The GCTE Soil Erosion Network

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Abstract: The aims of the Global Change and Terrestrial Ecosystems "Soil Erosion Network" are (1) to design and undertake experimental and monitoring programmes to provide a predictive understanding of the impacts of changes in climate and land use on soil erosion; (2) to define and adapt current erosion models for use in global change studies from plot to regional scale. This network was launched in March 1994 at an international workshop organised in Paris, and was accepted as GCTE Core Research in 1995.

Three approaches have been taken to achieve the SEN's aims. The first component is the creation of a meta-database holding details of erosion datasets and models. To date, 42 members from twenty countries have donated metadata for 12 models from 6 countries; 17 experimental datasets from 14 countries; 18 monitoring datasets from 10 countries.

The second component of GCTE-SEN's activities is the evaluation of current erosion models. Models are being evaluated separately for each of the categories: (i) Plot/field-scale water erosion, (ii) catchment-scale water erosion; (iii) landscape-scale water erosion; (iv) wind erosion. To date, a first round of evaluations have been being carried out for models of soil erosion by water at the plot/field scale (Oxford, September 1995), and at the catchment scale (Utrecht, April 1997). For both, common present-day datasets were used. These were split into a 'training set' and a 'testing set' and distributed to the participating modellers. Initial evaluations of wind erosion models and of landscape-scale water erosion models are still to be arranged. However, the second stage of evaluation (using global change data) of both field- and catchment-scale water erosion models will be taken forward at a meeting in Belfast, Northern Ireland, in early 2003. This will be a joint meeting with EU-funded COST Action 623 'Soil Erosion and Global Change'. Other future GCTE-SEN meetings include the ICAR5/GCTE-SEN Wind Erosion and Aeolian Processes Conference; and the joint meeting of the Fifth International Conference on Aeolian Research and the GCTE-SEN, Texas Tech University, Lubbock Texas, 22—25 July 2002.

The third component of GCTE-SEN's activities includes experimental and long-term studies. Both experimental and monitoring data are essential to calibrate, initialise, evaluate and improve soil erosion models. The objectives of this component are aimed at understanding: (1) How erosion processes at different spatial and temporal scales interact; (2) How coarser scale processes act as constraints to processes causing erosion at a lower hierarchical level; and, in turn, (3) How the dynamics of finer scale processes lead to threshold conditions that enable soil erosion to occur at a higher level; and *vice versa*. Key questions are: (1) At what level and when is loss of a given function critical? and (2) What are the processes and properties responsible for soil resilience, and what are their predicative indicators? (3) How can we better predict rill and gully erosion rates?

These questions relate to practical issues in land management, with a particular emphasis placed on the response of erosion to the rapid land-use changes in the Tropics. An example of critical ratio and threshold is the ratio of soil organic matter production to decomposition and loss by water and wind erosion. Another example is gully erosion. In order to monitor the change in extent and intensity of gully erosion, it is necessary to start from base line data, which still do not exist at the global scale, and launch a global monitoring network. This is one of the objectives of the 2nd International Symposium on Gully Erosion Under Global Change, May 22—25, 2002, Chengdu, China, as a follow-up to the COST meeting on gully erosion held in Leuven in April 2000.

Advances made by the GCTE-SEN network are feeding into and improving existing soil erosion models and also have useful applications in advice to farmers, land managers and those concerned with off-site pollution.

It is also important to note that the GCTE-SEN does not aim to compete with the many national and international research programmes which focus on the effects of land-use change on soil erosion, but rather aims to address the need for international co-ordination of such studies in order to improve predictive capacity for erosion under global change scenarios. Finally, although GCTE is not a source of funding for research (since GCTE itself has no fund to support research activities), GCTE can and does assist in obtaining funding for research meetings. Its function is thus as a facilitator for international collaboration.

Keywords: water Erosion, wind erosion, global change, network, modelling

1 Introduction

The Global Change Terrestrial Ecosystem research on soil degradation concentrates on erosion issues. The severity, frequency and extent of erosion is being altered by changes in land use and most likely by changes in rainfall amount and intensity, and by changes in wind. Global change will thus amplify many current problems of soil erosion, and as certain soil thresholds are exceeded, potentially new and different problems could arise. It is therefore crucial to understand the potential impacts of global change on soils to allow the developments in predictive capability necessary to improve their management in the future. The GCTE Soil Erosion Network is dedicated to this goal, and forms a key component of GCTE's soil research.

Both water and wind erosions are commonly accelerated by land-use change (especially the clearing of vegetation cover), presently the main manifestation of global change. Since erosion processes have a certain threshold set of conditions, emphasis needs to be put on the determination of such thresholds, on reversibility of processes, and on soil resilience. Infrequent climatic events, such as heavy storms, typhoons, etc. can trigger severe erosion that would be unpredictable from short-term records. Long-term erosion monitoring is therefore essential to observe possible transient and non-equilibrium responses to climatic and land-use changes.

The general aims of the GCTE soil erosion studies are (i) to refine and adapt current soil erosion models for use in global change studies in a wide range variety of conditions; and (ii) to design and undertake experiments to provide improved mechanistic understanding of the relationships between global change and soil erosion, to aid model development.

The objective of this paper is to briefly present some of the main achievements of the GCTE-SEN network as well as planned activities.

2 Implementation

The GCTE Soil Erosion Network (SEN) (see http://www.nmw.ac.uk/GCTEFocus3/networks/erosion.htm) was launched in March 1994 at an international workshop organised by ORSTOM (now IRD) in Paris, and was accepted as GCTE Core Research in 1995 (Ingram *et al*., 1996). The aims of the SEN's Core Research Projects are (1) to design and undertake experimental and monitoring programmes to provide a predictive understanding of the impacts of changes in climate and land use on soil erosion

(Poesen *et al.*, 1996); (ii) to define and adapt current erosion models for use in global change studies from plot to regional scales (Favis-Mortlock *et al.*, Williams *et al.*, 1996; Boardman and Lorentz, 2000).

The Soil Erosion Network brings together the experimental and modelling studies so as to develop the models necessary for predicting erosion from plot to regional scales (Ingram *et al.*, 1999). GCTE-initiated research started with the collation of existing experimental and monitoring datasets and models, and the systematic evaluation of models. The experimental research phase concentrates on improving process-based understanding at scales from plot to catchment, while the modelling aspect undertakes model sensitivity and comparison exercises. The experimental and modelling aspects are closely integrated, leading to the development of the models necessary for predicting erosion from plot to catchment scales.

The Network is coordinated by the GCTE Soil Erosion Network Working Group, Dr Christian Valentin (chair), Professor Dr Jean Poesen, Professor Mike Kirkby, Professor Peter Gregory, Dr Mark Nearing, Dr John Boardman, Dr Ted Zobeck and John Ingram, assisted by the GCTE Focus 3 Office.

The Soil Erosion Network is working in close collaboration with the European Cooperation in the Field of Scientific and Technical Research (COST) Action 623, Soil Erosion and Global Change, http://www.nmw.ac.uk/GCTEFocus3/networks/erosion.htm. This ongoing COST Action 623 is a very valuable mechanism for promoting networking and synthesis of information on a European basis, and through GCTE-SEN, to link this to research worldwide.

3 Metadabase and erosion modelling

The first component of the network is the creation of a meta-database holding details of erosion datasets and models (GCTE, 1997). To date, 42 members from twenty countries have donated metadata for 12 models from 6 countries; 17 experimental datasets from 14 countries; 18 monitoring datasets from 10 countries.

The second component of GCTE-SEN's activities is the evaluation of current erosion models. Three different types of modelling can be distinguished according to objectives:

- To improve land management. These models assist land users to select the best land practices to prevent soil erosion, to sustain production and possibly to restore the land. Because these models attempt to provide rapid answers to urgent questions, they are usually site specific. These models are most often empirical, stochastic or expert-system based.
- To test hypotheses. This family of models is more directly science-driven. The overall aim is generally not so much to predict erosion than understand its processes. These models are very necessary for the progress of knowledge. They are physically based and can thus be considered as tools to be used in a variety of circumstances. Given the various factors and processes involved in soil erosion, these models are necessary to establish a hierarchy among them, and thus to provide indicators which will be helpful for the other types of models of. Furthermore, these models help determining the critical thresholds of these indicators.
- To predict soil erosion under global change. Will soil erosion extend under a climate with more frequent high intensity rain? With extended cropland? etc. As for the first group, this family of models correspond to a social demand, the users being the policy-makers and the environmental agencies, but this demand applies to a longer run than the previous family of models, which are most directly developed for land users.

Attention must be paid to the sensitivity of these latter models to climate change and/or land use change. To identify which models are most robust for global change studies, they need to be compared using datasets from a wide range of environments. This is been done in a systematic way, using internationally agreed protocols for data storage and exchange. Models are being evaluated separately for each of the categories (Favis-Mortlock *et al.*, 1996): (1) Plot/field-scale water erosion, (2) catchment-scale water erosion; (3) landscape-scale water erosion; (4) wind erosion. To date, a first round of evaluations have been being carried out for models of soil erosion by water at the plot/field scale (Oxford, September 1995: Boardman and Favis-Mortlock, 1998; Boardman and Lorentz, 2000), and at the catchment scale (Utrecht, April 1997: Jetten *et al.*, 1999). For both, common present-day datasets were used. These were split into a ‘training set’ and a ‘testing set’ and distributed to the participating modellers. General conclusions included: (Jetten *et al.*, 1999)

- Total discharge is generally better predicted than peak discharge and both are better predicted than sediment discharge.
- In general event-based catchment models perform better to predict peak discharge than continuous models, basically because the latter operate with large time steps and calculate peak flow independent of surface water depth (revised USLE, curve number).
- Spatial resolution in this catchment did not seem to play a role: catchment models using a few elements to describe the catchment (10 — 60) performed as good or better than models using 4000 or more grid cells.
- Uncalibrated use of catchment models is not advisable. Calibration is imperative for small and medium scale catchments applications (10 — 1000 ha), where the influence of the spatial variability on the runoff and erosion processes is strongly influencing the simulation.
- Even in a catchment for which the model is calibrated, it is not sure that the model will have a good predictive quality if the event lies outside the range of calibration events. The reason for this is that within storm dynamics, e.g., the change of soil surface structure or processes like incision and simple overflow of drainage paths is not incorporated in most models.
- Results improve if more data is available about agricultural activity (including runoff routing aspects) and the interaction between climate and soil surface. This data can be descriptive in nature, as it helps the modeller in constructing the database.
- Modellers tend to emphasize the successful part of the simulation only, while much more can be learned from difficulties encountered.

The second stage of evaluation (using global change data) of both field- and catchment-scale water erosion models will be taken forward at a meeting in Belfast, Northern Ireland, in early 2003. This will be joint with EU-funded COST Action 623 ‘Soil Erosion and Global Change’ (http://www.cost623.leeds.ac.uk/cost623/).

Initial evaluations of wind erosion models and of landscape-scale water erosion models are still to be arranged (see http://www.lbk.ars.usda.gov/wewc/icar_v/icar_v.htm: ICAR5/GCTE-SEN Wind Erosion and Aeolian Processes Conference; and the joint meeting of the Fifth International Conference on Aeolian Research and the GCTE-SEN, Texas Tech University, Lubbock Texas, 22—25 July 2002. Email: tzobeck@lbk.ars.usda.gov and jeff.lee@ttu.edu). This conference, which follows on that of Hawaï in January 2001 (e.g., Hagen, 2001; Zobeck et al., 2001), will be a milestone for the CGTE-SEN activities related to wind erosion.

4 Experiments and long-term monitoring of land-use change impacts on soil erosion

Experimental studies test a clearly defined hypothesis whilst monitoring studies involve the measurement of baseline variables (e.g. rainfall and wind intensity, soil moisture, surface roughness, soil erosion rates, etc.) over several years but need not involve the testing of a clear initial hypothesis. For example, long term dust records in the Southern High Plains of USA showed a continuing decrease in wind erosion activity over the past four decades (Stout, 2001). Both experimental and monitoring data are however essential to calibrate, initialise, validate and improve soil erosion models.

Most soil erosion research (e.g. runoff plot measurements) has been undertaken with objectives that made it unnecessary to consider different temporal and spatial scales. To predict the effects of global change on the landscape, however, we must understand erosion processes operating at different spatial and temporal scales. The second objective of the GCTE-SEN is aimed therefore at understanding: (1) How erosion processes at different spatial and temporal scales interact; (2) How coarser scale processes act as constraints to processes causing erosion at a lower hierarchical level; and, in turn, (3) How the dynamics of finer scale processes lead to threshold conditions that enable erosion to occur at a higher level; and *vice versa*. An integrated approach is needed to understand and predict effects of global change on soil erosion. A peculiar attention is paid in the GCTE-SEN on the response of soil erosion to the rapid land-use changes in the Tropics (e.g., Valentin, 1996; Chaplot et al., 2002; Planchon & Valentin, in press)

Loss of soil quality or quantity may be reversible up to a point if land management is improved. Most soils however reach thresholds beyond which recovery is very slow. The rate of soil formation is usually many times slower than even modest rates of soil erosion. Although it may be obvious when these thresholds have been crossed, it is usually very hard to know when a threshold is imminent. It is important for the maintenance of soil condition that we identify the approach of these thresholds, so that remedial action can be taken in good time. In many cases this is made possible because some critical states are not true thresholds but rather critical ratios for which the balance of processes crosses a safe value. Key questions are: (1) At what level and when is loss of a given function critical? and (2) What are the processes and properties responsible for soil resilience, and what are their predicative indicators? (3) How can the approach of rilling and gullying be better predicted?

These questions relate to practical issues in land management.

An example of critical ratio and threshold is the ratio of soil organic matter production to decomposition and loss by water and wind erosion. General conclusions of the GCTE-SEN/COST623 workshop held in Reading in 1999 include: (special issue of "*Agriculture, Ecosystems and Environment*", in press; Kirkby and Powlson, eds)

(1) Organic matter can be regarded as a valuable indicator for soil structure and thus soil conservation at the local scale. For larger spatial scales it is very difficult to get detailed information on the spatial and temporal variability of soil organic matter. Its indicator value is therefore higher at plot and field scales compared to catchment or regional scale where soil organic matter information needs to be inferred from other more accessible factors such as land use, vegetation cover or agricultural practices.

(2) The non-linearity between organic matter content, soil structure, infiltration, water and wind erosion have been illustrated by examples from Europe and Africa. Although the complexity of the numerous factors involved, including soil variability (texture and clay mineralogy), soil faunal groups (worms, ants, termites, collembola and enchytraeidae), and soil cover (i.e. straw mulch in China; dung manure in Niger; fallow in Ivory Coast), biological activities above and in the ground tend to improve soil structure and soil conservation.

The formation of rills and gullies in the landscape gives rise to a massive increase in erosion rates. This threshold is important in influencing off-site pollution events: almost all cases of damage (sediment and chemical) to watercourses and property by runoff from agricultural land relate to rilling and gullying. The GCTE-SEN therefore places a particular emphasis on gully erosion. This form of erosion is particularly difficult to study and to predict because it results from an array of factors and processes. It requires a very sound field experience as well as historical data on soil, landform, climate and land use. By their very nature, these data are site-specific, which makes it difficult to transfer results, models and predictions to other conditions. Because of the variety of processes (e.g. from snowmelt to piping in non-cohesive soils), "universal" models cannot be "uniform". Another difficulty arises from the time scale to be addressed. By nature ephemeral gullies, but also "regular" gullies can be formed or evolved during one rainfall event. This time-scale cannot be overlooked. At the other end of the spectrum, historical and some global change studies require an account for hundreds or thousands of years. In order to monitor the change in extent and intensity of gully erosion, it is necessary to start from base line data, which still do not exist at the global scale, and launch a global monitoring network. This will be one of the objective of the 2nd International Symposium on Gully Erosion Under Global Change, May 22—25, 2002, Chengdu, China (Fax: +86-28-5238973 E-mail: htalent@mail.sc.cninfo.net, yongli32@hotmail), as a follow-up to the COST meeting on Gully erosion held in Leuven in 2000. The conclusions of the Leuven meeting include: (special issue of *Catena*, in press, Poesen and Valentin eds, Gully Erosion under Global change))

- Existing studies indicate that the contribution of gully erosion to overall soil loss by water erosion is quite variable (10 % — 90 %) and that in many environments this contribution is far from negligible;
- A preliminary diagnosis is necessary before setting up experiments on gully erosion;
- This diagnosis must be based on historical studies, especially in the regions that have been cultivated for a very long time. For example, in Europe, most of the observed gullies under present forests developed under cropping systems that can be rather old (medieval times);
- This diagnosis must also account for not only geomorphic and tectonic conditions, but also for soil structure and soil history. This means that surface conditions, although very important, are often not sufficient to explain the spatial patterns of historical gullying.
- More research is needed on factors (climatic, topographic, pedologic, land use, infrastucture, …) and subprocesses (seepage, hydraulic erosion, piping and tunnelling, tension cracking, mass

wasting on gully walls) controlling thresholds for incipient gullying, gully development and gully infilling;

- Given that most existing models predicting rates of water erosion only or mainly deal with sheet and rill erosion, more efforts are needed to develop or improve models to cope with gully erosion;
- More attention should be given to the interaction between gully erosion and other hydrological and soil degradation processes operating at the landscape scale;
- More efforts should be put in innovative techniques and strategies to prevent or control gully erosion.
- Because of the importance of historical and soil factors, models cannot solely be based on surface features (Hortonian models) but should also include process such as subsurface flow and piping/tunnelling.

5 Conclusions

Advances made by the GCTE-SEN network are feeding into and improving existing soil erosion models and also have useful applications in advice to farmers, land managers and those concerned with off-site pollution.

It is also important to note that the GCTE SEN does not aim to compete with the many national and international research programmes which focus on the effects of land-use change on soil erosion, but rather aims to address the need for international co-ordination of such studies in order to improve predictive capacity for erosion under global change scenarios. Finally, although GCTE is not a source of funding for research (since GCTE itself has no fund to support research activities), GCTE can and does assist in obtaining funding for research meetings. Its function is thus as a facilitator for international collaboration.

References

Boardman, J. and Favis-Mortlock, D.T. (eds) 1998. Modelling Soil Erosion by Water, Springer-Verlag NATO-ASI Series I-55, Berlin. 531 pp.

Boardman, J. and Lorents, S, 2000. The GCTE Soil Erosion Network and model evaluation studies. South African Geographical Journal, **82**(3):154-156.

Chaplot, V., Boonsaner, A., Bricquet, J.P., de Rouw, A., Janeau, J.L., Marchand, P., Phommassack, T., Toan T.D., Valentin, C., 2002. Soil erosion under land use change from three catchments in Laos, Thailand and Vietnam. 12th International Soil Conservation Organization Conference, Beijing, China.

Favis-Mortlock, D.T., Quinton, J.N. and Dickinson, W.T. (1996). The GCTE validation of soil erosion models for global change studies. Journal of Soil and Water Conservation **51**(5), 397-403.

GCTE, 1997. GCTE Gocus 3 Erosion Network: 1997 Model, Experimental and Monitoring Metadata, Global Change and Terrestrial Ecosystems Report No. 6, GCTE Focus 3 Office, Wallingford, UK. 136 pp.

Hagen, L.J., 2001. Validation of the Wind Equation Prediction System (WEPS) Erosion Submodel on small cropland fields. in: J.C. Ascough II & D.C. Flanagan (eds), Soil Erosion Research for the 21st Century. American Society of Agricultural Engineers, St Joseph, Michigan, USA, pp. 479-482.

Ingram J.S.I, J. Canadell, T. Elliott, L.A. Hunt, S. Linder, D. Murdiyarso, M Stafford-Smith and C. Valentin, 1999. Networks and Consortia: In B. Walker, W. Steffen, J. Canadell and J. Ingram (ed) The Terrestrial Biosphere and Global Change: Implications for natural and managed ecosystems. IGBP Book Series 4. Cambridge University Press, pp.45-65.

Ingram, J.S.I., Lee, J.J. and Valentin, C., 1996. The GCTE Soil Erosion Network: a multi-participatory research program. Journal of Soil and Water Conservation **51**(5), 377-380.

Jetten, V., de Roo, A.P.J. and Favis-Mortlock, D.T. (1999). Evaluation of field-scale and catchment-scale soil erosion models. Catena **37**(3/4), 521-541.

Planchon, O., Valentin, C., in press. Soil erosion in West Africa : present and future. In : D. Favis-Mortlock and J. Boardman (eds.) Soil erosion and climatic change. Imperial College Press, Oxford.

Poesen, J., Boardman, J., Wilcox, B., Valentin, C., 1996. Soil erosion monitoring and experimentation for global global change studies. Journal of Soil and Water Conservation, **51**(5):386-390.

Stout, J.E., 2001. Dust trends in the Southern High Plains. in: J.C. Ascough II & D.C. Flanagan (eds), Soil Erosion Research for the 21st Century. American Society of Agricultural Engineers, St Joseph, Michigan, USA, pp. 475-478.

Valentin, C., 1996. Soil erosion under global change. in : B.H. Walker and W.L. Steffen (eds.) Global Change and Terrestrial Ecosystems, Cambridge University Press, International Geosphere-Biosphere Programme Book Series, n°2, pp. 317-338.

Williams, J., Nearing, L., Nicks, A., Skidmore, E., Valentin, C., King, K, Savabi, R. 1996. Using soil erosion models for global change studies. Journal of Soil and Water Conservation, **51**(5):381-385.

Zobeck, T.M., Scott Van Pelt, Stout, J.E., Popham, T.W., 2001. Validation of the Revised Wind Erosion Equation (RWEQ) for single events and discrete periods. in: J.C. Ascough II & D.C. Flanagan (eds), Soil Erosion Research for the 21st Century. American Society of Agricultural Engineers, St Joseph, Michigan, USA, pp. 471-474.