Recognition of notable past soil scientists

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Abstract

The chapter highlights the achievements of notable scientists who have made considerable contributions to our understanding of soils.

Introduction

The technical chapters in this edition of the Encyclopedia of Soils in the Environment very clearly demonstrate the impact over the last 20 years that the application of new technologies has had on our knowledge of soil, the material from which, with sunlight, we derive our daily food. Although the varied characteristics of soil have long been recognized, it would be fair to claim that modern soil science started with Nicolaus of Cusa (1401–1464), who designed a theoretical experiment (in 1450) that Johannes Baptista van Helmont (1579–1644) carried out in what is claimed to be first quantitative experiment in history. He grew a willow tree (*Salix* sp., L.) for a period of 5 years in a pot of soil, enclosed with a perforated lid, and established that the plant removed water from the soil and there was little or no loss of soil solids (van Helmont, 1648). Building on this Stephen Hales (1677–1761) distinguished between the weight of water lost from the soil during the growth of sunflower (*Helianthus annuus*, L.) and the mass transpired (Hales, 1727), essentially separating transpiration through the plant from evaporation from the soil. Hales also estimated the quantity of water added to soil from dew. Philippe de la Hire (1640–1718), who is generally recognized as pioneering the use of lysimeters, and Edmond Halley (1656–1742), now more associated with astronomy and planetary motion, investigated the water balance following precipitation reaching the soil surface. Firstly, de la Hire (1703) demonstrated links between precipitation, drainage and plant water use and then Halley (1687, 1691), recognizing the large volume of water in the atmosphere, emphasized that a quantitative estimate of evaporation was essential to formulate the hydrological cycle between sea and land. However, Halley (1691) did not believe that rain (plus dew) was the source for all springs and rivers. John Dalton (1766–1844), now better known for his atomic theory (Dalton, 1805), also made use of a lysimeter in correctly establishing the components of the hydrological cycle and applying his understanding to derive a water balance for England and Wales (Dalton, 1802a). This required an estimate of the loss by evaporation (E) which he determined as a function of the temperature of the water and the vapor pressure of the atmosphere, together with wind speed such that

$$E = c\,(e^{*} - e)$$

where c is a factor depending on wind speed, e^{*} is the saturated vapor pressure at the temperature of the water and e is vapor pressure of the air over the period of observation (Dalton, 1802b). This provides an example of the development of a topic, in the period of the natural philosophers, that is so critical to the understanding of soil and ecosystem functioning in this era of climate change. In this chapter, the contribution of some past scientists to soils in the environment is recognized.

In the 1st edition of this encyclopedia, the biographical accounts of the activities of J.B. Lawes (1814–1900) and J.H. Gilbert (1817–1901), at what is now Rothamsted Research (Harpenden, UK) focused on their field-based investigations, which earned them recognition as the founding fathers of the scientific method in agricultural research (Johnson, 2005). What is not mentioned is their establishment of the first lysimeters built to retain the natural structure and profile of the soil and its use in determining the quantity and chemical quality of the deep drainage component of the soil water balance (Lawes et al., 1881a,b). The contribution of H. L. Penman (1909–1984), also at Rothamsted, to the science of evaporation of water from land, either cropped or uncropped and rainfed or irrigated, was described in the 1st edition of this publication by Monteith, who contributed to the equation for evaporation from cropped land that bears both their names. Penman's 1948 equation overcame contemporary equipment limitations to measurement of the temperature of an evaporating surface by combining thermodynamic and aerodynamic equations for heat and mass transfer from a surface, where water was freely available. The equation included a parameter

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representing the change in saturated vapor pressure with temperature, which could be treated as a constant over the range of temperatures involved in most systems involving natural evaporation.

The contribution of Monteith (1929–2012) was to extend the Penman formula for application to vegetation (Monteith, 1965). His approach was to rewrite the Penman formulation in a form applicable to single leaves, developing the idea that diffusion from saturated surfaces within leaves was a component of the transfer pathway of water to the atmosphere. This required addition of a parameter to describe stomatal restriction of the diffusion of water. Another parameter was required to represent the external diffusion resistance controlling the flux of water vapor from the leaf driven by the vapor pressure difference between the leaf surface and the free atmosphere. This modified Penman equation has become known as the Penman–Monteith (PM) equation. In 1998 it was taken up as the basis of a globally valid standard for crop water requirement calculations for the Food and Agriculture Organization (FAO) of the United Nations (Allen et al., 1998). The FAO PM equation has the form that only requires meteorological data as input and the predicted evapotranspiration applies to a hypothetical crop, 0.12 m tall, having a fixed canopy resistance and albedo. It is envisaged as resembling an extensive area of green grass of uniform height, that completely shades the soil and has an adequate water supply. It has also become the standard approach to establishing irrigation needs (Allen et al., 2023).

In 1967, Monteith was appointed Professor of Environmental Physics in the School of Agriculture at Nottingham University, creating a strong team with both teaching and research responsibilities. The research had a dual focus: first, microclimate and carbon balance of barley crops, including physiological, agronomic and hydrological components; second, the physics of the animal environment, particularly animal heat balance. In 1976, the work on microclimatology was extended to include tropical crops. Based on the notes for his greatly appreciated class lectures, Monteith published the highly influential text "Principles of environmental physics" in1973, which extended to four editions, the last three being jointly authored with Michael Unsworth (now Professor Emeritus, College of Earth, Ocean and Atmospheric Sciences, Oregon State University). Some 20 y after moving to Nottingham, during which he served as Head of the Department of Physiology and Environmental Science (1970–73 and 1979–82) and Dean of the School of Agriculture (1985–86), Monteith took up the position of Director of Resource Management Division at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in Hyderabad, India. His responsibilities also extended to outstations, including one in Niger in the sub-Sahel. Monteith effectively changed the way in which agronomists and crop physiologists considered the influence of weather on dry matter production by focusing on solar radiation, temperature and humidity. First, the rate of crop dry matter production was proportional to the rate at which a crop canopy intercepted radiant energy (the radiation use efficiency, e), when light was a major limiting factor, with crop yield being a linear function of the cumulative radiation intercepted over the growing season. Second, the dry matter produced per unit of water transpired (transpiration efficiency, q) is almost proportional to the mean value of the saturation vapor pressure deficit of the atmosphere (D) to which the canopy is exposed during the day.

Monteith then introduced the concept of normalized rainfall or irrigation (P_n), where

$$P_n = \frac{P}{D} \cdot D_0$$

P is the rainfall or irrigation in mm and D_0 is the normalizing factor, which has the same units as D (for D in kPa, $D_0 = 1$ kPa).

The dry matter produced per unit of water transpired can be similarly normalized and the slope of the ratio $j = e/qD$ provided a new climatic index and could be used to estimate the potential rate of transpiration (E), rather than by summing a radiation term and an aerodynamic term, as in the Penman equation.

The rate of dry matter accumulation per unit area is given by qE and by efS, where f is the fraction of solar radiation, S, incident per unit area

$$efS = qE$$

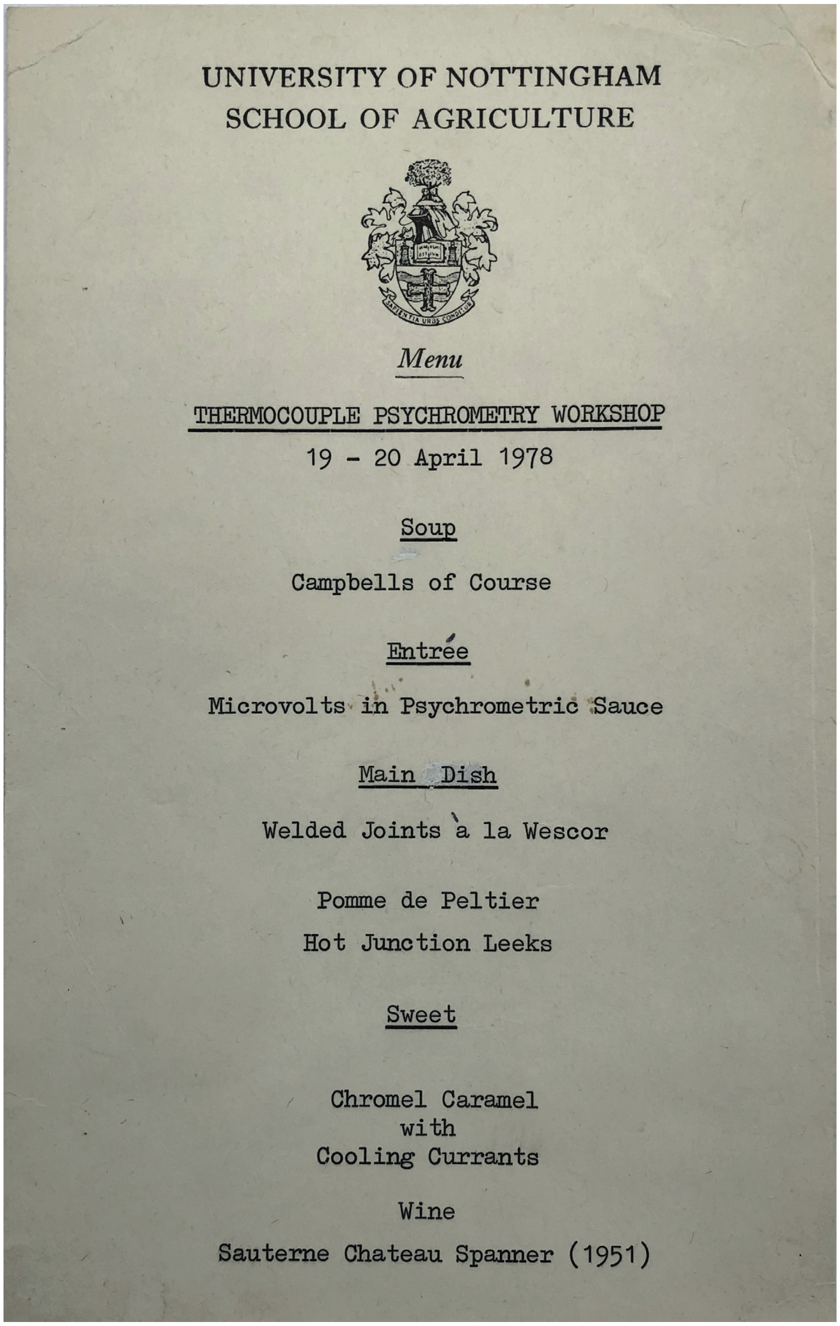
$$E = fjSD$$

Monteith plotted normalized monthly rainfall, j^*, against incident radiation over the same time period and indicated on the graph the relationship for a constant value of j per MJ m^{-2}. He argued that during those months where values of normalized rainfall, j^*, exceeded the value of j, crop production was energy limited but when $j^*$was less than j, it was water limited.

When water was limiting, Monteith's contribution was to demonstrate how crop transpiration depends on the rate at which the root system grows down and proliferates within the soil profile. The period available to the crop for growth is dependent on both soil and climate.

John Monteith was born on the west coast of Scotland but moved to Edinburgh at the age of eleven. Quietly spoken and friendly, he had a great sense of humor. At one workshop on thermocouple psychrometry led by his friend Gaylon Campbell, Monteith circulated a spoof menu for the dinner, offering "Campbell's soup, Welded joints à la Wescor (the main manufacturer at the time), with a sweet of chromel caramel (chromel is an alloy much used in thermocouple manufacture) with cooling currants all washed down with Sauterne Chateau Spanner" (Spanner had been a major proponent of thermocouple psychrometry) (Fig. 1). He is also reported to have jokingly attributed the origin of *albedo* to a fictitious American astronomer, Al Bedo, whom Monteith described as studying the reflectivity of stars!

Organic matter content is a critical component of soil, being crucial for structure, the chemistry and biology that underpin its functioning and associated ecosystem services. However, the chemical investigation of the material as a whole was based on its extraction from soil using a strong alkaline solution (now typically sodium hydroxide at pH 13) that was subsequently protonated



UNIVERSITY OF NOTTINGHAM
SCHOOL OF AGRICULTURE

Menu

THERMOCOUPLE PSYCHROMETRY WORKSHOP
19 - 20 April 1978

Soup

Campbells of Course

Entrée

Microvolts in Psychrometric Sauce

Main Dish

Welded Joints à la Wescor

Pomme de Peltier

Hot Junction Leeks

Sweet

Chromel Caramel
with
Cooling Currants

Wine

Sauterne Chateau Spanner (1951)

Fig. 1 Menu composed for dinner at a workshop on soil psychrometers by John Monteith.

to enhance its solubility. There have been a number of additional assumptions about the nature of soil organic matter (SOM) that have been associated with the analysis of the extracted material, including its recalcitrance and hence long residence time in soil. It has also been assumed that SOM has been formed following microbial breakdown of plant and animal remains, and the decomposed material being subject to secondary synthesis of compounds of large molecular weight under the influence of metals or extra-cellular enzymes. Recent assessments indicate that most of this picture of SOM chemistry is wrong, and only the role of soil microorganisms remains as key focus (Lehmann and Kleber, 2015).

The development of our understanding of the overall dynamics associated with SOM and the organisms involved owes much to Sir Edward John Russell (1872–1965), working first at Wye College, the School of Agriculture of the University of London, and then at Rothamsted. His research in the early years of the 20th Century provided new and broader understanding of microscopic soil organisms. His starting hypothesis was that the oxygen absorbed by uncropped soil was a measure of the total activity of microbes involved in decomposition processes and the release of plant nutrients. He devised a method to determine the uptake of oxygen into soil and used it to show that the rate of utilization in various soils of similar type (clayey, sandy, calcareous) correlated with their fertility. Furthermore, this rate was greater in surface soils where conditions of temperature and moisture were more likely to encourage microbial activity. However, oxygen uptake was greatly reduced after autoclaving the soil at 130 °C for 30 min, supporting the claim that it was the microorganisms that were creating the oxygen demand.

Serendipitously, when a temperature of only 95 °C was accidentally used instead of 130 °C, the rate of oxygen uptake into soil greatly increased instead of reducing. In collaboration with F.V. Darbishire, Russell followed up this observation of the effect of incomplete sterilization, and was able to obtain similar results after heating soil to 100 °C or treating it with volatile biocides (Darbishire and Russell, 1907). Importantly, they investigated the growth of plants in pot experiments comparing the effects of the incomplete sterilization of soil with untreated soil from the field. Growth was better and the uptake of N, P and K was greater in pots containing the treated soil; a result attributed to changes in the microbe population. Similar heat (95 °C) and biocide treatments also resulted in a considerable increase in the formation of ammonia as well as in bacterial numbers (based on plate counts) relative to the untreated control soil (Russell and Hutchinson, 1909). They attributed their results to the removal by the incomplete sterilization of a 'harmful factor' that limited the number and activity of soil bacteria. The factor was likely an organism or group of organisms that were bigger than and predatory on the bacteria, possibly protozoa that were larger and more susceptible to the treatments, and their absence would allow the large increase in number and activity of the soil bacteria. Russell and Hutchinson suggested that the ciliates and amoebae present in untreated soil fitted the experimental evidence. Their premise was that soil normally contains an active population of protozoa that prey on the bacteria, but which are more readily killed by partial sterilization, and this further stimulates the beneficial activities of the bacteria into quicker release of plant nutrients.

The discovery that soils typically contained a wide range of different active microorganisms opened up a new field of research within soil science. But Russell was keen to apply research findings to practical agriculture. Recognizing that it was not a practical option for arable agriculture and aware that soils used in the glasshouse industry had a limited life before they developed 'soil sickness' and became unusable for cucumber or tomato production. The nature of the phenomenon was investigated on commercial operations in the Lea Valley on the northeast fringe of London. The soils were found to have very limited bacterial activity, releasing very limited amounts of plant nutrients. However, partial sterilization of the soil again resulted in the stimulation of the bacteria with protozoan predation being the suspected cause of the 'soil sickness'. Heat or biocide treatment became standard practice for maintain good growing conditions and an industry-sponsored research station was established to support growers.

As already noted, the partial sterilization treatment affected the nitrogen available in the soil, which stimulated a survey of seasonal fluctuations in the NO_3^--N content of field soils together with linked data on weather, soil treatment and cropping. Russell and A. Appleyard then attempted to relate bacterial numbers to the decomposition of organic matter and the formation of CO_2 and NO_3^--N in the soil. Plate counts of bacteria were made, and the content of NO_3^--N and CO_2 determined in soil and soil atmosphere, respectively, from five plots on experiments at Rothamsted at a two-week interval over three cropping seasons. Russell and Appleyard argued that the fluctuations in numbers of bacteria matched those for CO_2 and NO_3^--N, sufficiently to indicate a causal relationship, with temperature and rain being the main factors controlling microbial activity.

Scarcity of fertilizer materials and the imperative for greater food production in the British Isles during World War 1 increased the requirement for organic amendments, such as animal manure and composts. Russell then developed practical schemes for the formation and use of organic amendments, which he identified as contributing to improved soil structure, providing food for the beneficial soil microbes as well as their activity providing the nutrients required by plants. From this effort, two publications resulted: "A student's book on soils and manures" (Russell, 1915) and "Manuring for higher crop production" (Russell, 1916). Both went into second editions by the end of hostilities in 1919! His most well-known publication, entitled Soil conditions and plant growth, was first published in 1912 and he wrote 7 editions before his son E. W. Russell produced three more editions, the last in 1973. Since then, there have been two more versions, one in 1988 edited by Alan Wild and the other in 2013 jointly edited by Peter J. Gregory and Stephen Nortcliff.

Russell was forced to give up his education at a technical school in Birmingham at the age of 14, when his family moved to London. Understanding that chemistry (a favorite subject) was practiced in chemists' shops (pharmacies), he opted to work in one and save money that he could use to go to college. He was quickly disillusioned by the reality of his duties but embarked on educating himself by reading and attending lectures and enrolling in courses at the newly-opened philanthropic venues for education and culture. After 3 years his father moved the family to Yorkshire and Russell, unable to find work with a chemistry link, first assisted in his father's Unitarian Chapel before embarking on a course in Wales to become a non-conformist minister. There his education was guided by the college Principal, who encouraged Russell to study for examinations that would eventually end in an open scholarship in science at Aberystwyth University. This he achieved in under 2 years. During his first year in Aberystwyth, he at last received direction in his scientific studies and, when he sat for the London Intermediate B.Sc., he came out top in chemistry and obtained an additional two-year scholarship. After his second year, Russell transferred to Owen's College, Manchester, where his two mentors gave him expert tutelage in chemistry. At the end of his second year at Manchester, he was awarded his B.Sc. in Chemistry and was then appointed Lecturer and Demonstrator. His post-graduate research was on the rates of explosion in gases and the reduced reactivity resulting from desiccation of some combustible gas mixtures, for which he was awarded the degree of D.Sc. by London University.

Russell was aware of the poverty that many were experiencing, causing him to consider the possibilities for resettling the urban poor in rural areas and providing training necessary for them to become contributing members of society. It also made Russell reassess his own career direction, leading him to considered the chemical changes induced by microorganisms. As a result, he obtained a lectureship in chemistry at Wye Agricultural College, where he recognized that building a team of scientists and allowing them to apply their different disciplines to the investigation of soil, plants and animals, presenting their results in a way that could allow experts, teachers and producers to use them, could help develop and improve agricultural practice. The possibility became a step nearer, when the Principal of Wye (A D Hall) became the Director of Rothamsted Experimental Station and subsequently in 1907 he invited Russell to become the 'Goldsmith's Company Soil Chemist'. Five years later, Russell was appointed Director to succeed Hall who had become a Commissioner of the Development Fund set up by the British Government to support the scientific development of afforestation, agriculture and fisheries. In the 31 years of his Directorship, Russell was able to increase the scientific staff from 6 to 70, with a similar increase in the number of support staff. He was able to oversee the purchase of the estate and the integration of the small experimental station at Woburn belonging to the Royal Agricultural Society. This allowed comparative studies on light sandy to the more clayey soils at Rothamsted. He put in place various arrangements to ensured that each department knew what the others were doing and encouraged cooperation between them. Russell also encouraged visitors to the station, including farmers, members of scientific societies and parties of schoolchildren. Individual visitors were accommodated for shorter or longer periods as 'voluntary workers'. Some came to discuss problems arising from their work or to learn some new experimental technique. Many people, especially from overseas, carried out research on a specific problem, often as part of their postgraduate studies.

Russell received the award of the Order of the British Empire in 1918, and was elected a Fellow of the Royal Society in 1917. In 1922 he was created Knight Batchelor.

In 1927 he was invited to a conference of the recently formed International Society of Soil Science, held in the USA, and decided to become more involved in such international activities, which he saw as helping some of the poorer countries to increase their food production. He was President of the International Soil Congress held at Oxford in 1935.

Russell's influence was not limited to Britain but included its colonies and other overseas territories for which it had responsibility. He became aware that there was little exchange of information on current research between local researchers and those in Britain, resulting in an over-dependence on US work and leadership. Following a conference he initiated, specialist information bureaux were established and added to the Imperial Bureaux of Entomology and Mycology, with the task of publishing abstracts of literature, produce monographs and to provide those seeking information with the relevant list of source publications appropriate for their research. This became the Commonwealth Agricultural Bureaux in 1947 and CAB International in 1986.

In 1957, some 14 years after Russell retired, David Stewart Jenkinson (1928–2011) began working at Rothamsted Experimental Station. After gaining first-class honors in Experimental Science for both BA and BSc degrees, he remained at Trinity College, Dublin and took his PhD in organic chemistry. After a short period in industry Jenkinson decided on a more academic approach to science and obtained a 3-year appointment in soil science at the University of Reading, investigating the chemical structure of 'humic acids' in soil organic matter. He quickly realized that even using the cutting-edge methods of the time, including electrophoresis and infra-red or ultra-violet spectrometry, the nature of the formation of humic materials and their linkage with mineral surfaces meant their composition was likely to be extremely variable. However, his efforts were not without reward as Jenkinson and his colleagues, Goulden and Tinsley, were able to demonstrate for the first time that humic material contained peptide bonds but there were no chemical signatures for lignin. These results refuted the hypothesis then being advanced that the compounds were lignoproteins. Jenkinson also learned from Tinsley how important was painstaking attention to detail in quantitative analytical chemistry! Throughout his career he passed on this lesson to all who worked with him.

Jenkinson began his career at Rothamsted with a study the decomposition and turnover of organic matter in soil incubated under ambient conditions in bottles buried upside down in an unplanted field. He first had to develop the means of uniformly labelling plant material with ^{14}C and of determining the amount of label remaining in the soil after periods ranging from weeks to years. He solved both challenges, designing a growth chamber into which $^{14}CO_2$ could be introduced and developing new techniques to determine the ^{14}C remaining in the soil. He was able to show the rapid breakdown of both root and shoot material over the first year, with little difference between them after the first 3 months, and slow decomposition over subsequent years. Jenkinson noted that the loss of carbon from the soil did not occur at a uniform rate throughout the year but reflected the temperature in the soil at 10 cm depth. Ten years later, working in Nigeria he and A. Ayanaba showed that the rate of decomposition in soil of similar clay content was four times faster under tropical conditions but followed the same trajectory as at Rothamsted. In addition to temperature, the soil water regime influenced decomposition, with the short-term rate being slower in the dry than in the wet season (Jenkinson and Ayanaba, 1977).

During the incubation experiments at Rothamsted, Jenkinson also started investigating the effects of "partial sterilization" of the soil on the decomposition of organic matter. In his classic 1966 paper he assessed the various hypotheses to explain the greater microbial activity that E.J. Russell had noted and others had continued to investigate. Jenkinson argued that the process used to effect partial sterilization of the soil might release previously unavailable organic matter but this could also result from the killing of some of the microorganisms present. Jenkinson's experiment consisted of mixing soil samples taken from his field incubation study containing ^{14}C-labelled organic material and subjecting the mixture to a wide range of sterilizing treatments of varying severity and then determining the carbon dioxide (CO_2) evolved during incubation, adding a 1 mL suspension of fresh soil as inoculum.

The treatments ranged from air-drying at 20 °C to autoclaving at 120 °C, γ-irradiation, fumigating with alcohol-free chloroform ($CHCl_3$) or bromomethane (CH_3Br), or oven drying at 80 or 100 °C for 24 h. In all treatments the total amount of CO_2 evolved during incubation increased relative to untreated (Control) soil as did the labelled $^{14}CO_2$, with the two fumigant treatments resulting in a greater proportion of $^{14}CO_2$ than the others and being more than threefold that of the control. Diluting the soil oven-dried at 80 °C with fresh soil had no effect on the $^{14}CO_2$ evolved. Jenkinson concluded that this latter result was inconsistent with proposed hypotheses about partial sterilization being associated with the presence of toxins in fresh soil, to prey-predator impacts, or to the changed presence of antagonistic microbial relationships. The results from all treatments were also inconsistent with hypotheses of changed availability of previously protected organic material, changed susceptibility to breakdown or to increased vigor of a surviving population following partial sterilization. The only "reasonably satisfactory explanation" was that the increased flush of CO_2 after partial sterilization was due to the decomposition of microbes killed by the treatment. Jenkinson then carried out some additional studies, using repeated partial sterilizations and showed that this initial conclusion was justified and that only a very small part of the $^{14}CO_2$ evolved came from a constant background production; heat and irradiation make some parts of the soil organic matter (both microbial and non-microbial material) more susceptible to decomposition but partial sterilization treatments generally do not prime non-microbial organic matter for decomposition. Killed or damaged microbes decompose more quickly than those unaffected.

With this background Jenkinson then developed the concept of a method to determine the quantity of C held in living cells in soil, termed the microbial biomass, requiring a treatment to "give complete or near complete" sterilization but does not change the susceptibility of non-microbial organic matter to decomposition and leaves no residues. He settled on chloroform fumigation as this was easier to use than bromomethane. Then by determining the increased CO_2 released by fumigation relative to untreated soil (F), the microbial biomass (B) is given by:

$$B = \frac{F}{k}$$

Where k is the proportion of microbial biomass carbon that decomposes in the post treatment incubation, which he determined experimentally for the ammonia oxidizing bacterium *Nitrosomonas europaea* as approximately 0.3 (based on a 10-day incubation at 25 °C).

The value for k suggested in Jenkinson (1976) was 0.5, taking account of a wide range of organisms. The method was investigated in detail by Jenkinson and Powlson (1976), in part stimulated by criticisms of the underlying assumptions made by E.A. Paul and colleagues in Canada – an example of scientific disagreement leading to additional in-depth investigation.

The limitation of the method for use as a monitoring or survey tool was clearly the long incubation time. Later work that Jenkinson undertook with Brookes and Vance, led to the introduction of extraction of chloroform-released organic-C using 0.5 M potassium sulfate (K_2SO_4) as an alternative to 10 days incubation.. Although the comparison with an unfumigated control was important, other than in very acid soils, and less carbon was extracted than released as CO_2, the procedure took hours rather than 10 days. Subsequently the fumigation-extraction method has been very widely used. The estimate of microbial biomass carbon was robust and the basic technique could be adapted to determine the biomass nitrogen (Brookes et al., 1985) with 0.5 M $NaHCO_3$ at pH 8.5 being used as the extractant for the phosphorus content of the biomass (Brookes et al., 1982).

In 1978 Jenkinson, in collaboration with J.M. Oades at the Waite Agricultural Research Institute in Australia, recognized the potential of determining the energy present in biomass by its adenosine-triphosphate (ATP) content. The main problem was the ability to extract ATP from cells without its breakdown and the nature of the relationship between ATP and the microbial biomass present. Jenkinson and Oades (1979) solved the problem of the extract, adopting 0.5 M trichloracetic acid (TCA), coupled with 0.25 M disodium hydrogen orthophosphate (Na_2HPO_4) and 0.1 M 1,1′ dimethyl-4,4′ bipyridylium dichloride (paraquat) (now replaced by 0.6 M Imidazole), where Na_2HPO_4 and paraquat serve to prevent ATP from becoming fixed to negative and positive charged sites in the soil during extraction.

Other extractants appeared to remove less ATP than did TCA, which also correlated well with the biomass estimated by the post-fumigation CO_2 flush determination. Results have also indicated that despite being a population that is largely inactive because of limited substrate availability, it maintains ATP levels that are more typical of actively growing populations in laboratory culture. There is no evidence that ATP from roots in soil being sieved prior to microbial biomass determination contribute to the total extracted.

Jenkinson made important contributions to the understanding of the nitrogen cycle in agricultural fields, particularly in constructing a nitrogen balance for the long-term arable experiment on Broadbalk at Rothamsted, recognizing the very significant contribution from the atmosphere as wet and dry deposition and encouraging its direct measurement. He also used ^{15}N-labelled fertilizer to identify that which was quickly taken up by the crop and that which entered the soil organic matter, observing its long-term fate, identifying losses to the environment via the drainage system as well as the factors that reduced fertilizer use efficiency. Similar investigations were aimed at understanding the fate of N under permanent grass.

The information gained was put to use in developing computer models that could help advise the agricultural community, both on managing N (the SUNDIAL model) and on managing soil organic matter (the RothC model). The latter has been widely adopted for use in conjunction with global and regional circulation models to identify effects on soils and their productivity as well as what changes in inputs might be required to maintain carbon stocks.

Born in Beverley Hills, California, Jenkinson moved to a small farm in County Armagh, Northern Ireland when he was 4 years old after his parents' fortune was adversely affected by the Wall Street crash. He was kindly, supportive to many scientific colleagues and quietly spoken until roused. He rarely gave direct instructions to his junior collaborators but if he "strongly suggested" a course of action he would be distinctly annoyed if it was not followed! He read widely and had interests in Irish folk music. It is possible to hear him talk of his experiences in a recorded interview at http://cadensa.bl.uk/uhtbin/cgisirsi/?ps=aCwKfqzhqr/WORKS-FILE/172200051/18/X246/XTITLE/Professor+David+Jenkinson+interviewed+by+Paul+Merchant.

In recognition of his research achievement Jenkinson was elected a Fellow of the Royal Society in 1991 and received Massey Ferguson National Agricultural Award in 1993 for his research on nitrogen fertilizers. He was elected an Honorary Member of the Soil Science Society of America in 1995 and of the British Society of Soil Science in 2007. He retired from Rothamsted in 1988 after 31 years.

Prof. Dr. Klaus Domsch (1926–2022) was an outstanding scientist with very broad human and scientific interests, who enhanced environmental sciences by bridging microbiology, plant physiology, soil science, biogeochemistry, and agroecology. His contribution to the development of soil biology as individual branch of science is impossible to overestimate.

Born in Chemnitz, he attended the princely school and "St. Afra" boarding school in Meissen. In 1944, at the age of 18, he was drafted as an auxiliary in the German Luftwaffe. After receiving an 'emergency Abitur', he trained as a mountain infantryman in Innsbruck. In 1947 he enrolled at the Humboldt University in Berlin and initially studied teaching. In 1949, he transferred to the University of Göttingen to study phytopathology. In 1953, he obtained his doctorate at the Institute of Plant Pathology. From 1954 to 1967, he held his first position at the Institute for Cereal-Oil Fruit and Forage Plant Diseases of the then Federal Biological Research Station in Kiel-Kitzeberg.

Since 1967, the name Domsch has been closely associated with soil biology. That was when he founded and became Director of the Institute of Soil Biology at the Federal Research Centre of Agriculture (FAL) in Braunschweig. Up to his retirement in January 1991, he had authored several books and more than 165 publications. As head of the institute, he was particularly concerned with mentoring new colleagues through scientific stimulation, personal empowerment, regular "eye-to-eye" discussions and pointing out the possible perspectives. During the period of his 24-years as Director, the Institute of Soil Biology obtained a world-wide international reputation for its excellent research and broad networking activities.

From the first publication in 1953, Domsch focused his research on soil fungi, the influence of pesticides on soil microorganisms and on microbial degradation of pesticides in soil. The research was summarized in several books including a "Compendium of Soil Fungi" (Academic Press, 1980), a book that was the bible for soil mycologists for many years and was cited more than 7000 times.

Domsch made a great contribution to soil biology with his instigation of physiological approaches for microbiology in soil research. In 1962 he introduced soil respiration as a basic parameter for environmental research and related the CO_2 evolved from soil to the activity of its resident microbes. This was a revolutionary step enabling quantitative estimation of soil microbial biomass by substrate-induced respiration (SIR method in cooperation with J.P.E. Anderson) (Anderson and Domsch, 1978); differentiation between fungal and bacterial activity (the fungal:bacterial ratio) and finally a development of an eco-physiological approach (Anderson and Domsch, 2010) based on microbial metabolic indexes – (the qCO_2 and C_{mic}:C_{org} ratio). Visiting scientists came from all continents to study these new methods. Publication of eco-physiological approach was awarded as a Citation Classic in Soil Biology & Biochemistry in 2010. For his great contribution to international science, Domsch was awarded the Gregor Johann Mendel Honorary Medal for Merit in Biological Sciences by the Czech Academy of Sciences in 1995.

His far-sightedness influenced a whole generation of scientists who are looking to link excellent basic research and practical agriculture in the field of soil biology; something so very important today if we are to make agriculture more sustainable, but also efficient.

Klaus was in great demand internationally and developed close and productive research involvements in the Netherlands (Centraalbureau voor Schimmelcultures, Baarn) and the USA (University of California at Riverside and at the Department of Plant Pathology Oregon State University at Corvallis).

As a scientist, he took enormous pride in and responsibility for the results of his research. Socially he impressed by the depth of his intellect, inexhaustible energy, wisdom, kindness, and charisma.

Domsch was an unconventional man and scientist. His motto in life was "Carpe Diem" (seize the day!). He was a living demonstration to junior colleagues that scientific excellence and enjoying life are not contradictions. His personal celebrations were unforgettable: full of (scientific) discourse, culture (music) and joie de vivre - an incentive for youth. His deep-rooted beliefs in classical philosophy and his humor were Inspiring!

After his retirement in 1991, he investigated his family history and the complexities of genealogy replaced that of the soil microbial world. On February 25, 2022, one day after Russia's invasion of Ukraine, Prof. Dr. Klaus Domsch, died in Wittmar, Wolfenbüttel County, at the age of 96.

Barbara Gertrud Hedwig Mosse (1919–2010) completed a Diploma and BSc in Horticulture before obtaining a First class Honours BSc in Botany, the latter while working as an Assistant Chemist for the Lawes' Chemical Company. In 1944 she moved to the Pomology Department at the East Malling Research Station in Kent, where she worked on rootstock incompatibility. Her results were reported in a technical communication for the Commonwealth Agricultural Bureau (Mosse, 1962). She published her first paper on mycorrhizas based on work that also formed part of her PhD, awarded in 1956. The paper in the journal Nature (Mosse, 1953) consists of four short paragraphs and a composite of three micrographs showing the hyphal connection between a "fructification" and a strawberry root, an enlargement of the point of entry of a hypha into the root and the colonization inside the root. The last paragraph describes her current efforts to "to synthesize mycorrhiza under controlled (aseptic) conditions." She states that she had produced typical mycorrhizal infections in seedlings grown in autoclaved soil in the test tube by taking spores from the sporocarp of a fungus associated with strawberry roots in the field. That was very much a break-through moment in the field of mycorrhizal research as prior to that time researchers could not even be sure whether the fungus they were observing was a mycorrhizal fungus. Furthermore, it allowed pot cultures of a mycorrhizal fungus to be established on different host plants. Now there was reason to separate spores from the soil to have access to different fungi. Mosse next established that mycorrhizal apple seedlings and clonal leaf bud cuttings were significantly larger than their non-mycorrhizal counterpart and recognized that this had implications for the nutrient levels in the soil and in the plants. The shoot content of not all nutrients were enhanced, with some such as copper, iron and potassium showing positive increases but manganese was reduced.

In 1960 Mosse transferred to Rothamsted Experimental Station. She continued to investigate the potential for inoculating plants with mycorrhizal fungi under aseptic and non-sterile conditions. The importance of early inoculation to obtain the greatest impact on growth was recognized for applicability in annual plants. The role that some bacteria (MHB) can play in helping mycorrhizal fungi enter a host-plant root was also identified.

Mosse surveyed plots on the Broadbalk experiment for spores of mycorrhizal fungi in 1961–2, 1966 and again in 1968. Together with G.D. Bowen from Adelaide She investigated soils from Australia and New Zealand, producing a key for identification of mycorrhizal spore types as well as assessing the conditions most conducive to the presence of spores. Moist conditions and well-worked soils, such as in gardens, and elevated nutrient levels were associated with fewer spores, but soils under natural vegetation were less numerous and diverse than in cropped land. They also concluded that where root growth and development was more sporadic there were more spores.

Much of the next decade was spent investigating the potential benefits from mycorrhizal inoculation. Several studies indicated that the benefits to the host plant could be attributed to the improved supply of phosphorus (P). In work with D·S. Hayman, it was confirmed using ^{32}P-labelling that the fungal partner did not access different sources of P compared with the host-plant roots but was more effective in absorbing it from soils with smaller concentrations and could capture it from outside the soil volume available to a root. In one experiment, there was some evidence that inositol could be a potential source, which later researchers have showed can occur if bacteria are available to break it down and release mineral P for the fungus to take up. Her work also demonstrated that increased concentrations of P and N in the soil could have negative effects on the level of colonization within the root, even to the extent of apparently excluding the fungus, which has been a major cause of concern and even for dismissing the relevance of mycorrhiza in intensively managed crops. The effectiveness of the fungus in supplying P varied between different hosts and fungi, results that subsequently have been extensively investigated by the research community in recent years. There was also evidence that the laboratory isolates were not always more effective than the indigenous mycorrhizal fungi. Mosse's work also foreshadowed the ability of roots to attract specific beneficial microbes from the bulk soil to the rhizosphere. She saw the potential for inoculation in parts of the world with soils with low levels of available P.

Another important aspect that attracted her attention was the potential for interaction between mycorrhizal fungi and rhizobia in N-fixing legumes. It was observed in one experiment on an acid soil that rhizobia only formed sufficient nodules when the plants had also been colonized by mycorrhizal fungi. This kind of information provided useful background when the significance of signaling between microbe and host plant as part of the symbiosis formation was being explored some 20-years later.

Mosse had many people visit her at Rothamsted to gain experience in her laboratory and one with a particularly significant outcome was with M. Giovannetti. Their paper (Giovannetti and Mosse, 1980) compared 4 methods for assessing the infection by mycorrhizal fungi in host-plant roots. The methods chosen were:

1 the Gridline intersect method. This was used to estimate the proportion of roots infected and the total length of root and counting the number of interceptions that stained roots made with grid-lines.
2 the Visual assessment. Quick estimate of what percentage of the root in the dish showed as stained. Both these methods could be done under a microscope.
3 Slide method 1. The roots were cut into 1 cm long sections and 10, randomly chosen, put on a single microscope slide and the length of stained root in millimeters determined for each root and the percentage of the total root calculated.

4 Slide method 2. On similar samples of roots the presence or absence of stain was recorded and then expressed as a percentage of the whole.

Both these latter methods were used under the microscope. The results were subjected to statistical assessment that allowed the minimum number of roots or root pieces needed to be used for each method to be determined as well as the sensitivity. In addition, Giovannetti and Mosse reviewed the potential sources of error in each method. It was the first time that the standardization of methodology for making the key assessment in such studies had been attempted.

Mosse managed to travel widely, obtaining several Fellowships that she took at the University of California, Berkeley (1956); the Department of Arboriculture at the University of Pisa, Italy (1960) and the University of Otago, New-Zealand (1966) and was Visiting Scientist in the CSIRO Division of Soils in Adelaide, Australia (1966). She gave courses on mycorrhiza in Brazil, Nigeria, Malaysia and Hawaii.

Nicolson and Gerdemann (1968) published and account of the mycorrhizal fungi identified as members of the genus Endogone, including a new species *E. mosseae* (now *Funneliformis mosseae*), named in her honor.

It is clear that she was very passionate about her work. When José-Miguel Barea was visiting Rothamsted, on being told he was working on phosphate solubilizing bacteria she was very clear that he should work on mycorrhiza. Her enthusiasm for the subject and her influence on colleagues around the world have, as one person stated “I believe that she was a fundamental pillar for the development of mycorrhizal research in Europe and throughout the world, at a difficult time, especially as a woman. I think she can be fairly considered as ‘the mother of mycorrhizae’.”

José-Miguel Barea (1942–2018) was a native of Granada and studied Pharmacy at the University of Granada but even before he completed his degree in 1965, he was working with microbes in the Department of Microbiology. He completed his PhD in Microbiology in 1968, and his thesis work laid the foundation for the further study in Spain of the application of microorganisms that promote the growth of plants by supplying essential nutrients. For both the quality and novelty and of his work he was given an Extraordinary Degree Award by the University of Granada.

In 1972 Barea spent a few months working on phosphate solubilizing bacteria (PSB) at Rothamsted Experimental Station, where at one teatime he had a chance meeting with Barbara Mosse, who asked what he was doing. He replied that he was working with PSB. Her response was to tell him that he needed to work with mycorrhiza, which were much more likely to help plants improve their P nutrition. His subsequent focus on mycorrhiza was therefor somewhat accidental but he considered it a stroke of fortune.

Barea obtained a position at the Consejo Superior de Investigaciones Cientificas (CSIC), Zaidin Experimental Station (called ‘El Zaidin’ by Barea). He developed the work begun at Rothamsted on the effects of diazotrophs on the growth of higher plants. The evidence suggested that in *Azotobacter paspali* there was no transfer of nitrogen to host plant roots but its enhanced growth was associated with the release of plant growth regulating compounds, such as auxins gibberellins and cytokinins. He then developed a rapid test using yeasts to identify such substances and went on to show that these microbial products were important in the early process of root colonization by the fungi and now known to be a key part of the process of establishing the symbiosis. Barea included mycorrhizal fungi in his studies and, linked to work with D.S. Hayman at Rothamsted, reported on possible synergistic interactions between the mycorrhizal fungus *Endogone* and phosphate-solubilizing bacteria in low-phosphate soils.

Retrospectively it is possible to identify three strands to his work on mycorrhiza: the interaction between beneficial fungi and rhizobacteria, the role of mycorrhizas in restoration of marginal and degraded soils and the biodiversity of mycorrhiza in natural habitats. The first of these developed from his early interest in PSB and the interaction between rhizobia and mycorrhiza (de Aguilar et al., 1979) which provided a basis for the use of microbes in the supply of nutrients and protection against root pathogens in sustainable crop production. One aspect was to enhance the supply of P from rock phosphate for plants by the joint use of PSB and mycorrhizal fungi. In one investigation it was found that although the inoculation of alfalfa (*Medicago sativa* L.) with the mycorrhizal fungus *Funneliformis mosseae* was more effective than the indigenous fungi, in combination they were even better. Another part of the focus was on enhancing the colonization of host plants using rhizobia as mycorrhizal helper bacteria and part was using mycorrhizal fungi to enhance the supply of P to support biological N-fixation by rhizobia, such as in non-crop woody legumes. The later aspect also contributed to restoring degraded land in semi-arid regions, including the Mediterranean basin.

Barea's interest in the restoration of degraded soil not only covered revegetation with fast-growing trees and shrubs but included improving soil structure through the use of mycorrhizal fungi and reclaiming soils contaminated with heavy metals, using mycorrhiza to protect plants from the toxicity. His investigations also led to an evaluation of the activity of indigenous mycorrhiza in desertified semi-arid land, which suggested that there was sufficient to support the recovery of vegetation cover. He also considered the potential importance of the protection provided by mycorrhiza against drought and studied their effects on preventing premature aging in plants under such conditions.

He developed a general interest in the conservation of endangered native flora found in Granada's Sierra Nevada, and in other natural habitats. It was typical that he would seek to evaluate the potential role for mycorrhiza, including their biodiversity. One of the products of this line of research was the identification of a new mycorrhizal fungus *Entrophospora nevadensis* (Palenzuela et al., 2010). Barea recognized that native mycorrhizal fungi from saline locations could be important in the recovery of areas affected by salinity in natural or agricultural environments. In the Cabo de Gata Natural Park, Barea investigated the community of AMF in the rhizosphere of *Asteriscus maritimus* L. a plant adapted to Mediterranean saline areas. He and his colleagues found from a sample of 40 plants, 30 AMF species belonging to three classes, five orders, nine families and 13 genera of the phylum Glomeromycota (Estrada et al., 2013).

Barea saw the significance the molecular era for mycorrhizal research, using it to combine his interests in the biodiversity of organisms with better understanding their potential functioning within their local habitat.

Barea served as the Head of the Microbiology Department and Vice-Director of the Institute between 1983 and 1987, and as Director between 1989 and 1998. He served as an advisor for the Joint FAO/IAEA (International Atomic Energy Agency) in Vienna, where he promoted the use of $^{15}NO_3^-$) as a tracer for nitrogen metabolism in microbial and plant studies. He was a charismatic and inspiring teacher and scientific leader.

Barea was an advisor for the International Foundation for Science (IFS), which is based in Sweden, and supports research and research training projects in developing countries – a project close to his heart.

He was elected to the Academy of Mathematics, Physics, Chemistry and Natural Sciences of Granada in 2004. In the same year, he was appointed as a distinguished Professor at the.

University of Buenos Aires in Argentina. In 2013, he received the President's Medal from the University of La Frontera (Chile) in recognition of his outstanding contributions to the formation of advanced human capital at the institute.

Barea had the reputation of working hard and playing hard. He enjoyed singing and was a member of a folk group which performed at many of the meetings that he organized.

Vladimir Victorovich Zelenev (1961–2021**)** was a multi-talented scientist combining unique expertise in soil science, soil microbiology, ecological modeling and environmental ecology. His academic career spanned a wide range of topics in the course of time. He received his MSc in Agrochemistry and Soil Science with honors from the Faculty of Soil Science of Moscow State University in 1983. Zelenev successfully defended his PhD thesis entitled "Spatial and temporal fluctuations in bacteria, microfauna and mineral nitrogen in response to a nutrient impulse in soil" at Wageningen University in the Spring of 2004. He received several fellowships from the International Agricultural Center and from the Graduate School PE&RC for PhD research at Wageningen University. His research on the production and emission of various greenhouse gases from soils in natural ecosystems (Van Bruggen et al., 2017), including carbon dioxide (CO_2) and methane (CH_4), led to Zelenev being given a prestigious fellowship from the Austrian Government to work at the International Institute for Applied Systems Analysis at Laxenburg.

Zelenev was the first scientist to write a simulation model for oscillating populations of bacteria interacting with their substrate (Zelenev et al., 2000, 2005). The unique aspect of this model was the realization that predators or parasites were not needed to initiate wave-like fluctuations in bacterial populations. There were many models describing oscillations in predators and their prey, but regulation of bacterial densities by interaction with their substrate was new. Zelenev introduced the concept of readily utilizable substrate. He realized that oscillations would ensue if growth and death rate curves crossed over at a particular substrate level, referred to as "scissors."

Zelenev was one of the recognized experts in the field of modeling decomposition of organic matter (Shahbaz et al., 2017). He was one of few modelers who combined a bottom-up and top-down approach to simulating organic matter decomposition. This resulted in the model "BACWAVE-WEB" with the necessary detail at the base and yet sufficient functional groups in the food web to be able to test some hypotheses about the role of these groups in organic matter decomposition and mineral nitrogen release (Zelenev et al., 2006). The "BACWAVE-WEB" model has excellent potential to predict responses of microbial communities to a disturbance, which could be used to characterize soil health: oscillations with greater amplitudes indicating poorer soil health.

Zelenev was an amiable and helpful friend and colleague to everyone who crossed his path. He had vast knowledge and interests, yet he always remained a modest person. He was very fond of literature, art and classical music, was fond of mountain skiing. Zelenev had many friends all over the world. He sang well, played the guitar, he was pleasant to talk to, witty, with an amazing sense of humor. He was a dedicated researcher and teacher, always and anywhere.

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