



From the Chair

Dear Colleagues,

This Pedometron appears in the wake of the 2010 World Congress of Soil Science. With effect from WCSS 2010, Thorsten Behrens and A-Xing Zhu become, respectively, Chair and Vice-Chair of the Pedometrics Commission. I wish them all the best in their endeavours. I should also like to thank Budiman Minasny, the outgoing Vice-Chair, for all that he has contributed to the life of the Commission since August 2006, not least as Editor of Pedometron which has risen to new heights during his time in office.

I have enjoyed the last four years as chair of the commission. I have had dealings with soil scientists from around the world, not least in response to articles in Pedometron. The overwhelming majority of these contacts have been interesting and encouraging. Most soil scientists are committed and enthusiastic, and with a wide range of intellectual interests. It has to be said that a few are (as colloquial English might put it) a few peds short of a pedon, but, mostly, this just adds colour to life's rich tapestry and to the email inbox.

If you will permit me a final paragraph, or two, to air a personal view, here goes. When the IUSS council voted on the formation of the Pedometrics commission there was at least one dissenting voice. The argument, a perfectly respectable one, was that pedometrics should not be a distinct group, but should be a part of what all the IUSS commissions do. That is history, but I think that we would do well to reflect from time to time on why the commission needs to exist. In my view there are two main reasons. First, while all branches of soil science should be making correct and effective use of quantitative methods, the fact is that they don't do so uniformly. A distinct group in which pedometrics is promoted, explained and exemplified is therefore essential, but it is also necessary that we engage with others. We have tried to do this over the last four years through the 'Non-pedometrician profiles' and through links with other commissions such as Soil Physics, Soil Geography, and

Soils and the Environment. We need to do more, most particularly in showing how pedometrics is not just about making maps, but can give real insight into soil processes.

The second reason is even more compelling. A few years ago I attended a meeting at the Royal Society in London. A venerable statistician gave a talk in which he asked 'why bother with statistical theory?' His answer was that, without theory, we did not really understand how statistics works, and therefore whether the estimates or predictions we produce are in any sense reliable or optimal, why the methods sometimes might not work, and how they might be made better. If pedometrics is just a work-horse, churning out maps from fashionable black boxes, then there is no need for a pedometrics commission (any more than we need a commission on mass spectrometry or on spades). On the contrary pedometricians should be criticizing and expanding our methodology, making sure we really understand it, and addressing new problems about the variation of soil in time and space because, as, JBS Haldane the English geneticist

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and founder of mathematical biology once put it, 'If you are faced by a difficulty or a controversy in science, an ounce of algebra is worth a ton of verbal argument.'

I am sure that the commission will continue in good health, and I look forward to attending Pedometrics 2011 in Třešť

Murray

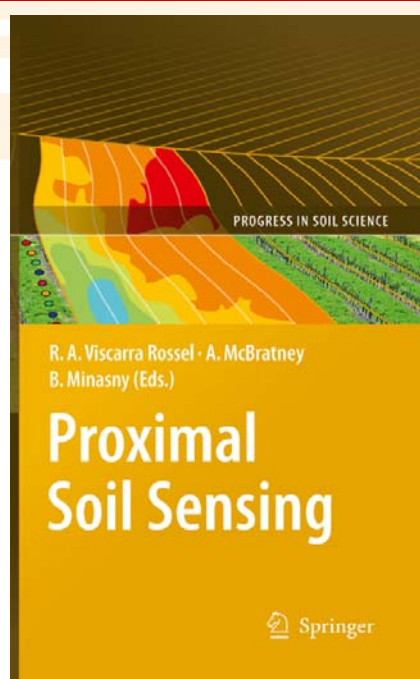
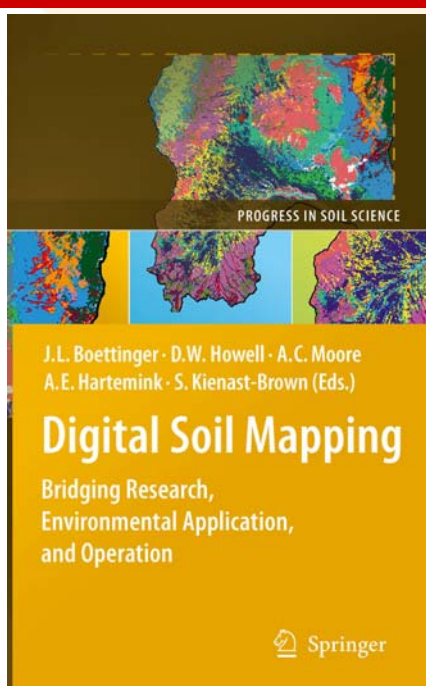
Best Paper in Pedometrics 2009

Alex McBratney, Budiman Minasny, and Dick Brus have, this year, undertaken the considerable task of preparing the nominations for best paper in Pedometrics 2009. All readers of Pedometron are invited to vote for the best paper, and to send their votes to Axing Zhu, azhu@wisc.edu.

List the papers by number (as below) in order of preference, with the paper you regard as the most worthy winner listed first. The vote will end at midnight (Wisconsin time) on 30th November 2010, and the result will be announced in Pedometron. Certificates will be presented at Pedometrics 2011 in Třešť.

1. Carré, F., M. Jacobson. 2009. Numerical classification of soil profile data using distance metrics. *Geoderma* 148, 336-345
2. Goidts, E., B. van Wesemael and M. Crucifix. 2009. Magnitude and sources of uncertainties in soil organic carbon (SOC) stock assessments at various scales. *European Journal of Soil Science* 60, 723-739.
3. Kaufmann, M., S. Tobias, R. Schulín. 2009. Quality evaluation of restored soils with a fuzzy logic expert system. *Geoderma* 151, 290-302.
4. Marchant, B. P., S. Newman, R. Corstanje, K. R. Reddy, T. Z. Osborne & R. M. Lark. 2009. Spatial monitoring of a non-stationary soil property: phosphorus in a Florida water conservation area. *European Journal of Soil Science* 60, 757- 769.
5. Yeluripati, J.B., van Oijen, M., Wattenbach, M., Neftel, A., Ammann, A., Parton, W.J., Smith, P. 2009 Bayesian calibration as a tool for initialising the carbon pools of dynamic soil models. *Soil Biology and Biochemistry* 41, 2579-2583.

New Books



THE RICHARD WEBSTER MEDAL:

J.J. DE GRUIJTER



The Richard Webster Medal is awarded for the best body of work that has advanced pedometrics. Jaap De Gruijter has been selected by the Pedometrics Committee on Prizes and Awards to receive the Webster Medal at the 19th World Congress on Soil Science.

Jaap is a very worthy winner as he has made a substantive contribution to the development of pedometrics over a period of more than 40 years. Jaap's contribution has been one of consistent innovation and extremely high quality. His approach to pedometrics has been one of finding elegant solutions to substantive problems in soil science rather than simply the application of statistical methods to soil problems. As examples of this we highlight Jaap's contribution to the development of an efficient formal method of estimating soil map quality, and his contribution to sampling theory and practice. Jaap was instrumental in setting up the Pedometrics Working Group, and throughout his career he has been a leader in pedometrics and has contributed to the development of the discipline, and particularly the mentoring of younger colleagues.

In 1987 Jaap wrote to the Secretary General of the ISSS Dr. Sombroek outlining the need for a working group on pedometrics. The arguments (see attached letter) were extremely well put, and the council of the ISSS approved the setting up of the working group in 1990. Jaap became the Secretary. The working group got off to a flying start with the initial conference by Jaap in Wageningen. Arising from the conference was the first Special Issue on Pedometrics published in *Geoderma*, jointly edited by Jaap. The Conference and Special Issue set the precedent for subsequent activities of the working group which has generally been recognized as the most successful and productive one in the IUSS. This ultimately led to its recognition as a Commission.

The 1977 thesis entitled 'Numerical classification of soils and its application in survey', remains to this day the most advanced and detailed treatise on numerical classification of soil. One of the significant outcomes was the realization that the non-hierarchical methods were most appropriate for soil classification.

Jaap worked on the early application of geostatistics to soil survey. The 1982 paper (Van Kuilenburg et al) is highly significant in that it was probably the first substantive test of the prediction quality of geostatistical methods compared with estimates from soil mapping units, based on an independent probability sample. The study showed that geostatistics has a place in general soil survey.

Jaap made a significant advance in measuring the quality of conventional soil class maps. In particular he devised the random transects sampling method. In this pre-GPS days when time needed for locating sampling points was prohibitive, this type of random sampling was a very efficient



method for estimating the purity and homogeneity of soil map units. Jaap also initiated a sampling programme for estimating the quality of the national Soil Map of the Netherlands at 1:50 000. This project ended at the turn of the millennium. The Soil Map of the Netherlands thus became the first national soil map to have been validated in its entirety by independent probability sampling.

Jaap extended his earlier work on numerical classification by developing a new algorithm for fuzzy k-means with extrapolades. This continuous classification approach by its nature permitted the application of geostatistical methods to soil classes. Jaap devised a novel geostatistical method, called compositional kriging.

The most influential was Jaap's work on design-based and model-based sampling methods. In his 1990 paper in *Mathematical Geology* he made clear that the idea of classical sampling theory making incorrect assumptions about independence of data, which was very common at that time, was incorrect. This misconception led to soil scientists and other geoscientists restricting themselves to model-based sampling methods, even in situations where this was suboptimal. This started a discussion which ultimately led to the recognition that both model-based methods based on geostatistics and design-based sampling methods based on classical sampling theory are valid and have their merits in soil sampling.

At the end of his career Jaap brought his outstanding knowledge of sampling methods for survey of soil and other natural resources together in the text 'Sampling for Natural Resource Monitoring'. This book continues to be widely acclaimed in soil, earth, environmental, agricultural, and statistical sciences.

Throughout his career, Jaap has mentored many soil and environmental scientists. He was the leader of the team on Soil Inventory Methods at Alterra (including Marc Bierkens, Dick Brus, Gerard Heuvelink, Martin Knotters, Wim te Riele and Dennis Walvoort). He supervised the PhD studies of Dick Brus, Nelleke Domburg and Martin Knotters.

OBITUARY

DR GEOFFREY MARK LASLETT

(JULY 8, 1949-JANUARY 9, 2010)

A FULL-TIME STATISTICIAN AND A PART-TIME PEDOMETRICIAN ON THE ALLUVIAL CLAY

BY DR JOHN TRIANTAFILIS (SENIOR LECTURER IN SOIL SCIENCE, UNSW)



The Statistician

Dr Geoff Laslett, formerly of the CSIRO Division of Mathematical and Statistical Sciences, and our esteemed friend passed away peacefully and in the company of his loved ones on January 9th this year.

He was a first-rate statistician capable of developing theory on the run and who understood science and natural processes. Predominantly he spent his scientific career working on applied problems in the mining industry (e.g. Laslett et al. 1987; Chem. Geol.) and fisheries (e.g. Laslett et al. 2002; Can. J. Fish. Aqua. Sci.) revelling in the areas of spatial statistics and analysis of large and very complex data sets.

The Pedometrician

Whilst Geoff was not a soil scientist he certainly was a pedometrician. In the mid 1980's, when they were both in CSIRO, he met up with Alex McBratney who introduced him to soil-related management issues and problems associated with mapping soil properties. Their initial collaboration led to the publication of a seminal paper on comparing soil prediction methods to map soil pH (Laslett et al. 1987).

Soon after, Geoff explained REsidual Maximum Likelihood (REML) to Alex, which led to a subsequent publication that introduced REML to the soil science community (Laslett and McBratney 1990). Recently the approach has been picked up by others (Lark and Cullis 2004; EJSS) and is gaining currency as the standard methodology for fitting spatial models.

More recently, and as part of Thomas Bishop's PhD (USyd), he worked on the development of a mass-preserving spline approach to model soil attribute

values with depth (Bishop et al. 1999). One of his last scientific contributions in the field of pedometrics was a finessed publication on the application of these splines to model soil carbon storage and available water capacity (Malone et al. 2009).

First Encounter

Alex first introduced Geoff to me out on a cotton growing farm, located on the Namoi River clay alluvial plain of northwest New South Wales, when I was Alex's PhD student. At the time I was in the middle of my first field trip collecting soil samples to calibrate a wooden prototype of an EM38 with Hal Geering (Senior Lecturer and an avid 2-pack a day smoker, USyd). It was 1992.

Despite the intense and unrelenting heat (i.e. 40°C) and humidity we hit it off immediately, discussing how this strange little wooden geophysical instrument could potentially be used to measure soil E_c with depth and subsequently map salinity in concert with georeferenced data from a handheld GPS unit. At the time we joked heartily, mostly at my expense, about the fact that rather than be able to navigate our way back to our first calibration hole of the day using the GPS, we instead found that Hal's "packets" of spent cigarette butts were of greater use!

Later on in the day, and unprompted, Geoff volunteered to join Hal and I for a second innings, so to speak, to collect additional soil samples. Despite the lengthening shadows it was clearly still too hot for Alex to be involved? Nevertheless, Alex and I had piqued his scientific interest and he was in for the long haul. Ultimately this initial meeting led to the development of a logistic function which Geoff, Alex and I developed to model the distribution of soil E_c with depth using the EM38 signal data.

The collaboration led to the formulation of what was my first, first author paper (Triantafilis et al. 2000). A paper I am proud to say counts amongst one of his



Pictured Mr Hal Geering (Senior Lecturer in soil methods, USyd) with EM38 and Dr Geoff Laslett (CSIRO Mathematical and Information Sciences) zeroing an EM38's on the Namoi clay alluvial plains (1992).

highest cited articles and toward his h-index of 21. OK so enough about the “pop-culture” statistics.

The Mentor

Of greater significance and importance was the fact that Geoff made himself available to spend time with a young soil scientist starting out on his scientific journey. In particular I very much appreciated the effort he put in to the formulation of the ideas in the manuscript and also carrying out the statistical work in Melbourne. All done one might say on a shoe-string budget. Subsequently, and once the work was done, a report written, the paper prepared and submitted, I was relieved to find that he was willing to pretty much drop everything to work through each and every one of the reviewers many and varied comments.

It was during this “invaluable” time, when he visited me, whilst I was based in Wee Waa (and again on the same Namoi alluvial clay plains), that I learnt much from him about the English language. I was very much impressed by the almost formulaic and mathematical way he went about the process of scientific writing. In addition, I also learnt from him the “art” of addressing and rebutting referee’s comments.

On reflection and subconsciously, I find that I go through all my research manuscripts “iteratively” and “line by line” as Geoff taught me and as if drafting mathematical code, thereby ensuring that there are no unnecessary words and that common themes and ideas flow throughout.

I will always remember the things he taught me, but I will also remember Geoff very fondly for his very dry and quick wit, his immense intelligence and general knowledge, his mathematical and statistical prowess but most of all his humility and generosity of spirit. All of these personal and scholarly attributes were clearly demonstrated by his actions toward me.

Concluding Remarks

I along with the soil science community at my Alma Mater (University of Sydney) will sorely miss his friendship, collegiality, statistical know how and in particular the ability to simply pick up the phone and “Dial up a statistician help line service” that he would offer free of charge. Vale Dr Geoff Laslett, a great raconteur, true gentleman and an outstanding scholar.

References

Laslett GM, Green PF, Duddy IR, Gleadow AJW 1987. Thermal annealing of fission tracks in apatite 2. A quantitative analysis. *Chemical Geology* 65, 1-13.

Laslett GM, Eveson JP, Polacheck T 2002. A flexible maximum likelihood approach for fitting growth curves to tag-recapture data. *Canadian Journal of Fisheries and Aquatic Sciences* 59, 976-986.

List of Pedometric papers

Laslett GM, McBratney AB 1987 Estimation and implications of instrumental drift, random measurement error and nugget variance of soil attributes - a case study for soil pH. *Journal of Soil Science* 41, 451-471.

Laslett GM, McBratney AB, Pahl PJ, Hutchinson MF. 1987 Comparison of several spatial prediction methods for soil pH. *Journal of Soil Science* 38, 325-34.

Laslett GM, McBratney AB 1990. Further comparison of spatial methods for predicting soil pH. *Soil Science Society of America Journal* 54, 1553-1558

Laslett GM, 1997. In Discussion of: D.J. Brus and J.J. de Gruijter, Random sampling or geostatistical modelling. *Geoderma* 80, 45-49.

Bishop TFA, McBratney AB, Laslett GM 1999 Modelling soil attribute depth functions with equal-area quadratic smoothing splines. *Geoderma* 91, 27-45

Triantafyllis J, Laslett GM, McBratney AB 2001 Calibrating an electromagnetic induction instrument to measure salinity in soil under irrigated cotton. *Soil Science Society of America Journal* 64, 1009-1017.

Malone BP, McBratney AB, Minasny B and Laslett GM 2009. Mapping continuous depth functions of soil carbon storage and available water capacity. *Geoderma* 154, 138-152.

Smoothing pycnophylactic quadratic splines

Geoff Laslett working with Tom Bishop and Alex in 1999 derived the solution to the problem of reconstructing the soil depth function given measurements from bulked sample from the soil horizons or layers. This follows an earlier work of Ponce-Hernandez et al. (1986).

The problem is formulated to minimise:

$$\frac{1}{n} \sum_{i=1}^n (y_i - \bar{f}_i)^2 + \lambda \int_{x_0}^{x_n} [f^{(m)}(x)]^2 dx. \quad (1)$$

where y_i is the measured bulk sample from layer i , $f(x)$ represents a spline function and \bar{f}_i is the mean value of $f(x)$ over the prescribed depth interval.

The first term represent the fit to the data, the second term measures the roughness of function $f(x)$, expressed by its m -th derivative $f^{(m)}(x)$. Parameter λ controls the trade-off between the fit and the roughness penalty.

For $m = 1$, Geoff proved that the optimal smoother with a square integrated first derivative penalty is a quadratic spline.

This is not just any smoothing spline, but it is a pycnophylactic (equal-area) spline which has properties:

1. It consists of a series of local quadratic polynomials with the 'knots' or positions of joins being located at horizon boundaries
2. For each horizon, the area of the fitted spline over a horizon is equal to the mean value of the horizon.

The solution of (1) for $m = 1$, can be written as a linear function:

$$[I + 6n\lambda (R^{-1}Q')'R(R^{-1}Q')] \bar{f} = y. \quad (2)$$

where R is the $(n-1) \times (n-1)$ symmetric tridiagonal matrix with diagonal elements $R_{ii} = 2(x_{i+1} - x_{i-1})$ and off-diagonal elements $R_{i+1,i} = R_{i,i+1} = x_{i+1} - x_i$ and Q is a $(n-1) \times n$ matrix with $Q_{ii} = -1$, $Q_{i,i+1} = 1$ and $Q_{ij} = 0$ otherwise. (See Geoff Laslett's report for details)

Solving this equation yields the fitted layer values \bar{f} ,

which are also the parameters of the spline.

The fitted values at the knots (horizon boundaries) can then be obtained from

$$\hat{b} = 6R^{-1}Q'\hat{f}$$

The predicted values of the spline can then be obtained simply as an interpolating spline through the fitted values.

The spline model was used to describe the change in soil properties with depth in Neil McKenzie's Australian Soils and Landscapes.

The attractiveness of this quadratic spline is the small number of parameters involved (no. parameters = no. layers) and the parameter itself is the fitted layer values. This allows us to map the parameters of the spline over the whole landscape and the values have practical meaning (Malone et al. 2009)

Extension of the depth function

For more complicated shape, we can set $m = 2$ in eq (1) and the solution is then a quartic spline, which can be more flexible, but the penalty is of course more parameters.

The quadratic smoothing spline, will always provide a smooth curve between the layers, however in soil profile, we can have abrupt change of soil properties, e.g. clay content in a texture contrast soil. Having a more complicated spline function will also not be able to resolve this problem.

A trick we can easily use is adding additional “virtual thin layers” in the data, this will force the spline to go through the exact value in a thin layer. For example Figure 1a on the left shows the clay content profile with the quadric spline fitted through the data. In Figure 1b we force the spline to change abruptly.

References

Laslett, G.M. Smoothing pycnophylactic quadratic splines. Unpublished report. CSIRO Mathematics and Statistics, Clayton, Victoria. Available from <http://www.pedometrics.org/paper/pycquad.pdf>

Ponce-Hernandez, R., Marriott, F.H.C. and Beckett, P.H.T., 1986. An improved method for reconstructing a soil profile from analyses of a small number of samples. *Journal of Soil Science* 37, 455-467.

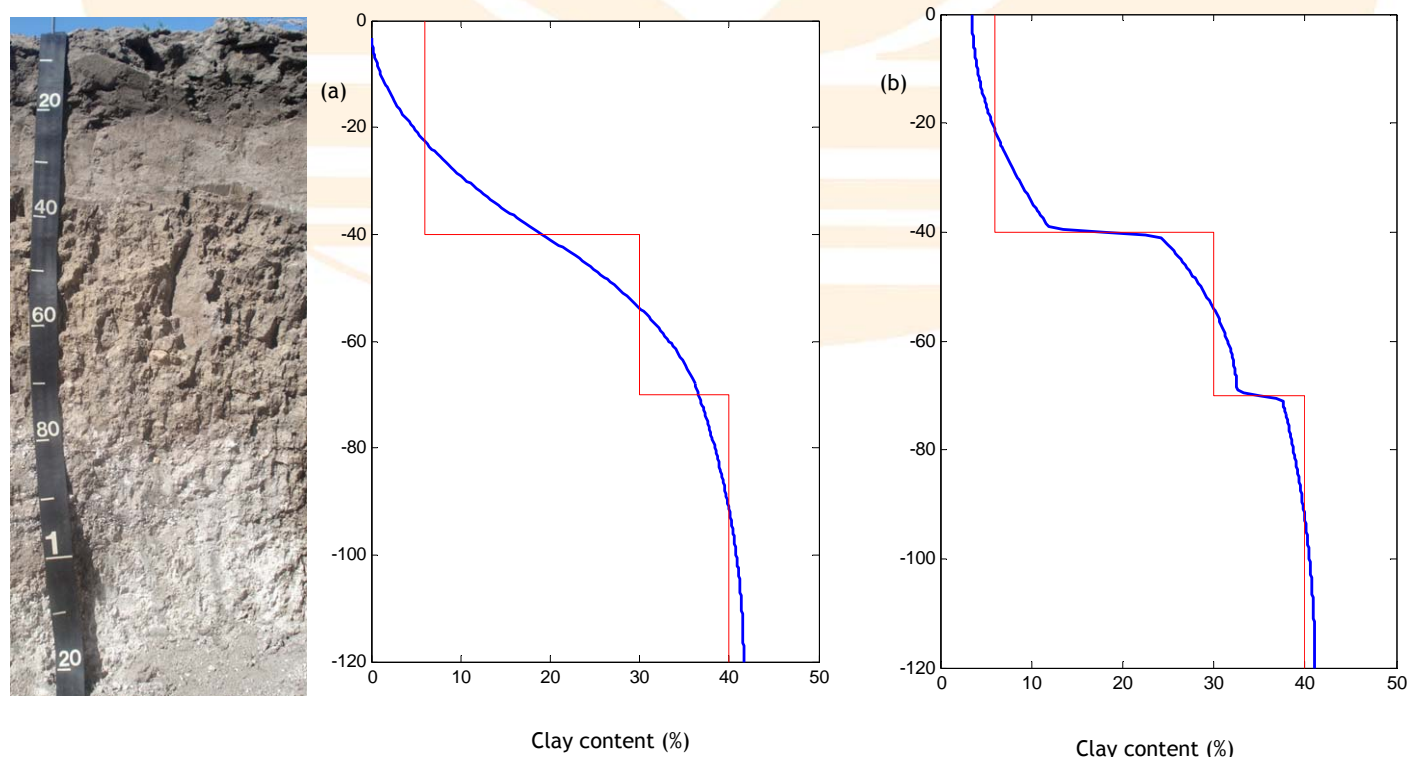


Figure 1. An example of the modified spline depth function to deal with abrupt changing soil properties. The graph on the left (a) shows the spline function fitted to the profile data. The graph on the right (b) shows a modification by including a virtual layer at the boundaries to force the spline to change abruptly at the boundaries.

Report from the 4th Global Workshop on Digital Soil Mapping

By Bas Kempen

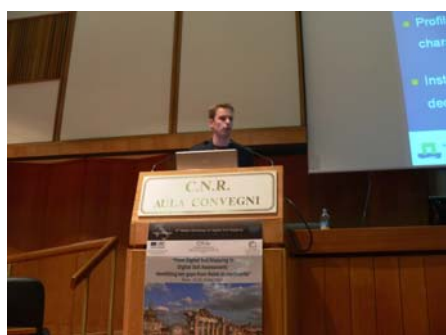


The 4th Global Workshop on Digital Soil Mapping, "From Digital Soil Mapping to Digital Soil Assessment: identifying key gaps from fields to continents" took place from 24-28 May in Rome, Italy. The workshop attracted 120 participants, which shows that the DSM community is still expanding. Previous workshops in the USA (2008) and Brazil (2006) attracted 99 and 75 participants, respectively. There were 105 contributions: 73 oral presentations and, for the first time in the DSM workshop history, 32 posters. These contributions came from 27 countries (10 more than the previous workshop). Stratification of the contributions on basis of the nodes of the global soil map project showed that 60 contributions came from Eurasia, 10 from North America, 4 from Latin America, 6 from East Asia, 7 from West Asia/Mediterranean Africa, 7 from Oceania and 1 from sub-Saharan Africa. Furthermore, there are currently two ongoing global projects: the global soil map (www.globalsoilmap.net) and e-SOTER (www.esoter.org). The latter has project areas in Europe, Morocco and China and also uses DSM techniques in one of its work packages. These inspiring examples show that DSM really has become a global venture. Indeed, the DSM community has come a long way since the first global workshop in Montpellier, France in 2004 as Neil McKenzie pointed out at the closure of the workshop.

The workshop program spanned three days from 24-26 May and was organized into three sessions which were subdivided into 8 themes: 1) Global DSM; 2) On Local DSM; 3) Innovative Inference Systems; 4) DSM and operational tools; 5) DSM in 3-D and Partially Dynamic DSM; 6) Digital Soil Assessment (DSA); 7) Modelling Uncertainties; 8) Data Quality Assessment and Evaluation and Harmonization of legacy data for DSM and DSA; with in between great Italian espressos, lunches and dinners.

Prior to the start of the first session three introductory presentations were given. Neil McKenzie, chair of the DSM Working Group, opened the workshop. He pointed out that the DSM community has the potential to become the leading community that is responsible for providing crucial soil data required by other scientific communities, policymakers, scientists and land users to address the major global environmental issues that are threatening the planet. He urged us to answer the challenge that Jeffrey Sachs as thrown at the soil mapping community: "Soil mapping is one of the pillars to the challenge of sustainable development". Giuseppe Scarascia-Mugnozza, head of the CRA Agronomy, Forestry and Land use Department (co-host of DSM 2010), informed us about the research conducted at CRA and the role of soil knowledge in agroforestry research in particular. Luca Montanarella, Action Leader in SOIL at the JRC, concluded the introductory part of the workshop by explaining the importance of DSM for the European Commission.

Two keynotes were delivered during the workshop. Alex McBratney presented the global DSM methodology: the use of spline depth functions to map five key soil properties at six depths. Marcel van Ooijen, an ecosystems modeller from the Centre for Ecology and Hydrology in Edinburgh, gave an interesting outsider's view on what was expected from the DSM community by soil data users in his presentation on current challenges in uncertainty quantification in process-based modelling for environmental assessment. Good quality soil data are imperative for their models with special interest in changes of soil properties in time. This might be one of the key gaps to be addressed by the DSM community: space-time mapping of soil, of which Budiman Minasny and S. Young Hong provided two interesting examples during the workshop.





The workshop was concluded by round table discussion that was convened by Alex McBratney, Neil McKenzie, Luca Montanarella and Rosario Napoli. Some of the issues raised during the discussion session:

- The DSM community is moving to a more mature phase. Workshop contributions focused this time much more on operational DSM activities.
- There is generally an underinvestment in soil information, compared to climate information for example. The next 10-20 years are critical years for soil scientists in providing data that is required to address major global environmental threats. We have very few people in our community who have influence in the political world and who are close to the 'big money'.
- It is worthwhile to look outside our community from time to time to other science communities. We can learn from the climate change and biodiversity communities in how they collect and share their data and methodologies. They provide great examples of global efforts, e.g. <http://data.gbif.org/>.

Legacy data has become an important data source for DSM activities. Especially since DSM research is moving towards larger and larger areas. Many participants incorporated legacy data (point data, maps, information derived from booklets accompanying soil maps, knowledge from experts) in their mapping activities. However, some consider legacy data as dirty data: age and quality of the data vary and must be carefully considered before use. However, legacy data can also be a great opportunity for DSM, for example for extracting trends in time.

Use of legacy data for mapping larger and larger areas also involves harmonizing soil data bases and soil maps. Using non-harmonized can result in maps with discrepancies or artifacts at boundaries of map sheets, counties or countries. Tomislav Hengl referred to such maps as 'Frankenstein maps'. Should we avoid creating Frankenstein maps or are they acceptable? The opinions differed.

Speaking of discussion, I would like to take this opportunity for a critical comment on the (on the other hand well-organized) workshop. The previous global

workshops had ample room for discussion in the program: each session was followed by a half hour discussion on the topic of that session. I think this was of the strengths of the global workshop on DSM and the very thing that set them apart from other conferences. These discussion sessions were greatly appreciated by many participants. In this year's workshop only one half-hour discussion session was scheduled at the end of the workshop. Although there was a lively discussion during this session, I think it was a bit too short and some issues were still left unaddressed. I hope that the workshop character returns for the next meeting in 2012.

The topic of the workshop was 'identifying key gaps from regions to continents'. So what are these key gaps? There were great presentations and discussions (albeit the limited time for the latter) on a variety of topics, but I feel that the topic of the workshop could have been addressed more explicitly in the end. So I will give it a try here:

- Use of legacy data for DSM: dirty data or data with opportunities?
- Data harmonization: how to harmonize data from different sources (institutes, counties or countries) and data at different scales? Are Frankenstein maps OK or should we get rid of discrepancies and artefacts (and how)?
- Digital soil assessment: from soil property maps to soil functional maps to assess soil functions and threats.
- Extending DSM methodologies from the 2- to the 3- and 4-dimensional domains.
- Perhaps we can extend the discussion on key gaps in DSM in 2010 a little bit to the Pedometeron, so please feel free to comment on this.

At the end of the workshop Bob MacMillan initiated the Peter Burrough prize for the most innovative idea presented at the workshop (poster or oral). Alex McBratney won this (back then unnamed) prize during the previous workshop in the USA and now got officially his award. Gerard Heuvelink won most of the votes this year for his presentation on 'Implications of



digital soil mapping for soil information systems'. Gerard and his co-authors propose an extension of current soil information systems with facilities that store DSM models that produce the soil maps instead of the soil maps themselves. This has several advantages: it gives flexibility in terms of extent, resolution and support of the requested map, it enables easy updating with new data, it automatically archives the way the map is created, and it saves storage capacity.

Neil McKenzie closed the workshop by announcing the new chair and vice chair of the working group and the

candidates for organizing the next workshop in 2012. Janis Boettinger will be the new chair of the DSM working group and Tomislav Hengl will be vice-chair. Candidates for organizing the next workshop are Amman, Jordan, Quebec, Canada and Sydney, Australia.

Finally, on behalf of the participants of DSM 2010 I would like to thank once more the organizing committee for making DSM 2010 a successful event. I am looking forward to the next meeting.



DSM 2010 Field Trip Report By Bob McMillan



Rome is Rome and Tuscany is Tuscany. What can one say about them? They overwhelm one with their beauty and their perfection.

The two day field trip organized for DSM 2010 by Rosario Napoli and led by Edoardo Costantini exposed the more than 60 participants to the beauty and functionality of the Tuscan landscape and to the inextricable link between the soils of the area and these traits. We experienced a landscape whose appearance and function were almost entirely crafted by human design and activities applied consistently over millennia. All that appeared so natural and beautiful had been carefully thought out and planned to create a harmonious whole that was both productive and sustainable.

All the soils that we saw had been modified to a greater or lesser degree by human endeavour and all uses had been matched to their most suitable soils. It was precision agriculture on a grand and historic scale. It was landscape and livelihood as art where visual beauty was a clear indicator of health and optimum functionality. Beauty and functionality are not mutually exclusive here; rather they are linked so closely that the productivity of the land can be measured almost exactly by its beauty. Tuscany was poetry in soil; a poem whose pattern and rhythm have endured for centuries.

The field trip departed from the DSM 2010 conference venue in Rome at 17:30 on Wednesday, May 26 and

proceeded past the hill towns of Umbria and the picture postcard pretty landscapes of Tuscany to arrive in Sienna in time for a fashionably late evening banquet. Along the way, Edoardo regaled us with his comprehensive knowledge of the geology, geomorphology, pedology and evolutionary history of the landscapes we were passing through. All this information had been meticulously catalogued in the detailed field trip guide provided to participants.

If Wednesday was a long and revealing day, Thursday was more so. We began with an excursion “under the Tuscan sun” to visit and learn about the precise relationship between soils and wine captured by the concept of a terroir. A visit to Brolio estates, one of the most famous and big vineyards in the Chianti region, owned by Baron Ricasoli, was animated by the informed knowledge of Massimiliano Biagi, the agronomic manager. Massimiliano and Edoardo gave detailed explanations of how the qualities of the soil were inextricably linked to the qualities of the wine that it produced. They told a story of how detailed soil investigations, including digital soil mapping, had been used to better understand that link. These investigations had been instrumental in re-establishing the pre-eminence of the Brolio brand by precisely characterizing the different terroir and their role in producing quality grapes and wines.

Several soil profiles, exposed in pits at the site, showed the wide range in soil conditions that occurred over short distances and how these differences were related to differences in management of the vineyard. Many were surprised to learn of the extent to which the natural soils had been disturbed and rebuilt to ensure optimum growing conditions for the vines. Grapes here are grown under conditions of natural rainfall, without use of irrigation to artificially control soil moisture levels and induce needed moisture stress. Consequently, it is important to establish adequate drainage in the soil so as to prevent vines from being exposed to excess moisture. This is done by techniques that range from a kind of deep ploughing to others that involve an almost complete excavation of the soil and replacement on top of a platform





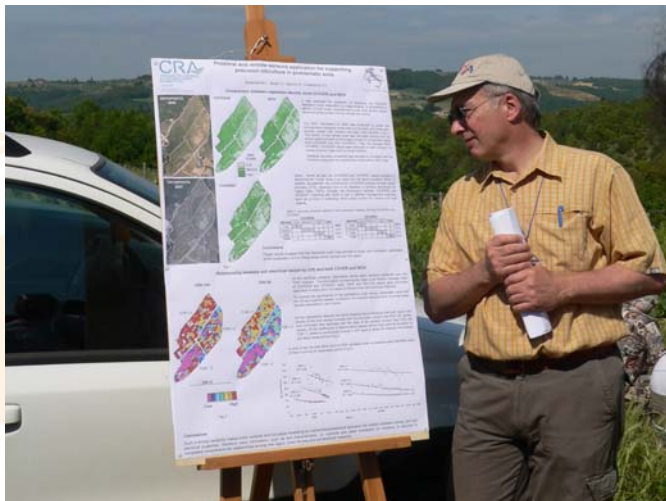
of rocks installed to enhance sub-surface soil drainage.

Activities highlighted included use of proximal remote sensing techniques to produce detailed soil maps for precision viticulture and use of radio isotopes to characterize the hydrological regime of soils at the time of maturity and harvest of grapes and to compute an isotopic fingerprint unique to each vineyard and each terroir within it. Most of the participants would have been happy to spend the entire day in the beautiful setting of the hillside vineyards but we moved on from seeing where the grapes were grown to learning about the wine they produced.

Massimiliano welcomed us into the caves where the wine is matured for an education in wine tasting and appreciation. We were instructed in how to judge and compare the colour, intensity, bouquet and density of each wine and then challenged to tell the two apart based on aroma or taste. Even the most un-educated palates seemed able to differentiate the two wines, through opinions varied about which one was preferred.

After the tasting, we were favoured with a five course feast in the dining room of the castle. This feast was enough to create a great desire for sleep but the tour continued with a visit the Castello di Brolio. The castle offered a glimpse of Italian history at the time of unification as well as stunning views of the surrounding countryside.

Back on the bus, we arrived at the location for the afternoon field visit around 6:00 pm. This site presented us with 10 profiles in a complex pedostratigraphic sequence characterized by the presence of paleosols. This paleosequence was interpreted to extract a reconstruction of the soil cover through time. Mercifully, most of the profile pits were inaccessible, as a long walk uphill through the forest was required to arrive at them. We contented ourselves with examining a paleosol at the bottom of the hillslope classi-



fied as an Acrisol and characterized by the presence of fragipans in the 130-150 cm depth range. This Middle Pleistocene soil was at the bottom of the hillslope with younger soils higher up in the landscape.

Friday's itinerary consisted mainly of a visit to Siena that started at the offices of the Siena regional government with a presentation given by Edoardo Costantini on the scientific results of the research made in collaboration with the Province Administration, and aimed at planning new vineyards plantation according to soil suitability, environmental protection, landscape impact, and safety for farm workers. We were generously welcomed to the province of Siena by Giovanni Pacini who explained again the importance of soils and of soil research in maintaining and enhancing the quality of the wines of the region.



Anne Richer de Forges, 2010

Carbon escaping from soil

Lost in the triangular diagrams of soil texture

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The information in this note comes from a paper by Richer de Forges et al. (2008) in which we presented the results of a comparison between numerous triangular diagrams of soil texture used in France and in the World.

There are numerous different triangular diagrams of soil texture in the world. Most of the texture triangles are adapted to the pedological context of their region of origin. Besides, the definitions of the particle-size fractions also differ between countries and even among organisations within a country. We tried to do a stocktaking of the texture diagrams in order to compare them.

Almost all the triangles are in agreement on extreme classes (classes where the dominant particle-size fraction is either clay, silt or sand). By contrast, there are many discrepancies between classes in the centre of the triangles, where mixtures of the particle-size fractions are represented. Nevertheless, some texture-class borders seem to be in general agreement. It seems, however, that any harmonization at worldwide level would be very difficult, given the challenges to agree on a norm. Some authors successfully produced algorithms to transfer class designations from one triangle to another, but these functions are far from general among all the triangles. Another possible approach would build transfer functions using parent material and pedogenetic classes and the continuous laser particle-size distribution, but it would require a

considerable work. As a result, and while we await a solution for harmonization, it is important that full information is provided on the different texture triangle references used in soil databases.

The triangle of soil texture appears in France and in US between 1906 and 1911. The first triangle of soil texture is the triangle of Lagatu (1905).

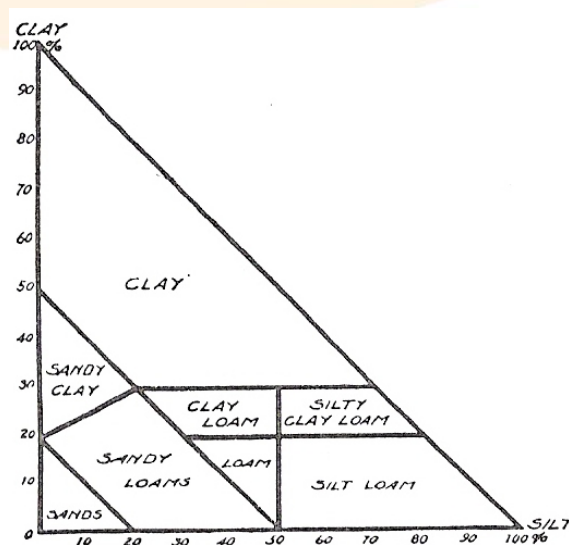
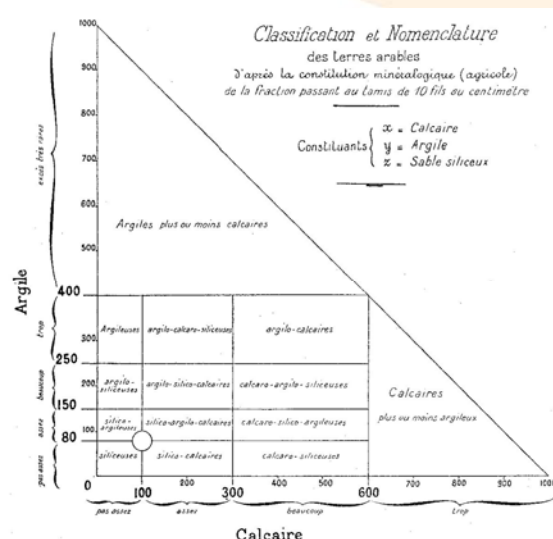
In this note we show some of the collection of triangles that we gathered.

Even within France, there are many different adaptations of the two triangular diagrams shown above. This is probably true in other countries.

If you use or know about another triangular diagram, please send it to me!

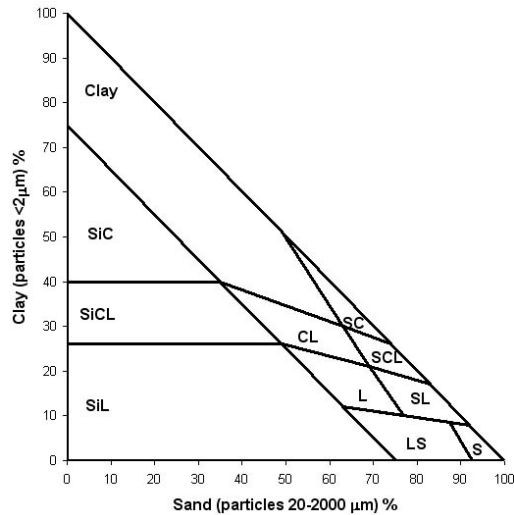
Reference

Richer de Forges A., Feller C., Jamagne M. and Arrouays D. (2008) Perdus dans le triangle des textures, Etude et Gestion des Sols, Volume 15, 2, pp 97 - 111. (paper in French with an English abstract). Paper freely available at: http://www.inra.fr/internet/Hebergement/afes/pdf/EGS_15_2_richerdeforges.pdf

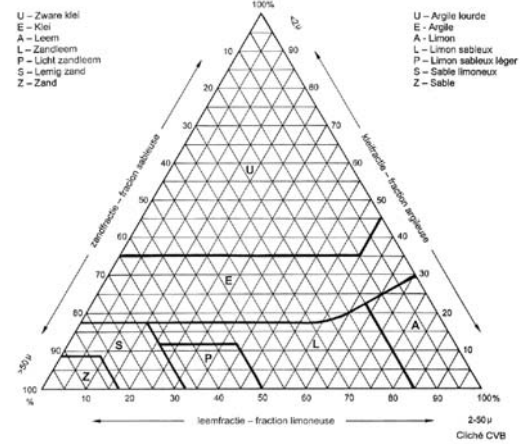


Soil texture triangle

Australia



Belgium



Canada

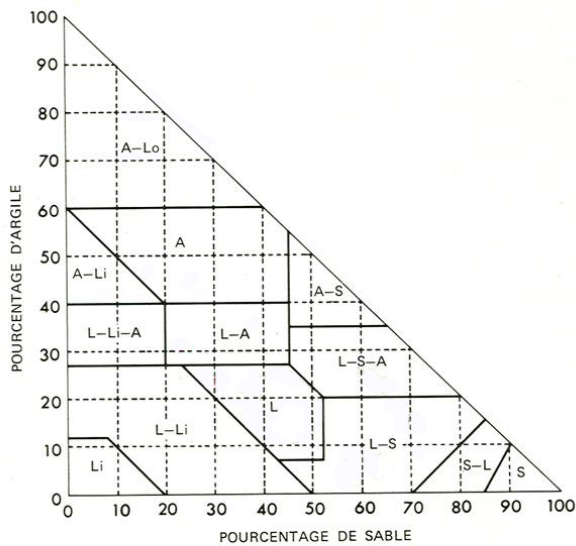
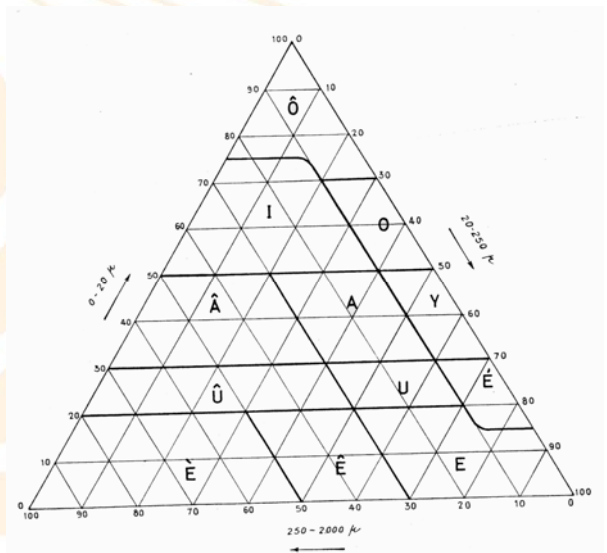
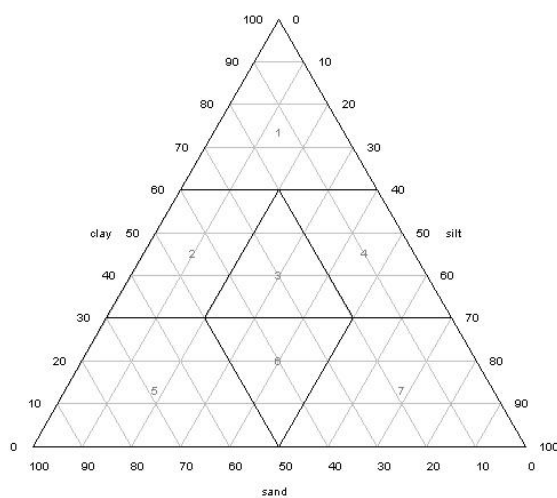


Fig. 37 Classes texturales du sol. Pourcentages d'argile et de sable dans les principales classes texturales du sol; le reste de la composition de chaque classe se compose de limon

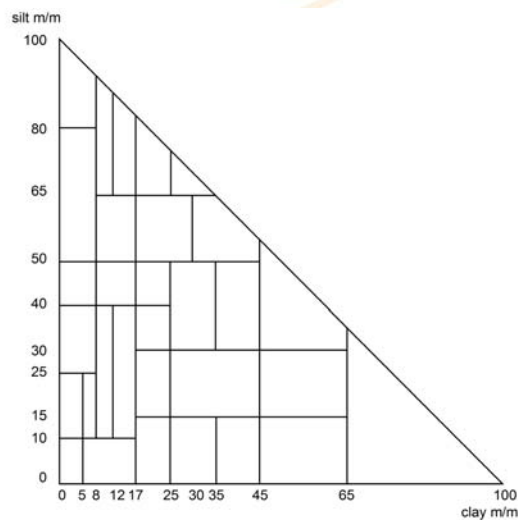
Congo (INEAC)



Finland



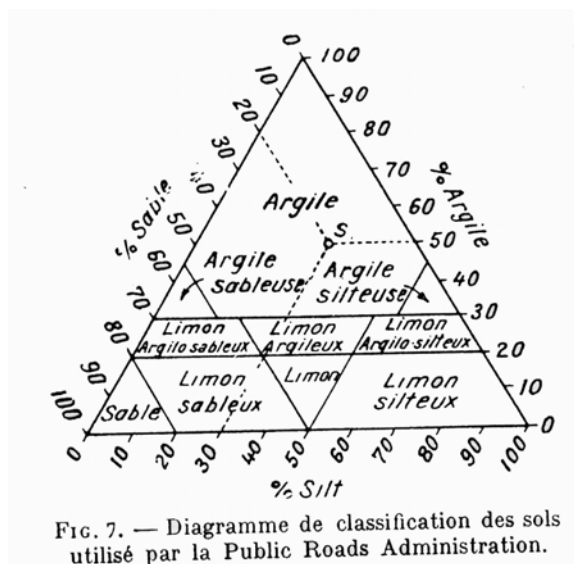
Germany



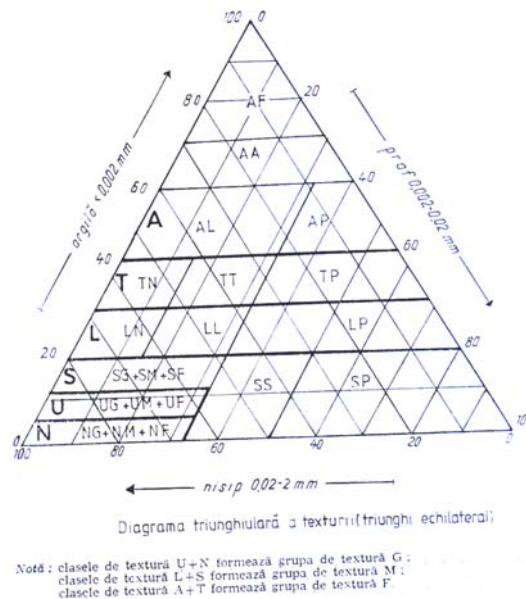
Ad hoc-AG Boden (2005): Bodenkundliche Kartieranleitung, 5., verbesserte und erweiterte Auflage. Eds.: Bundesanstalt für Geowissenschaften und Rohstoffe, Niedersächsisches Landesamt für Bodenforschung. Hannover: Schweizerbart'sche Verlagsbuchhandlung (in Komm.).

Soil texture triangle

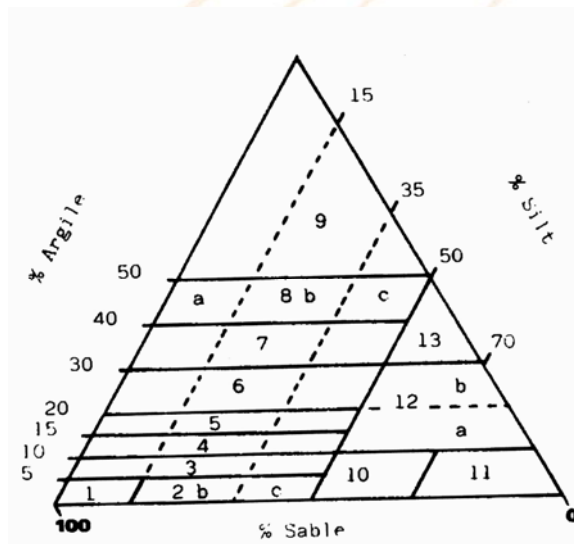
Public Road Administration (USA)



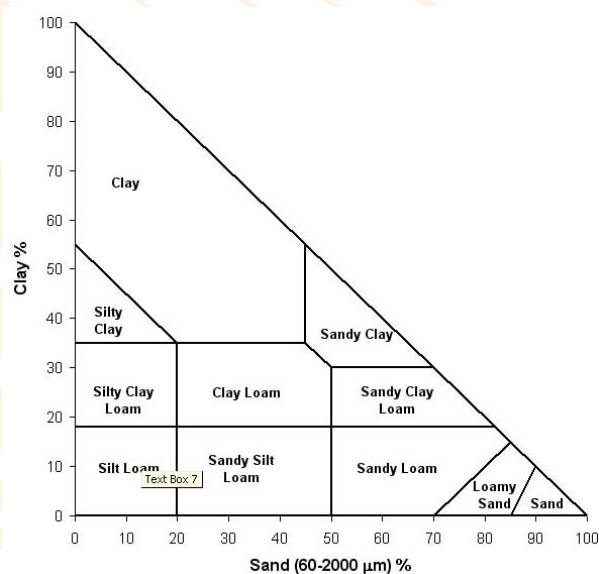
Romania



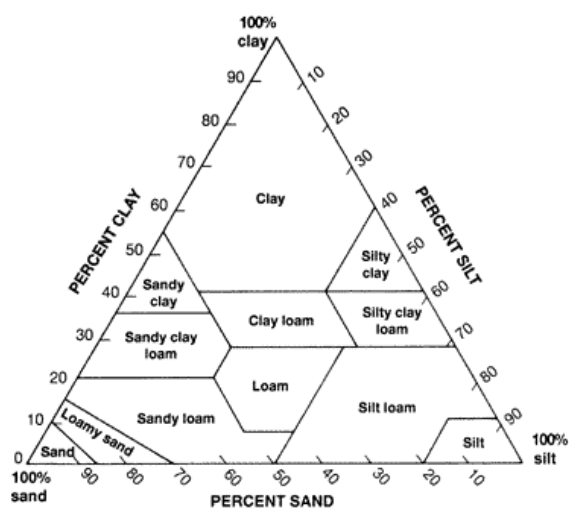
Switzerland



UK



USDA

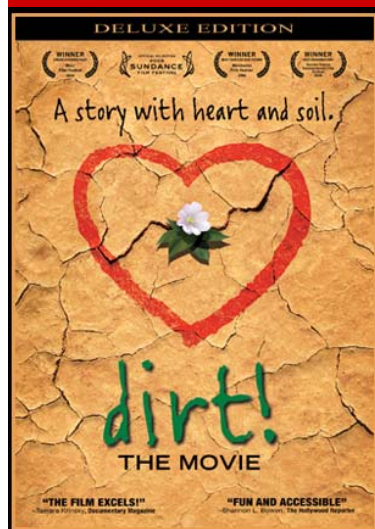


DVD Review: dirt! The Movie

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dirt! The Movie

Available from <http://www.dirtthemovie.org/>

Verdict: don't expect to like it but see it anyway



'Dirt! The Movie' premiered at the 2009 Sundance Film Festival and is a heartfelt documentary about; well you guessed it - that unglamorous yet essential stuff beneath our feet. It is also shown at the 19th World Congress of Soil Science in Brisbane.

Directed by Bill Benenson and Gene Rosow and loosely inspired by the book 'Dirt: The Ecstatic Skin of the Earth' by William Bryant Logan, Dirt! presents a quirky story quite atypical for film that should provide many a watchable moment for laypeople and experts alike. Now, assuming you can quiet the scientist from protesting at a few unfortunate factual errors and misrepresentations, Dirt! Encapsulates an effective method to engage children and the general public in a journey towards awareness of our humble soil. For the professional, this movie also serves as a timely elbow in the ribs about the growth in public interest in readily digestible soil education and highlights how much of the story is left to tell.

Unsurprisingly, Dirt! takes up the mantle of raising awareness from a social perspective, loosely hanging its 80 min narrative around the concept of a quasi-spiritual romance between human culture and dirt – young love, neglect, loss, suffering and then renewed love leading to hope for the future. Whilst initially off-putting to the more secularly inclined it is an ingenious technique of engagement and quite warranted given the topic. Considering that dirt is rarely held in high regard or even thought of by the general public (excluding those who prefer the term 'soil') this documentary represents a sincere effort to engage.

Narrated by Jamie Lee Curtis, Dirt! boldly starts at the big-bang and quickly follows with an almost too extensive line-up of talking heads, most of which are thankfully quite in-

spiring with only a few skirting the edges of rationality – yet even this comes across as forgivable given their obvious enthusiasm for the subject. The message from the talking heads is singular: dirt is alive, it is vitally important and societies who mistreat it ultimately only end up mistreating themselves.

Punctuated by an endearingly simple and surprisingly articulate animated dirt blob, concepts such as the consequences of soil sealing for hydrology, the inexorable march of cities into productive lands and soil degradation through industrial agriculture, war, economic imperatives, open-cut mining, over-grazing, land-clearing and loss of biodiversity are all somewhat depressingly explored. To remedy this bitter pill, Dirt! then proceeds to put forward several offerings in what is perhaps the most enjoyable part of the movie. One piquant and strangely uplifting anecdote from Wangari Maathai (Founder, The Green Belt Movement and Nobel Laureate) involving animated forest animals paralysed at the sheer enormity of impending wildfire left me personally identifying with the hummingbird – insignificant to the point of ridiculousness yet stubbornly persistent.

Other notable moments include rehabilitation programs for prisoners and streetscapes, a wine guru actually nosing on dirt in his earnest efforts to explain terroir and numerous examples of urbanites weaving a bit of jungle into their concreted lives. And the sight of heavy machinery pulling up asphalt so schoolkids could get to the dirt underneath?... well, wasn't that quite telling. These kids were not just excited but wide eyed with wonder – this dirt (with an exclamation mark or otherwise) actually meant something to them and that in itself, is worth watching for.

Other than that, just don't expect to hear from soil scientists (like I did the first time) with only one representative briefly sighted in front of the comforting order of a well cleaned pit face. Testament perhaps, to the tenuous foothold the discipline really has in this rising cultural movement, and how little perhaps, it would take for any profile gains to quickly erode elsewhere (re talking heads here). The only other general caveat needed for this movie then, is that any aversion to the usage of the word 'dirt' should be put firmly and resolutely to one side before viewing. There's no soil here, thanks.

Pedometrics 2011

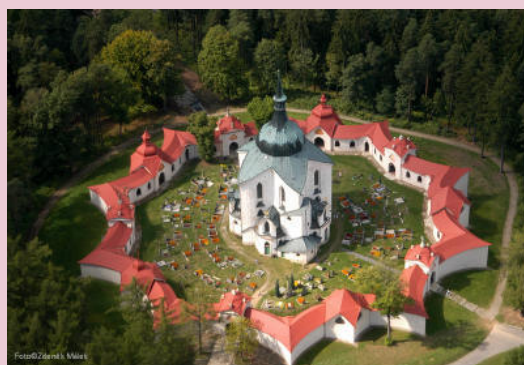
30 August — 3 September
Castle Hotel Třešť, Czech Republic

Innovation in Pedometrics

Organized by the Department of Soil Science and Soil Protection of the Faculty of Agrobiological Sciences, Czech University of Life Sciences in Prague, Czech Republic, in cooperation with the Pedometrics Commission of the IUSS and the Czech Society of Soil Science.

The conference will focus on the advances of pedometrical methods with topics as follows:

- Key challenges in pedometrics
- Soil sampling for survey and monitoring
- Soil geostatistics
- Fuzzy logic in soil science
- Bayesian statistics in soil science
- Data assimilation
- Signal processing of remote and proximal sensing applied to soils
- Pedometrical methods for soil assessment
- Space-time modelling
- Soil-landscape modelling
- 3D modelling in pedometrics
- Expert knowledge in pedometrics
- Uncertainty analysis, error propagation, accuracy assessment
- Key applications of pedometrics
- Linkages with other IUSS groups



The conference will be preceded by two days of special workshop taking place on the Czech University of Life Sciences in Prague. Proposals of up-to-date workshop topics and workshop lecturing will be appreciated.

A field trip including both pedological and cultural stops will be a part of the conference.

Please check the conference website <http://2011.pedometrics.org> or contact Luboš Borůvka (boruvka@af.czu.cz).

An early history of ordination in soil science

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For many years pedologists classified soil partly so that they could talk and write about the properties and behaviour of particular kinds of soil and partly so that they could express relationships between the soil and its environment. Farmers and their advisors wanted, and still want, to distinguish between acid, calcareous, salty and alkaline soil; each of those kinds requires its own specific ameliorative treatment and management different from those of the others. The early Russian pedologists observed the sequence of soil in profile as they moved from north to south from the tundra through coniferous forest to grassland and finally to desert scrub.

In the farming example a single property of the soil might override all other considerations and so be all that a farmer needs to know in the first instance. It might be the pH, to be corrected by liming if the soil is too acid or a combination of gypsum and irrigation if it is too alkaline or salty. It might be that the water table is too high, in which case the arable farmer should drain before worrying about anything else. In the second example, the sequence from north to south in Russia, there is no one property of the soil that characterizes the change. Rather several properties change more or less together. I write 'more or less' advisedly, because some properties can change in concert in some regions and in a much less concerted way elsewhere. We tend to regard the Podzol as characteristic of the boreal coniferous forest, and we might say that a bleached E horizon is an essential feature of it. But dig a trench and you see that the E horizon varies in thickness and even disappears in places, yet all the other horizons are there. Shall you call the profile 'Podzol' (ash soil) where the E horizon (the horizon with ash-like appearance) has shrunk to nothing? Or shall you give it another name, i.e. designate it as another class? If we do the latter then we create a division between two otherwise similar profiles and as a consequence obscure their similarity. For many years pedologists recognized other kinds of soil profiles consisting of leached horizons above ones that appeared to have accumulated material from above, and they called them 'Podzolic soil'. They were similar in that respect to Podzols, but different in many others. How could classification express similarities and differences? Systematists tried with varying success by creating hierarchies. The arguments that followed generated as much heat as light, and I am not going to revisit them here.

But one line of thought emerged from all this: is there not some way whereby we can express similarities and differences among multi-faceted objects such as soil profiles without first classifying them?

Plant ecologists faced similar problems. They wanted to identify communities of plants and to represent relations among those communities. In some instances they could recognize indicator species that would characterize communities, but most communities comprised numerous species no one of which could be regarded as either necessary or sufficient to characterize any one of them. The ecologists also wanted to express, preferably quantitatively, and to understand the relations between those communities and the environments in which they occurred. As early as 1930 they had devised direct gradient analysis for the purpose (Ramensky, 1930; Gause, 1930), though applications became popular only some 20 years later. Essentially the method was graphical, with species abundances plotted against a single environmental variable such as degree of pollution (e.g. Macan & Worthington, 1951) or wetness of the land (e.g. Dix & Smeins, 1967).

As in pedology, classification had been ecologists' principal tool for organizing multiple observations. But also as in pedology classification failed to express or reveal satisfactorily all the main relations that might be of interest, and ecologists thought of ways of arranging communities, characterized by counts of plants, without first classifying them. Direct gradient analysis was only one step in that direction. Goodall (1954), recognizing the continuous nature of multivariate variation in vegetation, proposed the term 'ordination' for arranging such data economically without classifying them; the term has stuck.

Principal component analysis

To understand ordination it is helpful to envisage the items of interest, be they quadrats in a forest, specimens of fossils in a museum, or soil profiles or sampling sites, as points distributed in a Euclidean space of p dimensions, where p is the number of variables, z_1, z_2, \dots, z_p , recorded on each. In ecology these variables may be the abundances of species; in pedology they are usually measured variables, and in both there are often many of them. Also in both there is

typically a great deal of redundancy in the records in the sense that the variables are correlated with one another. In these circumstances we may rightly seek to reduce the dimensionality so that we can display the relations among the points and hope to see meaningful structure in few dimensions.

Principal component analysis (PCA) is the most straightforward technique for achieving those aims. It takes account of the correlation and finds new axes in the multidimensional space such that the first axis has maximal variance, the second axis, orthogonal to the first, maximizes the variance among the residuals from the first, the third has maximal variance among the residuals from the first and second axes, and so on. Projections of the points on to planes defined by these few axes, the component scores, produce an ordination of the items in a much reduced part of the Euclidean space, and they can be graphed to display the result.

In the geometric setting PCA is simply a rigid rotation of the scatter of the data in p dimensions to new axes; it is no more and no less. It requires no assumptions about distributions, and it takes no account of anything else you happen to know about the data. If a result makes pedological sense then that is good fortune rather than a predictable outcome. In practice PCA has proved remarkably helpful in pedology, largely because of the moderate to strong correlations among the input variables.

The mathematics of PCA date back to the 1930s (Hotelling, 1933). Its application for ordination, however, had to await the advent of computers and some astute numerical programming to extract the eigenvalues and their associated vectors reliably from large matrices.

In an early application of PCA Cuanalo and I (Cuanalo & Webster, 1970) ordered 85 soil profiles. We had measurements of 15 soil properties made at two fixed depths, giving 30 variables in all, from 85 sites chosen by random sampling. The first two eigenvalues of our correlation matrix accounted for 48% of the variance, and we projected the sampling sites in the plane of the first two axes to display the structure. Later (Webster, 1977) I rotated the configuration in the two dimensions by the varimax method (Kaiser, 1958) so as to give clearer meaning to the axes. Rotated component 1 could be interpreted as representing the soil's water regime from wet to dry; rotated component 2 was essentially a measure of its particle-size distribution.

Another early innovative application of PCA to soil was that of Kyuma & Kawaguchi (1973) who wanted to rank sites for paddy rice according their 'chemical potential' for that crop. They had measured 23 mainly chemical properties on soil from 40 rice-growing sites in south-east Asia and did a PCA on their data. The first eigenvalue of the correlation matrix accounted

for 36% of the variance, and they found that the first component alone ordered the soils in an intelligible and useful way for their purpose.

There have been many applications of PCA in soil science since those days, though most have been simply to reduce the number of variables for later analysis rather than for revealing structure.

I mention a few further aspects of its practice.

1. The analysis may be done on any one of three matrices, namely the sums-of-squares-and-products (SSP) matrix, the variance-covariance matrix and the correlation matrix. Unless the variables have been measured on the same scales then one should either do the PCA on the correlation matrix or scale the variables to a constant variance of 1.
2. The use of only leading component scores in subsequent discriminant analysis is to be deprecated; there is no reason why those scores should discriminate between predefined classes. Lark (1996) and Ertlen et al. (2010) present examples of their failure. Clustering on leading components is less risky, but outlying small clusters in the higher-order dimensions are likely to be missed.
3. The eigenvectors of the matrix can be scaled to provide correlation coefficients between the principal components and the original data and so aid interpretation of the component axes.
4. Interpretation may be aided further if you scale the component scores so that they can be displayed as biplots on the same axes as the correlation coefficients or eigenvectors (Gabriel, 1971; Gower & Hand, 1996).

Distance matrices

Attractive though PCA is theoretically, and despite the ease with which it can be done on modern computers with well-accredited software, it is restrictive in that all data must be on linear scales (of which binary is the extreme), and all variables must be relevant for all items. One cannot include, say, colour of mottles if there are no mottles in some profiles. For counts, presence-or-absence variables and multistate variables such as soil structure and mixtures of such variables more elaborate techniques are needed. In these instances the first step in the analysis is to compute similarities or dissimilarities between all pairs of n items. We may regard dissimilarities as 'distances' of some kind in the p -dimensional space and assemble these distances in a matrix, D , of dimension $n \times n$. Most methods of ordination are variants on the treatment of this matrix, a matter to which I return below.

Polar ordination

Hole & Hironaka (1960) seem to have been the first pedologists to attempt multivariate ordination as distinct from discrimination. They used a form of polar ordination, a method devised by their ecologist colleagues in Wisconsin, Bray & Curtis (1957), and one form of which may be envisaged as a development of gradient analysis. Two items are chosen as poles to

define an axis through the p -dimensional space. They may simply be the two items that are furthest apart or near the ends of an elongated cloud of points, or they may be chosen because they seem to represent extremes of environment. The positions of the remaining items on this axis are then calculated from the distance matrix. Other pairs may be subsequently selected as poles to give more than one axis through the space and the positions of the items on these axes calculated.

In one exercise Hole & Hironaka computed the dissimilarities between all pairs of 25 major groups of soil for which they had representative data. They selected as poles three pairs of the major groups separated by large distances, and they projected the remaining 23 groups on to the axes so formed. They treated the axes as orthogonal and displayed their results in a projection of a cube. In another exercise they chose just eight major groups, computed dissimilarities between them, cut rods with lengths proportional to the dissimilarities and joined the ends of the rods as best they could to fit them together in a three-dimensional physical structure. In a similar exercise Bidwell & Hole (1964) arranged 29 soil profiles typical of their classes on three axes. They were somewhat surprised to discover that most of the profiles lay close to one another near the centre of the configuration and that the classification was hardly sustainable.

Principal coordinate analysis

The next significant publication embodying ordination in pedology was by Rayner (1966). Rayner similarly investigated relations between soil profiles that had been described as typical of certain major groups. He faced the following two problems.

1. The data were of three main kinds, namely measurements on linear scales, presence-or-absence (binary) and multistate. Further, some of the binary variables were significant if they were present but not otherwise.
2. The data were recorded by horizons, which varied in number, kind and order from one profile to another. Rayner was helped by his colleague at Rothamsted, J.C. Gower, whose deep understanding of matrix algebra enabled him to solve these problems.

A general coefficient of similarity. Gower (1971) solved problem 1 by devising his general coefficient of similarity between any pair of items i and j :

$$S_{ij} = \frac{\sum_{k=1}^p y_{ijk} w_{ijk}}{\sum_{k=1}^p w_{ijk}}, \quad (1)$$

where y_{ijk} is a value for the comparison of the k th variable and w_{ijk} is the weight assigned to it. For continuous variables

$$y_{ijk} = 1 - \frac{|z_{ik} - z_{jk}|}{r_k},$$

where r_k is the range of the variable z_k . For qualitative variables $y_{ijk} = 1$ if $z_{ik} = z_{jk}$ and 0 otherwise. The weight w_{ijk} is set to 1 for a valid comparison between items i and j for variable k and to 0 if z_{ik} or z_{jk} or both are unknown or not applicable. Rayner had to decide what to do about binary characters when both z_{ik} or z_{jk} were 0. He distinguished between a pair of significant zeros, giving the comparison weight $w_{ijk} = 1$, and a pair of non-significant zeros for which he assigned weight $w_{ijk} = 0$ and effectively making no comparison. In this way Rayner computed similarities between all pairs of horizons in his set of data to give a similarity matrix S of dimensions $n \times n$, where n is at this stage the number of horizons in the set of data, not whole profiles.

Rayner's next step was to obtain similarities between profiles, which he did from the similarities between their horizons as follows. Consider any pair of profiles, say P_1 and P_2 . The first horizon of P_1 is compared with each horizon of P_2 in turn, and the best match (largest similarity) is identified. The second horizon in P_1 is then compared with each horizon in P_2 , starting with the best match found for the first horizon and proceeding downwards, and again the best match is identified. The third horizon in P_1 is compared with the horizons in P_2 at and below the best match for horizon 2, and so on to the bottom of the profile is reached. The roles of P_1 and P_2 are reversed and the process repeated. When all matches have been identified the similarity between P_1 and P_2 is finally computed as the average of the similarities between the matched horizons. In this way Rayner obtained a new matrix of similarities between all pairs of profiles rather than between horizons. Notice in particular that he took into account the similarities between horizons and the order in which the horizons occurred down the profile.

Principal coordinates. Gower's second major contribution was to transform matrix S so as to represent the coordinates of the items in a multidimensional Euclidean space. The first step is to scale the similarities in the range 1 (for identity) to 0 for maximum dissimilarity to give, say S'_{ij} , and compute distances

$$d_{ij} = \sqrt{2(1 - S'_{ij})} \quad (2)$$

for all i and j to give a matrix D . This matrix is then transformed into another such that the distance between any two points i and j whose coordinates are the i th and j th rows of the matrix equals d_{ij} . Gower (1966) called the method 'principal coordinate analysis'. The method is quite general; many kinds of similarity can be used to build matrix S . In particular, if the S_{ij} s in Equation (1) are Pythagorean distances then Gower's method gives the same results as principal component analysis.

Rayner transformed his similarities calculated as above into principal coordinates and thereby obtained an ordination of the profiles. It was a tour de force.

What next?

After such an ingenious and comprehensive treatment pedometricians were bound to wonder what else was left to do. Anderson (1971) thought that it might be better to minimize a somewhat different loss function when reducing the dimensionality. He pointed out that principal coordinate analysis minimizes

$$\sum_{i=1}^n \sum_{j=1}^n d_{ij}^2 - d_{ij}^2(q),$$

where q is the reduced number of dimensions. He proposed the following quadratic loss function:

$$L = \sum_{i=1}^n \sum_{j=1}^n \{d_{ij}(q) - d_{ij}\}^2,$$

and he showed that it made a more sensible ordination of Rayner's data to minimize this quantity. As far as I know no one else has used this refinement.

One difficulty at the time was that computers were too small and too slow to handle more than about 100 items; they had to be able to hold and manipulate the lower triangle of an $n \times n$ similarity matrix; that would require a minimum of $n(n+1)/2$ words (the matrices are symmetric). And if there were on average four horizons per profile then the analysis was limited to 25 profiles.

It was far from certain whether the advantages of the method over simpler ones justified the amount of computing or of tailoring investigations to fit into the computers of the day. Rayner himself wondered, and he and Williams (Williams & Rayner, 1977) compared similarity matrices computed by his zig-zag method with ones computed by simpler techniques and found little advantage. If one could avoid computing similarities between horizons in the first place and treat whole profiles or sampling sites as the items then, of course, one could handle a hundred or so of them. Campbell et al. (1970) and Webster & Butler (1976) took this approach and used principal coordinate analysis to order sampling sites at which they had recorded variables of mixed modes in few dimensions, and in a further innovation Oliver & Webster (1989) combined variograms with principal coordinates to constrain soil classification spatially.

A lesson learned

The ordinations obtained both by Hole & Hironaka and by Rayner made pedological sense; they showed relations among profiles representative of soil classes much as expected. However, the ordinations of profiles selected at random and on grids, and even those purposively selected by Bidwell & Hole (1964), showed a feature that was not expected by most pedologists at the time. The items when projected on to principal axes appeared as single clouds of points with no gaps and no distinct clusters. The ordinations by Cuanalo & Webster (1970) and Webster & Butler (1976), for example, and others, such as that by

Oliver & Webster (1987), revealed the arbitrariness of classification and explained why hierarchical classifications in particular were so contentious and so difficult to construct. The revelation caused pedometricians to switch their attention to non-hierarchical classification, a result that is still with us today.

Postscript

No history is comprehensive. As they say, history is written by the victors, or, in this case, by someone involved early in the action, and I apologize to those pedometricians who feel they have a place but whose work on ordination I have overlooked. I want to conclude, however, by praising someone who rarely figures in the annals of pedometrics and to whom we owe a great debt: John Gower. I have already mentioned his contribution to Rayner's research and the use made of his innovations by other pedologists. His principal coordinate analysis effectively generalizes several methods of multidimensional scaling, including correspondence analysis popularized in France by Benzécri (1973) and widely used there, in particular by the soil biologist J.-F. Ponge and his co-workers (e.g. Ponge, 1999, and Ponge & Delhaye, 1995). Gower also devised his 'add-a-point' method whereby new items could be added to an ordination by principal coordinates and so lift the severe limitations on the number of items in a set of data that could be ordered that way (Gower, 1968). Menk (1981) took advantage of the technique to order almost 6000 soil profiles from field records after an initial ordination of a sample. Gower generalized biplot methods and illustrated them with soil data (Gower & Harding, 1988). He also devised his Procrustes rotation to fit one ordination of a set of items to another (Gower, 1975), a potentially valuable technique in pedology but not one that has seen light in publications as far as I know. He has played an impressive role behind the scenes in our history.

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Copulas for Pedometricians

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Model-based geostatistical methods lead to powerful representations of the spatial variation of soil properties. However, existing model-based methods are not general enough to describe many of the patterns of variation actually exhibited by soil properties and in such cases lead to unreliable predictions of the property. We describe how copula-based models, which are commonly applied in financial risk assessments, might lead to a more general description of soil properties. We see that a relatively simple copula-based model leads to a more appropriate description of soil cadmium content across France than existing geostatistical models and we discuss the potential to generalize further the copula-based description of soil properties.

Introduction

Over the past decade the use of model-based geostatistical methods has become increasingly popular amongst pedometricians. These methods use likelihood approaches to fit models of spatial variation to observations of a soil property and then predict the distribution of the property, conditional upon the observations, across the study region. Many pedometricians prefer model-based methods over conventional geostatistical approaches based upon the method of moments because:

1. The likelihood is a meaningful measure of the appropriateness of a spatial model. In contrast the weighted sum of squared errors used by the method of moments is a more arbitrary measure which can be greatly influenced by a practitioner's choice of weights or the manner in which the comparisons between pairs of observations are divided amongst lag bins.
2. The uncertainty of the estimates of the model of variation can be expressed in terms of the Fisher Information matrix or by Bayesian techniques which are fully compatible with model-based methods.
3. Model-based methods can be extended to more

complex models such as linear mixed models or linear models of coregionalization which describe the relationship between the property of interest and covariates.

4. The model-based methods lead to a prediction of the distribution of the property at an unsampled location. Thus it is possible to extract pertinent information, such as the probability of the property exceeding a critical threshold. The conventional methods yield a prediction and prediction variance at each unsampled location but this is less informative since the distribution is not specified.

Diggle & Ribeiro (2007) provide a thorough and accessible description of the theory of model-based geostatistics and present examples of the successful application of the methods. However there is one key problem with the use of model-based geostatistical methods as general representations of soil properties. The methods are based upon the assumption that the soil property, possibly following a transformation, is a realization of a multivariate Gaussian random function. This assumption is implausible for many soil properties because either the marginal distribution or the dependence structure of the soil property is not consistent with the multivariate Gaussian model.

The marginal distribution refers to the univariate distribution from which we assume that each observation of the soil property is drawn. It is not plausible to assume that observations of soil metal content that include extreme values because of point source contamination are drawn from a Gaussian distribution. The same is true for bimodal distributions of soil organic carbon observed in areas which contain a mixture of organic and mineral soils.

The multivariate dependence structure describes the spatial correlation between the different observations. The assumption of a Gaussian dependence structure is restrictive for two reasons. Firstly, it implies that observations drawn from the tail of the marginal distribution are independent of each other. This would mean that extreme observations of soil contamination are assumed to be independent of each other although they might arise from the same local-

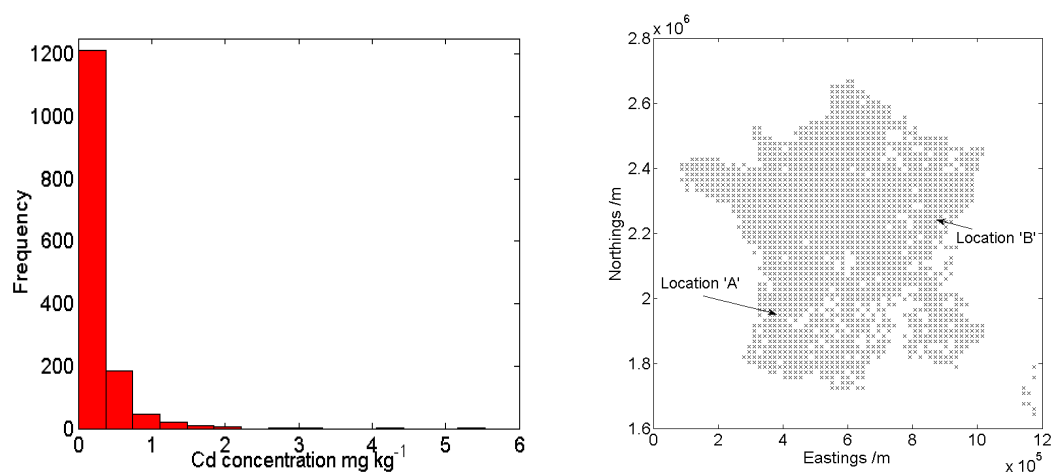


Fig. 1: Histogram of Cd across France (a) and sites of Cd observations (b)

ised source. Secondly, the Gaussian dependence structure is radially symmetric which implies that the pattern of correlation for small values of the property is the same as that for large values. However, small and large observations of a soil property are often the result of different physical processes which act over different spatial scales and lead to different magnitudes of variation. Thus there is a need for more general models of the variation of soil properties.

This need for non-Gaussian models of variation is not limited to soil properties and pedometricians. Statisticians have long recognised that Gaussian-based models of financial stocks are not sufficient to conduct risk assessments where the dependence between extreme values is critical (Embrechts, 2009). Financial statisticians have developed copulas as tools to generalize multivariate models of variation. Within a copula-based model it is possible to specify any marginal distribution and any multivariate dependence structure model and hence build a very general model of variation. The dependence structure model is referred to as the copula. Mathematically, a copula is an n -variate distribution defined on the n -dimensional unit hypercube. It can link any set of n marginal distributions to form an n -variate distribution.

Copula-based models were introduced to spatial statistics by Bárdossy & Li (2008) who used them to model hydrological variables. Further developments including Bayesian analyses of copula-based models were made by Kazianka & Pilz, In Press. We have applied copula-based models to a non-Gaussian soil property, namely soil cadmium (Cd) content observed across France and briefly summarize this study below. Full details of the theory underlying the models and the application of them to the Cd data are described in Marchant et al.

(submitted).

A case study: Cadmium in France

Soil Cd content was measured (Fig. 1a) at 2200 sites on a 16-km regular grid across the 550 000-km² French metropolitan territory as part of the baseline survey of the French National Soil Monitoring Network - RMQS: Réseau de Mesures de la Qualité des Sols - (Saby et al., 2006). The sites of the 1842 observations available at the time of this study are shown in Fig. 1b. The observations included some extreme values because of geological anomalies or localised pollution which were not consistent with a Gaussian marginal distribution. We therefore built a copula-based model where the Gaussian marginal distribution was replaced by a generalized extreme value distribution (GEV; Coles, 2001) and the dependence structure model was a Gaussian copula. We compared the performance of this model with a Gaussian model and a Box-Cox trans-Gaussian model (Diggle & Ribeiro, 2007) upon leave-one-out cross validation.

The quantile-quantile (QQ) plot (Fig. 2a) for the Gaussian model mostly lies above the $x=y$ line indicating that the uncertainty of predictions is overestimated at the majority of sites. This is because the small number of extreme values have caused the estimated variance to be greater than the underlying variance. The uncertainty at the sites of outliers is under-estimated and the QQ curve for these sites lies below the $x=y$ line. In contrast for the copula-based model, the deviation between the QQ curve and the $x=y$ line is much smaller (Fig. 2b). This indicates that the copula-based model is a better representation of the Cd variation than the Gaussian model. It is well known that one method of relaxing the assumption of a Gaussian marginal distri-

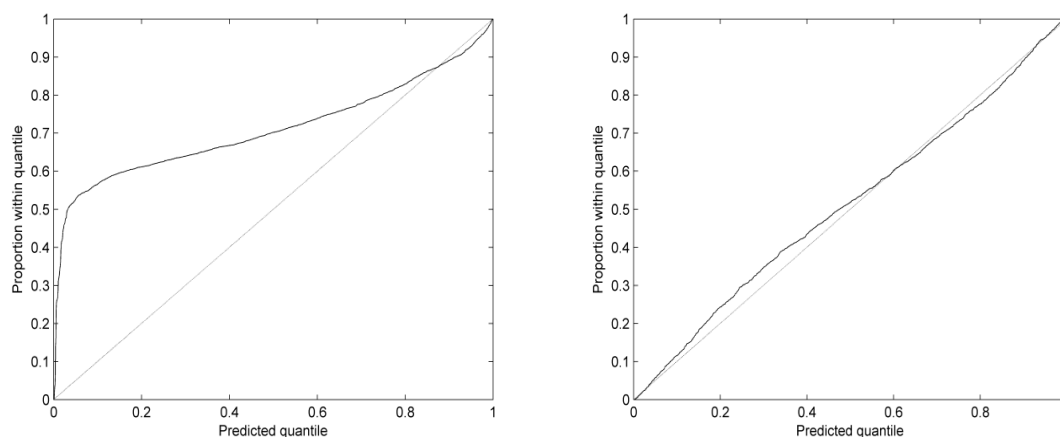


Fig. 2. QQ plots for (a) Gaussian model and (b) simple copula-based model

bution is to transform the variable prior to analysis. When a Box-Cox transform was applied to the Cd data prior to model fitting the resultant QQ plot did resemble the one from the copula-based model. However the copula-based model was superior to the Box-Cox trans-Gaussian model both in terms of the mean absolute deviation between the QQ curve and the $x=y$ line and the standardized prediction areas.

The predictions from the copula-based model are shown in Fig. 3. Location A in the west of France is within the Landes of Gascony. This is a region of sandy soils with low soil metal concentrations. From the predicted distribution we can see that the Cd concentration at this site is unlikely to exceed 0.5 mg kg^{-1} . Location B is in the Jura Mountains where large Cd concentrations are known to arise from natural sources. The distribution here is non-Gaussian with a heavy tail. At this site, concentrations greater than 3.5 mg kg^{-1} are plausible. In the centre of Fig. 3 we map the probability that the Cd concentration exceeds 0.8 mg kg^{-1} which is a regulatory threshold in Switzerland. This information can be extracted from the predicted Cd density at each site in France.

Discussion

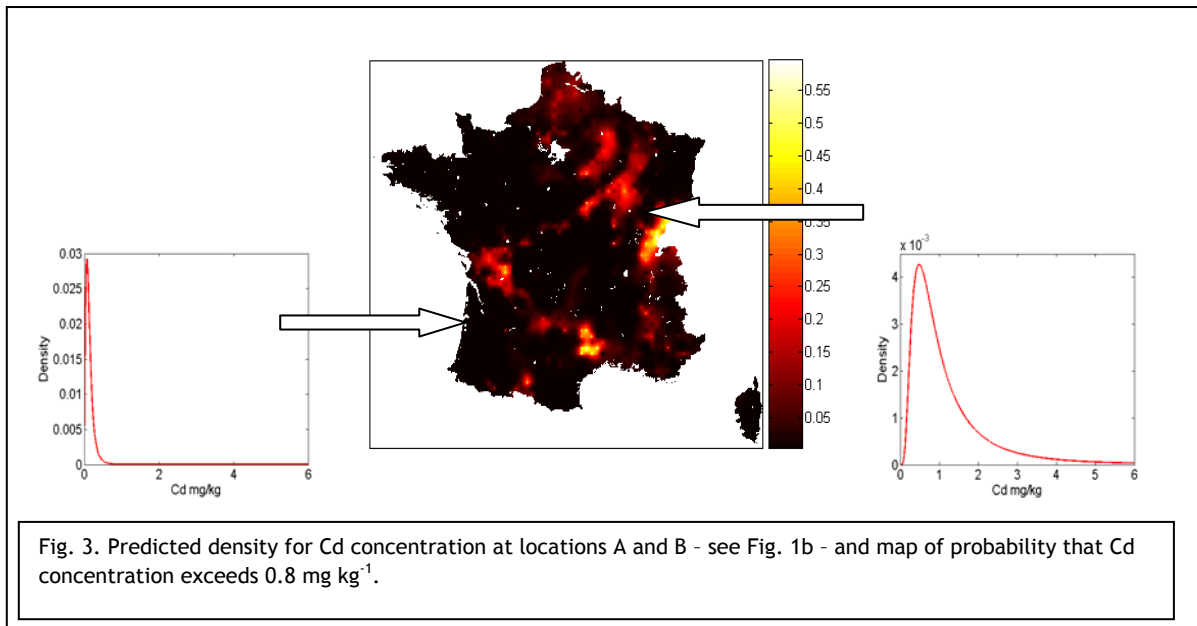
Our case study has demonstrated that a copula-based model can be used to relax the assumption that the marginal distribution of a soil property is Gaussian. The cross-validation results suggest that this simple copula-based model - which combines GEV marginal distributions with a Gaussian copula - performs better than a Box-Cox trans-Gaussian model. However the real strength of the copula-based model is that it permits non-Gaussian dependence structures.

Some commentators have claimed that the use of Gaussian dependence structures led to the global financial collapse of 2008-2009 (Salmon, 2009). Bond managers who used these models underestimated the risk of multiple seemingly-reliable debtors defaulting because their models of risk assumed that each default was an independent event. If they had used a copula which permits dependence between extreme events, such as the multivariate t copula, the risk would have been quantified more appropriately. Similarly such a copula could represent the dependence between extreme soil pollution events or a χ^2 copula could permit non-symmetric dependence structures for soil properties.

The cost of these more realistic models of the variation of soil properties is additional computational complexity. For example the formula of a χ^2 copula is a sum of $2n$ terms where n is the number of observations. It is not practical to calculate the likelihood exactly for $n > 15$ and approximate methods must be used. Further work is required to implement these more complicated copulas and determine whether the benefits in terms of more realistic and flexible models of variation counter the additional computation cost.

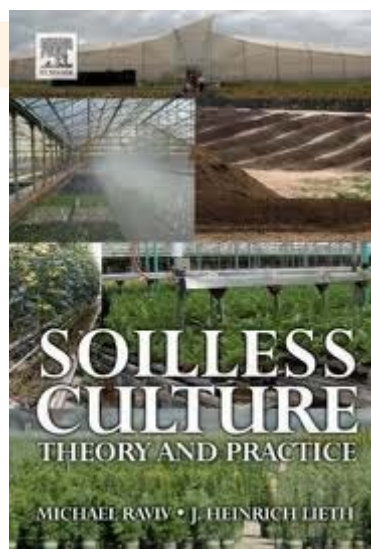
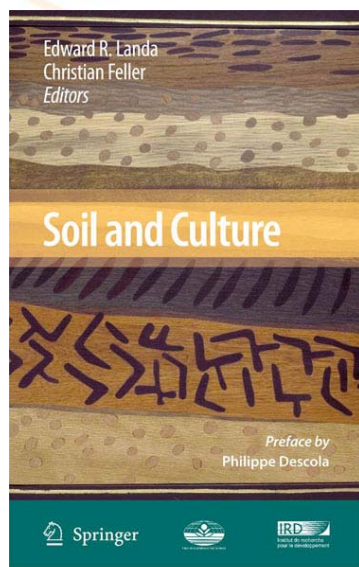
Conclusion

Copula-based models have revolutionised financial risk assessments. There is potential for these models to have a similar impact on the prediction of soil properties. Initial results from simple copula-based models have been encouraging but further work is required to realise the full potential of this novel methodology.



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A Comprehensive Fieldsheet for Soil Profile Description

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Much important soil information is recorded in the field by expert surveyors. However, profile description in the field presents ergonomic challenges, which have received little attention. The surveyor must manipulate equipment: a lens, a knife, a rule, a level among others. He or she may also carry a small library: field sheets, Munsell Colour charts (Munsell, 2000), and the survey organization's field handbook. All this is done in the outdoors, pleasant at times, but liable to be wet, windy and too hot or cold for comfort according to the season. In many fields where human decisions and expert judgement are critical to success, attention has been paid to the ergonomic efficiency of the system, to maintain quality and ensure the well being of the staff. In field soil description the surveyor must fill in field sheets. These do not necessarily correspond simply to the field handbook, and the surveyor may feel the need to supplement the sheet with marginal notes, which necessarily are not done according to a standardized system.

In order to improve the efficiency, ease and repeatability of field soil description, we have designed a Comprehensive Field Sheet for Soil Profile Description (CFS-SPD) [http://www.pedometrics.org/docs/A%20Comprehensive%20Fieldsheet%20for%20Soil%20Profile%20Description_CF-SPD_v3.pdf]. It incorporates directions (so that the handbook need not be frequently consulted), and it sets out to standardize and simplify profile description, which is done as a 'box-ticking' procedure.

The first side of the field sheet covers description of the profile site, drainage conditions, surface properties (cover with rock fragments), sealing, erosion, crusting and cracks. This provides information needed for erosion prediction with the Universal Soil Loss Equation (Wischmeier et al., 1965) and for land capability classification (Gallardo et al., 2006).

Two sheets are then provided per horizon that is to be described. An overlying organic layer can be described on the sheet for the first horizon, this part of the sheet is left blank for subsequent horizons.

The user is asked to provide an estimate of the volumetric content of stones larger than 20 mm, and determination of the 2-20-mm fraction is made subsequently in the laboratory. The second page for each horizon includes the description of pores and roots, to be made on a horizontal exposure. When a particular profile feature is absent (e.g. cutans) then there is a space to write "no" on the form so that the result is unambiguous, and indications of further properties of these features are then left blank. When more than one feature occur in a section of the form then their descriptions can be made unambiguous by using rectangles or ovals to enclose the relevant features, or underlining. This is illustrated in Fig. 1.

The aim of this sheet is to allow a standardized field description to be readily completed, without a lot of writing, but recording a thorough description.

Roots: Describe it in a horizontal plane. Record the average quantity from 3 to 5 areas				Biological features No
Horizontal area assessed	Size (diameter)	Quantity (per unit area)	Location	
1 cm ²	Very fine < 1 mm	Very few < 0.2	Inside structural units	Artefacts
1 cm ²	Fine 1 – 2 mm	Few < 1	Between structural units	Open burrows
1 dm ²	Medium 2 – 5 mm	Common 1 – 5	Layer boundaries	Infilled burrows
1 dm ²	Coarse 5 – 10 mm	Many ≥ 5		Charcoal
1 m ²	Very coarse ≥ 10 mm			Earthworms channels
				Earthworms excreta
				Krotovinas
				Fungi

Fig. 1. An example of the description sheet.



A profile from Soria province (Spain), described in the field [http://www.pedometrics.org/docs/A%20Comprehensive%20Fieldsheet%20for%20Soil%20Profile%20Description_CF-SPD_v3.pdf] by mean of CFS-SPD is attached, and a standard format [http://www.pedometrics.org/docs/A%20Comprehensive%20Fieldsheet%20for%20Soil%20Profile%20Description_Example_v3.pdf] presentation is available for download. We are grateful to INIA-CIFOR for permission to use this profile description from the BioSoil Project.

fall-Erosion from cropland east of the Rocky Mountains. Guide for selection of practices for soil and water conservation ARS USDA Agriculture Handbook. N° 282. Washington D.C.: U.S. Department of Agriculture.

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Outgoing Chair's profile

Murray Lark

Rothamsted Research.

How did you first become interested in soil science?

I went to Oxford to study zoology, but I changed direction during my first term after a series of lectures on soils and geomorphology given by Philip Beckett. I switched to a course on Pure and Applied Biology, which allowed me to focus on soil science and biometrics. We were taught soil science by Philip Beckett, Peter Nye and Bob White, who were among the most productive and innovative soil scientists in the UK at that time. By the end of my undergraduate course I had sufficient field experience to be able to undertake a conventional soil survey of new land on the University farm. We were taught statistics by various Oxford statisticians (John Bithell, Peter Armitage) and by H. Colyear Dawkins a forester with a deep understanding of sampling and experimental design.

How were you introduced to pedometrics?

It was the mid 1980s in the Oxford soils lab; Dick Webster's work on kriging soil properties, conducted in Oxford with his student T.M. Burgess, was still new – you couldn't fail to discover pedometrics! At the end of my second year I went on a field course in eastern England, and one evening in a Norfolk pub Philip Beckett explained the basic principles of the variogram. On returning to Oxford I dug out and read Dick Webster's papers on soil geostatistics. The next term I told Philip Beckett that I wanted to do graduate work in that area. I started work with him in 1987.

What recent paper in pedometrics has caught your attention and why?

Goidts, E., van Wesemael, B. & Crucifix, M. 2009. Magnitude and sources of uncertainties in soil organic carbon (SOC) stock assessments at various scales. *European Journal of Soil Science*, 60, 723-739.

This paper, from Esther Goidts's PhD, is a really nice example of pedometrics in action. It is engaged with a real problem but does not shy away from theory, it focusses on uncertainty and its quantification, and it deals with the question of spatial scale.

What problem in pedometrics are you thinking about at the moment?

I am thinking about how we can relate processes, at scales from pores to the landscape, to the observed statistics of soil variation. For example, I think that there are ways in which we can use stochastic geometry to explain the common forms of landscape-scale soil variogram, and to make inferences from data to plausible sets of underlying processes. Process to operator to distribution inference is the future for pedometrics, not empirical modelling! Pedometrics without a growing underlying body of theory is dead.

What big problem would you like pedometricians to tackle over the next 10 years?

How can the burgeoning suite of technology for examining the soil at micro-scales (tomography, nanoSIMs etc) be effectively deployed to answer questions about soil behaviour at the scales of management?



Outgoing Vice Chair's profile

Budiman Minasny

The University of Sydney

How did you first become interested in soil science?

It was my third year during my undergraduate degree in Agriculture at Universitas Sumatera Utara in Indonesia, and we have to choose a specialization. I chose Soil science at that time, as it is the most interesting subject with the highest quality lecturers. It is always the right decision.

How were you introduced to pedometrics?

I was doing my Masters of Agriculture degree in 1995 at the University of Sydney. Alex McBratney taught pedometrics in the Soil Resource unit of study. I instantly got interested in the application of statistical and mathematical to solving soil problems.

What recent paper in pedometrics has caught your attention and why?

Gerrit Schoups and Jasper Vrugt (2010) A formal likelihood function for parameter and predictive inference of hydrologic models with correlated, heteroscedastic and non-Gaussian errors. Water Resources Research doi:10.1029/2009WR008933

Not strictly pedometrics, the authors are looking at a new Markov Chain Monte Carlo technique for parameter inference. We are now not just trying to obtain a best set of parameter that minimizes the error, but Bayesian analysis that can identify the distribution of the parameters.

The application of MCMC for parameter inference in model prediction is something pedometrics should be looking more closely.

What problem in pedometrics are you thinking about at the moment?

Looking through legacy soil data and trying to understand the dynamics of soil properties over time.

What big problem would you like pedometricians to tackle over the next 10 years?

Combining mechanistic models and empirical observation and modelling to unravel the intricacy of soil. Linking soil observations with physical and empirical models will allow us to have a greater understanding of soil variation in space and time.

Pedomathemagica Answers



Answers to Pedomathemagica No. 28 by Gerard Heuvelink

Problem 1 (EASY)

Let the mass of one beer glass be g , that of a beer bottle be b , that of a beer mug m and that of a beer-mat a . We have:

$$g + b = m \rightarrow m = g + b$$

$$b = g + a \rightarrow a = b - g$$

$$2m = 3a$$

Eliminating a and m gives:

$$2 \times (g + b) = 3 \times (b - g) \Rightarrow b = 5g$$

Thus five beer glasses equal the weight of one beer bottle.

Problem 2 (HARD)

Name the rocks in random order a, b, c, d and e . Next execute three of the total of five weighs with the scales as follows:

1: $b + c$ against $d + e$

2: $b + d$ against $c + e$

3: $b + e$ against $c + d$

Three situations may now occur:

I: One of the four rocks is always at the heavy side of the scales.

Suppose that this is rock b (but the argument also holds if it is another rock). In that case:

$b + c$ is heavier than $d + e$

$b + d$ is heavier than $c + e$

$b + e$ is heavier than $c + d$

This can only happen if $b = 5$ kg and $a = 4$ kg.

To determine the weights of c, d and e you do two final comparisons:

4: c against d

5: a against $c + d$

If, for example, c is heavier than d , then we use the fifth weigh to determine the three remaining weights:

if a is heavier than $c + d$ then $c = 2$ kg, $d = 1$ kg and e

$= 3$ kg.

if a is as heavy as $c + d$ then $c = 3$ kg, $d = 1$ kg and $e = 2$ kg.

if a is lighter than $c + d$ then $c = 3$ kg, $d = 2$ kg and $e = 1$ kg.

II: One of the three weighs is in balance while the other two are not.

Suppose that the first weigh is in balance and that the other two are heavier (again, the argument also holds in other cases). We have:

$b + c$ is as heavy as $d + e$

$b + d$ is heavier than $c + e$

$b + e$ is heavier than $c + d$

You now carry on as follows:

4: d against e

Let the outcome be that d is heavier than e , in which case the fifth weigh is:

5: a against $c + e$

If a is heavier than $c + e$ then we must have $a = 5$, $b = 4$, $c = 1$, $d = 3$ and $e = 2$ kg.

If a is as heavy as $c + e$ then we must have $a = 3$, $b = 5$, $c = 1$, $d = 4$ and $e = 2$ kg.

If a is lighter than $c + e$ then we must have $a = 1$, $b = 5$, $c = 2$, $d = 4$ and $e = 3$ kg.

III: One of the four rocks is always at the lighter side of the scales.

Suppose this is rock b :

$b + c$ is lighter than $d + e$

$b + d$ is lighter than $c + e$

$b + e$ is lighter than $c + d$

Then b must be 1 kg and a must be 2 kg.

To determine the weights of c, d and e you do two final comparisons:

4: c against d

Supposing that c is heavier than d , do:

5: c against $b + e$

We can now conclude:

if c is heavier than $b + e$ then $c = 5$ kg, $d = 4$ kg and $e = 3$ kg.

if c is as heavy as $b + e$ then $c = 5$ kg, $d = 3$ kg and $e = 4$ kg.

if c is lighter than $b + e$ then $c = 4$ kg, $d = 3$ kg and $e = 5$ kg.

Pedomathemagica

Pedomathemagica by Murray

(1). Alf and Bert, the soil surveyors, arrive at their base camp at the start of a new campaign. At midday they set off for a walk, first on level ground and then climbing up a mountain. As they go they discuss their previous survey (Survey A), coming to some important conclusions. When they reach the mountain top, fog has descended and both their watches have stopped, so they turn and retrace their steps exactly, arriving back at the camp at six p.m. During the return journey they discuss the new survey (Survey B), arriving at some important strategic decisions.

On returning, they receive a text message from their organization's bureaucrats (who can now terrorize field surveyors at all times of day and night by means of new technology). The message states the following.

1. Time spent on each survey campaign (including discussion time) to be recorded on time sheets to the nearest half-hour.
2. Total distances walked for all purposes to be recorded.
3. All records under (1) and (2) above to be consistent with Soil Survey regulation walking speeds of 4 miles per hour (mph) on the level, 3 mph ascend-

ing slopes and 6 mph descending slopes (ascending and descending speeds being with respect to distance travelled along the slope).

If Alf and Bert assume that they have walked at regulation speeds what number should they put down for the total distance walked, and at what time (to within half an hour) should they assume that they reached the mountain top, and changed their topic of conversation from Survey A to Survey B?

(Note, this problem was first published in 1880 by the English mathematician Charles Dodgson as a puzzle or 'Knot' in a popular magazine. His story was about knights, not soil surveyors. Dodgson is better known for his publications under the name Lewis Carroll).

- (2). What is the curious mathematical property of the following sentence?

Be cunning, o denizens of pedology!

Note that the punctuation should be ignored.