WORLD INVENTORY OF SOIL EMISSIONS

Proceedings of an International Workshop
held at
Wageningen, the Netherlands
(24-27 August 1992)

Report of working group discussions and recommendations

N.H. Batjes (Editor)
September 1992

Sponsored by
**NETHERLANDS NATIONAL RESEARCH PROGRAMME ON
GLOBAL AIR POLLUTION AND CLIMATE CHANGE**

INTERNATIONAL SOIL REFERENCE AND INFORMATION CENTRE

WISE

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1 INTRODUCTION

1.1 Background

The atmospheric concentrations of a wide range of radiatively active trace gases, popularly known as "greenhouse gases", are increasing. Since these trace gases absorb thermal radiation they *enhance* the global warming of the atmosphere. Changing patterns of evapotranspiration and overall reflectance (albedo), as associated for instance with progressing deforestation and desertification, are also important in this respect. Many greenhouse gases, and some of their derivatives, also interfere with the photo-chemistry of the atmosphere. While some greenhouse gases, such as the CFCs, solely result from human-activities, others are also produced naturally in the biosphere.

Soils are important sources and sinks of water vapour, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The soil conditions and processes which regulate the production/absorption and emission of these radiatively active gases in terrestrial ecosystems are incompletely understood and are only poorly quantified. This consideration prompted ISRIC to initiate a project on "World Inventory of Soil Emissions", with the acronym WISE. It follows a logical development from the 1990 International Conference on "Soils and the Greenhouse Effect" (Bouwman, 1990).

1.2 Place in NOP programme

The WISE project, which started in September 1991, has a duration of 3 years. It is carried out within the framework of the Netherlands National Research Programme on Global Air Pollution and Climate Change (NOP). The NOP programme comprises 120 projects (anticipated number) with an average duration of 2-4 years each. The first phase of the programme, with a financing of 63 million guilders, is to be completed by the end of 1994. A first external, international review meeting of the NOP programme took place in Apeldoorn, 17-21 August 1992.

The NOP programme has been initiated to support policy development and contribute to international research efforts in the field of global air pollution and climate change. It is funded by seven ministries of which the Ministry of Housing, Physical Planning and Environment (VROM) is the major coordinator. The 23 "clusters" of the programme are grouped under five broad themes: (A) the System, (B) the Causes, (C) the Consequences, (D) Integration, and (E) Identification of Permanent Sustainable Solutions (see Schneider *et al.*, 1991). WISE reports under Theme-B, the projects of which are organized within five clusters. These include clusters on research projects investigating the sources of the major greenhouse gases (i.e. CO_2, CH_4 and N_2O), a cluster on database development, and a cluster concerned with the socio-economic causes of climate change (*cf*. Wiegant, 1992).

1.3 Objectives of WISE project

The main aim of the WISE project is to arrive at a geographic quantification, at the global level, of the soil conditions and soil processes which regulate fluxes of CO_2, CH_4 and N_2O. The influence of the heat and moisture balance upon the movement of moisture and gases is also considered.

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The first phase - September 1991 to September 1992 - encompasses a literature study to identify the currently known biological, chemical and physical controlling factors. It also served to indicate what information on the identified soil factors can be derived from the 1:5 M Soil Map of the World (FAO/Unesco, 1971-1981). Techniques for calculating global emissions of methane, carbon dioxide and nitrous oxide from soils at the global level, and their data requirements, were also reviewed (Batjes & Bridges, 1992).

The second phase of WISE, which ends in September 1994, includes two main goals. First, a global soil database with a grid size of 1/2° longitude by 1/2° latitude is to be compiled from the "cleaned" digital-version of the 1:5 M Soil Map of the World (FAO *in prep.*). Secondly, global emissions of methane from natural wetlands and/or irrigated rice soils are to be calculated using the WISE database, ancillary databases (e.g. climate and vegetation/land use) and from field measurements of methane emissions.

1.4 Contents of report

This document contains a report of an international workshop which was organized and hosted by the International Soil Reference and Information Centre (ISRIC) from 24-27 August 1992 in Wageningen, the Netherlands, to discuss the recommended plan of action for the second phase of the WISE project.

Following a word of welcome by Dr L.R. Oldeman, Director of ISRIC, and an introduction by Dr T.S. Schneider, Programme Leader of the Netherlands National Research Programme on Global Air Pollution and Climate Change (NOP-MLK), the aims and objectives of the WISE project and workshop were introduced by Dr E.M. Bridges, Project Coordinator. Subsequently, 9 oral presentations were given, the titles of which are listed in Appendix II. The texts of these presentations, where applicable, will be published as a separate volume of the workshop proceedings by ISRIC. This report contains a summary of the working group discussions.

Stimulating and lively discussions took place during the workshop sessions leading to the findings and recommendations. They have been regrouped according to their general themes in Chapter 2. In Chapter 3 a plan of action for the second phase of the WISE project is proposed, which the workshop participants considered to be "more compatible" with the possibilities of finances and time of the project. Chapter 4 summarizes the concluding remarks. A list of acronyms and abbreviations is attached as Appendix I, the programme of the workshop forms Appendix II and Appendix III is the list of participants.

The proposal to hold a workshop was notified to 46 individual scientists and institutions internationally, identified from the literature and by personal contacts as having interests in the general area of research covered by the WISE project. A fairly large number of these could not attend the workshop through prior engagements, but asked to be kept informed about the progress of the WISE project. It is hoped the present report will generate a response from a wide range of potential users of global soil databases. This form of "feed-back" is considered essential to develop a widely accessible and compatible product for a wide range of studies at the macro-level.

2 REPORT OF WORKING GROUP DISCUSSIONS

2.1 The Soil Map of the World (SMW)

According to the FAO representative the most important limitations for the use of the Soil Map of the World (FAO/Unesco, 1971-1981) are:
1) The scale of the map restricts its use to continental or global issues.
2) The map format and rather complex legend make the use of the map rather limited, scaring away non soil-scientists.
3) The inaccuracy and errors in the map and now outdated material, especially in the first maps to be produced, e.g. South America.
4) The "translation" of the classification to users of the product has been neglected. The soil unit names were "not-attractive" or "inaccessible" to many potential users.

Positive points of the Soil Map of the World are:
1) The scale of the map is suited for global studies, and especially in view of growing environmental concerns, for instance global warming, deforestation, land degradation, there is an increased interest in using the comprehensive map, for which no alternative exists at present.
2) The Soil Map of the World will very soon be available in digitized form, as ARC/Info files, with corrections and country boundaries.
3) ISRIC, UNEP, ISSS and FAO support the SOTER[1] approach, on which basis a 1:1 M or smaller scale new map can be prepared. Compilation of an up-to-date 1:1 M map on world soils is a very major task to undertake, estimated to be in the order of 10-20 years.
4) FAO has started with updating the 1:5 M SMW of Brazil and China. Hopefully funds can be found to also update NE-Africa and the remaining part of South America. The information of SMW is linked to the Agro-ecological Zonification studies at FAO which, according to Dr Sombroek, has been adopted as a framework for the CGIAR Institutes. Dr Sombroek added that the existing soil and AEZ databases should be improved and suggested a pooling of WISE and FAO funds for updating the SMW part of South America at 1:5 M scale. The legend which is to be used was not specified, but it was noted that the "Composition Rules" used in the AEZ software are based on the 1974 Legend. A direct conversion of the original Legend (FAO-Unesco, 1974) to the Revised Legend (FAO, 1988) is difficult, unless reference can be made to the original sources.

During the initial discussions it was concluded that:
1) Interpretation of the information contained in the compound mapping units is difficult. Griding of SMW to a 30 x 30 minutes resolution, as is necessary for the WISE database, without loosing information was considered problematic (see Section 2.3).
2) A number of soil and land properties, including aspects of land use and farming systems, of importance for studying methane production and emission of trace gases, are not regularly collected nor used for placing soils in any soil classification unit, since they are not diagnostic or discriminating criteria.
3) It is possible to group soils broadly, but this results in a large or very large range of properties.

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[1] SOTER is the acronym for World Soils and Terrain Digital Database (cf. Van Engelen & Pulles, 1991).

4)   Existing soil profile databases are restricted in their uses and at present are not available as a single source of information. The data from USDA-Lincoln, ORSTOM-Paris and ISRIC-Wageningen are not comparable because of differences in collection and analytical methods. The database used by Dr Post of the Oak Ridge National Laboratory (ORNL) has data for over 4000 soils, but these do not have classification units attached to them. (During a discussion after the workshop Dr Post indicated plans to access the original sources to obtain additional information on the relevant soils, including their classification and land use at the time of sampling).

2.2   Past and future uses of SMW

1)   Current applications of SMW by FAO include the Agro-ecological Zones project (AEZ), in which SMW has been incorporated with an analysis of climatic conditions. This assessment was followed by a suitability classification of the 12 main foodcrops in the world. In four countries (Mozambique, Bangladesh, Kenya and China) this study was executed in more detail, but in these studies more detailed national maps were also used.

2)   The most important use anticipated for an updated version of the Soil Map of the World (by FAO) will be in the field of optimalisation of information to obtain potential calorie production within each mapping unit of the map by means of linear programming. Other important issues are an assessment of population supporting capacity and the development of scenarios for studies on global change.

3)   At the moment FAO uses the "traditional" land evaluation approach. In it, the land suitability classification is rated on the basis of expert opinions. This means soil attributes are not directly used in this assessment. It would be useful if FAO and ISRIC could offer a "minimum soil data set", linked to SMW, to enable that different user-groups extract information in a uniform manner using the Soil Map of the World as data source. In principle, this is possible but it will take a great deal of work as profile data will have to be incorporated (see Section 2.4).

4)   Possible applications of the WISE database include:
   a)   Modelling of global emissions of greenhouse gases from soils (e.g. Bouwman, 1992). Similarly, fairly accurate descriptions of soil conditions are needed in modelling of soil organic matter turnover (e.g. Available Waterholding Capacity (AWC), texture, depth, organic carbon, nutrients; W.M. Post *pers comm.*). It was observed the WISE programme could help in identifying the "missing carbon" (see also Chapter 4 in Batjes & Bridges, 1992).
   b)   Input for Global Circulation Models (GCM), for instance with respect to soil moisture holding capacities of the components of specific soil mapping units. The grid size of the next generation of GCM's will be 1 x 1 degree latitude-longitude.
   c)   Assessment of the vulnerability of soils to specified scenario's of pollution (e.g. Hekstra, 1992)
   d)   Application in vegetation-succession models.

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2.3   Griding of SMW (30' x 30')

1)   Initially, FAO will rasterize the "cleaned" 1992 digital version of SMW at 5 x 5 minutes; such a "fine" rasterization procedure is necessary for WISE to preserve the spatial resolution of SMW. During the rasterization all information on soil classification, topsoil texture, slope and phases will be retained using FAO's "Conversion Rules" (FAO, 1991). This information is then to be "aggregated" to the 30 x 30 minutes grid cells necessary for the WISE project. A suitable procedure and algorithms for the aggregation activity still have to be developed and tested.
After the workshop, the FAO and ISRIC representatives discussed the "griding" issue *en petit commité*. Several griding procedures have been proposed. It was agreed FAO's GIS-unit would tests the alternatives for their suitability for selected parts of SMW. The test-areas are to include both "intricate" and "simple" map patterns. ISRIC staff are testing possible griding alternatives for a small section of the SMW of Africa. Results of the trials will be used to identify the most appropriate sampling method for WISE; it is crucial that FAO and ISRIC present consistent soil data sets!

2)   For each 30 x 30 minutes grid cell, 2 attribute files are to be generated:
       a)   The first file will indicate the type and relative extent of the "spatially" dominant FAO soil units (plus their topsoil texture, slope, phases where meaningful). It was suggested that the FAO soil units which account for the first ≈ 60% of a particular grid's area are to be specified in the WISE database. Specification of all possible combinations of soils, topsoil textures, slopes and phases in the WISE database may result in an unmanageable data set and is not considered necessary for WISE.
       b)   In case inclusions of the original FAO associations comprise potential methane producing soils (e.g. Histosols, Gleysols, gleyic soil units) their relative percentage of occurrence and type must be also specified in the database (This is the only information on possible natural wetlands that can be derived from SMW).

3)   It is anticipated that similar algorithms may be used for the activities listed under 2a) and 2b) but this aspect still has to be confirmed.

2.4   Minimum soil data sets

1)   Besides information on the relative extent and type of the "main" FAO soil units of a particular 30 x 30 minutes grid (see Section 2.3), the WISE database must present information on their characteristics. The basic set of attributes required for a wide range of studies at 1:5 M scale is difficult to define because modellers do not always know *a priori* which soil data they would require to model certain processes at a particular scale. Generally, sensitivity analyses are needed to show which are the most important soil factors at the considered scale. This means it would be useful for modellers to know what type of attributes can be presented/obtained in the WISE database.

The initial focus should be on specifying and quantifying "relatively stable" soil characteristics. These can be recombined into land qualities having a distinct effect on processes influencing, for instance, greenhouse gas emissions and soil vulnerability.

Some of the necessary soil attributes cannot be derived from the FAO soil classification proper. The only way to increase the current knowledge about these attributes would be to derive them from available soil profile data. An important aspect in proposing any list of soil attributes is whether the relevant information can be collected or inferred for all the FAO soil units of the world with sufficient confidence and accuracy.

A preliminary list of soil attributes for the WISE database, which was distilled from the workshop discussions, is shown in Table 1 (see Section 2.5 for additional parameters needed for methane). Software for storing and handling the data sets has to be developed, but the structure could be adapted from the Soil Data Base (FAO/ISRIC, 1989) or SOTER (Van Engelen & Pulles, 1991).

Table 1.   Proposed basic-set of "inferrable" soil attributes for FAO soil units in the WISE database*.

General
FAO soil unit
FAO phases
Mineralogy
Soil depth to hard layers
Drainage class

Per horizon (or topsoil resp. subsoil)

- Physical
Bulk density (impervious layers)
Structure
Particle size distribution (clay, silt, sand)
Stoniness (as phase)
Water holding capacity

- Chemical
Total organic matter content
Type of organic matter (C/N quotient)
Soil reaction (pH)
Depth of occurrence of $CaCO_3$
Cation exchange capacity (CEC)
Base saturation percentage
Salinity (ECe)
Alkalinity (ESP)

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*: See item 4) below for additional soil attributes needed for modelling potential methane production.

2) The workshop participants agreed that, as a first step, expert-estimates would have to be presented for all soil units (Figure 1). Then soil profiles are to be used to refine the knowledge and confidence in the presented attribute data. Possible alternatives for obtaining the necessary soil profiles were discussed; it was indicated that it will be no simple task to present a consistent set of data in view of differences in methodological and analytical approaches used at the international level.

3) At a later stage, the range in the considered soil characteristics will be given in terms of median value and range for each soil unit (minimum-maximum or confidence intervals?). As more pit descriptions become available for a given FAO soil unit, the confidence in the values will increase. Nevertheless, confidence intervals may remain large (*cf*. study of Post *et al*., 1985). For the FAO units for which there are not enough appropriate soil profiles in the literature, expert-estimates are to be used since "empty slots" will not be allowed in the database. Collection of new soil profiles to permit further quantification of soil attributes is part of ISRIC's mandate as an international information and reference centre for world soils.
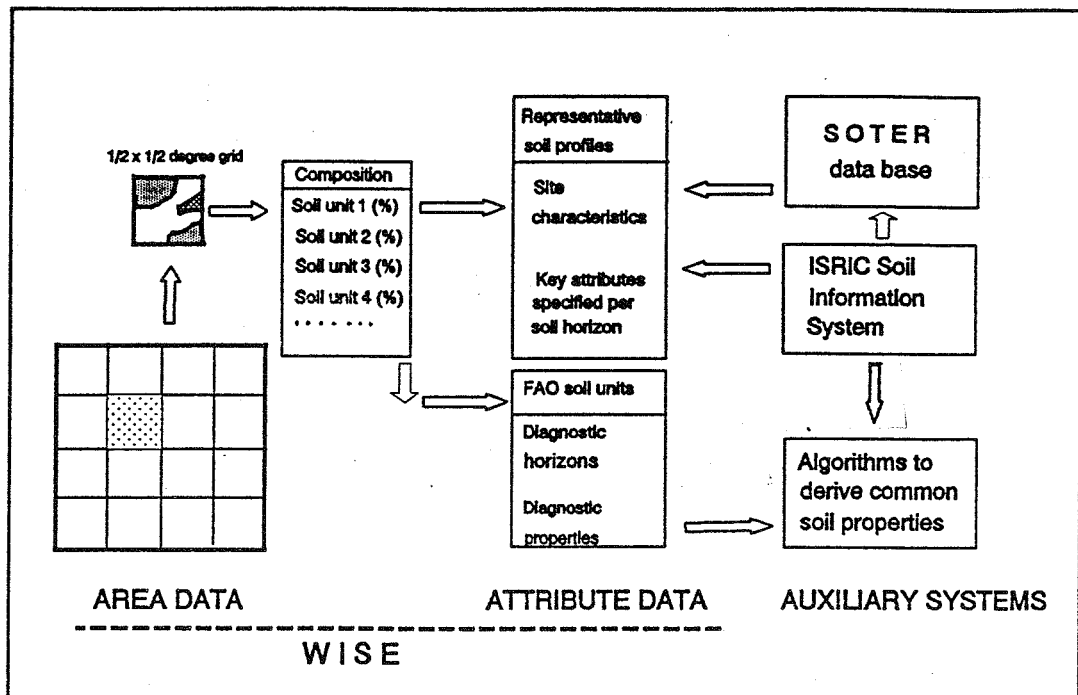
Figure 1. Schematic representation of the proposed WISE database.

4) An important question that arose with respect to Table 1 is whether a 1:5 M soil databas/e can provide the soil inputs which are considered necessary to model potential methane production according to current knowledge. If so, can this be done with better ranges that is currently the case? How can the model/list of attributes be expanded in the database? Crucial in this respect are redox- and pH-buffering capacity and soil temperature. Initially, we may have to look at baseline soil data. For example, verify that redox is essential for methane production. A

differentiation should be made between factors which control potential methane production and emission pathways (see Section 2.5).

5) The importance of spatial and temporal variability in soil characteristics was recognized by the workshop. For instance, marked differences in "dry bulk density" may be observed before and after puddling rice soils. This kind of data is essential to calculate the amount of nutrients and organic carbon present in a certain volume of soil at a particular time of the growing season. Similarly, soil pH may change rapidly upon flooding in soils with high organic carbon contents and relatively low contents of free-Fe. Critical information necessary in this context is the amount of free-Fe, not the total Fe-content. One very "coarse" clue to the amount of free-Fe present could be provided by soil colour. It would be useful to develop "proxies" that consider soil texture and mineralogy. Regressions between free-Fe and texture/mineralogy should be established, possibly using the extensive data sets available for Japanese rice fields (*cf*. Dr Kimura).

6) Soil characteristics that have an influence on the production of methane are considered more important than soil characteristics that have an influence on the transport of methane to the surface, because most methane comes to the surface through the rice plant and only a minor amount through the soil. Alternatively, upon drying, the soil's mineralogy may determine whether methane will be oxidized, e.g. in slowly cracking illitic soils, or be emitted rapidly from widely and deeply cracking smectitic soils.

7) Soil temperature may be inferred from the radiation as recorded by satellites in combination with models of heat transfer through the soil. It would then be possible to calculate bare soil temperature; soil temperature being a transient property it can not be stored in a data base. To calculate the heat balance the following would be needed: thermal conductivity, thermal capacity and diffusivity. The importance of land cover type on the soil heat balance was discussed. On longer time scales (> weekly data), soil temperature regimes may be derived from synoptic data.

2.5   Discussions on modelling

1) The WISE soil database alone will not suffice to model trace gas fluxes between the soil and atmosphere. Necessary auxiliary databases include: climate, land use, vegetation cover, wetland ecology, water regimes, net primary production, fertilizer practices. The workshop participants recognized that the collection of this kind of information is beyond the present scope of the WISE project. The primary task of WISE shall be to develop a consistent, attribute-oriented soil database with a spatial resolution of 30 x 30 minutes. Hopefully, other organizations such as the Food and Agricultural Organization of the United Nations (FAO), the International Geosphere-Biosphere Project (IGBP) will have the finances to develop some of the necessary databases at a resolution similar to the one adopted for WISE. NOP maintains a depository of global databases.

2) Several approaches to modelling are feasible, ranging from empirical to process-based. Discussions arose as to the need of considering the importance of microbiological activity in the production of greenhouse gases such as CH_4 and N_2O. As the type and kinetics of the controlling

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biological, chemical and physical processes are not completely understood, it remains difficult to develop process-based models at field level.

3) Discussions were held to discuss approaches to model CH_4 emission on a global scale. Dr Kimura presented a possible modelling approach for CH_4 production in wetland rice soils. Several remarks were made about the structure and parametrization of the model as complex interactions of CH_4 production with temperature, Eh and pH will require a sophisticated model development.

Since a model based on processes is not realistic on a global scale, the task of WISE can be seen in identifying "sensitivity" factors of soils that play a crucial role in determining the magnitude of CH_4 emission. Bachelet & Neue (1992, Table 6) proposed a rating scheme for the "methane emission potential" of FAO soil units. Recent research at IRRI indicates that the potential of rice soils for methane production vary in a very broad range, but soils can be "clustered" in 4 groups with very different methane production potentials (Denier van der Gon *et al.*, 1992). The discussion of the workshop stressed the role of organic carbon and amorphous Fe in the context of CH_4 production potential. Since the analytical procedure for quantifying amorphous Fe is not trivial, the Eh buffer capacity may serve as a criteria for soil classification purposes.

4) There was an agreement WISE should try to integrate a broad range of activities in the field of CH_4 emissions. WISE should make best use of field measurements of CH_4 emissions from rice paddies, i.e. to use data sets from past and current measurements for model development and verification. WISE should also try to integrate available field data on CH_4 emission from natural wetlands. However, with regard to the pronounced diversity of these ecosystems, model approaches are not feasible on a global scale.

5) The workshop recommended that a questionnaire should be sent to all groups involved in field measurements of both CH_4 emissions from rice paddies and natural wetlands. Basic features of the questionnaire were discussed in detail. WISE should attempt to receive soil samples from the experimental sites and to conduct appropriate soil characterizations.

6) WISE should try to establish a close relationship with inter-regional networks. The workshop explicitly proposed two networks as possible counterparts:
   a) A "window" approach for Japan. Recent attempts in Japan are aimed to coordinate all Japanese field stations that are measuring CH_4 emissions from rice paddies. Considering the climate range and the relatively high number of existing and envisaged field systems in Japan, this data set could offer an excellent tool for modelling soil specific effects under (roughly) similar climatic conditions.
   b) Inter-regional network in Asia. IRRI has started to conduct extensive field measurements of CH_4 emissions jointly with the Fraunhofer Institute. In addition to the existing field system located at IRRI, 8 field stations for measuring CH_4 emission rates in main rice growing areas of Asia will be implemented soon, so that a total of 9 stations can be integrated in an inter-regional network.

7) Beyond the direct contact with the individual research groups, WISE should give special emphasis to institutions with integrative character, e.g. IGBP working groups. A close

cooperation with these type of institutions could function as platform for communication between WISE and field researchers.

8) In his session report, Dr Wassman commented that the entire discussion on model approaches dealt with CH_4 production, and not with CH_4 emission from rice paddies. Dr Wassman's interpretation, derived from this observation and from remarks made in previous sessions of the workshop, is that WISE should focus on an inventory of soil emission potentials rather than soil emissions *per se*. Like other agro-ecosystems rice fields are subjected to a multitude of anthropogenic influences, such as water regime and cultivar selection. These agronomic measures may significantly alter the emission in a spatial and temporal scale and may overshadow soil specific effects.

9) Procedures to estimate "actual" CH_4 emissions need to be developed. This will require experiments to screen different rice varieties for their "CH_4-transporting" properties. The effect of organic amendments and soil temperature should be considered in these studies. It was observed that some plant properties, such as aerenchyma size and the production of root exudates vary not only with the cultivar but also with "environmental" stresses.

10) Process-based modelling of N_2O is not part of the WISE project and is not currently anticipated as this requires too much information (e.g. hourly rain data). Coupling of N_2O fluxes to the C-cycle would helpful. The turnover of carbon has to be coupled to the nitrogen turnover rate; this would require information on e.g. the lignin content. Subsequently, processes of nitrification and denitrification should be linked to the measured C-fluxes, with subsequent extrapolation to N_2O fluxes.

2.6 Miscellaneous

1) The SMW alone does not allow a proper demarcation and characterization of natural wetlands (contrary to what has been suggested in the project document). Only some information on the seasonality of the soil water regime can be inferred the FAO classification, e.g. for Histosols, Planosols and Plinthosols. The proposal to model CH_4 emissions from natural wetlands was considered too ambitious for WISE. Nevertheless, there remains a need to collate research data for methane emissions from natural wetlands. There is also a need for wetland investigations; how are these to be accomplished and who is going to finance these activities?

2) The site conditions are often insufficiently documented in published studies of trace gas emissions (e.g. climate, soil classification, land use, fertilizer practices, water regime). ISRIC is willing to carry out soil analyses for long-term "seasonal" measurement sites of greenhouse gases, but this would require additional financing.

3) There is a need for a few carefully selected and well described sites where fluxes can be monitored on a continual "long-term" basis (*cf*. research plots of TIGER and NOP programmes and related activities of CGTE and IGAC working groups of IGBP).

4) The workshop stressed the need for standardization of results of methane groups so that they may be linked to WISE and ancillary databases.

5) There is a need for comparability and quality assurance. Incubation experiments to measure potential methane production could, in principle, be continued using standardized incubation procedures. IRRI should take the initiative, and then link the results to the WISE database. If the reverse procedure was followed, protocols would have to be adapted to those proposed by WISE, which would not work as several protocols are already in operation.

6) The need for co-operation of a wide range of researchers involved in methane and other greenhouse gas studies was indicated. Feedback on the database approach proposed for WISE is crucial, so that the final product will be widely accepted and used (e.g. compatibility aspect). Co-operation is necessary with respect to identifying possible applications of the database and model development. Awareness about the WISE project can be obtained by participating in international conferences (e.g. First IGAC Conference at Eilat, Israel, 1993).

7) The possible importance of slope and aspect on microbial activity was raised. The location of N_2O production can change independently of the topographic position. Nevertheless, the topographic position remains an important factor. For instance, it can give an indication of areas prone to seasonally poor drainage. Run-off containing soil materials rich in organic matter into depressed areas may form an additional C-input for microbes (e.g. effect of insolation on NPP; drainage of soil; run off of sediments and organic matter or pollutants), which in turn may affect the CH_4 or N_2O emissions.

8) The concept of "puddleability" may be seen as a measure for the ease of liquefaction of soil particles under water saturated conditions and their ability to remain in a "suspended" state. It can be described as a function of texture, mineralogy and salt concentration. The "puddleability" of sandy soils and kaolinitic soils, for instance, is low. Flooding with brackish water will increase the "puddleability", particularly for smectitic clay soils.

9) The possible importance of soil capping on diffusion of gases from the soil was mentioned. It would seem that under aerated conditions there remain sufficient "cracks" to allow gaseous diffusion. Under water saturated conditions, however, the diffusivity of the gases would be greatly reduced.

10) It would be useful to make the FAO/ISRIC soil data base system available in the main official languages of FAO.

11) The representative of the NATO Scientific Council indicated the possibility for ISRIC organizing a meeting in the "Advanced NATO Scientific Series" on the current theme. Application forms for such a workshop, which would be partly financed by NATO, would have to be circulated well in advance of the proposed meeting. A possible date for organizing such a workshop would be towards the end of the WISE project in September 1994. Although interested by the proposal, the ISRIC directorate indicated that the organization of a NATO workshop would likely extend beyond the financial capability of ISRIC. The NATO Scientific Council representative pointed

at the possibility of organizing a joint meeting with other institutes; ISRIC was asked to reflect upon this possibility.

12) The question arose whether preparation and circulation of the "rice land" and "natural wetland" questionnaire should be the responsibility of the WISE project or of the "long-term" methane research groups? One discussed alternative is that the questionnaire prepared by ISRIC would be sent to IRRI (*cf.* Neue) for subsequent circulation through IGAC.

13) The invited papers presented during the WISE workshop do not relate to one consistent block of topics. Therefore, the participants agreed that:
   a) A report of the workshop discussions should be prepared and the executive summary sent to Newsletters/Journals (e.g. TIGER eye, NOP Newsletter).
   b) The invited papers are to be published as proceedings by ISRIC.
   c) The background document for the workshop should be published as a Technical Paper series of ISRIC.

3   PLAN OF ACTION FOR IMPLEMENTATION PHASE

The workshop participants proposed the following framework for proceeding with the implementation of the WISE project:
1) Griding of cleaned vector FAO Soil Map of the World (1992 digital version) to 30 x 30 minute basis.
2) Derivation of set of expert estimates for soil attributes for both the topsoil and subsoil of all FAO soil units. (This preliminary dataset would be used to prepare some output with the WISE database; elements of items 8) and 9) would be needed here)
3) Development of database structure for 2) (*cf.* ISIS and SOTER).
4) Collection of profile data for all FAO soil units as shown on SMW. (With special reference to the soils of special importance to the WISE project)
5) Development of database structure (same as for 2).
6) Maintenance, updating and distribution of the ultimate WISE database.
7) Identification of additional databases needed (*cf.* database set of NOP).
8) Development of soil-climate-land use CH_4 models (potential production and emission models) and other natural greenhouse gases from soils.
9) Identification of pilot areas: modelling of actual emissions in "windows". Models should be tested in past SOTER pilot areas to show what is feasible.
10) Detailed inventory and characterization of natural wetlands (FAO is seeking funding to develop a 1:1 M map of flooding and submergence zones).
11) Incorporation of those sections of FAO soil map that have been updated in the WISE database.

The workshop considered activities 1) to 5) to be feasible in the context of the WISE project. Additional time/funding will be necessary for the other activities. In order to produce some output, items 8) and 9) should be addressed. Staff of the WISE project alone cannot develop and validate soil-climate-land use methane emission models as these activities require a strong field-research

component; ISRIC being a soil reference centre, there is a clear need for inputs from cooperating research institutes.

With respect to activity 1) the workshop participants agreed it to be crucial that FAO makes a clear (time) commitment with respect to the preparation of a 30 x 30 minutes grid version of SMW for WISE. This is essential as the digital grid map will provide the basis for linking information on soil attributes to the various FAO soil units of the respective grid cells.

Collection of soil profile data as listed under activity 4) is seen as an open-ended activity which is part of ISRIC's mandate. The list of attributes proposed for the SOTER-shell was seen as a viable alternative for activity 4). The workshop recommended the WISE project should first concentrate on quantifying the attributes of soils of particular relevance to methane production.

The workshop participants emphasized the need for updating the Soil Map of the World using results of new soil surveys completed and published since the 1960s. This long-term activity was seen as the primary responsibility of FAO. The updating activity is to be carried out in close collaboration with national soil survey organizations and ISRIC within the framework of its SOTER project.

4   CONCLUDING REMARKS

A co-operative and fruitful discussion of the issues took place throughout the workshop when the group tackled the problems involved and procedures necessary for developing the WISE database. Possible methodologies for modelling potential methane production in rice paddies and natural wetlands were also discussed. Most workshop participants indicated studies concerning irrigated rice lands should be given priority. Already better estimates of potential CH_4 production than are currently available should be possible with WISE, even though it was realized a 1:5 M soil database may not be able to provide all the necessary detail on the main CH_4-production controlling soil characteristics. There remains a considerable uncertainty in assessing the importance of the various biological, chemical and physical factors which control the production of methane in wetland rice soils ($cf.$ Table 5 in Neue & Roger, 1992). The need for developing appropriately scaled ancillary databases on e.g. land use, flooding regimes, NPP was again stressed; all of which form essential layers of a global Environmental Geographic Information System.

In closing the workshop, the Director of ISRIC reviewed the aims of the WISE project, indicating the primary aim of the WISE workshop in identifying the way to proceed during the implementation phase has been met. The workshop recommendations will be used by ISRIC to "revise" the scope of the WISE project document, which is to be done with the agreement of NOP.

The wish for continued cooperation with research institutes, such as Nagoya University, IRRI, ORNL, Fraunhofer Institute and working groups of the TIGER, NOP and IGBP programmes was expressed, specially with respect to developing appropriately scaled models for various applications. The good cooperation between FAO and ISRIC was also appreciated. The hope was expressed that other organizations, not represented at the workshop, would show an active interest in the activities of the WISE project.

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APPENDICES

App. I   **List of acronyms and abbreviations**

GCTE	Global Change and Terrestrial Ecosystems Project (IGBP)
CGIAR	Consultative Group on International Agricultural Research
FAO	Food and Agricultural Organization of the United Nations
ICSU	International Council of Scientific Unions
IGAC	International Global Atmospheric Chemistry Project (IGBP)
IGBP	International Geosphere-Biosphere Programme: A Study of Global Change (ICSU)
IRRI	International Rice Research Institute
ISIS	ISRIC Soil Information System
ISRIC	International Soil Reference and Information Centre
ISSS	International Society of Soil Science
NATO	North Atlantic Treaty Organization
NOP	Netherlands National Research Programme on Global Air Pollution and Climate Change
ORNL	Oak Ridge National Laboratory
SMW	Soil Map of the World (1:5 M, FAO/Unesco)
SOTER	World Soils and Terrain Digital Database
TIGER	Terrestrial Initiative in Global Environmental Research (UK)
UNEP	United Nations Environment Programme
Unesco	United Nations Educational, Scientific and Cultural Organization
USDA	United Stated Department of Agriculture
WISE	World Inventory of Soil Emissions

Monday, 24 August

8:30 - 9:00	Registration at ISRIC

Formal opening

Chairman: L.R. Oldeman; rapporteur: N.H. Batjes

9:00 - 9:15	Word of welcome by Dr Ir L.R. Oldeman, Director ISRIC
9:15 - 9:30	Introduction by Dr T. Schneider, Programme Leader of "Netherlands National Research Programme on Global Air Pollution and Climate Change" (NOP-MLK).
9:30 - 9:45:	Aims and objectives of the project on "World Inventory of Soil Emissions" by Dr E.M. Bridges, Project Coordinator, WISE.
9:45 - 10:00:	Brief introduction of participants. Nomination of session chairmen and rapporteurs.
10:00 - 10:30:	Coffee break

Oral presentations

Chairman: E.M. Bridges; rapporteur: N.H. Batjes

10:30 - 11:00:	Dr G.P. Hekstra, *"Can climate change trigger non-linear and time-delayed responses to pollutants in soils, sediments and groundwaters?"*
11:00 - 11:30:	Dr H.R. Oliver, *"Studies of the spatial and temporal variation of soil temperature and soil heat flux"*
11:30 - 12:00:	Dr W.M. Post, *"Soil organic matter dynamics in the global carbon cycle"*
12:30 - 13:30	Lunch

Chairman: H.R. Oliver; Rapporteur: E.M. Bridges

13:30 - 14:00:	Dr M. Kimura, *"Methane emission from paddy soils in Japan and Thailand"*
14:00 - 14:30:	Ir H.A.C. Denier van der Gon, *"Controlling factors of CH_4 emission from rice fields"*
14:30 - 15:00:	Dr R. Wassmann, *"Methane emissions from Chinese rice paddies as influenced by different fertilizers"*
15:00 - 15:30:	Tea/coffee break

Chairman: M. Kimura, Rapporteur: E.M. Bridges

15:30 - 16:00	Ir A.F. Bouwman, *"Methodology and data used to estimate natural N_2O emissions"*
16:00 - 16:30	Dr F.O. Beese, *"Effects of liming, nitrogen fertilization and clear-cutting on emissions of CO_2 and N_2O from temperate forests"*
16:30 - 17:00	Ir N.H. Batjes, *"The WISE database: General considerations on possible structure and attributes."*

Tuesday, August 25: **Working group discussions**

8:45 - 10:00	*Chairman: F.O. Beese, Rapporteur: E. Veldkamp* Trace gas emissions from soils (with particular reference to CH_4, N_2O and CO_2): the process controlling factors and current measurement techniques.
10:00 - 10:30	Coffee break
10:30 - 12:30	*Chairman: E.M. Bridges, Rapporteur: E. Veldkamp* Presentation by Dr J. Goudriaan on *"Modelling the carbon cycle"*. Current methods of modelling trace gas fluxes from terrestrial ecosystems and possible means of scaling up at a global level.
12:30 - 13:30	Lunch
13:30 - 15:00	*Chairman: F. Nachtergaele, Rapporteur: J.H.V. van Baren* Role of soil classification (particularly the Legend of the FAO/Unesco Soil Map of the World) in identifying and locating soils with similar potential for emission/absorption of specified greenhouse gases.
15:00 - 15:30	Tea/coffee break
15:30 - 17:30	*Chairman: A.F. Bouwman, Rapporteur: N.H. Batjes* Soil input data for "greenhouse gas emission" and other global models: what should (and can) be the attribute data of a 1/2 by 1/2 degree grid 1:5 M soil data base for the world?
19:00 -	Preparation of session reports by relevant chairmen and rapporteurs.

Wednesday, August 26: **Working group discussions**

8:45 - 9:15	*Chairman: V.W.P. van Engelen, Rapporteur: E. Veldkamp* Presentation and confirmation of session reports
9:15 - 10:15	Likely applications of an updated 1/2 by 1/2 degree grid soil data base in a global GIS; compatibility requirements.
10:15 - 10:30	Coffee break
10:30 - 12:30	*Chairman: V.W.P. van Engelen, Rapporteur: N.H. Batjes* Formulation of mutually accepted procedure, structure and attribute data for compiling the WISE database; cooperation with other agencies (e.g. FAO, IRRI, etc.).
12:30 - 13:30	Lunch

	Chairman: H.U. Neue, Rapporteur: R. Wassman
13:30 - 15:00	Recommended approach to modelling methane emissions at the global level in context of WISE programme. Availability of ancillary data bases (e.g. land use, climate, flux data).
15:00 - 15:30	Tea/coffee break
	Chairman: E.M. Bridges, Rapporteur: N.H. Batjes
15:30 - 17:30	Miscellaneous discussions points of relevance to WISE
19:00 -	Preparation of session reports by relevant chairmen and rapporteurs.

Thursday, August 27: **Concluding session**

	Chairman: E.M. Bridges, Rapporteur: N.H. Batjes
8:45 - 9:15	Presentation and confirmation of session reports
9:15 - 10:15	Findings and recommendations; formulation of priorities and realistic plan for implementation phase of WISE; other matters arising.
10:15 - 10:30	Coffee break
10:30 - 12:30	**Closing session**
	Chairman: L.R. Oldeman, Rapporteur: N.H. Batjes
12:30 - 13:30	Lunch
	Plenary lecture
16:00 - 17:30	Dr H.-U. Neue, *"Wetland rice: soil-plant interactions"*

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