Loïc Pagès, founding scientist in root ecology and modelling

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Editorial

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Root system scientists strive to understand how a single root, emerging from a plant's seed, can form a complex, dynamic and plastic network of thousands of individual roots. They investigate how such a network is ideally suited to perform a number of functions required for the harmonious development of the whole plant. Everyone in the community also knows how complicated it can be to study root systems, with tasks ranging from digging plants out of the soil, creating experimental setups that allow the observation of the roots, to quantifying the root network itself or the processes underlying its formation. Within the community, there is one person, Dr Loïc Pagès, who has been working on all these tasks for many years, and who has moved the field forward numerous times. On the occasion of his soon-to-be retirement, we would like to express our appreciation to him via this editorial.

Loïc Pagès started studying the development of root systems almost 40 years ago and has not stopped ever since. Providing an exhaustive summary of Loïc's achievements would be a daunting task (according to Scopus, Loïc has published over 130 papers, with more than 249 collaborators; Fig. 1). Here we would like to highlight some of his key contributions to the field.

Loïc has been working on many facets of root research. Most importantly, Loïc spent a lot of time observing roots. He dug out and quantified thousands of root systems of more than 60 different plant species, sometimes from his own garden (Pagès and Kervella 2018). One root system at a time, this rich experimental work was Loïc's foundation for the discovery and conceptualization of a parsimonious set of developmental rules that he was able to apply to a wide range of plant species (Lecompte *et al.* 2001; Pagès 2016; Pagès and Kervella 2018). Briefly, these rules highlight the importance of the range—and not the average—of root diameters that can be found within a root system and the allometric relationship between roots of different orders. The unique approach of Loïc was to rely on these rules for designing and implementing computational root models.

Loïc Pagès is one of the founding fathers of root system modelling. When he published his first computational model, SARAH, in 1988 (Pagès and Ariès 1988), there were only a handful of scientists working in this emerging research area: him, D. Lungley (Lungley 1973), A. Fitter (Fitter 1987) and A. Diggle (Diggle 1988). SARAH was a simple root growth model that included all the available knowledge about root system development. This was so new at the time that it is easy to imagine the scepticism of some contemporary agronomists (Loïc's personal communication). But this did not stop him from continuing on this path. Since then, Loïc has published more than 15 different root models (Fig. 2). His modelling work spanned from purely structural models of single species (maize (Pagès *et al.* 1989), peach tree (Pagès *et al.* 1992), rubber tree (Thaler and Pagès 1998), *Arabidopsis thaliana* (Brun *et al.* 2010)), to generic structural models capable of representing a broad range of root systems, from grasses to trees (RootTyp (Pagès *et al.* 2004) or RSCone (Pagès *et al.* 2020b)). Loïc has also developed functional–structural models that included various functions such as water flow (Doussan *et al.* 1998), carbon allocation (GRAAL (Drouet and Pagès 2003), MassFlowDyn (Bidel *et al.* 2000)), nutrient allocation (GRAAL-CN (Drouet and Pagès 2007)) or interaction with the surrounding soil (Gérard *et al.* 2017; Cast *et al.* 2019). However, the model that best sums up Loïc's work is probably ArchiSimple (Pagès *et al.* 2014). As its name suggests, ArchiSimple (SuperSimple in English) requires less than 10 parameters to simulate a complex root system, but is nonetheless able to represent a wide range of complex root architectures (Pagès and Picon-Cochard 2014; Lobet *et al.* 2017). As such, ArchiSimple is a powerful tool to synthesize complex and diverse architectures with a small set of data points.

Loïc never stopped questioning his modelling approaches: from the use of meta-modelling approaches (Pagès *et al.* 2020) to the suggestion of new ways of representing the relationship between apical root growth, root diameter and local carbon availability (Pagès *et al.* 2020). In addition to his modelling work, Loïc has been involved into the thinking and development of sampling techniques in the field (Pellerin *et al.* 1994; Pagès *et al.* 2012) and under controlled conditions by designing rhizotrons (Drouet *et al.* 2005), root image analysis tools (DART (Le Bot *et al.* 2010), SmartRoot (Lobet *et al.* 2011)) and root data analysis pipelines (archiDART (Delory *et al.* 2016), Root System Markup Language (Lobet *et al.* 2015)). Recently, Loïc has also contributed to the writing of an exhaustive root ecology handbook that provides detailed guidelines and standardized protocols for sampling and classifying roots as well as measuring root traits (Freschet *et al.* 2021).

Finally, in addition to being a leading research scholar and, for part of his career, the head of his department at INRA Avignon, France, Loïc has been a supervisor, a mentor and an enthusiastic colleague and friend to many of us in the field. His door was open to discuss everything related to root system development and beyond, and his advice was always helpful.

Dear Loïc, as root researchers, we would like to thank you for everything you have brought to the community, for every model you have developed, for every new concept you have formalized, as well as for all the advice and heated debates you have shared with many of us. We thank you and wish you a long and happy retirement, taking care of your gardens, grandchildren and bees. Thank you, Loïc!

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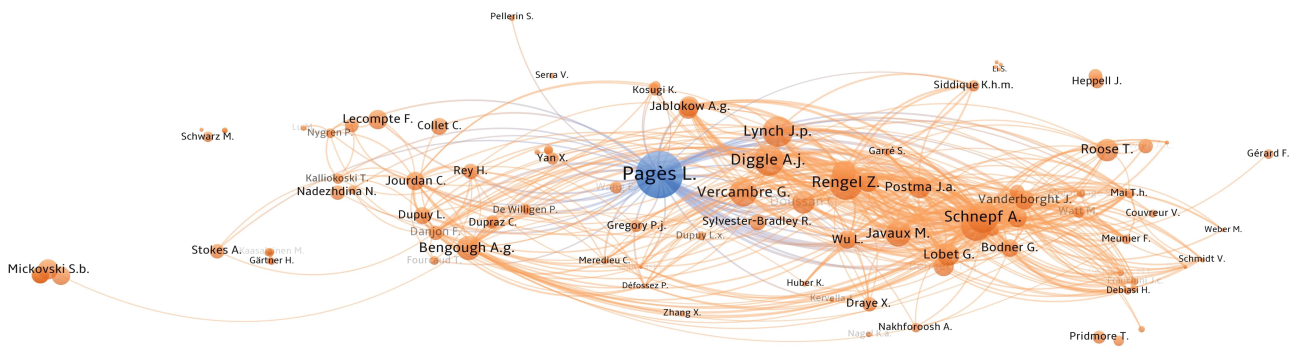

Figure 1. Author citation map based on root system modelling papers from the years 1980–2021 (109 authors in the citation network). The connecting lines indicate the 500 strongest citation links between authors. The size of the nodes stands for the total number of citations. Loïc's major contribution to this research field is highlighted by his central position and the highest number of papers (33), citations (1394) and links with other authors (99). Sources: Scopus, Software: VOSviewer.

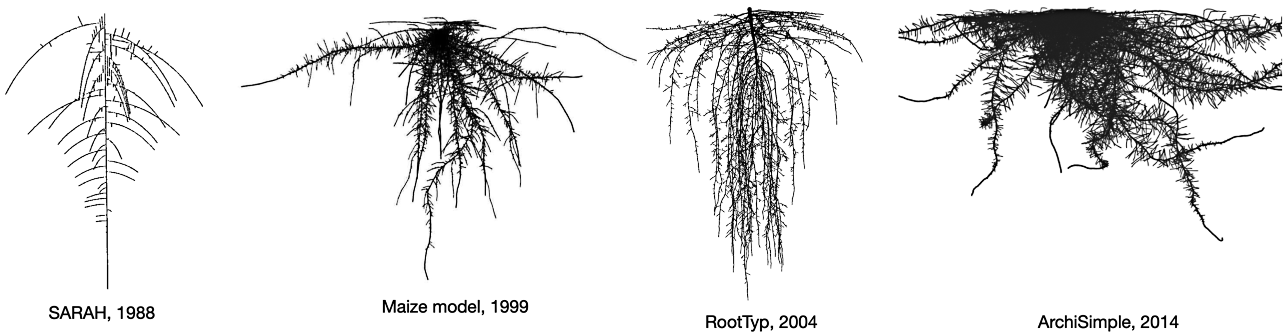

Figure 2. Visual output of four models developed by Loïc. We should add here that Loïc strongly prefers showing graphs illustrating and analysing the model outputs rather than the model visual outputs themselves. We hope he forgives us for this.

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