensively sampled according to a 3-D grid, and in field spread manures. The results confirmed the expected variability of the manure storage and were used to evaluate a range of sampling strategies, the conclusions supporting current advice that to obtain a representative sample from a solid manure heap in a well-constructed solid manure storage, a minimum of ten samples are needed (Fig. 6a). Where visual examination suggests a more variable and uneven (e.g. shape, size and age) manure heap, a greater number of samples is likely to be necessary (Fig. 6b). The results also



Figure 6. Solid manure storage heaps sampled in the variability study; (a) tidy 'A' shaped storage heap; (b) untidy storage heap.

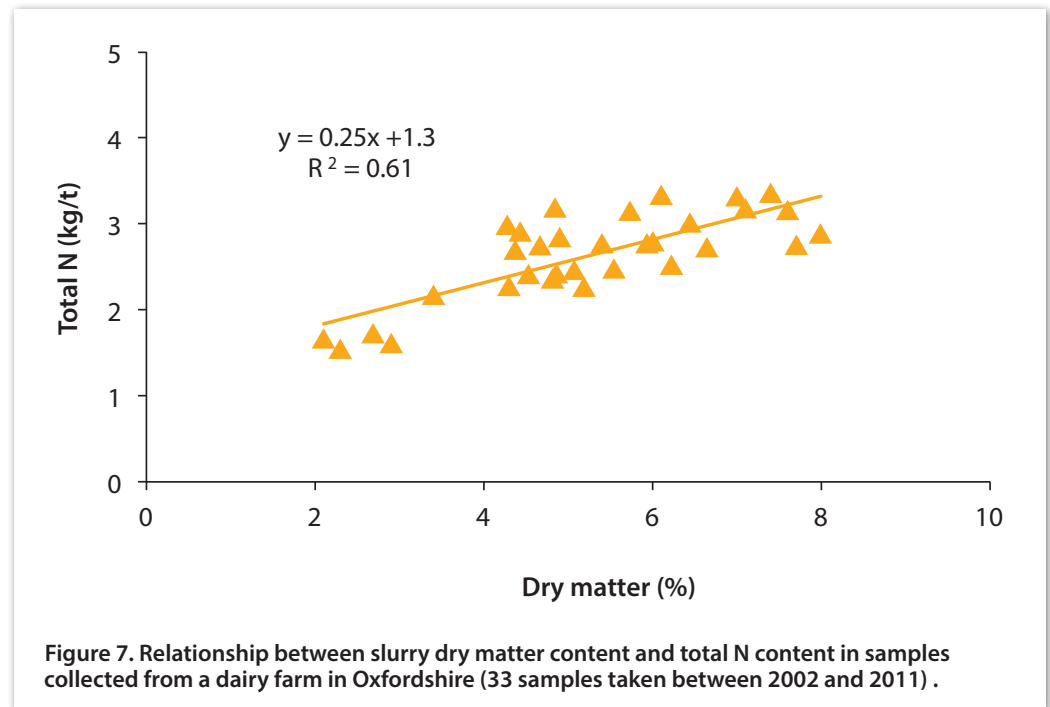
indicated that the variability in analysis from samples collected following spreading was reduced compared to that in storage, with variability (CV%) from field samples at less than half that of samples from storage, indicating that mixing of the manure during loading and spreading effectively reduces manure variability.

Overall, the research has confirmed the potential of NIRS to provide a rapid, reliable and inexpensive analysis for farm manures, slurries and biosolids. The calibration models for conventional analyses were improved by excluding very dilute effluents, where low contents of nutrients and solids reduce the reliability of the reflectance assessment. A commercial service has recently been launched in the United Kingdom with a suggested threshold limit of between 2 and 5% solids content, below which NIRS should not be used. It is envisaged that improvements in the predictive capability for mineralization of organic N will significantly enhance interest in NIRS as an analytical tool.

Conclusion — an integrated approach


Because farmers are unaware of the nutrient supply from manures, they tend to apply unnecessarily high rates of inorganic fertilizers (Anon. 2010), in addition to the often substantial nutrient supply from the manures as “insurance” for optimal yields. Interest in manures and biosolids as nutrient sources has increased as a result of increasing fertilizer prices and farmers are more receptive to the use of practical aids for improved recycling of manures, provided these are accessible, easy to use and inexpensive. Also, there is significant interest in the potential for application of NIRS for monitoring the quality of anaerobic digestate, composts and in other waste processing. The limited uptake of laboratory services for manure analysis is perhaps understandable, due to often slow service, the expense and sometimes inconsistent results (sampling difficulties). It is hoped that the development of NIRS will address at least some of these concerns. Given the proven effectiveness of on-farm quick tests (including slurry hydrometer, N meters and conductivity meter), a strategy integrating the use of on-farm tests with NIRS service seems to offer significant potential.

A number of factors are known to influence manure nutrient content, notably livestock type, diet, bedding type



and use, manure management and storage system, water management and, in particular, the extent of slurry dilution. This explains the substantial variability in typical manure analysis (Fig. 1a & 1b). However, where management and other factors remain fairly consistent, e.g. on an individual farm basis, the variability in manure analysis may also be less (Fig. 7). Under such circumstances, the regular use of on-farm tests supported by an occasional laboratory analysis may allow the confidence for improved manure use, reduced fertilizer inputs and reduced environmental emissions. Whilst the associated costs are likely to be minor, based on recent fertilizer prices, the potential value of manures is high (e.g. pig FYM — \$22/t; cattle slurry — \$8.00/m³; broiler litter — \$50/t) and the economic benefits may be substantial.

Acknowledgements

The research on NIRS was funded under the Department for Environment, Food and Rural Affairs (DEFRA) Sustainable Arable LINK Programme (Project LK0988), and the support of the following industry sponsors is gratefully acknowledged: AHDB-HGCA Ltd, AHDB-DairyCo Ltd, AHDB-EBLEX Ltd, AHDB-BPEX Ltd, Potato Council, GrowHow UK Ltd., Yara International ASA, Bruker UK Ltd., Agrivert Ltd., Spreadwise Ltd., Vion Foods UK Ltd., Severn Trent Water, Yorkshire Water. 

References available online at www.farmwest.com

Ken A. Smith ADAS Wolverhampton, Woodthorne, Wolverhampton, UK | ken.smith@adas.co.uk

David R. Chadwick The School of Environment, Natural Resources and Geography (SENrGy), Bangor University, UK.