ΠΕΔΟΜΕΤΡΟΝ

Newsletter of the Pedometrics Commission of the IUSS Issue 48, April 2024

From the Chair

Welcome to the 48th edition of the Pedometron. It was great to see many of you a few weeks ago at the New Mexico Pedometrics conference. The conference was a success with a good number of participants and a wide range of topics presented. We had two field excursions and perfectly organized sessions by our local organizers. For those who could unfortunately not attend, we included a report with the highlights from the conference written by one attendee. You will also find feedback from the organizer, with the hope that this will be useful for future organizers.

In this issue, we have prepared the regular items with some scientific items on Frontier-line analysis and Bottom-up digital soil mapping, a cartoon, and the pedomathemagica. We also proposed the regular item “in conversation with” to Dr. Ma, who is the recipient of this year’s Margaret Oliver Award.

Pedometrics is one of the most active commissions of the IUSS. In the last weeks, Division 1 has examined the requests for closure and extensions of several IUSS working groups that fall under the umbrella of Pedometrics. All active WGs that requested extensions seemed to be approved. This is certainly good news but also expected given the upcoming conferences in digital soil mapping and Global Soil Map and IUSS centennial with so many Pedometrics-related scientific sessions.

Another important announcement is the opening of a Special Issue on addressing the 10 pedometrics challenges. This issue is open in the European Journal of Soil Science. It was open to receive contributions from the presenters of the recent Pedometrics conference but is open to anyone who wishes to send an outstanding pedometric paper addressing one or several of the challenges.

Alexandre Wadoux
April 2024, Montpellier, France

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Delivered by

Chair
Alexandre Wadoux
Vice-chair
Simone Priori
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Announcements

Special Issue is now open in the European Journal of Soil Science. We are looking for outstanding papers that address one or several Pedometrics Challenges.

Addressing the 10 pedometrics challenges

Submission deadline: Monday, 15 July 2024

Pedometrics, the application of mathematical and statistical methods to the study of the distribution and genesis of soil, has broadened its scope over the past two decades. During this time, the increasing need for quantitative digital soil information for environmental modelling and management has compelled pedometricians to address many soil-related questions from a quantitative point of view. This special issue aims to showcase advances in pedometrics and research that attempt to tackle one or several of the pedometrics challenges.

Pedometrics challenges emerged through a collaborative research effort attempting to define knowledge gaps and suggest new concepts to overcome them. This special issue welcomes contributions about any aspect of pedometrics that addresses one or several or the following research questions: i) How to better understand soil formation? ii) How to improve methods to obtain relevant soil data? And iii) How to improve our ability to address demands by soil users?

The objective of this Special Issue is to bring together pedometricians and environmental scientists in collaborative, interdisciplinary research to address challenges related to the quantitative study of soils.

Topics for this call for papers include but not restricted to:

- Spatio-temporal variation of soil properties
- Soil-landscape evolution models
- Numerical soil classifications
- Pedotransfer functions
- Scaling issues and change of support
- Quantification of soil functions and services
- Uncertainty quantification and propagation
- Soil sensing and monitoring
- Pedodiversity and pattern of soil biodiversity

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Announcements

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Best Pedometrics paper awards 2022

The Awards Committee announced that the winner of the 2022 Best Pedometrics Paper, based on the vote of the members, is:

Nenkam, A.M., Wadoux, A.M.C., Minasny, B., McBratney, A.B., Traore, P.C., Falconnier, G.N. and Whitbread, A.M., 2022. Using homosoils for quantitative extrapolation of soil mapping models. *European Journal of Soil Science*, *73*(5), p.e13285. https://doi.org/10.1111/ejss.13285


European Journal of Soil Science
BRITISH SOCIETY OF SOIL SCIENCE

ORIGINAL ARTICLE | Open Access

Using homosoils for quantitative extrapolation of soil mapping models

Andree M. Nenkam, Alexandre M. J.-C. Wadoux, Budiman Minasny, Alex B. McBratney, Pierre C. S. Traore, Gatien N. Falconnier, Anthony M. Whitbread

Congratulations to the authors.
The rules and members of the Awards committee can be found online http://pedometrics.org/awards/

Upcoming conferences

Centennial Celebration and Congress of the International Union of Soil Sciences
May 19-21, 2024
Florence, Italy

Several sessions are available on pedometrics topic. You can still register and attend !
https://centennialiuss2024.org/

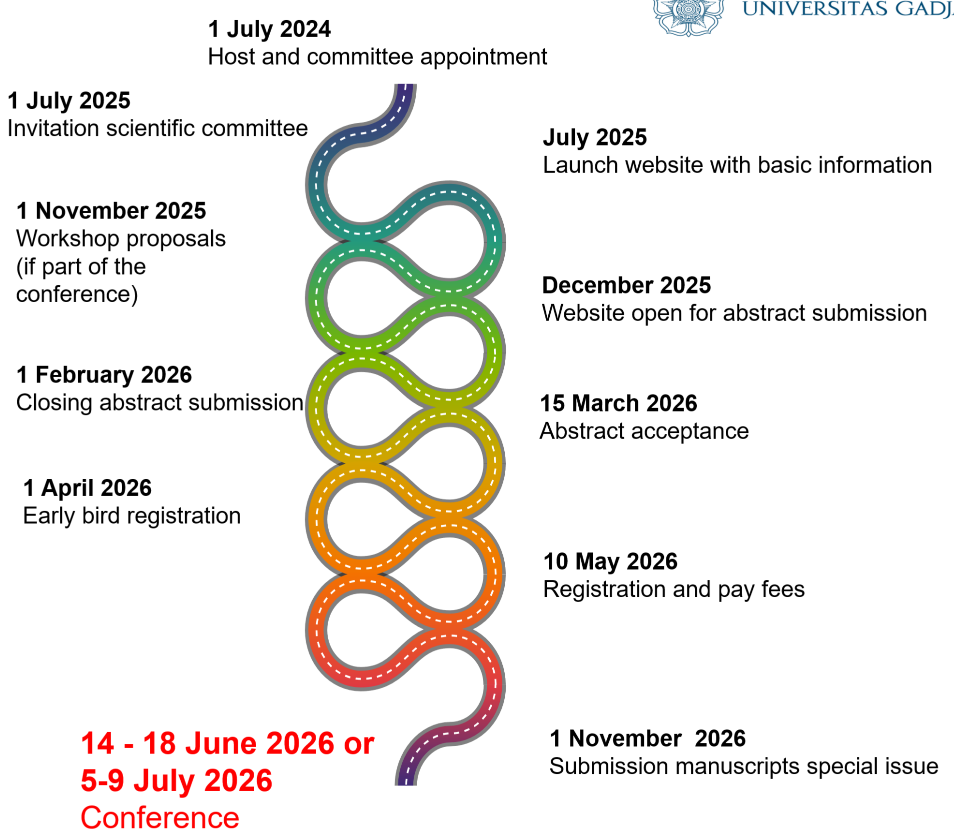
Digital Soil Mapping and Global Soil Map WG joint conference in India,
Karnal
Information : https://dsm2025.eventsdashboard.in/

Important Dates
Abstract Submission Deadline: 1st August, 2024
Abstract Acceptance Notification: 1th September, 2024
Early Bird Registration Deadline: 1st October, 2024

Upcoming conferences

The Next Pedometrics Conference

Proposed date of PEDOMETRICS 2026 and Timeline



Frontier-line analysis: a novel pedometric technique for estimating potential carbon sequestration

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Maximum carbon storage

The globe is warming, and scientists are now agreed that the cause is the increased concentration of CO_2 in the atmosphere in the last 100 years or so. Much of that extra CO_2 has come from our burning fossil fuels to heat our buildings and generate electricity. Manufacturing industry and transport have played their parts. So too has agriculture. The clearance of forests, land drainage and cultivation for arable crops have led to the oxidation of carbon in the soil and the release of huge quantities of C as CO_2. The International Panel on Climate Change (IPCC) reckons that the globe will soon be 1.5°C warmer than before industrialization. Delegates at the recent meeting COP27 wished to limit that increase by 2050, but they failed to agree on cuts to emissions to achieve it. Worse, if emissions continue at the current rate then an increase to 2°C is likely sometime this century. Such warming is predicted to have dire consequences: a rise in sea level globally, submergence of island nations and coastal settlements, increased flooding in some regions and drought in others, more wild fires, ... If we are to avoid such ills and prevent global warming's exceeding 1.5°C then we need to limit the net increase in CO_2 in the atmosphere to zero. Scientists, stake-holders and politicians are therefore turning their attention to the capture and storage of gases and sequestration of C; their aim is 'net zero' emissions.

The capture and storage of CO_2 at source from factories and power stations are matters of technology. Those from the atmosphere must depend on Nature—by photosynthesis, and on land by storage of C in the soil. The soil could store more C than it does by more judicious land use and sound management. In that way the soil would provide a more long-lasting store of C than that in the vegetation; and it would also improve the soil as a medium for plant growth and ecosystems services such as greater storage of water and reduced run-off, erosion and flooding. The question then is: could the soil store in the long term more C than it does at present while at the same time sustaining its productive use?

We know from long-term field experiments that for any given form of land management the amount of C in the soil reaches an equilibrium in which gains balance losses, and some experiments seem to show that there is a maximum amount that the soil can store (West & Six, 2007). The soil gains C initially as organic residues or manure, largely as only partly decomposed particles. Those are mineralized rapidly by soil organisms, and approximately 90% of the C is lost within 30 years (Basile-Doelsch *et al.*, 2020). Much of the rest decomposes more slowly into smaller molecules that bind to mineral surfaces where they are protected against microbial attack and thereby stabilized in the soil, i.e. sequestered (Lehmann & Kleber, 2015). We call this material mineral-associated organic carbon, abbreviated to MAOC, and it is this form that we consider when we assess the soil's ability to store more C.

Given the above, we might expect that the larger is the soil's specific surface area of the mineral fraction the greater is the soil's potential to sequester C, and we might expect the relation to be linear. Following this line of reasoning Hassink (1997) obtained data from several sets of experiments and by simple linear regression he found that the MAOC depended on the soil's clay+silt <20-μm fraction. The fit was reasonable. Of course, the regression line does not express the maximum amounts of C that the soil could store: it passes through the means of the data. However, Hassink also found less than half as much C in the samples of Australian soil as in samples from other parts of the world for the same proportions of the <20-μm fraction, the significance of which we return to below.

Hassink & Whitmore (1997) modelled the interaction between C and the soil's fine fraction as one of adsorption–desorption kinetics. They showed that the rate at which any new C could be captured depended on the capacity already occupied by C; the closer the soil was to full capacity, the slower was any further accumulation of C. Six *et al.* (2002) pursued these ideas. They too regressed the MAOC on the fine-particle fractions of soil, and ones with various mineralogies. They nevertheless postulated asymptotic increases in the soil's organic C with increases in carbon inputs, with an asymptote's being the soil's storage capacity. Feng *et al.* (2013) recognized that a linear regression inevitably underestimates the maximum amounts of C that soil with given proportions of clay+silt. So instead they fitted boundary lines to the scatter of the upper tenth percentile of organic C and its corresponding proportion of clay+silt. This still left some values of C above the boundary line. Since then several groups of scientists have fitted regressions, boundary lines and other functions to estimate the potential of the soil to store C; we list them elsewhere (Viscarra Rossel *et al.*, 2024). Among the most recent are Georgiou *et al.* (2022); they estimated the stocks of MAOC and maximum storage capacity of the soil at 1044 sites around the world by fitting a quantile regression to the data and treating the upper 95% bound on the regression as the maximum capacities of the soil to store MAOC. Boundary lines and quantile methods are undoubtedly better than ordinary least-squares regression for finding the storage capacities of the soil. They do not estimate the maxima, however, because they fit through data, and there are always values of MAOC that lie above the fitted upper bounds.

The alternative which we believe serves to determine the maxima is to fit frontier lines. It is a technique which as far we know has not been used by soil scientists before. We illustrate its application with data from Australia.

Data and their frontier lines

The data that we (Viscarra Rossel *et al.*, 2024) have recently rigorously analysed and to which we have fitted frontier lines comprise estimated stocks of MAOC (in t ha^{-1}) and proportions of sand, silt and clay in the topsoil (0–30 cm) at 5089 sites. These are essentially the data used by Viscarra Rossel *et al.* (2019) to derive understanding of the composition of organic carbon of Australian soil.

Frontier-line analysis

The frequency distribution of the MAOC is strongly positively skewed. To stabilize the variances for statistical analysis we transformed the estimates to common logarithms, though for illustration we graph the results on the original scale.

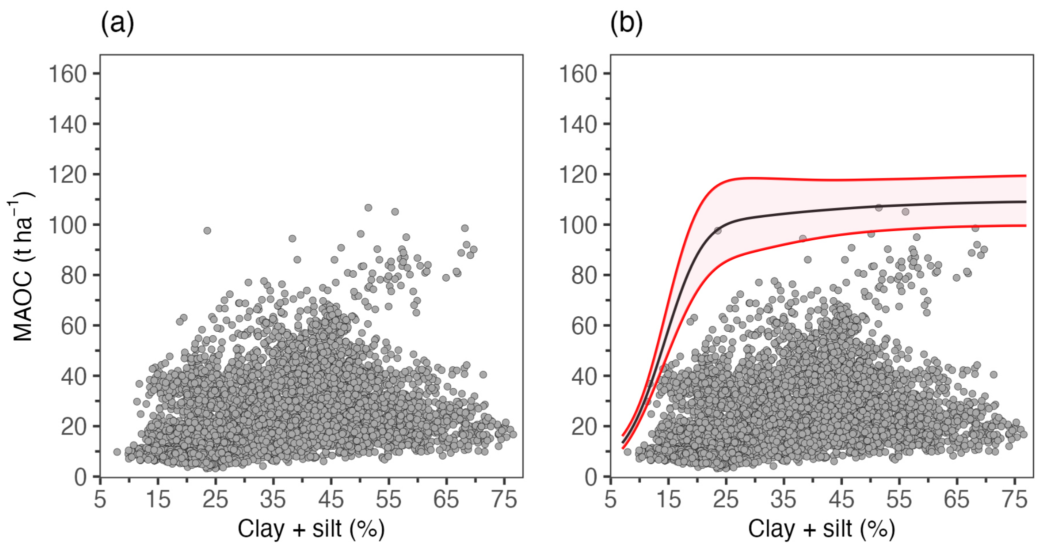

Figure 1. MAOC plotted against the percentage of clay+silt: (a) simply showing the data; (b) with the fitted frontier line in black and the 95% confidence bounds in red.

Figure 1(a) shows the MAOC plotted against the percentage of clay+silt. Clearly, there is a wide range of MAOC for any give percentage of clay+silt. The lower bound on the scatter appears to be approximately linear for the range 25% to 75% clay+silt. The apparent upper bound is certainly not linear: it increases sharply from its value at about 10% clay+silt, and then its gradient decreases steadily until it is almost negligible. This upper bound connects the maximum values of the MAOC in the data, and we can regard it as representing the potential carbon storage capacity of the soil over the range of percentage clay+silt. Finding a mathematical expression for the bound is problematic. To make sense of the physical chemistry of carbon stabilization we want a line that is smooth, monotonic non-decreasing and ideally differentiable. The solution to the problem lies in economic theory and practice where production outputs are related to inputs. Economists aim to find the most efficient practices and companies by fitting frontier lines to data (Parmeter & Racine, 2013). By analogy, our aim is to estimate the soil's maximum storage capacity for MAOC for any given proportion of clay+silt.

Several forms of frontier-line analysis have been proposed. The details are complex and are described by Parmeter & Racine (2013). We have chosen the smooth non-parametric analysis with the above desirable qualities as implemented in the R library SNFA (McKenzie, 2022). The method finds a locally weighted average of the non-linear relation between $\log_{10}$MAOC, the dependent variable, and the percentage of clay+silt as predictor. It does so with a smoothing kernel and optimal weights determined for a Nadaraya–Watson estimator. To ensure that the estimated frontier lines were robust we took 100 bootstrap samples, fitted a frontier line to each in turn and computed the averages of the lines to obtain our final frontier estimates. This also enabled us to place 95% bounds on the lines.

Frontier-line analysis

Selected results

We have fitted frontier lines to the data for all 5089 soil samples, to subsets for various forms of land cover, and separately for all classes of the Australian Soil Classification (ASC) (Isbell, 2016). Here we present a few examples, for which Table 1 summarizes the statistics.

Table 1 Mean stocks of mineral-associated organic carbon

Land cover and Soil	N_{obs}	Mean MAOC / t ha^{-1}
All data	5089	26.2
Native grassland	876	19.9
Improved grassland	2420	31.5
Vertosols	829	21.0
Chromosols	509	34.3

In Figure 1(b) we show the frontier line fitted to the whole set of data. Figure 2 shows the frontier lines for MAOC in (a) native grassland and alongside it (b) shows the frontier line for MAOC in improved pastures. Figure 3 shows the frontier lines for two widespread classes of the ASC, (a) Vertosol and (b) Chromosol.

All five graphs have the same general form: an initial steep rise in the frontier lines to 20–25% clay+silt, a fairly tight curve for clay+silt in the range approximately 25 to 35%, and thereafter a gentle increase, or for the Vertosol, Figure 3(a), no further increase.

Interpretation

What should we infer from these results? Clearly the maximum MAOC does not increase linearly with increases over the whole range of the fine fraction. Our interpretation is that in coarse-textured soil containing less than ≈20% clay+silt, i.e. in the range within which the relation appears to be linear, the mineral surfaces are saturated with organic C. In contrast, once the clay+silt fraction exceeds 35% the mineral surfaces are no longer saturated. The reason, we believe, is that there is not enough organic C in the soil to be sequestered in this way. There is too little vegetation to produce the organic residues to decompose to MAOC. There are two reasons for that. One is that even in the most favourable conditions of ample soil water and plant nutrients photosynthesis limits plant production, as Janzen *et al.* (2022) remark. Further, Powlson *et al.* (2022) point out that arable cropping leaves the ground bare for some time, and so even less organic matter is produced than under natural systems. The second reason is that dry weather, shortage of plant nutrients and other soil conditions such as strong acidity, salinity and alkalinity seriously stunt plant growth.

The latter constraint can to some extent be alleviated by land management: by irrigation, the application of fertilizers, by liming to counter acidity and gypsum to limit the effects of salt in the soil. The contrast between the native grassland and the improved pasture in Australia, displayed in Figure 2, illustrates what can be achieved. There is more MAOC in the soil of the improved pasture than in the soil of the native grassland. Fertilizers have been applied, and legumes such as clover have been incorporated in the swards to produce more plant growth. Perhaps surprisingly, the frontier lines are little different. There are evidently local patches of relatively fertile soil in otherwise oligotrophic grassland. There plant growth matches that in the improved pasture, and so roughly the same amounts of MAOC are available to give similar maxima on the mineral surfaces.

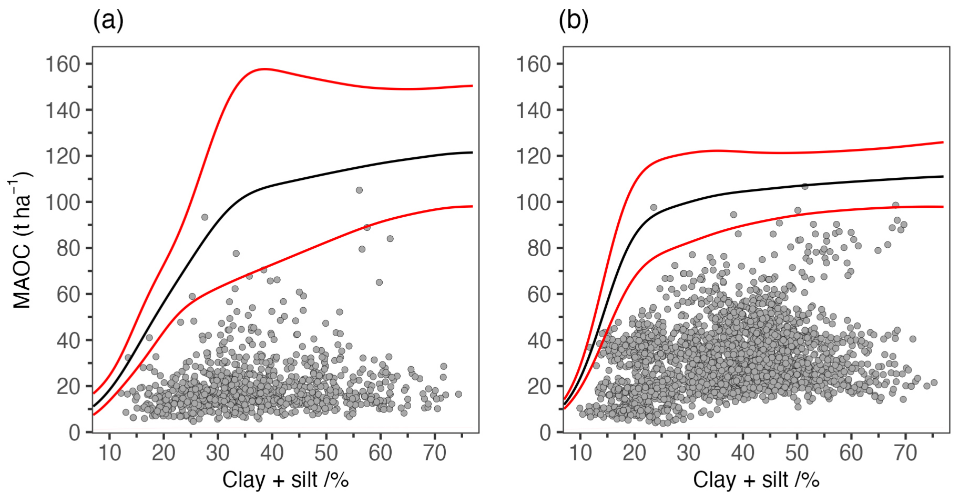

Figure 2. Frontier lines in black and their 95% confidence bounds in red fitted to MAOC against the percentage of clay+silt: (a) for native grassland; (b) for improved pasture.

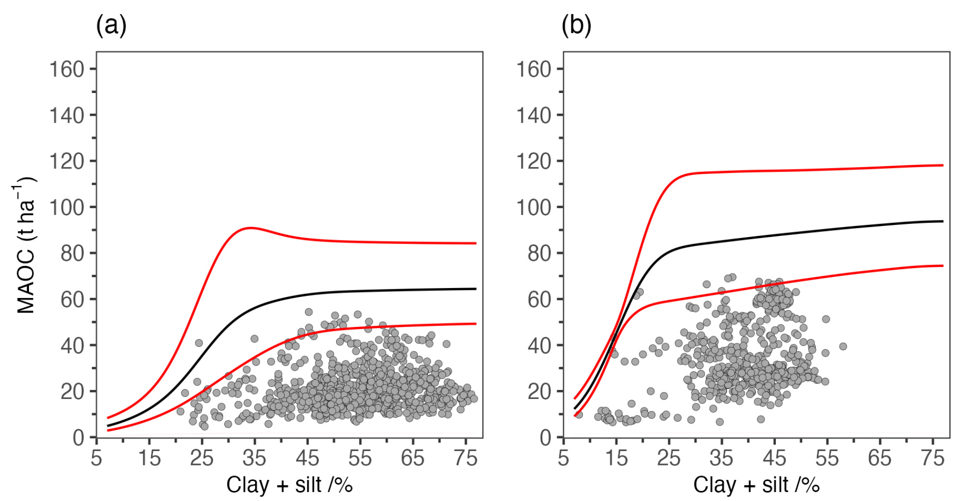

Figure 3. Frontier lines in black and their 95% confidence bounds in red fitted to MAOC against the percentage of clay+silt: (a) for Vertosols; (b) for Chromosols.

Perhaps even more surprising is the graph for the Vertosol, Figure 3(a). Contrast it with the graph for the Chromosol, Figure 3(b), which is a fairly typical for example of the relations between MAOC and the fine fraction. The samples of the Vertosol have the largest proportions of clay+silt, and one might expect them to store the most C. In fact they do not; they store almost the least, and certainly their maxima on the frontier line are the smallest of all the soil types recorded. The reason is that they occur in the arid and semi-arid parts of Australia where the climate severely restricts plant growth.

Conclusion

We may draw two sets of conclusions from the investigation.

1. The frontier lines well represent the maximum amounts of organic C that the soil with given proportions of the fine mineral fraction can sequester *in their current environment, climate and land management*. They overcome the shortcomings of least-squares regressions and quantile estimates. The technique is one that pedometricians should have in their toolboxes.

2. The actual maximum amounts of the organic C that can be stored by soil containing more than about 20% of clay+silt is limited, not by the specific surface area of the mineral fraction, but largely by the environment and only to small degree by improved land management—we call these their *attainable maxima* (Viscarra Rossel *et al.*, 2024).

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Looking back at Pedometrics 2024 in New Mexico

Pedometrics2024 Report

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Maximum carbon storage

The Pedometrics2024 conference welcomed 74 in-person and 20 remote participants from 22 countries to the campus of New Mexico State University from Feb 5 – 9th, 2024 to discuss recent advances and progress on long-standing challenges in the field of Pedometrics (Fig. 1). Pedometrics is a commission of the International Union of Soil Sciences (IUSS) Division 1 "Soil in Space and Time" which convenes soil and environmental scientists who apply the use of statistical and mathematical tools to analyze and interpret soil data. Conference attendees consisted of a wide range of individuals from experienced Pedometricians involved in the field for decades to 24 graduate students beginning their own research.

The conference was structured around the "Ten challenges for the future of Pedometrics" (Wadoux et al, 2021; Table 1). Individual sessions were held for each challenge except for challenge 8 which did not receive enough submissions to justify an individual session and challenge 6 for which presenters could not attend. A separate session about the application of "Pedometrics in governmental, scientific, and commercial organizations" was also held. Challenge 4 received the greatest number of accepted abstracts (Table 1) and was split into three separate sessions on spectroscopy, proximal sensing, and digital soil mapping. Sessions were designed around a 15-minute keynote presentation that provided an overview of the state-of-the-challenge and 10-minute oral presentations. When sessions included too many abstract submissions for every abstract to be allotted 10 minutes, some abstracts were assigned 5-min rapid oral presentations. Subsequently, 15-20 minutes was allocated for a discussion following all presentations. Participant feedback from past meetings indicated attendees were willing to accept shorter presentation times in exchange for longer discussions.

The final conference session was a discussion of the overall conference and a reflection on future directions needed in the field. While the discussion was wide ranging and covered many topics, Gerard Heuvelink (Wageningen University, NL and ISRIC - World Soil Information) suggested that a Pedometrics textbook was needed to teach Pedometrics methods to teach accepted and advanced methods, and there was general agreement that such a resource would be highly beneficial. Also discussed with the unique focus of Pedometricians on the users of our data products and there was a lively discussion about applied vs basic pedometrics research.

Three four-hour intensive training workshops were held the day before the meeting that covered "Containers for reproducible Digital Soil Mapping at different scales", "Assessment of spatial patterns of soil properties predictions", and "Deep learning for soil spectroscopy". A planned workshop on "Algorithms for Quantitative Pedology (AQP)" had to be cancelled because the workshop leader was not allowed to travel to the conference.

Table 1. Pedometrics challenges and number of abstracts per challenge

Challenge	Central Question	Number of Abstract Submissions
	How can we better understand soil formation?	
1	Can we produce quantitative models of the complex short and long-term processes of soil formation which are predictive of the spatio-temporal variation of soil properties?	4
2	Can we develop a quantitative and numerical global soil classification that unifies the existing systems and enables transfer between them?	4
3	In what ways can we use data-driven models to learn about pedological processes?	4
	How can we improve methods to obtain relevant soil data?	
4	Can we measure soil properties more efficiently?	35
5	Can we develop workable techniques to derive predictions of soil characteristics at scales appropriate for modelling and decision making, by up- and downscaling observations in 3D space and time?	7
6	Can we incorporate mechanistic pedological knowledge in digital soil mapping?	2
	How can we improve our ability to address demands by soil users?	
7	How to recognize, quantify and map soil functionality?	4
8	Can we find ways to connect pedodiversity to soil biodiversity, and translate the connections to relevant soil services and soil management practices?	0
9	Can we find ways to express the uncertainty of predictions of soil properties or class allocations which are meaningful to the users of those predictions?	8
10	How to quantify soil contributions to ecosystem services with a framework enabling both local and regional soil management?	9

A significant benefit of international conference participation is to network with colleagues and potential collaborators. This was facilitated through two ½ day field trips and four social events. The 1st field trip highlighted soils developing in modern floodplain alluvium (Figure 2), ancestral Rio Grande alluvium (Figure 3), and piedmont slope alluvium derived from Organ Mountain Rhyolite (Figure 4). The second field trip demonstrated piedmont slope alluvium derived from Organ Mountain Monzonite (Figure 5) followed by a field trip to White Sands National Park where participants discussed the influence of ground water chemistry on dune formation and soil formation, as well as participated in sand sledding (Figure 6). Additionally, participants enjoyed a welcoming-social, were taught American-style football and played a friendly game of both football and soccer, participated in an early morning run near the Organ mountains, and enjoyed a museum tour and dancing during the conference dinner held at the New Mexico Farm and Ranch Heritage Museum.

Looking back at Pedometrics 2024 in New Mexico

Figure 1. IUSS-Pedometrics meeting field tour at White Sands National Park, February 8, 2024.

Figure 2. Conference participants inspecting soils formed on young Rio Grande Alluvium at New Mexico State University's Leyendecker Plant Science Center's long-term soil health research site. Experimental treatments include tillage, cover crops, compost, and biochar. This soil is classified as an Intensively Managed Cropland (leveled, flood irrigated), Fine-Loamy over Coarse-Loamy, Typic Torrifluvent. Plow line ~20cm, Gypsum crystals 60-70 cm, Crossbedding > 110 cm.

Overall, participants enjoyed presentations on cutting-edge Pedometrics research, in-depth topical discussion, arid-land soils, and extensive collaborative opportunities among peers.

As an organizing committee, this was our first time organizing and hosting a large international scientific conference. As such we had the following questions. We provide possible answers to these questions and some lessons-learned in an effort to assist future conference organizers to host a successful meeting and avoid as many missteps as possible.

Looking back at Pedometrics 2024 in New Mexico

1. How many participants do we expect?

    a. The number of participants is perhaps the most important piece of information as it will determine almost all of the logistics. Past Pedometrics conference attendance has been variable, but we suggest that 100 would be a good number to start with. Attendance may be higher in Europe where travel distances are generally shorter.

2. What costs should we anticipate?

    a. Please see Table 2 for an estimate of line item costs.

Table 2. General line items as budgeted (not realized) as a percent of the total conference budget

Expenditure	Percent of total budget
Conference	
Conference rooms (included lunches and coffee breaks)	27.8
Student support	6.0
Program book	1.9
Printing (name tags, etc.)	0.4
Zoom (remote presentation option)	0.8
Field trips	
Transportation	16.5
Snacks + drinks (hydration)	0.7
Soil pit excavation	17.6
Social events	
Flag Football/soccer sporting event	0.2
Conference dinner	
Museum	1.4
Venue	3.7
Dinner	13.5
tip	2.7
Security	1.9
Bar	1.9
band/music	3.0

3. Where will we hold the event?

    a. This was the second most important information and was initially a difficult decision because we had never before tried to find a venue to host a scientific conference. Our approach was to ask the few other scientists who had recently hosted a conference. This resulted in the discovery of two options. We chose to host the conference on the NMSU campus because this was the cheaper option (and they gave NMSU departments a 10% discount) and it made logistics much easier. Had costs between both options been comparable we still would have chosen the venue that worked the most frequently with the university as it made communication and payment the simplest.

4. Where will I host the conference webpage?

   a. We chose to use pedometrics.org to host the conference webpage, but others have used their own websites. We did discover that pedometrics.org is not a secured http**s** website so one participant within a US federal agency could not access the webpage.

5. Is there a software to automate conference organization?

   a. Yes. EasyChair is a commercial conference planning software. Our initial discussions with previous conference organizers suggested that this was an inelegant solution so we chose not to use this software, however, our solutions (see below) were clunky and also inelegant so a commercial conference planning software may have been easier.

6. Our solutions to conference management:

   a. How will participants submit abstracts?

      i. We worked with university IT staff to set up a formsite where participants could submit abstracts because this is the resource that was available to us. This allowed us to semi-automate emails (we discovered mail-merge!) and to some extent automate the review process.

      ii. We accepted all abstract submissions with little guidance as to abstract structure as either MS word or PDF format. *Do not do this*. Instead, if possible provide a template for abstract submissions that includes title, presenting author, author contact information (email), co-authors, institution, country, and student (yes/no), a topical session/challenge (if relevant), their preference for oral vs. poster, and a box in which to copy and paste their abstract text. A separate text entry may be difficult if the abstracts include graphics, but this will improve your ability to organize the abstracts, and more importantly, it will enforce consistent and standardized type settings. It turns out, unsurprisingly, that different countries use different type settings so if everyone uploads their own abstract it becomes exceptionally laborious and tedious (meaning we spent multiple days until way too late at night) to get all abstracts to format consistently in MS word (or any other program).

   b. How will abstracts be reviewed?

      i. We solicited a scientific committee that consisted of established Pedometricians from around the world to review the abstracts. Each member of the scientific committee reviewed between one and five abstracts.

      ii. This was achieved through formsite emails, but a more centralized software might have been easier.

      iii. We first very briefly reviewed each abstract and found that one or two were completely irrelevant to Pedometrics (and soil science in general) so these were discarded. We then asked the scientific review committee to rank each abstract on a scale of 1-10 (10 being the most suitable) for the abstracts' suitability as a keynote, oral, or poster.

iv. We found that the scientific committee assessed abstract quality based on the presence or absence of quantitative results, meaning that abstracts with more quantitative results were often judged to be more suitable for an oral presentation. However, the lack of concrete results can mean either that 1) the results are still pending (which would mean the abstract could be quite novel) or 2) the abstract is conceptual and could be good for a keynote presentation. Just something to keep in mind.

v. We then used the scientific committee reviews to assign presentation times. Those that were ranked highly as keynote or oral presentations were assigned 10 min talks. We ultimately chose to not have any posters so abstracts with high poster scores were assigned as 5-min rapid orals.

vi. This worked for us, but we are sure that there are better ways to quantify the review process. We also decided not to reject any presentation if it was related to pedometrics.

vii. We decided not to release abstract reviews to the authors because they contained the names of the reviewers, but it would be good to find a way to provide this feedback to the abstract authors.

c. How will participants send their presentations?

i. We chose to have each participant email their presentation to the conference organizers three days before the conference and asked that each submission be numbered and named in a particular format. About 1/3rd of the participants followed the requested naming convention. We then manually put each presentation into the correct session folder. There was an option for presenters to also upload their presentation during the break before each session and many presenters took advantage of this opportunity. In our own experience, we often finish our presentations on the flight to the conference so a last-minute presentation upload option is advantageous.

ii. In retrospect, we would have preferred a semi-automated solution that enforced a consistent naming scheme and generated a 'received' email.

d. Make sure participants can select a vegetarian option during registration (we made this available but did not communicate this clearly to the participants).

7. How should payment be accepted?

a. We worked with NMSU to leverage an existing payment service. This was useful because it also automatically emailed a receipt to the registrant. Be aware that some individuals will need a more detailed invoice to submit for reimbursement and these are probably most easily done manually.

b. It is most convenient for participants to pay with a credit card. Some people would like to pay with a bank transfer, but everyone wound up using a credit card in the end.

8. How much should we charge for registration?

a. The best way to arrive at a registration price is to sum all of the expected costs, add 10% for unexpected costs, and divide by the minimum number of registrations you expect.

9. Should we expect to make a profit?

a. No. You should aim to break even and definitely avoid a deficit. However, we found it helpful to include a budget line-item for student volunteers to help with the conference organization. We used this line item to compensate NMSU's soil judging team for their time and the team will use this small amount of compensation to help defray team travel costs.

10. How should we organize field tours?

    a. We chose to hold two ½ day field tours in the afternoon. This was largely a practical decision based on the conference sessions and because we wanted more time for people to socialize while experiencing the soils of the area. We were also able to do this because the Las Cruces area is dry and participants would not be 'muddy' after a few hours in the field.

    b. Make sure you have garbage bags after providing a box lunch.

    c. Make sure there are restroom facilities available on the field trip (particularly after lunch).

11. Will we have a remote participation option?

    a. Most people enjoy an in-person meeting because most of the conference value lies in connecting with others and enjoying extended discussions and collaborative opportunities. However, there are always interested individuals who can not attend and a remote presentation option is useful. We did not announce a zoom option until 1 week before the start of the conference because of internal logistics; we are unsure what effect an earlier announcement would have had on conference attendance.

    b. Should remote participants be able to present? We opted for only allowing one keynote speaker to give a remote presentation because we were unsure about our technical ability to ensure smooth transitions between speakers and because in-person attendees do not like too many remote presentations.

    c. We were asked if the presentations would be recorded and made available later. We decided against recording the presentations because we felt that any video recordings are the property of the presenter and this would become very difficult to edit and host videos later. However, it might be possible to allow presenters the option to record their video if permission was given during abstract submission.

12. What should I plan for the conference dinner?

    a. We opted for a museum tour (because it was available at the dinner venue), short conference program, and dancing.

    b. It is customary during the dinner program to announce recent award winners including the best paper in Pedometrics and the Margret Oliver award. It is also a good time to announce the location of the next Pedometrics meeting if known. We opted not to, but it would also be appropriate to very briefly announce conference statistics such as the number of abstracts, attendees, and countries in attendance at the conference during this presentation. However, most people like this to be short.

c. After dinner dancing seems to be an intermittent Pedometrics tradition, but most people will eventually participate if the music is lively and easy to dance to.

13. How should we organize the program?

a. Program creation was by far the most labor intensive, difficult, and time-consuming part of conference organization.

b. We were fortunate to have the 10 challenges around which we organized the program. This provided a useful way to organize the program and (we think) greatly streamlined the process of organizing abstracts because each abstract submitter was asked to pick one of the 10 challenges. We still spent a lot of time organizing abstracts into the most logical possible order, but having predefined topics to organize abstracts greatly helped. Without any organizing topics we would have been left to organize the abstracts into similar sessions which we think would have been a daunting task.

i. The organization of the final program was accomplished by printing out all of the abstracts and manually organizing them into piles/sessions. When some sessions had too many abstract submissions to feasibly fit into the available time we either moved the abstract to a closely related session or shortened the speaking times.

c. Sessions should be 1.5 hours, but 2 hours is probably a maximum. Students have a hard time sitting and listening for 1.5 hours and professional scientists are no different!

d. Avoid parallel sessions as much as possible. No one likes parallel sessions.

e. We chose to organize sessions with an initial 15-minute keynote presentation that provided an overview of the state-of-the-challenge and then subsequent 10-minute oral presentations. When sessions included too many abstract submissions for every abstract to be allotted 10 minutes, some abstracts were assigned 5-min rapid oral presentations based on reviewers' comments. This was a trade off and should be considered carefully. Should conference participants only be given a 5 min presentation if they fly halfway around the world to attend the conference? We decided, somewhat naively, that this was an acceptable trade off because it gave us the ability to hold discussions following each session and participants seemed to greatly value the discussions.

i. Decisions about who got 10 min and who got 5 min were greatly helped by the abstract reviews from the scientific program.

f. Session discussions allowed conference attendees to engage with the larger conference. We generally left the format of these discussions to the moderator in charge of each session, and two formats were tried: 1) all session speakers were invited to the stage and the audience asked questions, 2) the moderator opened a discussion with specific questions about the session topic without inviting speakers back to the stage. Both formats invited wide-ranging topical discussion.

i. It may be useful to ask someone to take notes during each discussion to record these ideas and share with attendees.

g. Session moderators were chosen from conference attendees not presenting in the session.

h. Someone should be dedicated to run the Audiovisual equipment and to assist with opening slides between presentations so that the presenter can walk to the podium and start presenting.

14. What about a timeline?

a. International flights are the least expensive if booked at least 2 months before the travel date. This means that it is ideal to notify abstract submitters of abstract acceptance at least 2.5 months before the start of the conference. Also tell presenters what day and general time (morning or afternoon) their presentation will be. Specific times within each session can be finalized closer to the meeting.

b. Not all participants will be able to attend the entire meeting and may only be able to attend for a day or two.

c. The scientific committee should have at least two weeks to review the abstracts (most will take shorter) so this means that abstracts should be due at least three months before the conference start date.

d. Visas can be an issue. Some scientists were unable to get US visa's even when applying for a visa 3 months in advance.

e. Set clear end dates for registration and enforce it (unless you are waiting to see if last-minute governmental travel will be approved!), but also be flexible as there may be last minute changes such as local scientists who would like to join at the last minute.

f. Expect some people to submit abstracts, but then withdraw the abstracts because they are not able to attend because of personal reasons, unfunded travel, or visa difficulties.

References

Alexandre M.J.-C. Wadoux, Gerard B.M. Heuvelink, R. Murray Lark, Philippe Lagacherie, Johan Bouma, Vera L. Mulder, Zamir Libohova, Lin Yang, Alex B. McBratney. Ten challenges for the future of pedometrics, Geoderma, Volume 401, 2021. https://doi.org/10.1016/j.geoderma.2021.115155.


Figure 3. Conference participants viewing soil development on a very old river terrace of the ancestral Rio Grande looking west towards Las Cruces, NM and the Organ Mountains. Sediments here were deposited by the Ancestral Rio Grande and the soils are estimated to be 800,000 years old. This soil is a Coppiced Mesquite Shrubland, Sandy, Typic Petroargids. Bedded Sands under Prosopis glandulosa 0-20cm (left), argillic 40-70cm, laminar carbonate Stage IV 120-180 cm, multiple other stages. Total departure from expected condition.

Looking back at Pedometrics 2024 in New Mexico

Figure 4. Dave White and Dr. Colby Brungard (left) and Dr. Shawn Salley (right) explaining soil taxonomic diversity within a short 40-meter walk along an arroyo near Tortugas Mountain. Soils form in the Picacho geomorphic surface with approximately 100,000-250,000 years of pedogenesis. All these soils are managed as the gravely ecological site.

Figure 5. Dr. Curtis Monger (NMSU) explaining Soil-geomorphic landscape relationships of the Organ Mountains Fan-Piedmont showing cyclic sedimentation and soil formation. The soil is a Creosote Shrub Dominated, Coarse-Loamy, Typic Calciargids. Bedded sands under Larrea tridentata 0-20cm (center), Argilic 65-100cm, carbonate Stage III 100-150cm. Multiple other buried soils. Moderate departure from expected condition.

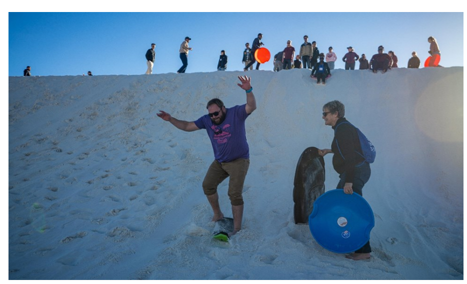
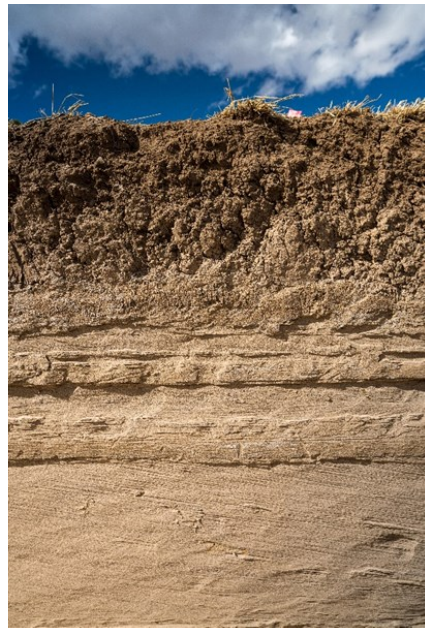


Figure 6. Pedometrics2024 participants enjoying sand sledding at White Sands National Park

Conference report

Report on the Pedometrics 2024 conference in Las Cruces, NM, USA

Malithi Weerasekara



As a dedicated graduate student from Oregon State University, I recently had the privilege of stepping away from the wintry and rainy embraces of the Pacific Northwest to attend the Pedometrics 2024 conference in sunny Las Cruces, NM. This gathering from February 5th to 9th brought together the brightest minds in soil science to tackle the "10 Challenges for the Future of Pedometrics," shedding light on the path ahead for our vital field of study.

The conference kick-started with discussions on the first three challenges which involved modeling soil formation and processes, numerical soil classification, and data-driven models to learn pedological processes. Notably, the emphasis on open science and the call for enhanced multidisciplinary collaborations resonated with me, underscoring areas that need further improvement. It was quite interesting to listen to the research that was done by speakers from industrial and government on these topics, highlighting the commercial and national magnitude of the Pedometric application.

Day two was a whirlwind, especially for someone as immersed in proximal soil sensing and digital soil mapping as I am. It was a deep dive into the frontiers of these fields, capturing the collective ambition to push the boundaries of soil science. Most of the work highlighted the integration of novel technologies and machine learning algorithms to enhance soil property predictions, underscoring a pivotal shift towards more accurate, efficient, and sustainable soil management practices. The emphasis on combining sensor data with sophisticated computational models to improve the accuracy of soil property predictions was something that caught my attention. Presenting my research in this domain, I was inspired by the collective drive to harness cutting-edge technology judiciously, ensuring transparency and accounting for uncertainties in our models—a takeaway that will undoubtedly refine my doctoral research.

I appreciated the conference's approach of allocating thirty minutes for discussion after every alternate session. This arrangement effectively united all session attendees, creating a collaborative atmosphere for sharing questions and insights with the wider conference audience. This approach cultivated a warm and engaging dialogue, contrasting with the typical pressure of constrained two-minute Q&A sessions for each presenter. The conference wasn't just about discussions and presentations. The field trips on day three and four offered us a tangible connection with the very subject we study. The intricate stratification observed in the soil profiles, resulting from river sediment deposition, was a captivating highlight and witnessing such well-defined layering for the first time was quite special for me. Moreover, the presence of a 20-30 cm thick calcic horizon presented a striking visual, underscoring the remarkable geological and pedological phenomena that define desert soils. Witnessing these soil profiles and exploring the mesmerizing white sand plains of NM was not just educational but a moment of awe that reminded us of the diversity and beauty of soil landscapes.

Days three and four shifted the focus towards mapping soil functionality and addressing uncertainties. I found myself particularly drawn to the discussions on interactive soil multifunctionality mapping, recognizing its potential for a breakthrough in terms of the connection of science and the user experience. Exploring alternatives to conventional raster maps for decision-making, along with the advantages and limitations of employing raster maps, provided engaging and insightful conversations. Wrapping up, the final day focused on soil health and ecosystem services, and the soil health dominated the discussion. It was enlightening to see the breadth of research dedicated to providing a more comprehensive view of soil health, a perspective that enriches my own research endeavors.

Reflecting on my time at the conference, the journey towards making pedometric work accessible and practical for end-users stood out. This vision of creating user-friendly, practical tools aligns with my aspirations, fueling my ambition to contribute meaningfully to our community. The discussions centered on the erosion of foundational pedological knowledge and the erosion of the specialized skills within our community. Particularly, the over-reliance on machine learning at the expense of (geo) statistics, uncertainty, and uncertainty propagation sparked a vital conversation. The call for a technical textbook on Pedometrics could not be more timely, promising to guide the next generation of soil scientists through the complexities and wonders of our field.

Connecting with esteemed soil scientists, engaging in fruitful discussions, and gaining invaluable insights has been profoundly inspiring. As I continue my academic journey, the lessons and connections from Pedometrics 2024 will undoubtedly shape my path to becoming a more impactful soil scientist.

A cartoon

Talks in the deserts of New Mexico

By Dominique Arrouays, Anne C. Richer-de-Forges

In Conversation with Yuxin Ma

The Pedometrics Commission of the International Union of Soil Sciences (IUSS) is delighted to announce Dr. Yuxin Ma as the recipient of the 2023 Margaret Oliver Prize

Perhaps we can start this conversation by looking at your educational background. You have a fantastic academic record in Pedometrics. What motivated you to go on an academic journey?

My academic path in Pedometrics has been shaped by a profound curiosity about the intricate relationships between soil, land, and the environment. During my undergraduate studies in Land Resources Management at Anhui Agricultural University in China, I discovered the complexities of soil science and land classification. Each course felt like unlocking a new layer of understanding about our natural world. Transitioning to Nanjing University for my master's degree opened doors to explore physical geography, geomorphology, and the exciting fields of geostatistics and remote sensing. Under the guidance of Prof. Ganlin Zhang's group at the Institute of Soil Science, Chinese Academy of Sciences (ISSCAS), I focused on studying the spatial and temporal distribution of soil properties, which solidified my interest in Pedometrics.

Following graduation, I worked as a research assistant at ISSCAS, where I further honed my skills and expertise. During this time, I volunteered at the 6th Global Workshop on Digital Soil Mapping in Nanjing, where I met Prof. Mogens Greve who offered me an opportunity to study at Aarhus University in Denmark for a few months. This experience allowed me to deepen my understanding of soil spectroscopy and its applications. Ultimately, it was this combination of curiosity, mentorship, and hands-on experience that motivated me to embark on an academic journey in Pedometrics.

At the Pedometrics conference in Wageningen, 2017

How did you start your Ph.D. research career, and what was the biggest gain in your doctoral research?

During my time at ISSCAS, I found mentorship and inspiration from Prof. David Rossiter during his annual visits. His friendship and passion for learning motivated me to pursue a Ph.D. Securing the University of Sydney International Scholarship, I embarked on my Ph.D. journey under the guidance of Prof. Budiman Minasny and Alex McBratney.

In Conversation with Yuxin Ma

Navigating through my doctoral research wasn't entirely smooth sailing. However, with unwavering support from my supervisors, who provided regular meetings and assigned manageable tasks, I was able to keep progressing. We maintained daily communication, promptly addressing any issues to prevent setbacks. Through this process, I learned how to approach complex problems with analytical depth, think creatively, and push the boundaries of existing knowledge in Pedometrics.

What scientific issues does your research focus on? What excites you about these research topics?

My research focuses on addressing key scientific issues within the field of Pedometrics. One primary objective is to integrate empirical modelling, soil sensing technologies, and mechanistic modelling to advance our understanding of soil properties and processes, thereby uncovering the complexity of the soil system.

For example, in collaboration with experts at the University of Newcastle, Australia, I focused on refining a coupled soilscape–landform evolution model to simulate the vertical, lateral, and temporal evolution of soil particle size distribution. Our findings, presented at the 25th-anniversary Pedometrics conference in Wageningen, marked my introduction to the international scientific community.

Furthermore, my research explores the complex interactions among soil carbon turnover, soil redistribution, climate change, and land-use change. This involves integrating mechanistic soil carbon dynamics with soil water erosion models, in partnership with experts at UMR SAS, INRA, Agrocampus Ouest, France.

Beyond soil dynamics, I have focused on developing a novel soil provenance technique using digital signatures from a portable X-ray fluorescence sensor. This pioneering work was highlighted at the Pedometrics conference in Ontario, Canada.

Additionally, in collaboration with colleagues at the University of Sydney and Sydney Informatics Hub, I have explored advanced machine learning and deep learning algorithms for high-accuracy soil mapping. I am also dedicated to challenging current machine-learning techniques and investigating improved methods for 3D soil mapping.

Overall, my research endeavors excite me as they allow me to contribute to the advancement of Pedometrcis through leveraging innovative technologies and interdisciplinary collaborations, paving the way for more informed land management practices and environmental stewardship. In recognition of my contributions, I have been awarded the Dan Yaalon Young Scientist Medal by the International Union of Soil Sciences.

With Mottly, Victoria's state soil - a Mottled Brown Sodosol, 2018

In Conversation with Yuxin Ma

After obtaining your doctoral degree, what are your future research plans? Which specific research topic will you focus on? Additionally, what do you perceive as the significant challenges and opportunities in Pedometrics moving forward?

After completing my Ph.D. and joining Manaaki Whenua – Landcare Research as a pedometrician, I broadened my research scope to include the simulation of greenhouse gas (GHG) emissions in agricultural lands. Looking ahead, I aim to tackle several key challenges in Pedometrics through my future research endeavors:

1. Integrate pedology and digital soil mapping, and incorporate soil genesis, soil classification, and mineral assemblages into the spectral machine-learning modelling process. By incorporating soil knowledge into these models, we can enhance our ability to predict soil properties and improve the accuracy of soil mapping.
2. Develop a 4-dimensional (three spatial and one temporal dimension) soil-landscape model based on fundamental land surface processes. This model will combine empirical spatial data with process knowledge to characterize soils in space and time, enabling a comprehensive understanding of the impact of soil changes.
3. Enhance mechanistic soil carbon evolution models to accurately predict soil carbon dynamics under changing environmental conditions. These refined models will provide valuable insights for land management decision-making.
4. Integrate advanced machine learning techniques with process-based biophysical models to improve the accuracy and efficiency of simulating GHG emissions from agricultural lands.

Beyond these specific research goals, numerous opportunities for innovation and advancement exist in Pedometrics, particularly with the proliferation of advanced sensing technologies, open-access data repositories, and diverse modeling approaches. By leveraging these opportunities and fostering interdisciplinary collaboration, we can further advance the field of Pedometrics and contribute to sustainable land management practices and environmental conservation efforts.

At the World Soil Day activity at the University of Sydney, 2019

Soil biota: species probability

Luc Steinbuch

Our much appreciated soil biology colleagues have discovered a new, very rare soil species that seems to occur in one in every 10,000 random soil samples. They have a long discussion about the question: should they call it Invertas Probabilitas Decimus, Invertas Probabilitas Centesimus or perhaps Invertas Probabilitas Millesimus?

(Picture from https://www.wur.nl/en/research-results/research-institutes/environmental-research/show-wenr/micro-organisms-are-gamechangers-in-ecosystem-restoration.htm)

They developped a detection method based on DNA extraction and sequencing which provides a yes, detected / no, not detected answer. As with most scientific tools (and most things in real life anyway), this detection method is not perfect: if a soil sample does contain the organism, the DNA sequencing method will indicate this correctly 99.8% of the time. And if the sample does not contain the organism, this method will give a 'false positive' 0.1% of the time.

If we take a random sample of a unit of soil and it tests positive, what is the probability that the sample actually contains the organism? So, can you help our colleagues to find a suitable name?

Pedomathemagica

Readable code?

We, scientists who often learned on-the-fly to put our ideas in programming languages such as R, Python, Matlab etc, are supposed to write our code clearly and understandable. Let's turn it around for a short exercise: can you just see what the `answer` will be, given the following code?:

```r
## Option one
vector <- as.hexmode(c("D", "F", "E", "F", "6", "9", "5", "C", "4"))
answer <-
  paste0(
    unlist(
      sapply(vector,
             FUN=function(x){letters[x]}
      )
    ),
    collapse = ""
  )
answer

## Equivalent option two
library(dplyr)
vector <- c("D", "F", "E", "F", "6", "9", "5", "C", "4")
answer <-
  letters[vector %>% as.hexmode] %>%
    paste0(collapse = "")
answer
```

Advantages to Bottom-up Approaches for Digital Soil Mapping

Bradley Miller and Meyer Bohn

Department of Agronomy, Iowa State University, Ames, Iowa, USA

Digital soil mapping is gaining more and more ubiquity as more people become trained with its methods and demands for higher quality environmental data increase. The need for this work will expand as we shift from a philosophy of soil maps as a one-time survey of resources to an inventory that requires monitoring over time. There are many logistical questions about how our science can best serve these needs, among them being choices between top-down or bottom-up strategies for making soil maps (Mulder et al., 2016).

Top-down models offer efficiency benefits for providing continuous coverage over areas that did not previously have comparable soil information available. These models are trained on larger sets of soil observations, so they are exposed to a greater range of soil-forming environments for relating covariates with resulting soil properties. In this way, top-down approaches tend to be very efficient in producing soil maps for large extents. As exemplified by SoilGrids 2.0, they provide an essential resource for global environmental models and communities that past generations of soil maps have underserved.

Beyond those great things about top-down approaches, we have observed two potential drawbacks. First, there is a challenge with local engagement, both in terms of involving local stakeholders in the importance of soil information and in incorporating local knowledge of soil-landscape relationships to better guide the soil mapping process. While research can test the impacts of different methodologies on soil map qualities, we must be cognizant of socio-political interactions to help perpetuate public support for soil mapping activities (Lagacherie, 2023).

The second potential drawback for top-down approaches stems from the statistical approaches for differentiating predictive patterns from 'noise'. All models are generalizations, seeking to fit equations to trends and avoiding overfitting to details in the training data that may or may not be real. When a model is overfit, it will show a strong goodness of fit for the training data and then not make good predictions when applied to new, unseen data. A common metric of overfitting is high variance due to a model attempting to incorporate small fluctuations in the training data. However, high variance and small fluctuations are relative, especially in the context of the scale of analysis. What appears as a small fluctuation in a global dataset may be a large fluctuation in a local dataset.

In contrast to top-down approaches, bottom-up approaches focus on smaller regions and then attempt to merge them to assemble a composite map with more extensive coverage. In many ways, this is the strategy of the GlobalSoilMap (Arrouays et al., 2014) initiative, where individual countries produce their own maps. The respective maps are created to match a collective standard to enable their compatibility with one another better when merged. This approach is less efficient than top-down methods because it requires building separate models for each component area. However, each of those models can capture patterns that are useful at the local scale, which may have been considered overfitting at the global scale. Because the localized models can focus on a smaller range of environments, they do not need to be as complex to include more local nuances between landscapes.

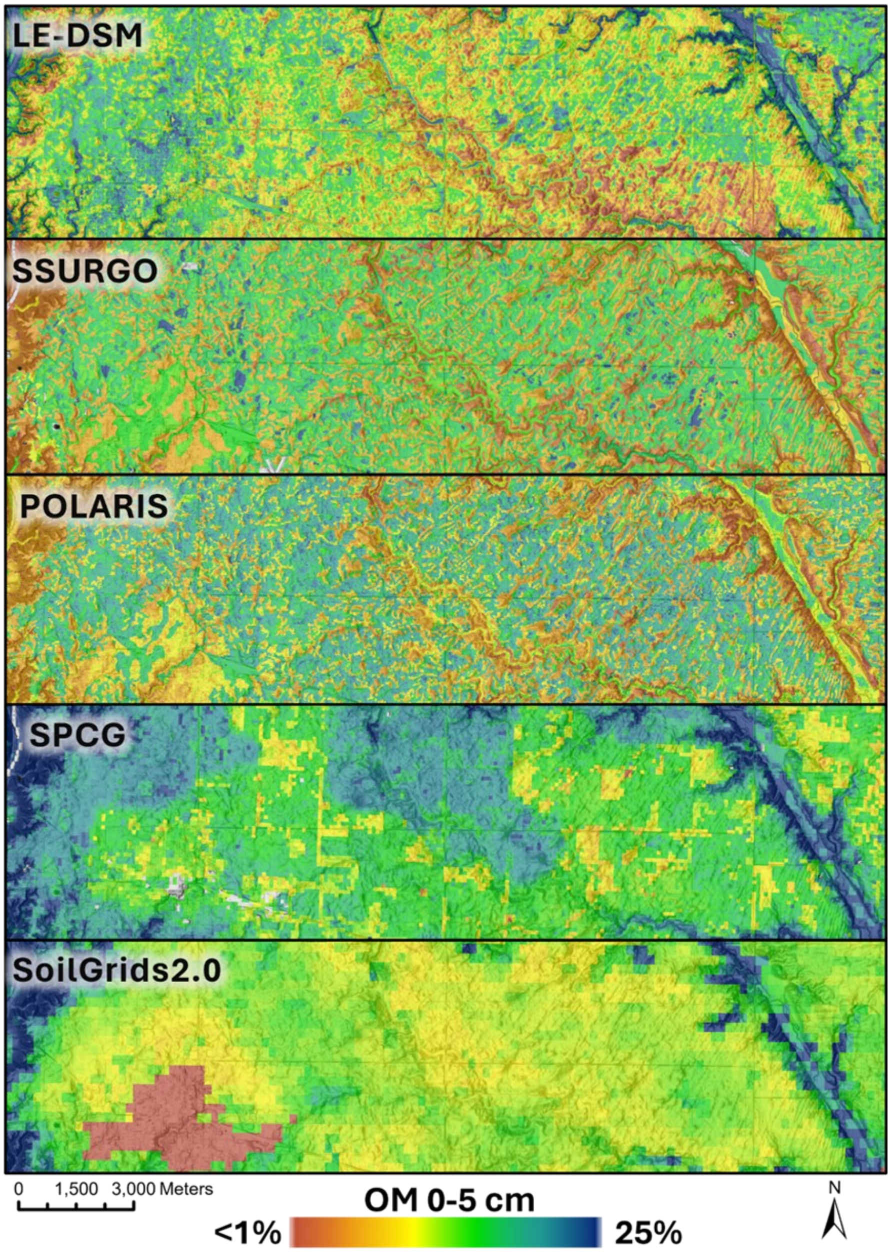


Figure 1. Conference Surface soil organic matter maps ordered descending from finest resolution (LE-DSM, 10m) to coarsest resolution (SoilGrids2.0, 250m) for a 140 km^2 area northwest of Ames, IA, USA. This area is characterized by Mollisols formed in calcareous, fine-loamy till of late Wisconsin glaciation age under mesic conditions with gently sloping washboard moraine relief.

Bottom-up digital soil mapping

In Bohn and Miller (2024), we tried to leverage the advantages of bottom-up approaches to digital soil mapping. That effort included focusing on a region that was relatively homogenous in geologic history and land use, targeting new soil samples to fill gaps found in the legacy data, and curating the covariate stack to ensure the machine learning process considered soil landscape relationships identified by local expertise. While we do not advocate for limiting a covariate stack solely based on expert knowledge, local experience with a soil landscape can offer ideas for covariates that must be added to the covariate stack to represent previously observed relationships. Also, in this case, the regional scale of the map enabled the use of finer resolution covariates that would have been too computationally intensive for producing larger extent maps.

We then compared this 'locally enhanced' digital soil map (LE-DSM) with other map products available for the same area (Figure 1). Existing digital soil maps included SoilGrids2 (Poggio et al., 2021), POLARIS (Chaney et al., 2019), and Soil Properties and Class 100m Grids of the USA (SPCG; Ramcharan et al., 2018). While SoilGrids2 is a truly global model, POLARIS and SPCG were also considered top-down approaches given their large extent for covering the conterminous USA. The soil properties considered were clay, silt, sand, and organic matter content at the standard depth intervals of 0-5, 5-15, 15-30, 30-60, 60-100, and 100-200 cm.

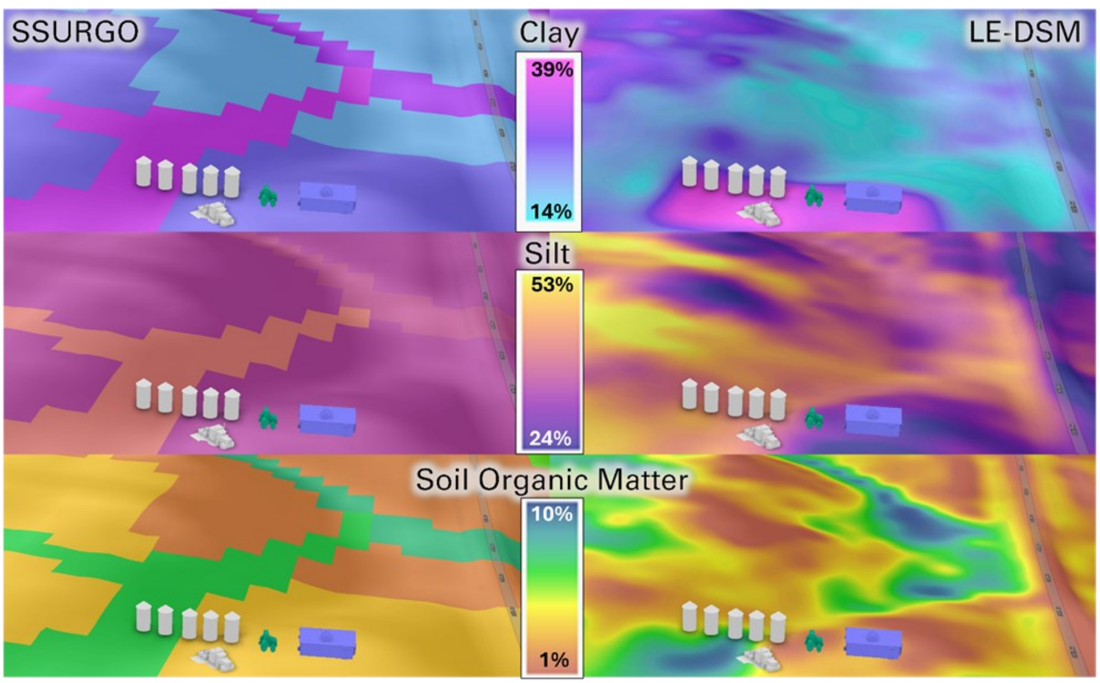


Figure 2. A 3D visualization at the subfield scale illustrating the enhancement of detail for soil surface silt, clay, and organic matter content that the LE-DSM (right) offers compared to the conventional soil survey map, SSURGO (left).

For 71% of the target soil properties, LE-DSM outperformed the top-down maps in terms of RMSE by a 10% independent validation set. Although the LE-DSM did have the advantage of being trained on some newly collected sample locations, this validation performance seemed particularly strong, considering the top-down models had technically used the validation set during their training process. That is, the independent validation set was not genuinely independent for this study's validation of SoilGrids2, POLARIS, or SPCG because those same sample locations were used in the creation of those models.

In this study, we also compared all the digital soil map products with the digitized version of the conventionally produced soil survey maps (SSURGO) for the study area (Figure 2). This comparison was critical because SSURGO is the most trusted soil map source in the area. For any other method of soil mapping to be considered, it would need to be demonstrably more accurate than the reigning standard. Previous digital soil mapping efforts have yet to be shown to be more accurate than SSURGO, even when SSURGO was used to inform the digital soil mapping model.

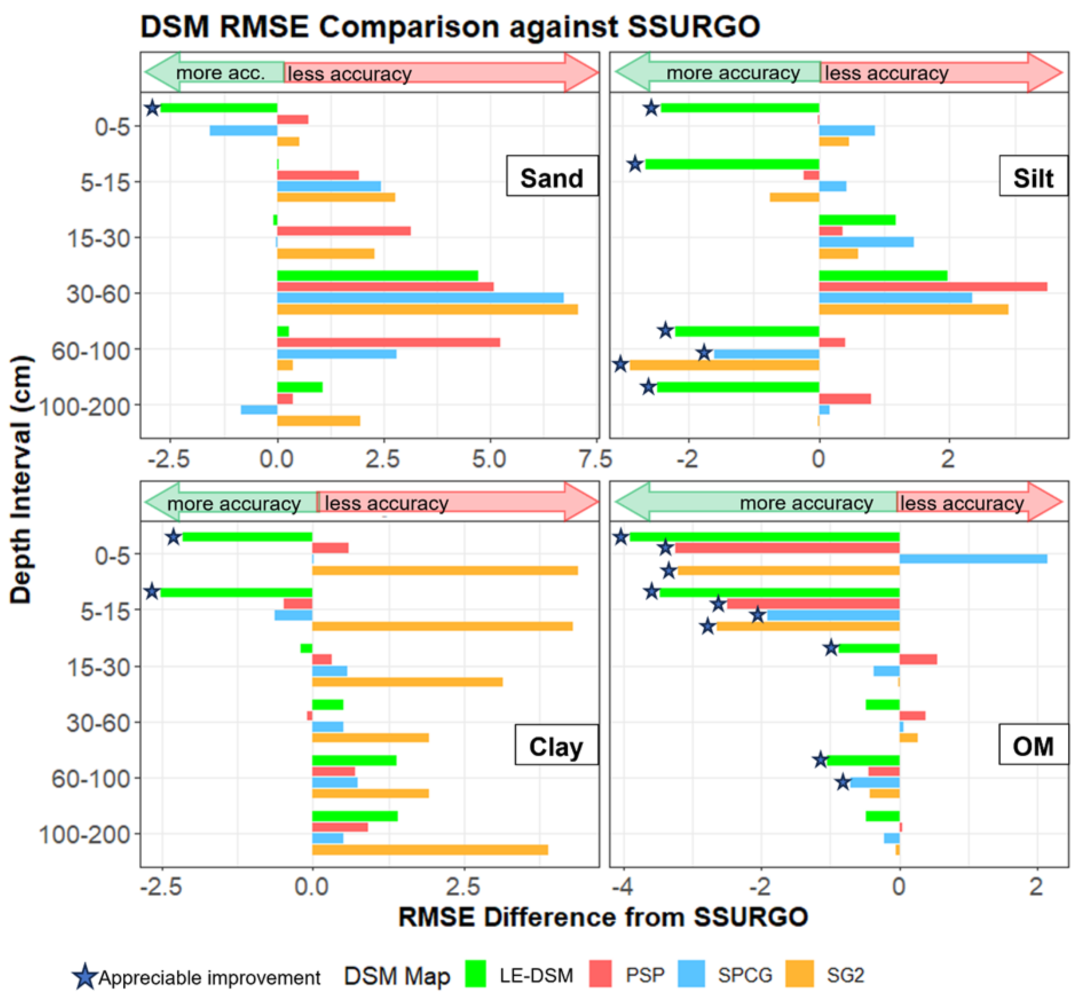


Figure 3. Control column chart comparing DSM product RMSEs with the SSURGO RMSE as the baseline (0). Bars extending to the left indicate an accuracy greater than SSURGO, and bars to the right indicate an accuracy less than SSURGO. Blue stars mark appreciable improvements in RMSE as defined by being more than one standard better than the mean for RMSE improvements.

Bottom-up digital soil mapping

Comparison with SSURGO was also crucial because it is an exemplary case of a conventional soil map implemented with a bottom-up approach. Around the world, conventional soil maps vary in cartographic scale and standards used in production. SSURGO resulted from standards set by a national program (i.e., National Cooperative Soil Survey) and significant investments to create individual maps at the county level (~200-500 km^2). Each county soil survey map took around four soil scientists about four years to complete. The area considered in this study is among the best for conventional soil mapping because the land is highly valued for agricultural production, and the seasonal cropping system allows for periods of bare soil to be aerially photographed. With county maps produced at cartographic scales between 1:12,000 to 1:15,840, areas as small as 0.6 to 1 ha could be delineated, respectively (Schoeneberger et al., 2012). These maps were later digitized and merged to create SSURGO.

From the four soil properties mapped at six different depths, the LE-DSM was more accurate than SSURGO 67% of the time. Moreover, 46% of the LE-DSM maps had over one standard deviation improvement in RMSE over SSURGO (Figure 3). Apart from silt content, all the digital soil maps tended to perform best closer to the surface, suggesting that SSURGO may still have some advantages for predicting soil properties at depths greater than 15 cm. Overall, the digital soil maps performed the best at predicting organic matter content. Together, these two trends indicate an advantage for digital soil mapping when predicting soil properties that are relatively more likely to change. This pattern could potentially be explained by work on SSURGO being most active 30-40 years ago, while the digital soil mapping products tend to utilize covariates from the last decade.

These results demonstrate the potential for digital soil mapping to improve the spatial soil information available at all scales. Global soil mapping has demonstrated its utility to provide complete coverage of the Earth at resolutions that would have been impractical for conventional soil mapping. At the local level, however, the competitiveness of digital soil mapping with conventional soil mapping was less clear due to different styles and levels of investment made in existing conventional maps. With the LE-DSM, we could produce maps that were more accurate than some of the best bottom-up, conventional soil maps in the world. This outcome suggests a bright future for digital soil mapping as both a global and grassroots venture.

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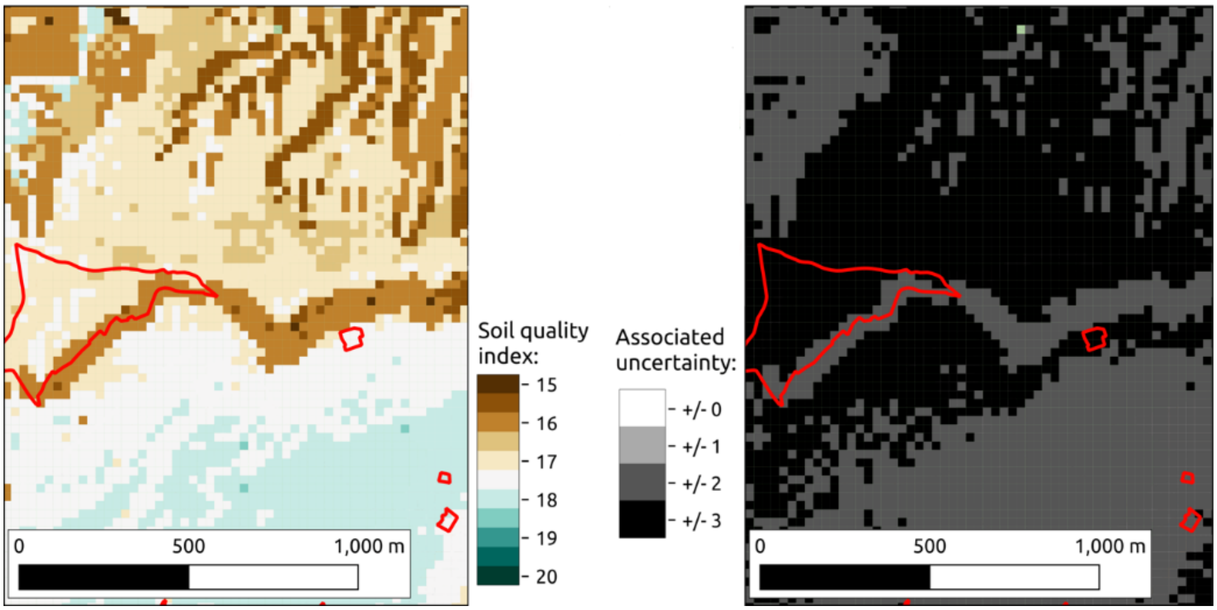
A survey

How is the uncertainty of soil maps taken into account?

by Léa Courteille



Have you ever tried to use the soil maps you produce to make concrete decisions?

As part of my thesis work, I'm conducting a survey to characterize the behavior of decision-makers when faced with maps with quantified uncertainty.

This survey makes you step into the shoes of a land planner who has to decide which plots to protect/ artificialize based on soil quality maps.

Click the following link to take part!

https://sondages.inrae.fr/index.php/485952?lang=en

The results of this study will help us provide decision-makers with more operational maps, for them to be mobilized in the context of numerous policies for the preservation of natural areas.

The survey lasts 20 minutes, but you can leave at any time and return when you wish.

Many thanks for your participation!

Best regards,

Léa Courteille and Philippe Lagacherie