

## Sarah Elizabeth Smith 1941–2019

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Sally Smith (1941–2019) was a world leader in the study of arbuscular mycorrhizal symbioses between plants and soil fungi that allow a wide range of plants to grow in soils low in nutrients, especially phosphate (Fig. 1). Her work has been relevant to both plant ecology and agricultural productivity. Sally obtained a tenurable position at the University of Adelaide after many years' employment on short-term contracts. She rapidly developed a large and active group that researched at scales ranging from advanced microscopy through molecular biology and physiology to plant ecology. Sally established long-standing international collaborations and was awarded many honours. She was a keen cook and gardener, and became an avid birdwatcher, travelling the world with her husband Andrew in pursuit of their hobby.

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### Early years, family and school education

Sally (sometimes 'Sal': she was never known as Sarah) was born in Oxford, UK, on 10 May 1941, daughter of John Laker Harley and Lindsay, née Fitt. Both parents had completed DPhil programs in plant science at the University of Oxford, although Lindsay never submitted her revised thesis for final examination after an examiner criticised the statistics that she had used.<sup>1</sup> Jack (he was never known as John) obtained a postgraduate scholarship and just before the Second World War broke out he was appointed as a departmental demonstrator in botany. He very soon volunteered for army service and became an officer in the UK Royal Signals. Sally's younger brother Richard was born in 1943 after Jack had departed from the UK for India and then the Burma campaign; he ended as Lieutenant-Colonel. After the war ended Jack returned to the University of Oxford Department of Botany, where he increasingly specialised in the physiology and ecology of forest trees, especially the role of ectotrophic mycorrhizas, a widespread beneficial plant-fungus symbiosis in forests.<sup>2</sup> Lindsay gave up a scientific career apart from helping Jack maintain a growing list of plants that form the various types of mycorrhiza, later published along with supplements in *New Phytologist*, a prominent journal then and now.

Jack and Lindsay often spent weekends cycling round the countryside, each with a child on a carrier seat until Sally and then Richard began to ride bicycles themselves. Later the family had many active walking holidays in England. Sally went to Headington School outside Oxford, close to where her parents lived. Lucy Hughes, an old friend since early school days, has a Headington class photograph taken in 1947. It shows 'a small girl sitting cross-legged in the front row frowning ferociously at the camera as if it were a problem to be solved—a portent of scientific curiosity to come'? Lucy says that they shared a lot through their school years, living a few doors from each other, cycling to school together,



**Fig. 1.** Sally on her election to the Australian Academy of Science, 2001. Photographer unknown. Reproduced with the permission of the Australian Academy of Science.

walking dogs before breakfast, spending long days cycling and walking in the countryside in the holidays and a good deal of time in each other's homes. They had adventures at Girl Guide camps and a memorable guiding trip to Italy.

Both of Sally's parents were very keen gardeners, as had been her grandparents, as well as being botanists. Sally went out on early morning trips with Jack to collect tree rootlets for his experiments. Her parents had several close academic friends who were botanists. Paraphrasing Sally's own words in an invited profile that she wrote for *New Phytologist*, as a teenager she became resistant to learning much about plants and by the time she left school wanted to become

<sup>1</sup> The thesis was on the malting quality of barley, with the complex data technically very problematic for the primitive statistical methodologies then employed. In later years Sally sometimes gently pointed out to her mother that malting quality is an ongoing field of research.

<sup>2</sup> Ectotrophic: the fungi sheath the growing root-tips.



**Fig. 2.** L to R: John Raven, Sally Smith, Enid MacRobbie and Andrew Smith enjoying lunch, Cambridge, c. 1965. Photographer unknown. Photograph in possession of Andrew Smith and reproduced with his permission.

an animal physiologist.<sup>3</sup> In that respect, she followed her father, who when he went to the University of Oxford had planned to specialise in zoology.<sup>4</sup>

### University education (1959–65)

Sally was accepted for a BA degree course at Newnham College, University of Cambridge, involving biochemistry, organic chemistry, zoology and (inevitably) botany. Plants took over her interest, thanks to the lecturers who most influenced her. Again paraphrasing her words, Sally did not do well in her last undergraduate year and was not immediately eligible for a government research scholarship to undertake a PhD project in plant physiology as she had hoped. She was rescued by a famous plant pathologist, S. D. (Denis) Garrett (FRS 1967), who found sufficient funding in the university to ‘give her a year and see how she goes’. The project was on effects of carbon and nitrogen supply on another class of mycorrhizal symbiosis, that with orchids. Sally worked successfully, obtained a UK government scholarship and was awarded her PhD in 1965.<sup>5</sup>

This study was pioneering in that it involved the use of radioisotopes (still very new in plant-based research) and Sally obtained helpful advice from Tom ap Rees, formerly one of Jack Harley’s many PhD students and Enid MacRobbie (FRS 1991), both of whom had been recent appointments to the Cambridge Botany School.

MacRobbie’s pioneering research into plant membrane transport also involved radioisotopes and she was the PhD supervisor of Frank Andrew Smith (‘Andrew’), who used the same techniques.<sup>6</sup> MacRobbie had the only automatic Geiger counter in the department, otherwise it was a matter of individual samples, stop-watches and an eye kept on the dials. After MacRobbie’s own samples had been loaded at the end of the day, Andrew and Sally were allowed to load theirs, not a quick process. They had been contemporaries in their undergraduate studies but used to say that they fell in love over a Geiger counter (Fig. 2).

### Marriage, move to Australia and a rather fragile start to Sally’s research career

Sally and Andrew had made a pact that they would marry after they handed in their PhD theses, and they did so in 1965 at Old Marston near Oxford, very close to where Jack and Lindsay lived. Sally was happy to become Dr Smith: she said that it helped remove identification as ‘Jack Harley’s daughter’. Andrew obtained a post-doctoral scholarship still working with MacRobbie. Sally turned down a job opportunity at Aberdeen because, in her own words: ‘it wasn’t the custom for married women to split up and go and live in far distant parts of the country’. She tutored in some university colleges, taught at the Cambridge Technical College, marked

<sup>3</sup> Smith (2019).

<sup>4</sup> Taken from Jack’s unpublished autobiography ‘As luck would have it’.

<sup>5</sup> Harley (1965).

<sup>6</sup> The following text involving the present authors uses names, not ‘I’ or ‘we’.

overseas high-school examinations and was a part-time research assistant for MacRobbie.<sup>7</sup> Sally and Andrew rented a rather down-at-heel house in a village outside Cambridge, already occupied by a large number of bats. These lived under the roof until dried droppings increasingly percolated through cracks in the bedroom ceiling. The hole under the roof was blocked up by Andrew one morning before dawn and the bats rather sadly had to find a new home somewhere. Sally became interested in restoring the derelict garden, no doubt to her parents' surprise and pleasure.

Professor R. N. Robertson (FAA 1954, FRS 1961) from the Department of Botany at the University of Adelaide visited MacRobbie's laboratory and pointed out that there would soon be a position for a lectureship at Adelaide for a plant physiologist researching plant membrane transport, his own area of interest. Andrew applied and was duly appointed. The Smiths departed from England at the end of April 1967. Sally was by then visibly well developed in pregnancy, which sped them through the immigration procedures, formidable though they could be at the time. Their first daughter, Caroline, was born in July that year.

Quite soon afterwards Sally started a little research on orchid mycorrhizas. In those days departments at the university had their own stores for chemicals, glassware and so on, and a little 'free money' (meaning unallocated funds). She also started some hourly-paid tutoring/demonstrating in the first-year biology course and then proceeded to a salaried half-time position, annually reappointed. Her second daughter, Hilary, was born in 1970. This was a time of university expansion in Australia and the appointment of many young staff with children. Sally was heavily involved in the establishment in 1969 of the University of Adelaide Pre-School and Nursery Centre Inc., founded by a parental group with some support from the university. Caroline and then Hilary were soon enrolled.

An advantage of Sally's half-time appointment was that botany was taught in the first half of the academic year that started in February and she was able to arrange her teaching to accompany Andrew with their daughters on sabbatical trips overseas that started in the second half. The first one was to Oxford, where Andrew was introduced to ectomycorrhizas and Sally mostly had 'time off' with the children. The second trip was quite adventurous. They flew across the Pacific to Peru and visited Machu Picchu among other places. Caroline was then aged 8. Hilary, aged 5, did a little excavating and some human bones had to be taken from her, much to her displeasure. She concealed some small ones that were later left in a hotel bedroom waste-bin. The Smiths proceeded to Dundee in Scotland, where Andrew had arranged to work in the Department of Biological Sciences at the University of Dundee with John Raven (FRS 1990), another of Enid MacRobbie's past PhD students and a friend of both of Andrew and Sally.

Dundee in autumn and early winter was a culture shock. Caroline and Hilary were enrolled in a primary school on the university campus. It was quite international, but at the end of the first day the girls had started to develop Scots' accents. Sally had made no arrangements to do research, but two other staff members, Melvin Daft and Janet Sprent, took her under their wings. Melvin was a pioneer in research into growth and functioning of arbuscular mycorrhizas,<sup>8</sup> by far the biggest group of mycorrhizas and one that occurs in most plants worldwide. Janet was an expert in plant-bacterial N<sub>2</sub>-fixing symbioses. The fortuitous collaboration with Melvin,<sup>9</sup> established the interest that led Sally to her ongoing career, while thanks to Janet she developed wider interests in plant-microbe symbioses.

### The next uncertain phase

After returning to Australia, Sally continued her tutoring/demonstrating and not long afterwards was offered a tenurable senior tutoring position in the Adelaide Department of Botany, but she turned down the offer as she had become determined to pursue a career in research. She looked around for funding opportunities for a post-doctoral position in Adelaide. In those days there was no opportunity to apply for your own salary as a research fellow or equivalent position. Sally realised she needed an established staff member to submit grant applications, what she referred to as 'a research god-father or front-man'.<sup>10</sup> Professor Donald Nicholas, head of the then Department of Agricultural Biochemistry and Soil Science at the university's Waite campus, agreed to take on this role but he studied the biochemistry of N<sub>2</sub>-fixing symbioses and said that he knew nothing about mycorrhizas. He suggested that Andrew join in as applicant, as Andrew's interest in plant membrane transport was starting to extend to arbuscular mycorrhizal (AM) symbiotic functioning in terms of exchange of plant photosynthetic carbon for soil nutrients obtained via the fungus. Andrew was rather dubious about technically being Sally's employer but she seemed unperturbed. As Sally later explained, she had the major role in drafting proposals and carrying out experiments, although the applicants were officially by Donald Nicholas and Andrew.<sup>11</sup> Donald's role should not be underestimated, however. He was expert at seeking out grant opportunities, knowing how much funding might realistically be requested, and in polishing applications to be more persuasive. Initially the focus was on interactions between AM fungal colonisation and N<sub>2</sub> fixation,<sup>12</sup> but these were complex and N<sub>2</sub> fixation dropped from the research, although there were some detailed investigations of uptake and assimilation of soil inorganic nitrogen and the associated enzymology.<sup>13</sup> Parallels with AM symbiosis were remembered for some later publications, and have been well shown in recent years by others.<sup>14</sup>

<sup>7</sup> Interview by Lynette Zeitz (2014: 313). This book contains much material about Sally's career.

<sup>8</sup> 'Arbuscular' from the microscopic tree-like interfaces within the plant root that occur in most of the symbioses. The symbiosis was originally called 'vesicular-arbuscular', but vesicles are not formed by all of the fungi.

<sup>9</sup> Published as Smith and Daft (1977).

<sup>10</sup> The sexist terms were appropriate given the extreme gender imbalance in senior academic positions across Australia.

<sup>11</sup> Smith (2019).

<sup>12</sup> For example Smith and others (1979).

<sup>13</sup> For details see bibliography (Supplementary Material).

<sup>14</sup> Limitation of photosynthetic carbon supply to the AM fungus caused by shading was also examined and was revisited many years later.

Fortunately, rural grant agencies in Australia supported research much further ‘from the farm gate’ (meaning crop productivity and profits) than is now the case, and the team tried to be realistic as to how much knowledge of functioning in AM symbioses might be applied in relation to improving crop yield. This is still a contentious issue. The first application to the Australian Research Grants Committee (ARGC; forerunner of the Australian Research Council, ARC), in order to move away from the farm gate depressingly failed: not unusual, of course. Fortunately, there was a last-minute successful application for short-term funding for innovative research that used Australian Reserve Bank levies on crops (the Rural Credits scheme); this was almost literally a Christmas present that filled the funding gap and the clouds lifted. Ongoing funding from ARGC that followed allowed the team to focus on functioning, developmental and structural aspects of AM symbiosis and Sally was able to establish fruitful collaborations in these areas.

Alan (N. A.) Walker (FAA 1982), a plant cell biophysicist from the University of Sydney who specialised in plant cell membrane electrophysiology and collaborated with Andrew became interested in the dynamics of colonisation and growth of the AM fungi in roots in relation to root growth. The end-result was, and still is, conventionally expressed as percent of root-length colonised at any given time. Alan undertook some detailed mathematical modelling, based on Sally’s laborious microscopic measurements.<sup>15</sup> Mark Tester undertook a BSc (Honours) project with Sally on the same theme.<sup>16</sup>

A little later Sally started to collaborate with Vivienne Gianinazzi-Pearson (INRA, France) on pioneering enzymic studies of the possible role of membrane-bound  $H^+$ -ATPase in powering nutrient transport across the arbuscular interface.<sup>17</sup> Together they wrote an important review of physiological interactions between plant and AM fungus.<sup>18</sup> The order of their names on a later paper that became widely cited was determined rather unusually by a bet as to how long one of Vivienne’s sons, who had accompanied her on a visit to Adelaide, would bathe in the cold wintery sea. Perhaps not surprisingly, Vivienne’s estimate was closer, so she was first author, Sally was second, and their husbands were also among the ‘and others’.<sup>19</sup>

During this lengthy phase of Sally’s research career she remained technically half-time although in practice it was more than that. Not long after Jack Harley retired in 1979 he approached Sally to contribute to *Mycorrhizal Symbiosis*, a book planned as the successor to Harley’s earlier book *The Biology of Mycorrhiza*, written when very little was known about AM symbiosis.<sup>20</sup> Harley (FRS 1964) pursued a very successful research career, mostly at Oxford, but he had not kept up at all with AM research, which had rapidly developed since the 1960s. Again in her own words, Sally

found that collaborating with her father was a challenge, both academically and personally.<sup>21</sup> He and Lindsay visited Adelaide very soon after the Smiths had moved to a house in the Adelaide Hills, partly as an ‘insurance policy’ as regards activities such as garden restoration by Sally if her research career ended. Builders were doing some house restoration and one remarked to Andrew that it was a pity that Sally and her father did not get on well—there were so many loud arguments. Andrew reassured him that this was just vigorous scientific discussion. Also in Sally’s words, it went well. Sally wrote about half of the book, which was soon published.<sup>22</sup> Sally commented that all chapters were exchanged and edited by the co-author and in the final stages ‘the whole book was read aloud!’—hence the vigorous discussions.<sup>23</sup> Like her father, Sally had a clear, rather loud ‘Oxford’ voice that was an advantage when giving talks, asking questions in large gatherings and calling husband and children in from the garden. At conferences, she tended not to sit at the front, especially if her father were also there—which possibly helped still to disguise that she was ‘Jack Harley’s daughter’. In fact they got on very well, although there were certainly minor disagreements over the years about mycorrhizal matters. Sally, Andrew and their children paid many visits to Jack and Lindsay’s house at Old Marston.<sup>24</sup>

In May 1990, Sally submitted a thesis for the award of a University of Adelaide DSc and this was formally awarded early in 1991.<sup>25</sup> It was an unusual award for a staff member who had never held a tenurable academic position, and marked an important stepping stone in her career.

### Career security at last: overview

Sally’s determination paid off when in 1991 she obtained a tenurable position as a senior lecturer in the Department of Soil Science at the Waite campus. A problem had been previously that mycorrhizal symbiosis fell between departmental stools: it was not seen at the university as mainstream plant science or agricultural science, and was certainly not plant pathology. The appointment occurred not long after the arrival of Harold Woolhouse as director of the Waite Agricultural Research Institute. He had a mission of extending the activities at the Waite to wide areas of natural resource management beyond agricultural science, and Sally certainly fitted. She was rapidly promoted to associate professor and in 1995 was awarded a personal appointment as professor at a time when only two or three such promotions were awarded every three years. Sally became involved in the usual range of academic activities, including undergraduate teaching at all levels at the

<sup>15</sup> Smith and Walker (1981); Walker and Smith (1984); see also (FA) Smith and Beilby (2015).

<sup>16</sup> Tester and others (1986). Mark then abandoned mycorrhizas and went to Cambridge to start his highly successful research career with a PhD on plant cell membrane transport supervised by Enid MacRobbie, thus making her, as she said, a research grandmother.

<sup>17</sup> Like Sally, Vivienne’s research career started when she followed her husband Silvio to his research base (Gianinazzi-Pearson 2020).

<sup>18</sup> Smith and Gianinazzi-Pearson (1988).

<sup>19</sup> Gianinazzi-Pearson and others (1991).

<sup>20</sup> Two editions: Harley (1959, 1969).

<sup>21</sup> Smith (2019).

<sup>22</sup> Harley and Smith (1983).

<sup>23</sup> ‘Read aloud!’: comment with emphasis in Smith (1991).

<sup>24</sup> Harley received many honours and retired as professor of forest science in 1979, with award of CBE. He collapsed and died shortly before Christmas 1990 from a sudden heart attack, aged 79.

<sup>25</sup> Smith (1991).



university's three teaching campuses, especially in the areas of soil biology and ecology, with concomitant course arrangement and responsibilities.<sup>26</sup>

Sally's university duties included spells as head of department and then deputy head and acting head but she turned down requests to serve at higher levels, including responsibility for undergraduate teaching at the Waite and Roseworthy campuses and as the faculty associate dean responsible for recruiting international students. Her reason was that at last she had time and opportunity to pursue her own research career without fear of it collapsing from funding problems. There were no family complications. Andrew was teaching and researching plant membrane transport on the North Terrace campus, and was collaborating with Sally at the Waite.<sup>27</sup> Caroline was in the later stages of the medical degree course (MB, BS) and Hilary was studying for a BA in geography, both at the University of Adelaide. They went on to University of Adelaide PhDs and successful careers.

### Development of the research group and ongoing research

Sally's overarching mission was to pursue her research career and develop an active research group. She rapidly extended her knowledge by maintaining previous research contacts, participating in many major conferences and workshops overseas, usually by invitation, and visiting some prominent research groups to establish more collaborations. The Smiths had sabbatical leave in 1994 with Larry Peterson's group in Guelph, Canada, where Sally did advanced microscopy and Andrew gained much new knowledge about structural diversity in AM mycorrhizas that led to a major review.<sup>28</sup> They had two sabbaticals at Iver Jakobsen's laboratory at Roskilde, Denmark (1998 and 2002) to learn and then modify his innovative use of radioactive phosphate (<sup>32</sup>P and <sup>33</sup>P) to track and quantify nutrient transport from soil through the AM fungal hyphae into the plant. Some highly cited papers resulted (see later) and the technique was adopted by Sally's growing research group at the Waite. A collaboration in Australia involving molecular biology was developed with Susan Barker, University of Western Australia. It involved the use of a tomato mutant that greatly reduced mycorrhizal colonisation (*rmc*) and was further studied at the Waite.

Sally had already started to supervise Honours students and a few PhD students before her new appointment. As well as her ongoing personal research, she supervised ~35 PhD students overall with about half as principal supervisor. Just over half of the latter were from overseas: from Argentina, Brazil, China, India, Indonesia and Mexico. One of them once commented that most forms of English were heard at the regular laboratory group meetings. In addition there were growing numbers of short-term overseas visitors. Overall, the gender balance in the group was about equal, although once a notice appeared briefly on an office door saying 'Men Wanted'.

Sally became increasingly supported by Andrew—not a response to the notice on the door! After some intensive university administration, at the end of 2000 he gave up attempts to combine

research activity in the rapidly growing areas of plant membrane transport and mycorrhizal symbiosis. Andrew 'retired' to the Waite campus with an adjunct professorial appointment and an emeritus award for professorial retirees. Andrew became a born-again researcher as Sally's second-in-command and PhD co-supervisor, both unofficially and officially.

PhD projects for which Sally was chief supervisor mostly involved AM symbiosis, but some were in wider areas of soil biology (see Supplementary Material). Group meetings included presentations in which students discussed their plans and possible outcomes. Everyone had input and discussions always ended with better experimental design. All of the PhD students who studied AM symbiosis experienced the long plant growth experiments with watering to well defined soil weights, followed by harvesting and separation of tissue samples and intensive microscopy to identify and quantify AM fungal structures. The projects covered Sally's interests as they developed and were influenced by various collaborations. An important research theme developed by the Smiths in collaboration with Iver Jakobsen and involving several PhD students was the importance of diversity in AM functioning. Their approach included work both in the glasshouse and in the field.

Sally was adamant that the students should prepare articles for publication. An early project that received considerable attention when results were published was by John Baon on the range of effects of AM symbiosis on cereal growth—positive down to negative—extended later by Huiying (Lisa) Li. Sandy Dickson followed up the contacts with Larry Peterson with advanced confocal microscopy and image analysis. Evelina Facelli studied AM effects on plant competition, Tim Cavagnaro examined fungal morphology and growth of arbuscular mycorrhizas, including the two structural classes 'rediscovered' by the Smiths. Lingling Gao compared colonisation patterns in the *rmc* mutant, and discovered that one AM fungus overcame the genetic block; she collaborated with Tim Cavagnaro to some extent. Maria Manjarrez further studied cellular responses and fungal activity of the *rmc* mutant. Emily Grace used molecular biology to focus on gene expression in relation to diversity of AM functioning. At a higher scale, Patrick O'Connor researched ecological aspects of AM symbiosis. In addition, Donna Glassop, a PhD student of Frank W. Smith (CSIRO; no relation) examined the molecular biology of P transporters in rice, and Katrine Poulsen, a visiting student from Iver Jakobsen's laboratory in Denmark, who also used the *rmc* mutant.<sup>29</sup> When Andrew was involved there were sometimes different views about written material, including frequency of comma use, as duly noted in margins on manuscripts and subsequently resolved harmoniously. Some of the PhD work was continued by former PhD students who obtained postdoctoral positions in the group.

Sally herself continued hands-on research as much as possible and also did a lot of writing. The second edition of *Mycorrhizal Symbiosis* was published in 1997, co-authored with David Read, professor at the University of Sheffield (FRS 1990).<sup>30</sup> Read had broad knowledge of the different classes of mycorrhiza, especially as regards their

<sup>26</sup> Woolhouse sadly died from brain cancer in 1996.

<sup>27</sup> He had been appointed professor of botany in 1990 and became FAA in that year.

<sup>28</sup> Smith and Smith (1997).

<sup>29</sup> Papers by PhD students can be identified in the bibliography (Supplementary Material).

<sup>30</sup> Smith and Read (1997).

ecology, and he too had strong opinions. Sally and David had vigorous discussions when they met, although rather quieter than with Harley. The book became the 'bible' for mycorrhizal researchers worldwide. When Tim Cavagnaro started his PhD project in 1998 he asked if Sally could recommend a good textbook on the topic. She quietly handed him *Mycorrhizal Symbiosis* and simply said 'this might be useful'. Sally was sometimes heard to say 'Did we really say that?' when it was cited (perhaps incorrectly), or 'I wish people would cite the original reference, and not rely on "The Book"'.<sup>31</sup>

Sally made sure that the students for whom she was the principal supervisor all gained experience at conferences, whether in Australia or overseas. In 2001, Sally was the chief organiser of the Third International Conference on Mycorrhizas (ICOM3), held in Adelaide. ICOM conferences were at the time not organised under the auspices of a professional society and had developed from series held alternately in North America and Europe. Adelaide 'captured' the conference after a hiatus in that arrangement and ICOM3 was held under the auspices of the University of Adelaide. Sally and Andrew, who was the 'treasurer', had some sleepless nights but the conference attracted over 500 delegates, with a large number of postgraduate students and it ran at a small profit. Sally's group was heavily involved and some of the delegates stayed on for some weeks to carry out and plan joint research. Many friendships were made or renewed.

The Smiths made several visits to China, initiated by Yongguan Zhu, who held a research fellowship in the department (then named Soil and Water) between 1998 and 2002 and collaborated with them. He returned to China and a highly successful career in institutes of the Chinese Academy of Sciences (CAS). Several publications resulted from these visits (see Supplementary Material).<sup>31</sup> As a result of the close relationship with China, a joint laboratory with Zhu's institute in Beijing was opened at the Waite in 2003. Depending on time available, Sally and Andrew, when present, often went birdwatching during these travels. This hobby, which became Sally's passion, had developed thanks to Alan Walker who was a keen birdwatcher, and with whom they spent holidays in Australia. Sally kept some detailed records in notebooks and entered in a database, never published in the end.

The many research activities inevitably required external funding. The summer holidays with Walker in the 1990s were not just to look at birds. The mornings were spent by all three writing research grant applications, and afternoons were the time for birdwatching. Sally used her considerable experience in writing applications, now no longer needed for her own salary, which together with Andrew's previous experience resulted in ongoing success in competitive funding, especially from the ARC. An important joint project was with Susan Barker, involving the *rmc* tomato mutant. This support provided essential research assistance for Sally's own hands-on research and in particular the time-consuming care of cultures of AM fungi. Rebecca Stonor gave loyal service as research assistant

and 'lab. dragon' to help keep the PhD students in order;<sup>32</sup> she continued for some time after Sally officially retired. Meanwhile, the funding greatly helped to support the PhD students and eventually the post-doctoral appointees Helle Christophersen, Sandy Dickson, Evelina Facelli and Lisa Li, along with international visitors.

Sally and Andrew obtained a grant from the ARC to fund exchanges for mycorrhizal research with Iver Jakobsen, Bengt Söderström (Lund) and Sari Timonen (Helsinki), involving several PhD students. During visits to China Sally helped PhD students improve their English-language skills. A later grant for Australia-China research exchanges also included funding for teaching English-language skills by a team led by Margaret Cargill, who had this role at the University of Adelaide. Patrick O'Connor was recruited and Andrew too.<sup>33</sup> Sally also obtained some funding to establish a university Centre for Soil-Plant Interactions (CSPI). This was a network of mycorrhizasts (a word coined by Jack Harley) and researchers studying N<sub>2</sub>-fixing symbioses, from across Australia and with overseas visitors, who participated in workshops in Adelaide. This initiative led to several more research collaborations. External competitive grants awarded to Sally and her associates, mainly by the ARC, from the time of her tenured appointment until she retired total about \$AU3 million, excluding a very large ARC-funded Australia-New Zealand Network for Vegetation Function led by Mark Westoby FAA, in which Sally was involved.

### Active research beyond 'retirement'

Sally ceased paid employment at the end of 2006 and became an adjunct professor in the department. No successor was appointed in the same field. CSPI ceased and the research group gradually dispersed, to Sally's intense regret.<sup>34</sup> Three major research projects continued beyond 2006 for 2–3 years. Two, both 'Smith and Smith',<sup>35</sup> had been funded by the ARC, one on roles of AM fungi in plant competition and the other on reduction of uptake of arsenic by AM fungi. The third was part funded by the South Australian Grains Industry Trust and examined the influence of AM fungi on uptake of fluid fertilisers by wheat.<sup>36</sup> Funding from research-related consultancies and donations supported research for some time.

The Smiths had long been very interested in depressions in plant growth that are sometimes caused by AM fungi, much to the irritation of researchers who unexpectedly experience them. Applications to ARC to test possible causes were unsuccessful. Nevertheless, a big consolation prize was that Iver Jakobsen put in a successful application to Danish and EU sources for a similar project, to include the Smiths, who visited Roskilde again in 2012, although the growth depression mystery was unresolved. The final project was literally close to the farm gate. Funded by the Australian Grains Research and Development Corporation, it adopted the technique developed with Iver Jakobsen and involved

<sup>31</sup> Yongguan Zhu was elected Academician of CAS at the end of 2019.

<sup>32</sup> Rebecca succeeded Sandy Dickson and Debbie Miller in this important role. She co-authored some papers: see Supplementary Material.

<sup>33</sup> Cargill and O'Connor went on to write a highly successful textbook on developing English-language skills in science publication.

<sup>34</sup> The Adelaide-Beijing joint laboratory was short-lived, mainly because Yongguan Zhu moved on to lead a new CAS institute at Xiamen, which Sally and Andrew visited. It had a different research focus (urban ecology).

<sup>35</sup> As in the publications, the order of names was determined by who did more of the work in preparation.

<sup>36</sup> Publications are in Supplementary Material.

application of  $^{33}\text{P}$  in small compartments in the field to track P uptake via AM fungi into wheat.<sup>37</sup>

Tim Cavagnaro's appointment as an Australian Research Council Future Fellow at the Waite in 2014 (now a professor) re-established research into AM symbiosis in the wider context of soil ecology and Sally enjoyed going to the laboratory group meetings. She still attended major conferences in Australia and overseas and did a lot of writing. The third edition of *Mycorrhizal Symbiosis* (Smith and Read) appeared in 2008.<sup>38</sup> Sally and Andrew wrote a major review that critically evaluated beliefs about functioning in AM symbioses and their role more widely, as in ecology.<sup>39</sup> Other articles were co-authored with some of Sally's many colleagues worldwide. At the time of writing, the three editions of 'The Book' have been cited over 16,000 times, according to 'Google Scholar' (October 2020). One of the articles that followed collaborations with Iver Jakobsen to examine diversity of AM growth responses has been cited nearly 750 times,<sup>40</sup> and two others from a previous visit have together been cited nearly 1,500 times.<sup>41</sup> Sally's enormous number of citations in a wide range of journals is impressive for a research area that can still fall between disciplinary stools.<sup>42</sup>

### Honours and awards

As Sally's reputation increased she received many honours, one of the first being honorary membership of the Mycorrhiza Association of Indonesia (1997) following development of links with Indonesia that involved a memorable workshop with young researchers, held at Bogor. In 2001, Sally was awarded the Clarke Medal of the Royal Society of New South Wales and was elected Fellow of the Australian Academy of Science in the same year. She served as a council member of the academy (2005–8) and later served on one of the committees that select new fellows. In 2001, Sally was awarded an Australian Centenary Medal for services to biology. Following the development of strong links with China, Sally was appointed in 2001 honorary professor at the Chinese Academy of Sciences' Centre for Eco-Environmental Sciences, Beijing, where Yongguan Zhu then held a senior position, and also at China Agricultural University, also in Beijing (2002). Sally greatly enjoyed her appointment from 2005 to 2011 to the board of directors of the Asian Vegetable Research and Development Center, later known as the World Vegetable Center, based in Taiwan, and visited its research stations in India, Tanzania and Thailand. She was vice-president of the board for two years. Later she was involved in a USAid project in Central America for a short time. She was awarded the Taylor (2006) and Prescott (2012) Medals of the Australian Society of Soil Science. Not least, after refereeing many papers in a variety of scientific journals Sally became an advisor to the editors of *New Phytologist*, *Plant and Soil* and the *Australian Journal of Botany*.

### Last years

As active involvement in research decreased, Sally's interest in birdwatching further increased. There were regular overseas trips,

some still added on to attendance at conferences. In August 2015 the Smiths enjoyed attending the 8th International Conference on Mycorrhiza, held in Flagstaff, Arizona, before and after which they went birdwatching. Soon after returning to Adelaide Sally became unwell and a blood test revealed that her platelets had decreased to dangerously low levels that would have prevented blood clotting if she cut herself. Sally was whisked to hospital, where after treatment for a few days the levels rose back to normal. The haematologist was greatly relieved, commenting that although as a biologist Sally wanted to know the original cause, his job was first to cure the problem. In fact the cause was not discovered. There had been no fever that would have indicated dangerous tick bites on the field excursions in Arizona.

Regular blood tests followed and Sally continued to attend laboratory meetings and seminars and co-authored more papers. Her routine included walking around the neighbourhood, considerable gardening (now with paid help), family holidays and the frequent local birdwatching trips that are recorded in her many notebooks. She became an even keener cook, especially with Asian food, no doubt reflecting the earlier visits to China (Fig. 3). However, Sally also suffered some pelvic fractures of unknown origin, arthritis and consequent walking problems, resulting in frequent medical visits. In March 2016, her diary, that she had used only to record medical and other appointments, there is the comment: 'rather disheartened' with a brief note later added: 'not totally unexpected'. However, she was outwardly cheerful and was well enough to go on more small-group birdwatching tours, chosen with the approval of her specialist medical advisors. Sally adopted the use of a folding walking stick with fold-out seat on top, and very convenient when travelling and also sitting down at social functions when most people were standing—she hated being 'left out' sitting round the edges.

In May 2017, Sally went with Andrew on a birdwatching trip to Alaska, one for which the specialists gave very cautious approval. Early on, the group was delivered in pouring rain by two boats on to wet sandbanks in order to look at the many shorebirds. A breakdown in one of the boats caused considerable delay before the long return to base. Sally with her folding stick, which did not sink into the sand, chose to be among the last to leave and thoroughly enjoyed this experience along with Andrew, although not all members of the group did so. Most of the time was spent on a small converted fishing trawler. The other eight group members were mostly UK medicos, with spouses or partners, not all of whom were avid birdwatchers. Sally and the guide were the ones who spent most time on the deck along with a quiet lady who was later found to have been high in the UK medical establishment. The group got on very well, especially as alcohol was consumed freely by most of them (literally: it was free). There were vigorous discussions about many issues, one of which got down to tribalism. The quiet lady said firmly that if we all had to join tribes she would join one led by Sally. Later in the year the Smiths went on two more trips, one to northern

<sup>37</sup> Smith and others (2015).

<sup>38</sup> Smith and Smith (2011).

<sup>39</sup> Smith and Read (2008).

<sup>40</sup> Smith and others (2011).

<sup>41</sup> Smith and others (2003, 2004).

<sup>42</sup> The review that resulted from the visit to Larry Peterson's laboratory has been cited about 700 times (Smith and Smith 1997).





**Fig. 3.** Sally Smith in retirement; this time not cooking Asian food, 2015. Photographed by Andrew Smith and reproduced with his permission.

Queensland and the other in South Africa that was advertised for comfort, food and wine as well as nature. This suited Sally because there was little walking, especially in the national parks for obvious reasons (lions).

In February 2018, Sally had a successful knee replacement. Professional activities were mainly limited to laboratory meetings, although a long review about the costs of P acquisition that had caused her considerable anguish in the many revisions was published.<sup>43</sup> Sally's diary records nothing that alarmed her about her state of health. Restlessness inevitably set in again and in December the Smiths had a private birdwatching tour to south-west Western Australia.

Early in 2019 the Smiths went birdwatching in Cuba, her specialists having once more given Sally approval: they well knew her determination. Not long after returning, the Smiths went to the UK for a 'winter escape' to celebrate Sir David Read's 80th birthday, where they met up with many old mycorrhizist friends. This was followed by a short holiday in the wonderful Isles of Scilly, with Sally's brother Richard and his wife Annie.<sup>44</sup> Sally's walking was now getting limited but otherwise she was very happy. She had not quite fully retired from science and still attended laboratory

meetings, taking notes and asking questions as usual. Her *New Phytologist* 'Profile' was published, as was the last research paper that she helped plan and co-author, a detailed study of AM functional diversity by Rohan Riley, a PhD student visiting the Waite from the University of Western Sydney.<sup>45</sup> The University of Adelaide suddenly woke up to the fact that Sally had never formally been awarded the title of emeritus professor and quickly rectified this omission. As the title had been used widely in university correspondence and announcements Sally was highly amused when the award was officially announced, though many colleagues were bewildered about the apparent duplication.

Despite the earlier trips in 2019, Sally was keen to have another gentle birdwatching trip to Western Australia and this occurred successfully in August. Not long afterwards there were visible symptoms of the blood problem. Sally immediately went into hospital. This time the stay was longer but the blood cell levels rose progressively. She became very bored and was desperate to get home. After visiting Sally, granddaughter Penny, then aged 16, said that she was greatly impressed by Sally's determination to keep fit, and was only now really getting to know her well. Sally returned home in the afternoon of 12 September with instructions: 'don't overdo it', recorded in her diary. In the evening she and Andrew sat happily discussing possible holidays in 2020. Both went to bed early and late in the evening Sally woke with a very painful headache. An ambulance arrived very quickly but when Sally arrived at the Royal Adelaide Hospital she was totally unconscious and could not be resuscitated. Sally died just after midnight, on 13 September.<sup>46</sup> It was a haemorrhage in the brain, possibly a rare complication of the blood problem.

Sally was cremated, and a private celebration of her life was held in the beautiful gardens at Stangate House, very close to the Smiths' house. Richard and Annie Harley arrived in time to be there. When Tracy Crisp, the funeral celebrant and friend of Caroline, was delivering a moving oration a magpie flew in and walked in front of her. Sally's ashes were scattered on Island Beach on Kangaroo Island, close to Caroline and Bob's beach house, by Andrew, Caroline, Bob, Penny, Hilary, Hilary's long-time partner Ken Boer, Richard and Annie. They drank a glass of champagne to celebrate Sally's life and achievements, watched by a group of pelicans. Later there was a large gathering on the Waite campus of many of her PhD students and colleagues.

## Conclusions

These sad reminiscences are not the way to end Sally's story. Peter Rathjen, recently appointed vice-chancellor, had only just become aware of Sally's ongoing achievements and at very short notice he arranged for her to be added to a group of 45 women who have been strongly associated with the University of Adelaide since its foundation in 1874 and who have—in the words of the university—'blazed the trail for gender equality'. The university erected large banners prominently on the North Terrace campus for several months. Sally was described as 'world-leading scholar in soil-plant interactions'. Sally's family is very proud of this unusual honour

<sup>43</sup> Raven and others (2018).

<sup>44</sup> Richard had retired as professor of physics at the University of Southampton. Annie was still employed there, also a professor of physics.

<sup>45</sup> Riley and others (2019).

<sup>46</sup> Not just before midnight, as Andrew previously announced.





**Fig. 4.** L to R: Hilary Smith, Caroline Smith, Andrew Smith, Penny Casson and Bob Casson when the University of Adelaide's lamp-post banner celebrating Sally's achievements was put up on campus, November 2019. Photograph by M. Roos. Photograph in possession of Andrew Smith and reproduced with his permission.

(Fig. 4). Sally was not an activist in feminism and was sometimes dubious about positive discrimination to solve gender imbalances, at least in the academic world, given that the problem starts much earlier with parental attitudes or in early schooling. Her mission was simply to show by example that women are as good as men, and she encouraged her female students and associates to think similarly

in whatever pathway they wanted to pursue. Her most important advice to all was 'never give up' and if anything went wrong in experiments she said 'it was part of life's rich tapestry'. If all worked out well, Sally said 'goodoh'. Sally never did give up and her achievements were recognised very shortly before she died by the Eminent Mycorrhiza Award of the International Mycorrhiza

Society, an organisation never even imagined when Sally began her research career all those years ago and one which the Adelaide conference in 2003 helped establish. As this memoir was being finalised, *New Phytologist* published as a tribute to Sally an open online ‘virtual issue’ with thoughtful contributions by several close colleagues who have cited selected papers that highlight Sally’s research achievements. It expands on the present memoir.<sup>47</sup>

In her personal tribute to Sally, her old friend Vivienne Gianinazzi-Pearson commented on Sally’s scientific rigour, enthusiasm and persistence in the face of challenges: she offered inspiration to those embarking on a scientific career that would continue in future. Sally ‘always insisted on the importance of being open-minded to other opinions (to which she listened patiently and graciously even when not in agreement) and of establishing collaborations with experts in other disciplines across the globe’.<sup>48</sup>

### Conflicts of interest

Professor Andrew F. Smith is the widower of Sally Smith. Professor Tim Cavagnaro and Dr Sandy Dickson are former students and colleagues.

### Acknowledgements

We thank *New Phytologist* for providing the photograph later used on the University of Adelaide’s banner, and also for inviting Sally to write the ‘Profile’ that we have cited here, along with the short extract from Lynette Zeitz’s recorded interviews (see Zeitz 2014). We also thank Caroline and Hilary for their reminiscences and comments. We are grateful to Vivienne Gianinazzi-Pearson and Lucy Hughes for their written tributes, and to past students and other professional colleagues who have told us of their experiences with Sally. We have focused very much on the ‘big picture’ and are sorry that many major studies have not been mentioned due to space limitations. We also apologise if any publications have been inadvertently omitted in the extensive Bibliography (Supplementary Material).

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