



## Modeling microbial respiration: Additional benefit of CENTURY 4.0 Model

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### ARTICLE INFO

#### Article history:

Received: 19 February 2015;

Received in revised form:

15 November 2015;

Accepted: 20 November 2015;

#### Keywords

Variables, Simulated, Measured, Microbial respiration, Soil carbon, Complimentary, Supplementary, Land management, Perturbations, Human civilisation, Soil regeneration, Soil health, Modelling.

### ABSTRACT

The CENTURY 4.0 Model have many variables that can be simulated. One of them is microbial respiration. In soil carbon studies there are three principal parts: total organic carbon, CO<sub>2</sub>-C and CO<sub>2</sub>. They are used to quantify soil carbon storage, microbial biomass and microbial respiration respectively. Soil total carbon comes from photosynthesis, translocation, decomposition, mineralisation processes. Soil CO<sub>2</sub>-C gives basic mass of microbial communities while soil CO<sub>2</sub> is indicator of microbial respiratory activities. They are complimentary and supplementary approaches to virtual soil health. They are strong indicators of life in the soil media. The CENTURY 4.0 Model has additional benefit of simulating microbial respiration. In this study measured and simulated soil microbial respiration was compared in a Hanslope Soil under different land management practices. The simulated results started with ages record of 59.6 g m<sup>-2</sup> y<sup>-1</sup> soil respiratory rate to as low as 0.001 g m<sup>-1</sup> y<sup>-1</sup> in other periods of perturbations and human civilisation that impinged on natural processes of soil regeneration.

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### Introduction

Living cells need a constant supply of energy, which for heterotrophic microflora is derived from the transformation of organic matter such as cellulose, proteins, nucleotides and humidified compounds. Energy supplying reactions in the cell are redox reactions based on the transfer of electrons from a donor to an acceptor. Through aerobic respiration, that is the oxidation of organic matter by aerobic micro organisms oxygen functions as the terminal acceptor of the electrons. The metabolic activities of soil micro-organisms can therefore be quantified by measuring the CO<sub>2</sub> production or O<sub>2</sub> consumption (Alef, 1995; Nannipieri *et al.*, 1990).

Soil respiration is one of the oldest and still most frequently used parameters for quantifying microbial activities in soils (Kieft and Rosacker, 1991). Basal respiration is defined as respiration without the addition of organic substance to soil. Substrate-induced respiration (SIR) is the soil respiration measured in the presence of an added substrate such as glucose. Respiration is not only restricted to micro-organisms but is also carried out by other organisms inhabiting the soils. Like other metabolic activities it depends on the physiological state of the cells and is influenced by different factors in the soil (Alef, 1995).

Respiration is influenced by soil moisture, temperature, the availability of nutrients, soil structure and tillage. Air drying significantly reduces soil respiration. Re-moistened soils however show very high initial activities, probably as a result of the high concentration of easily degradable organic compounds such as amino and organic acids caused by chemical and physical processes at the moistening of dry soils (Clark and Kemper, 1967; Anderson, 1975; Wilson and Griffin, 1975a, 1975b; Kowalenko *et al.*, 1978; Krockel and Stolp, 1986; Kieft *et al.*, 1987).

The re-moistening of air dry soils containing carbonate also causes the release of abiotic CO<sub>2</sub>. In this case it is recommended that the O<sub>2</sub> consumption be measured (Anderson, 1982; Kieft *et al.*, 1987). Soil respiration decreases with the depth of soil and

correlates significantly with SOM (C<sub>org</sub>) and most microbial parameters (Stotzky, 1965; Thalmann, 1968; Parkinson *et al.*, 1971; Alexander, 1977; Gray and Williams, 1977; Anderson and Domsch, 1978a,b; Domsch *et al.*, 1987; Alef *et al.*, 1988; Suttner and Alef, 1988; van de Werf, 1989; Alef, 1990).

Soil respiration changes according to soil treatment and cultivation methods and has been used as a measure of the effects of chemicals such as pesticides and heavy metals (Jaggi, 1976; Anderson *et al.*, 1984; Beck, 1984a, 1985; Malkolmes, 1985; Carlisle and Trevores, 1986; Domsch and Schroder, 1986; Wilke, 1986; Somerville and Greaves, 1987; Alef *et al.*, 1998; Schlosser, 1988; Schuster, 1988)

Basal soil respiration can be followed for long periods of time. However, changes in the composition of aerobic microflora can occur during long term incubation. In the case of the SIR method, a change in population is expected when the incubation period is longer than 4 – 6 h (Anderson and Domsch, 1978b). The incubation temperature used varies between 20 and 30°C and the water holding capacity between 50 and 70%. The pH value of the measurement is usually that of the soil in water (Alef, 1995)

Several process-based models exist for the assessment of environmental parameters. They have been developed after several years of continuous monitoring, testing and re-validation. Two of the most widely used models are the CENTURY 4.0 and the RothC (Farage *et al.*, 2005; Parton, 1996; Smith *et al.*, 1996). Modeling helps to understand the principal mechanisms affecting ecosystem functioning and the causes of disturbances to them. They are essential for long term predictions and in making recommendations aimed at reducing harmful effects and preventing environmental disturbances (Ifremer, 2005). Many authors have demonstrated the benefits of using computer models in agriculture (Igboji, 2015; Farage *et al.*, 2005; Paul *et al.*, 2003; Webb *et al.*, 2003; Pumpanen *et al.*, 2003; Qian *et al.*, Parton, 1996; Smith *et al.*, 1996, 1997).

The CENTURY model version 4.0 embodies the best understanding to date of the biogeochemistry of C, N, P, and S

(Parton *et al.*, 1993). The primary purposes of the model are to provide a tool for ecosystem analysis, to test the consistency of data and to evaluate the effects of changes in management and climate on ecosystems. The CENTURY Agroecosystem Version 4.0 was developed to deal with a wide range of cropping system rotations and tillage practices, for the systematic analysis of the effects of management and global change on productivity and sustainability of agroecosystems. Version 4.0 integrates the effects of climate and soil driven variables including agricultural management to simulate C, N, and H<sub>2</sub>O dynamics in the soil-plant system. Simulation of complex agricultural management systems including crop rotations, tillage practices, fertilization, irrigation, grazing and harvest methodologies are possible in the model (Parton *et al.*, 1993). The CENTURY model is a general FORTRAN model of the plant-soil ecosystem that has been used to represent C and nutrient dynamics for different types of ecosystems (grasslands, forest, crops and savannahs). Aspects of the 4.0 version have been discussed in Metherell (1992) while a more detailed description of the CENTURY model are in Parton *et al.* (1983), Parton *et al.* (1987) and Sanford *et al.* (1991). The validity of the model in predicting soil carbon have been widely tested as detailed in Igboji (2015). The broadness of its parameters made simulation of soil microbial respiration possible.

## Materials and Methods

### Site description

The details site have been given in Igboji (2015)

### Century model overall structure

This have been fully described in Igboji (2015)

### Century key model processes and assumptions

These have also been detailed in Igboji (2015)

### Century inputs requirements, weather and management information

These have been described in Igboji (2015).

### The Century Environment

These have been detailed in Igboji (2015)

### Century parametisation and events scheduling

This have been fully described in Igboji (2015)

### Characteristics of the study periods scheduled

This is as detailed in Igboji (2015).

### Scheduling of arable land under barley

This was presented in Igboji (2015)

### Scheduling of grassland under permanent pasture sown with red clover a year before stocking

This was presented in Igboji (2015)

### Scheduling of grassland under permanent pasture on 5 year ley before stocking

This was done in Igboji (2015)

### Scheduling of deciduous woodland

This was presented in Igboji (2015).

### Statistical and data analysis

Simulated soil microbial respiration was left as  $\text{g m}^{-2}$ . To compare simulated soil microbial respiration rate in  $\text{g m}^{-2} \text{y}^{-1}$  with that of measured soil microbial respiration in  $\text{g m}^{-2} \text{h}^{-1}$  the simulated results were divided by 8760 hours (365 days x 24 h). Regression analyses was done on measured and simulated microbial respiration to determine goodness of fit (Zar, 1999).

## Results and Discussions

### The effects of land management on measured and simulated soil microbial respiration

A comparison was made between measured and simulated soil microbial respiration in order to assess the proximity of the simulated data to actual results. The differences in measured and simulated soil microbial respiration in all sites were not

statistically significant. A weak relationship was established between measured and simulated soil microbial respiration in first year ( $R^2 = 0.4$ ).

### Changes in soil microbial respiration from historic agriculture to post green planet

#### Arable land under barley

This site was under barley during the model period but was previously under different cropping and nutrient management regime for the past 40 years and was assumed to be in model time management up to 2055 as in the schedule described by Igboji (2015). Fig 1 shows the changes in soil microbial respiration on 39 – 40 year basis in this site from 1942 – 2055. Soil microbial respiration dropped from  $22.3 \text{ g CO}_2 \text{ m}^{-2} \text{ y}^{-1}$  between 1942 – 1947 to  $<10 \text{ g CO}_2 \text{ m}^{-2} \text{ y}^{-1}$  between 1948 – 1981 (post agricultural revolution). The fluxes between 1982 – 2021 was remarkable but less than  $20 \text{ g CO}_2 \text{ m}^{-2} \text{ y}^{-1}$  (green planet). From 2022 to 2055 (post green planet) it will remain  $<5 \text{ g CO}_2 \text{ m}^{-2} \text{ y}^{-1}$  under the current land management

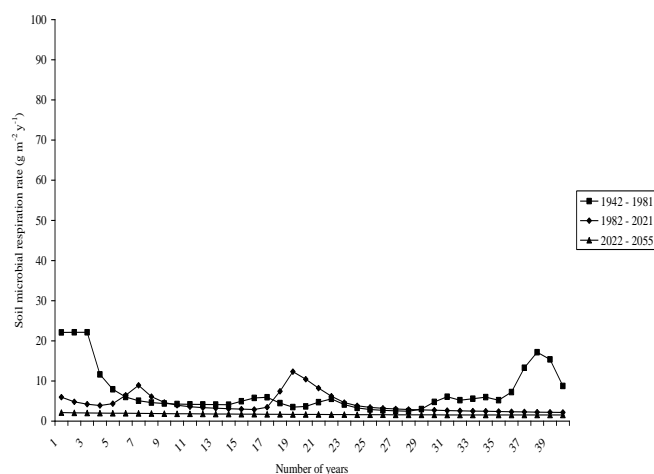


Fig 1. Changes in soil microbial respiration ( $\text{g m}^{-2} \text{y}^{-1}$ ) in arable land under barley

#### Grassland under permanent pasture sown with red clover a year before stocking

This site was sown with red clover as part of rye-grass rejuvenation before stocking during the model period but was previously under various cropping/nutrient and pasture management for the past 40 years and was assumed to be in model time management up to 2055 as indicated in the schedule of Igboji (2015). In this site the changes in soil microbial respiration on 39 – 40 year basis from 1933 – 2055 is presented in Fig 2. The rate of soil microbial respiration during the period 1973 – 2012 was more than that between 1933 – 1972 (from  $28.2$  to  $52.4 \text{ g CO}_2 \text{ m}^{-2} \text{ y}^{-1}$ ) arising from similar factors described in Igboji (2015) but remained  $<30 \text{ g CO}_2 \text{ m}^{-2} \text{ y}^{-1}$  at other periods.

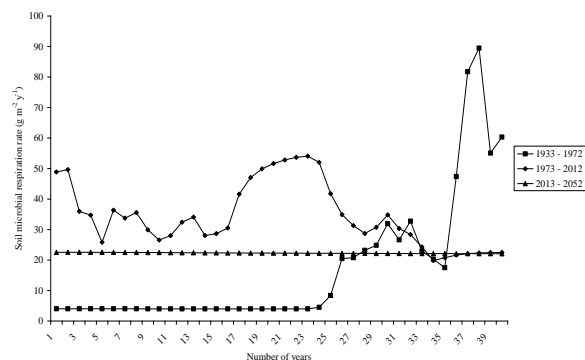
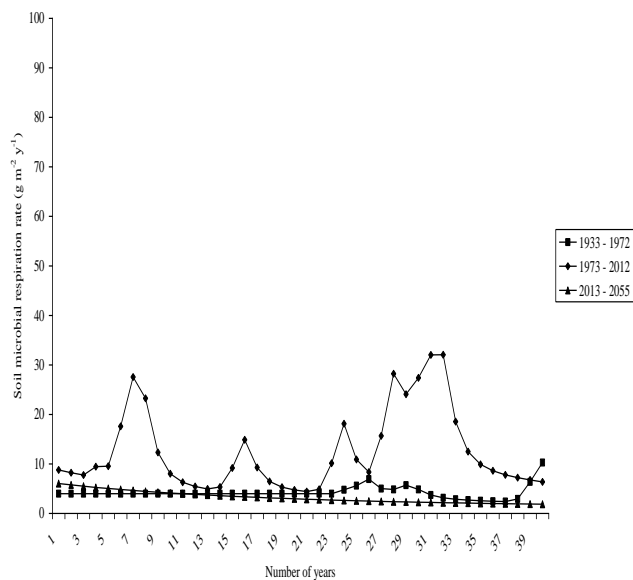


Fig 2. Changes in soil microbial respiration ( $\text{g m}^{-2} \text{y}^{-1}$ ) in grassland under permanent pasture sown with red clover a year before stocking

### Grassland under permanent pasture on 5 year ley before stocking

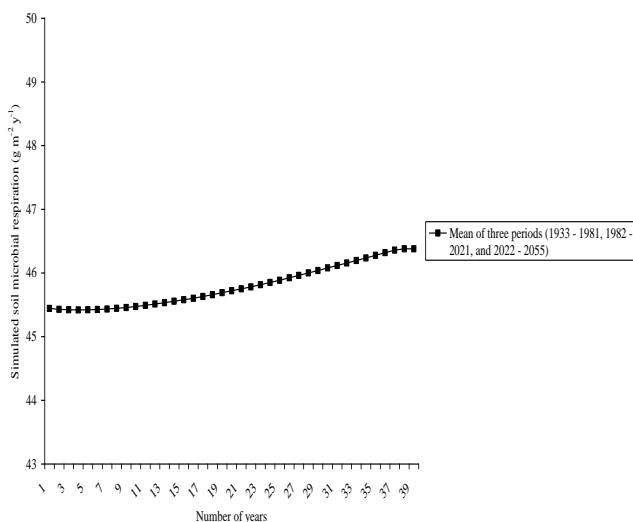
This site was on 5 year ley in the course of rye-grass rejuvenation before stocking during the model period but was previously under various cropping/nutrient and pasture management for the past 40 years and was assumed to be in model time management up to 2055 as indicated in the schedule (Igboji, 2015). The changes in simulated soil microbial respiration on 39 – 40 year basis between 1933 – 2055 is shown in Fig 3. A considerable flux in soil microbial respiration was recorded between 1973 – 2012 ( $9.8 - 32.5 \text{ g CO}_2 \text{ m}^{-2} \text{ y}^{-1}$ ) while other periods recorded  $<10 \text{ g CO}_2 \text{ m}^{-2} \text{ y}^{-1}$ .



**Fig 3. Changes in soil microbial respiration ( $\text{g m}^{-2} \text{ y}^{-1}$ ) in grassland under permanent pasture on 5 year ley before stocking**

### Deciduous woodland

This site was deciduous woodland during the model period and was scheduled as such for the past 40 years and up to 2055. The changes in soil microbial respiration on 39 – 40 year basis from 1933 – 2055 is shown in Fig 4. In this site soil microbial respiration remained nearly uniform over the assessed periods at  $45 - 46 \text{ g CO}_2 \text{ m}^{-2} \text{ y}^{-1}$  due to no tillage and nutrient management.



**Fig 4: Changes in soil microbial respiration ( $\text{g m}^{-2} \text{ y}^{-1}$ ) in deciduous woodland**

### The effects of time and land management on simulated soil microbial respiration

Simulated soil microbial respiration during prehistoric agriculture (6000 BC to 1200 AD) started with  $59.6 \text{ g m}^{-2} \text{ y}^{-1}$  in all sites and ending with 6.1, 4.7, 4.7 and  $46 \text{ g m}^{-2} \text{ y}^{-1}$  in arable land under barley, grassland under permanent pasture sown with red clover a year before stocking, grassland under permanent pasture on 5 year ley before stocking and deciduous woodland respectively. The rough grazing practiced in three sites with the exception of deciduous woodland affected soil microbial respiration. Soil microbial respiration decline in deciduous woodland over this period is dependent on several factors, example loss of SOM during the geobiochemical cycling of C. During the historic agriculture (1201 – 1699) simulated soil microbial respiration started with 6.1, 4.7, 4.7 and  $46 \text{ g m}^{-2} \text{ y}^{-1}$  in sites 1 – 4; increasing to 22.1, 23.6, 21.9 and  $46.2 \text{ g m}^{-2} \text{ y}^{-1}$  in sites 1 – 4 respectively. The same factors that enhanced simulated C (Igboji, 2015) may also have enhanced soil microbial respiration.

During the agricultural revolution (1700 – 1904) simulated soil microbial respiration stood at 22.1, 23.6; 21.9, and  $46.2 \text{ g m}^{-2} \text{ y}^{-1}$  in sites 1 – 4, declining to 4.2, 4.0, 4.0 in sites 1 – 3 but increasing to  $46.3 \text{ g m}^{-2} \text{ y}^{-1}$  in site 4 (deciduous woodland). The agricultural land management practices at this period as described by Igboji (2015) also played significant role.

During the post agricultural revolution (1905 – 1986) simulated soil microbial respiration started with 4.2, 4.0, 4.0 and  $46.3 \text{ g m}^{-2} \text{ y}^{-1}$  in sites 1 – 4; increasing to 4.3, 28.1, 5.3 and  $46.4 \text{ g m}^{-2} \text{ y}^{-1}$  in sites 1 – 4 respectively. The increase in soil microbial respiration was the aftermath of cropping and grazing pattern introduced at this period.

During the green planet (1987 – 2025) simulated soil microbial respiration started with 4.3, 28.1, 5.3 and  $46.3 \text{ g m}^{-2} \text{ y}^{-1}$  in sites 1 – 4 declining to 2, 22.4;  $3.7 \text{ g m}^{-2} \text{ y}^{-1}$  in sites 1 – 3 but increasing to  $46.4 \text{ g m}^{-2} \text{ y}^{-1}$  in site 4. The impact in management regime for this period as described by Igboji (2015) may have affected simulated soil microbial respiration.

As at the post green planet era (2026 – 2055) simulated soil microbial respiration started with 2, 22.4, 3.7 and  $46.4 \text{ g m}^{-2} \text{ y}^{-1}$  in sites 1 – 4, declining to 1.5, 22,  $1.8 \text{ g m}^{-2} \text{ y}^{-1}$  in sites 1 – 3 but remaining at  $46.4 \text{ g m}^{-2} \text{ y}^{-1}$  in site 4 (deciduous woodland).

When two years model simulated values was assessed soil microbial respiration started with 8.2, 34.8, 27.4 and  $46.4 \text{ g m}^{-2} \text{ y}^{-1}$  in sites 1 – 4, decreasing to 4.6 and  $28.4 \text{ g m}^{-2} \text{ y}^{-1}$  in sites 1 and 2, increasing to  $32 \text{ g m}^{-2} \text{ y}^{-1}$  in site 3 and remaining at  $46.4 \text{ g m}^{-2} \text{ y}^{-1}$  in site 4. The ley used for rye-grass rejuvenation may have enhanced soil microbial respiration, while low soil organic carbon and nitrogen in arable land under barley may account for reduced simulated soil microbial respiration at this period. The reduction in simulated soil microbial respiration in clover pasture at the end of this period was very negligible and this was further manifested during the post green planet, where the reduction in simulated soil microbial respiration in this plot for 29 years was less than  $0.4 \text{ g m}^{-2} \text{ y}^{-1}$ .

Soil respiration can be influenced by several factors – type of soil and crop, pattern of cropping, crop harvesting and removal. Others include pattern and type of tillage, nutrient, pest and weed management. In this study only one type of soil was measured and simulated (Hanslope) with its distinct characteristics (high clay). A Hatfield or other types of soil in the area may have a different result. Likewise, the major crops were wheat and barley. Other crops like rape seed may give different value. Even though crop rotation was the practice during prehistoric agriculture, mono cropping became the rule

during the agricultural revolution up to green planet . Crop combinations including reforestation of arable or grassland may give a different scenario. Conventional tillage (horse drawn or plough) was used in sites since prehistoric agriculture. The scenario may be different with no or minimum till. Organic matter was added in the form of wheat or barley in arable plot (50% straw was assumed removed during crop harvesting and 50% straw was assumed retained in the field for incorporation into the soil during seedbed preparation. The addition of compost or farm yard manure may give a different result. There were also record of use of chemicals to control pests and diseases in the arable plots, but which could not be incorporated in the model used for this simulation

A similar model that can incorporate pest and disease control scenarios will give a different value. For grassland and pasture soils the effects of stocking density, carrying capacity, silage and hay making as well as periods of ley and pasture rejuvenation also play significant role on microbial respiration.

Apart from the stocking density which was grouped into low, moderate and high grazing in the model, other parameters like carrying capacity and periods of ley were not categorized in the model. The categorization of these parameters in models may enhance simulated values. Hence, these explain why for over 7200 years prehistoric agriculture there was high microbial respiration. This period was marked by natural regeneration of vegetation and little or no perturbations. The trend started dropping at other periods assessed

Micro-organisms are thus earth's most versatile inhabitants, surviving even the most extreme environments. They inhabit land, sea, and air as either free living, as parasites or in symbiotic relationships with other organism. One gramme of soil may contain billions of micro-organisms including bacteria, fungi, protozoa and algae. This population plays key role in maintaining life on earth, fixing atmospheric gases and breaking down dead plant and animal matter into organic substances that are used at the beginning of the food chain. Without micro-organisms, no other life on the planet would be possible (Ogunseitan, 2005, Bull, 2003; SGM, 2000; Pimm and Raven, 2000; UNEP, 1992). Soil micro-organisms play crucial role in determining the patterns of interaction of elements known as geochemical cycles.

They are major agents by which C and energy move through the soil. Soils provide a major source and sink for greenhouse gases particularly CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O (Pidwimy, 2005; RCEP, 1996; Houghton and Hackler, 1995). The world's soils represent a very large reservoir of C.

The release of CO<sub>2</sub> from soils is a natural process occurring through the oxidation of SOM and plant litter by microbial populations. The rate at which CO<sub>2</sub> is released depends on land use and soil management. Accelerated loss can be triggered by the changes in land use, for example when forests or grasslands are converted to arable cropping (RCEP, 1996). C can accumulate in soil when arable land is converted to grassland or forest but it takes about ten times to build up soil C following conversion to pasture than it takes to deplete C stocks after pasture land has been ploughed (RCEP, 1996). It has been observed that C accumulates much more slowly following a change from arable to pasture; 49 t ha<sup>-1</sup> might be added over 275 years, half of it in the first 38 years (RCEP, 1996; Cannel *et al*, 1994). Human influence on the natural cycle has resulted in the accelerated release as atmospheric CO<sub>2</sub>, from those contained in the chalk, limestone and fossil fuels formed over a very long time from oceanic sediments (RCEP, 1996).

## Conclusion

Simulation of soil microbial respiration has been made possible in CENTURY 4.0 Model given additional parameters. The differences in measured and simulated soil microbial respiration in all sites were not statistically significant. Closeness of fit between simulated and measured values were established. The different agricultural practices that affected soil carbon and sequestration in Igboji (2015) also affected soil microbial respiration for the respective periods.

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