Interview of John Passioura by John Kirkegaard
Expanded content

Ancestry

JK. Passioura is an interesting name – what is your heritage?

My father was Greek. He was born in Smyrna, a multicultural city on the west coast of Turkey. He lived there until his father became alarmed by the outbreak of the First World War and sent him and his brother to work in Sudan, away from the fighting. The boys stayed there until after the war, but then there was a war between the Greeks and the Turks in 1922 that resulted in the destruction of Smyrna. The family, which had been wealthy, barely escaped, having lost all of their possessions. Thereafter there was a major exchange of populations between Turkey and Greece and my father decided to migrate to Australia where he arrived in 1925 and settled in Melbourne. He had no problems speaking English. He spoke 6 languages fluently – French, Greek and Turkish when he was a schoolboy, and then added Arabic, Italian and English while working in Sudan, and, later, in Alexandria.

JK. How old was your father when he arrived and what did he do upon arrival?

He was 29 years old when he arrived in Melbourne, with very little cash in his pockets. However, he soon found a job with a greengrocer in St. Kilda, who required him to go to Melbourne's main fruit and veg market, some 8 km from St. Kilda and pick up his order to take back to the greengrocer. His transport was a horse and cart. Each morning he had to wake at 4:30 am, and then harness his horse to the cart. Once done, he would go to sleep in the cart, while the horse, which knew its job well, would trudge to the markets, wait obediently and then do the return trip.

JK. How long did he stick at that?

After about 3 years, he had saved enough money to rent a café in Fitzroy. There he met my mother-to-be, who was a waitress in the café. Her ancestry was very much working class Australian. She was very intelligent and was essentially the breadwinner for her family of 5 siblings and a chronically ill mother. Her father was itinerant, and his job was to roam the countryside repairing electricity generators in small towns.

JK. Did the café prosper?

The café did well for a while, but the onset of the Great Depression in 1929 sent them broke. Life was difficult for them, as for most Australians during the next few years. They decided to leave Melbourne and move to Balranald, a small town on the Murrumbidgee, where I was born, in 1938. Their life was itinerant until they were offered a milk bar near Elwood Beach shortly before the end of the Second World War. From then on they climbed out of poverty because Elwood Beach attracted tens of thousands of Melburnians on hot summer days who became eager customers. The milk bar came with a small kiosk at the other end of Elwood Beach, where I worked from the ages of 12 to 15 during the summer. That childhood experience convinced me that running a milk bar was definitely not for me.

JK. Did your parents encourage you towards science or were there other influencers in that?

Childhood influences

My parents had little idea of science but were aware of my interest in machinery. Like many small boys I was fascinated with machinery. I used to watch and talk to the refrigeration engineers who used to look after the several refrigeration compressors in the milk bar. We used to see them frequently, for the compressors were very unreliable then. It was clear to me from about the age of eight that I wanted to be "when I grew up" either an engineer or a scientist, or possibly both.

JK. Where did the specific interest in agriculture come from?

After I started school, a major influence on me came from spending several winter term breaks on a sheep station about 50 km out from Balranald on the road to Lake Mungo. The wife was a friend of my mother and lived with us before she married.

I became enthralled by her husband. He enjoyed children and was happy to show me the many things he had to do on the station – dealing with a severe rabbit plague; the maintenance of the windmills that pump water to the drinking troughs; the operation of the shearing shed and maintenance of the shearing equipment; and many others.

But above all, the one thing that fascinated me was his extraordinary knowledge of everything about running a highly successful sheep station. He could easily be viewed as a hayseed when in a city, but I knew him to be a complete master in his own environment.

That impression has stayed with me for the whole of my life, through my great admiration for the leading farmers with whom I have worked during my career. Indeed, it was his influence, though he wasn't aware of it, that led me later to enroll in the Faculty of Agriculture at the University of Melbourne.

JK. Early mentors such as you describe can have a profound effect when one reflects upon it. Were there other strong influences in your school days?

Schooldays

My mother was very conscious of her having missed four years of high school, for she had to leave school when she was 13. My father, who had completed school in Smyrna, was also strongly convinced of the need for a good education. Thus, they decided to enrol me in the nearest school of high repute at the first opportunity, which was in 1946.

That school was Wesley College. It had the Methodist reputation of being wowserish – no alcohol and no dancing - but was becoming much more tolerant and more positive at that time. It was close to the Melbourne synagogue and welcomed the enrolment of Jews, who constituted about 10% of the students. It had a strong ethos of community service, embraced students of any ethnicity, and arranged for all of us to spend time outside the school helping other people. These values lived on, beyond matriculation, in most of the students with whom I kept in touch.

JK. Your station owner and parents clearly helped set your compass towards studies in agriculture in Melbourne – what was it like in those days?

1955-1958: Life as an undergraduate.

I enrolled in the Faculty of Agriculture at the University of Melbourne in 1955, which was very small then, with only about 4000 full-time students. The first-year course covered fundamental science subjects: physics, chemistry, botany, and geology, which gave our intake a strong scientific background that served us well in the later years.

JK And you also got to spend time at a College farm in those days?

Yes, indeed. The second year of the course was held at Dookie college, about 200 km north of Melbourne. The college catered primarily for high school students who wished to become farmers. The pattern of the year was to have a fortnight of lectures followed by a fortnight on the farm, during which we dealt with pigs, dairy, sheep, beef, pastures, weeds, and so on. However, 1956 was a very wet year; the nearby Broken River flooded for several months during autumn and winter such that we got little experience in dealing with crops.

JK. Sounds like it was a great rounded curriculum?

The final two years of the course provided a broad agricultural curriculum that covered advanced scientific subjects: plant and animal physiology, biochemistry, soil chemistry and agricultural engineering. To these were added, no less importantly: economics, landscape geography, and sociology, the latter emphasizing interactions with farmers. Thus, by graduation, our education was remarkably broad.

JK. Do any specific subjects stand out as influencing your direction?

Soil chemistry was the most difficult subject. It was taught by Prof Geoffrey Leeper (GWL), a meticulous and critical thinker with broad interests who was held in awe by the students, including me. The awe was tinged with some fear, for the subject had a high failure rate.

Leeper's intellect and broad knowledge was daunting. He provided not only knowledge of soils and inorganic chemistry, but also an appreciation of clear writing, of rational thinking, and of philosophers of science, especially Karl Popper.

1959-1962: Life as a graduate student.

JK. So despite your obvious awe for Professor Leeper, you pursued a PhD with him?

Yes, after graduation, and with much trepidation, I asked Professor Leeper if I could become his student. He peered at me for a few moments, then asked me what my marks were in the final examination in agricultural engineering. I stumbled a little and then said that I believed that I had the top marks. Well, he said, let us give some thought to what you might do.

JK. Professor Leeper clearly had considerable influence on the chosen topic for your PhD?

His research interest was mainly in trace elements, especially manganese. Manganese is a crucially important trace element, too little of which can disrupt photosynthesis in a plant. The central thrust of my PhD thesis was to explore and interpret the intriguing agronomic observations by many farmers that, while manganese deficiency was rife on their farms, it never appeared in wheel tracks. Our first hypothesis was that compaction of the soil in the tracks led to oxygen deficiency, thereby releasing soluble manganese from insoluble manganese dioxide. However chemical analysis showed that not to be true.

JK. Did you get to the bottom of that?

Eventually, we showed that in compacted soil the pores in which the roots were growing became too small for the roots to grow in easily - the roots had to force their way into these pores thereby moulding themselves to the solid phase of the soil. We suggested that the roots themselves acted by "contact reduction", which liberates manganous ions, similar to the "contact exchange" proposed for cations in general by Hans Jenny, the leading soil scientist of his time, by his forcing of the close contact of clay particles.

JK. I understand that this, your first PhD paper was published in Nature – that's impressive!!

Yes, our paper was published in *Nature*, perhaps because of the remarkable observation that compaction can improve the growth of plants, which had never been noticed before, and which emphasized the importance of close contact between roots and the surfaces of soil particles on which many important nutrients were bound.

JK. You moved onto postdoctoral studies in the UK and Europe – how did that come about?

Post-doctoral time in Europe

In the 1960s CSIRO provided postdoctoral fellowships to study overseas. I was fortunate to get one of these, which enabled me to spend a year at the McCauley Institute for Soil Research at Aberdeen in Scotland, arriving there in late 1963. Unfortunately, I found the McCauley Institute to be very stodgy, and the research there to be mundane.

JK. How did you maintain your enthusiasm?

During the summer of 1964 I spent a month traveling around Western Europe: Scandinavia, the Netherlands, France, and western Germany. I was especially interested in what I saw at Wageningen University in the Netherlands and was offered a job there in the department of soil chemistry and soil physics. Gerard Bolt was a highly distinguished professor in that department and I learnt a lot from him. His central research interest at that time was in the physical chemistry of clay colloids and how their behaviour changed depending on the cations that adhered to them. I found the mathematics he used fascinating but daunting.

JK. Yes, there is a strong theme of physics and chemistry in your work, but your talent for mathematics is also emerging?

Well, harking back to when I was still a graduate student, I had become interested in the movement of soluble nutrients in soil. I wrote a paper at that time using rather rudimentary equations to describe the cylindrical flow towards roots which was driven by the transpiration rate of the plants. That paper, published in 1963, was included as an addendum to my PhD thesis.

Fortunately, in Wageningen, I shared a laboratory with Maurice “Mo” Frere, from USDA, who was on sabbatical leave in Wageningen. We shared the same interest in the transport of nutrients through the soil to the roots.

Mo was experienced in numerical methods of solving partial differential equations that could not be solved analytically. He introduced me to *Fortran*, an early computer language. Together we wrote suitable programs that were fed into an IBM 1620 computer, the first to become popular, although it took many hours, typically overnight, to solve the equations. We wrote a paper that was published in 1967, and so far as we knew, it was the first paper to use numerical techniques to study the flow of nutrients to roots.

JK. Did the CSIRO scholarship guarantee a subsequent job with CSIRO in those days?

Returning to Australia

Holders of CSIRO postdoctoral scholarships were expected, but not required, to join one of the divisions of CSIRO. Near the end of my time at Wageningen in 1966, I was approached by Ralph Slatyer to join his group in Canberra in the Division of Land Use Research.

Ralph was an outstanding scientist who later became Australia's first Chief Scientist. He worked in the field as an ecologist but also in the laboratory. He was one of the pioneers of measuring gas exchange in plants, i.e., CO_2 in, as the feedstock for photosynthesis, and water out, as it escaped through the necessarily open stomata, the holes in the leaf surface.

He had been expanding his group with people who could think mathematically and were comfortable in dealing with equations that could relate to the behaviour of plants and crops. He had noticed my interest in transport processes in soil and plants and thought that I could make a comparatively youthful addition to his group.

JK. So you accepted his offer, evidently a great decision!

Yes, I happily accepted the offer. We arrived in Canberra in September 1966, a pregnant wife, a two-year-old daughter, and me. We settled in quickly and soon moved into a house that was only about 200 m from CSIRO.

JK. What specifically did Ralph ask you to do?

I was given no specific directions from Ralph; his policy was to encourage new appointees to be usefully creative. I soon teamed up with Ian Cowan (FAA), who had also just joined Ralph's group. He had been working at Rothamsted with the great Howard Penman on the transport of water in plants from soil to atmosphere. Penman was the world's leading authority on micrometeorology at that time.

Ian and I collaborated on mathematical models of the movement of water in the soil to roots and the circumstances in which that movement became limiting. We made use of the numerical programs that I had for dealing with the cylindrical geometry of roots and their environment. We compared the results with the algebraic equations that Ian had produced. The agreement was good and showed that simple algebra was adequate to describe the flow of water given the notorious variability of soil.

I spent much time over the next 20 years exploring how roots and soil interacted to control the uptake of water, which, when it becomes limiting, reduces the growth rate of plants.

JK. I understand your work in those early days also took you to the much "discussed" (controversial?) Ord River project?

Yes, in the late 1960s, I joined another colleague who had a field experiment at Kununurra, in northern Western Australia, where the Division of Land Use Research had a team working at a pilot site. Cotton was being grown there to see if it would be suitable for the potential Ord dam and the large irrigated area it could serve. The agronomic interest was in making the most effective use of the large amounts of nitrogen fertiliser that the cotton required, about 250 kg/ha. The experiment included 3 forms of application: spread on the surface; dissolved in irrigation water; and banded 15 cm below the surface, running parallel to, and about 10 cm away from the row of plants. The banded form was by far the best in both the yield and in the recovery of the N.

JK. Did you again focus in on the root-soil interactions behind that observation?

Yes, it turned out that the reason for this was that the band was highly concentrated, so much so that it was initially toxic. Roots stopped growing towards the 1 cm wide band when they were about 5 cm away. However, they proliferated at this distance and took up the nitrate that diffused towards them, after the beginning of nitrification.

Eventually, the toxicity fell as the band slowly disappeared during the life of the crop. By this time the roots had formed a dense cylindrical cluster. Nitrification, i.e. the bacterial conversion of ammonia to nitrate, had occurred but no nitrate escaped, as it commonly does when fertiliser is spread on the surface or applied in irrigation water.

JK. I believe the unlikely pairing of radioactive phosphorus and a chain saw were put to imaginative use?

We were aware that phosphorus concentrates in root tips and we decided to inject radioactive phosphorus into the shoot; wait for a day or two; use a chainsaw to cut through the soil at right angles to the banded fertilizer; slip a chest X-ray film into the resulting slot; wait another day; then extract and develop the film. We were delighted to see the ring of black dots confirming a mesh of active root tips around the band of fertilizer.

JK. What became of the Ord River project?

CSIRO soon abandoned that project in Kununurra because it had become clear that growing cotton in the Ord Valley was a failure because of damage from uncontrollable bollworm caterpillars. The cotton group from there moved to Narrabri, where they became very successful in their breeding and agronomy, especially after the introduction of the Bt gene into cotton varieties; that gene, discovered in microorganisms in the soil, generated a toxin that killed the caterpillars, almost eliminating the need for sprays, and without harm to mammals.

Those of us who had been working at the pilot site, where we had a small experimental dam to work with, were not at all enthusiastic about going ahead with the Ord Dam. Its remoteness, and potential transport difficulties with any produce, were a concern. However, the Chief of Land Use Research, Alan Stewart, was keen on the dam, and so were many politicians, so its development was approved in the early 1970s.

The dam was completed in 1972. Its history has, however, been chequered, with $1.5B investment in the Ord irrigation scheme having so far returned only 17 cents in the dollar, as reported in *Wikipedia*.

JK. I can see that Ralph Slatyer clearly had a significant impact on the direction of your work. What observations would you make about his leadership style and how it came to influence yours?

An aside on Ralph Slatyer's leadership

The Division 0f Land Use Research that I knew in the late 1960s was a wonderfully exciting place to work in. Money was ample, for CSIRO was largely supported by a generous federal budget. Scientific leisure was abundant. By that I mean there were few intrusions into the scientists' time. The role of the administrative staff was to foster research, not to impede it, as happens today, with the many legal requirements, and the requirements of scientists to handle their own administrative chores, which the earlier, supportive, administration could deal with in less than a tenth of the time.

JK. "Scientific leisure" – what a great term – and a dream for my generation of scientists – can you expand on its benefits?

Abundant scientific leisure enabled colleagues to discuss new ideas whenever they felt like it, often by chance or during the considerable social interactions not only within the division but across divisions and with the ANU. For example, it was common for us to play croquet at lunchtime on the small lawn at the front of our building. The camaraderie induced by such social activity spilled over into vigorous scientific discussions, whether dealing with new ideas or debating current ones.

JK. How did Ralph foster this in the Division?

Ralph encouraged people in his group to meet every morning at about 10:30 around a coffee urn in my lab. There we discussed a wide range of topics. The numbers varied because several of the group worked periodically in Katherine on sorghum, exploring how its photosynthetic rate and water use varied with the weather.

In the mid-afternoon we met with the rest of the division, typically an average of about 50 people in the main gathering area (depending on how many were working in the field). There we chatted with many other colleagues, whose research was on a broader scale than ours, such as general land use, hydrology, and broadacre agriculture. Notably, in these daily meetings, everybody stood, so that the mixing was largely random, and many stimulating ideas were exchanged.

JK. These gatherings came to influence your thinking on other interactions in biology – can you elaborate?

This form of social interaction intrigued me, and I began to think about hierarchical structures and the interactions between different levels in such structures. For example, laboratory research on gas exchange by plants could be studied for its own interest, or it could be thought of in the context of field-grown plants and how modifying rates of gas exchange might help increase yields of crops.

In relation to hierarchical structures, I chanced upon a book called *Beyond Reductionism*, which contained a set of papers given at a remarkable conference organised by Arthur Koestler in Alpbach, Switzerland, in 1968.

The first paper in that book, written by Paul Weiss, dealt with the hierarchical structure of living organisms and was in part based on the idea of General Systems Theory that was pioneered by Ludwig von Bertalanffy, who wrote the second paper in that book. Weiss emphasized the difference between machines and hierarchical systems in this way:

<u>'In a system, the structure of the whole determines the operation of the parts; in a machine, the operation of the parts determines the outcome.'</u>

Both processes occur in living systems.

Weiss's paper was revolutionary. It guided me, at least subliminally, for the rest of my career. I doubt that Ralph was overtly aware of General Systems Theory, but his leadership did reflect it.

JK. In my world of crop agronomy, you are perhaps best known for your work on effective water use by crops – how did that work initially develop?

Back to specific research: the 1970s

One afternoon, during the informal get-together in the Division of Land Use Research that I just mentioned, I was chatting with Henry Nix, also in our Division, who told me about the work he had been doing in Biloela at the northern tip of the wheat-growing area in Queensland. He told me that he had found a remarkable correlation between the yield of wheat and the amount of water that was available in the soil around about the time of flowering.

For me, that conversation became a stunning example of Louis Pasteur's dictum that *"chance favours the prepared mind"*. It changed the direction of my research, for out of our conversation came the idea that conserving water in the soil for use during grain filling could lead to better yields. *No one had thought of that before*.

JK. How did you follow up that "Eureka" moment?

Stimulated by Henry, I set about doing experiments in a glasshouse in Canberra in which I manipulated the roots of wheat to maximize the grain yield in an environment such as Biloela's, where wheat was grown, in the winter, predominantly on water stored in the subsoil from summer rains.

The experiments were designed so that one wheat plant was grown in each pot of 100 mm diameter and 1 m tall that roughly contained the same amount of soil per plant that would be available in the field. Enough water was contained in each pot to mimic the supply available from the summer rains.

Roots emerging from wheat grains are known as seminal roots; generally, there are about 5 such roots per seed. Half of the plants were allowed to grow seminal roots freely, while the roots of the other half were limited to just one seminal root. All of the water used by the plant would have to flow into the shoot through this root. The prospect was that the reduced total length of single-root system would slow down the rate of uptake of water by inhibiting the grow rate of the leaves, thereby conserving more water for use around the time of anthesis and during the subsequent grain-filling so that the grain yields would be greater.

JK. Did your hypothesis, and the mortally wounded wheat plants win out?

The grain yields of the single-rooted plants were indeed greater, but when we measured the total root length we found that plants with a single seminal root had 20% more total root length than plants with all of the seminal roots free to grow. That was puzzling. If the single-rooted plants had more roots to extract water, why would its growth be slower?

We eventually realized that the flow rate of water was being limited by the single large central xylem vessel in seminal roots through which the water flowing to the shoot must move. Indeed, the speed of that water astonishingly attained a speed of 1 m/s where the single seminal root joined the shoot, for the diameter of the xylem in seminal wheat roots is only about 60µm. This discovery subsequently led to a breeding program to select narrower xylem vessels to impede that uptake of water, which in turn reduced the growth rate of the plants, thereby saving water for later and more important use, which I would like to cover later.

JK. Fascinating – and your move into plant physiology led to a sabbatical at Cambridge?

My excursion into plant physiology resulted in the Chief of the Division offering me a sabbatical year in Cambridge, where my contact was with Enid MacRobbie (FRS) in the Botany School who was a leader in studying the transport of water and metabolites across membranes. This I was pleased to accept, for my interest in the vascular system of wheat roots had extended to the phloem, which carried sucrose from the mature leaves to the growing areas, the rate of flow being determined by its transport across membranes. Thus, five years after returning to Australia we found ourselves back in Britain.

During my 12 months there I learnt much about general plant physiology from my new colleagues. I also met, and kept in touch with, many plant physiologists from UK and Europe. That knowledge gave me many ideas to build on in relation to agriculture.

JK. On your return to Australia in 1972, I believe you found a much-restructured CSIRO, prompting another career shift?

Yes, on returning to Canberra, I found that the Division 0f Land Use Research had been reorganised to deal solely with large-scale phenomena such as hydrology and broad considerations of how best to use land. Several of us who were concerned with crop and plant physiology had to leave. We were then attracted to move down the hill to the Division of Plant Industry by its Chief, Lloyd Evans.

JK. So back to the theme of more efficient use of water by plants?

I then returned to the idea of breeding wheat plants that had narrower xylem vessels in their seminal roots building on the work mentioned previously. I asked Lloyd if it was possible to recruit an appropriate breeder. He was happy to support that idea provided that we could fund it from the Wheat Research Council, then chaired by Max Day (FAA). Max was initially unimpressed but eventually Lloyd brought him around and we were lucky enough to recruit an excellent young plant breeder, Richard Richards (later FAA), who had just finished his PhD in Western Australia.

JK. I am sure breeders at that time were not focused on roots – how did you approach a breeding target such as that?

We began searching for wheat genotypes that had narrow xylem vessels, bearing in mind that even small reductions would have large effects according to Poiseuilles Law - namely that the hydraulic conductance of small tubes is proportional to the 4^{th} power of the diameter – for example, halving the diameter decreases the conductance by a factor of 16. It was not long before we found what we were looking for. Richard then embarked on a successful back-cross breeding program and eventually showed that the genotypes with narrower vessels could yield more than the associated controls in strongly water-limited seasons.

JK. Your interest in making better use of water when it is in limited supply continued to grow after that

I had been doing some more pot experiments to identify the optimal proportion of the water supply at the time of flowering to give the highest yields in water-limited plants. The optimum turned out to be about 30% of the total available water. Simultaneously, I was developing a simple equation, that related yield to 3 components:

- the water supply,
- the biomass of the crop divided by that water supply, and
- the harvest index, which is the ratio of grain weight to total biomass,

I showed experimentally that these three components did not have large trade-offs between them, and so I wrote a paper in a local journal, that of *the Australian Institute of Agricultural Science*. Thereafter, the analysis of crop yield in relation to water use became a major interest for me, over several decades.

JK. This equation is perhaps one of the most influential for breeders and agronomists alike, providing different but potentially additive targets for improvements in both genetics and management. Were you aware at the time of the impact it was going to have?

I had no idea that that equation would become famous and in use around the agricultural world. It seemingly stimulated both breeders and agronomists alike, increasing their focus on the time of flowering, and the optimal proportion of the water supply during late floral development that led to large harvest indices, the most variable of the 3 components in water-limited environments. I suspect that wide interest in the equation may have resulted from a talk that I gave in USA in 1982, subsequently published in 1983.

JK. How did you come to lead the Crop Adaptation Group at CSIRO?

Research in the 1980s

Lloyd Evans resigned in 1978 from being Chief of Plant Industry. Jim Peacock replaced him and he asked, in 1980, me to lead the Crop Adaptation Program, which involved the construction of a new building to bring together the several groups in the program that were scattered among several buildings. Jim was adamant that program leaders would spend half their time on their own research, which we welcomed.

The new building was completed in 1984, and we could all be under the same roof. I chose, as part of my role as program leader, to emulate Ralph Slatyer's style to ensure that there were ample opportunities for interactions among the staff. We met frequently in and around a coffee urn in a chemical-free lab, and every Friday we would have a brief talk by one of the staff members. Many good ideas and collaborations were born during these sessions. The several groups within the program were led by outstanding scientists, who could be left to inspire their groups.

JK. It was around this time that you met Rana Munns

In relation to my own research, and shortly after I became program leader, I did meet Rana Munns at a conference in Perth. I was much intrigued by the research that she had been doing as a post-doc on the behaviour of plants challenged with salinity. I was especially interested in the fact that exposure to salinity sharply reduced the growth of cereal plants, yet the expanding cells that were generating the growth did not contain significant amounts of NaCl. Rana was interested in coming to Plant Industry, and Jim Peacock was happy to recruit her.

JK. I believe you had developed an ingenious new apparatus that was central to your research with Rana

I had recently developed apparatus that centred on containing the roots and soil in a pot in a pressure chamber with the pot designed to seal the top of the pressure chamber. The top was a strong metal plate with a small central hole in it to allow the roots of a plant to grow into the soil, while the leaves grew outside. Once established, the hole through which the roots were growing was sealed with strong silicone rubber. Applying a pneumatic pressure in the chamber increased the water status of the leaves. It could increase it to the point at which a cut in a leaf that exposed some xylem vessels was on the verge of bleeding, i.e., the xylem sap there was at atmospheric pressure. Effectively the leaf was as happy as it could be in terms of water supply, while we could expose the roots to different soil challenges – dry, hard, or salty soil.

We could also calculate the hydraulic resistance of water flow through the whole plant by dividing the transpiration rate by the pressure needed to keep the leaf xylem sat the point of bleeding. That apparatus thus became a powerful way to explore further the effect of exposing growing plants to salinity, especially after we found a way to maintain the leaf at the point of bleeding automatically. Similarly, it could determine the circumstances in a drying soil at which flow through the soil became limiting.

JK. That experimental approach was the basis for numerous further investigations of root-soil interaction and the effects on shoot growth?

The collaborative work that we did over the next 20 years, often in conjunction with visitors, used the root pressure chamber to manipulate the water status of the leaves by controlling the pressure in the root chamber so that the leaves were fully hydrated. It resulted in several intriguing conclusions, including the discovery that inhibitory signals from roots were common in closing the stomata and/or slowing the growth of leaves when conditions in the soil began to deteriorate, but before water and nutrients became scarce.

We thought of this behaviour as a feedforward response that may have evolved to deal with the plants' somehow detecting deteriorating circumstances in the soil, despite there still being ample water and nutrients lower in the soil profile – that is, it is a predictive rather than a reactionary response.

During the 1980s, I wrote some reviews that expanded on my equation on the components of yield. Essentially, they were concerned with more detailed ideas about each of the components, especially water supply and harvest index.

At that time, the theory of water uptake by roots was based on the speed at which water would flow to the roots and the density of the root length in the soil. Applying that theory predicted that all of the remaining available water could be taken up in less than a fortnight. We knew, from field experience, that that was certainly not the case.

JK. So why was the uptake of water so much slower?

One obvious reason was that the roots were not uniformly distributed in the soil but were often clumped into cracks or large soil pores – often termed biopores. If that were so, the flow of water to the roots and its uptake was determined more by the distribution of pores and how well connected the roots were to the pore walls.

The implications of these biopores on root growth, water uptake and crop production was at the centre of many subsequent collaborative studies with soil scientists and agronomists for more than a decade, particularly as it seemed to be responsible for the slow growth of crops under no-till farming, which was being widely adopted by farmers at that time. No tillage meant more biopores and harder soil in between. Some inhibitory microorganisms could also colonize roots in these pores, or in the hard soil between them which ushered in an increased interest in microscopy and targeted microbiology focused adjacent to the surface of the roots.

JK. There were other sabbaticals while you were managing the program

Research and management in the 90s

Yes, in 1991 I spent 6 months at the Scottish Crops Research Insititute in Dundee, Scotland.

There I set out to explore the physiology underlying the growth rate of roots and leaves. I became especially interested in the expansion of young cereal leaves, an interest that was stimulated by a remarkable meeting in Corfu, a Greek island, entitled the *Mechanics of Swelling*. I met there an extraordinary collection of world leaders including Nobel-Laureate Pierre-Gilles de Gennes, who helped me develop a model for the re-arrangement of the hemicellulose polymers in the walls of growing cells that connected cellulose microfibrils to each other, the microfibrils generally arranged transversely across the cylindrical cells

The model explained the initially the behaviour of the growing leaves, whose elongation rate doubled when pressure was applied in the root chamber, thereby substantially increasing the turgor in the growing cells. But the faster growth rate was transient, and before long returned to the initial elongation rate. The reverse also applied: removing the pressure resulted in the leaves stopping their growth, but only transiently, before the growth rate returned to what it had been at the start of the experiment.

JK. And scaling back up to field crops, your interest in on-farm translation of research became very first-hand when you joined the GRDC?

Member of GRDC southern Panel 1995-2001

True - In 1995 I resigned from leading the Crop Adaptation Program. I had become frustrated by the reluctance of GRDC to support excellent projects in CSIRO Plant Industry. Fortunately, I was elected to the GRDC's Southern Panel. That Panel (of ten very able members, half of whom were farmers) was influential in many ways: in getting closer to farmers and their advisers; in identifying important projects related to the understanding and amelioration of subsoils; in crop genetics; and in novel agronomy. Although the membership was supposed to occupy about one month a year, it in fact required at least 3 months, and was very successful.

Life after "retirement" in 2002 - External and post-retirement activity

JK. John you were clearly an active retiree – and as an Honorary Research Fellow over 20 years you've ad ongoing and significant impact both in CSIRO and in other organisations. Which of those have meant the most to you and why?

There have been three major activities that have occupied my time during these last 20 years.

(1) I have written many reviews that addressed important themes from my experience. The most important theme, I believe, has been a widespread failure in the agricultural research community to recognise the hierarchical nature of agricultural plants. This has resulted in a slippage of understanding about how important it is to be aware of how higher levels in the hierarchy (e.g. those that a crop canopy has on an individual plant) can constrain behaviour in the lower, more detailed levels, so that experiments at those lower levels can be misguided.

(2) I have also been involved in reviewing major organisations. The first, in 2006, was a month-long review of the *CGIAR institute ICARDA (International Center for Agricultural Research in the Dry Areas)*, that was then based in Syria. Its bailiwick included North Africa, the Middle East, and Central Asia. The main conclusion of our review was that ICARDA should greatly augment its agronomic research, which was archaic, with grain yields that averaged less than half of what should have been easily attainable. Unfortunately, that advice was ignored, leaving at least North Africa and the Middle East in the position of having to import half of the wheat that is their mainstay of nutrition. In 2008 the price of wheat doubled thereby inducing food riots in the main cities – and that had major consequences, which, in Syria especially, are continuing.

Subsequently, I also worked as a consultant to the CGIAR, undertaking high-level reviews of several of their programs, existing or prospective, that involved fostering interactions between various CGIAR Institutes.

Closer to home, I have been commissioned to organise major workshops for the GRDC on how to deal with drought and effective water use (2007), and dealing with "Heat" (2017)

(3) I had a substantial involvement with three responsibilities of AAS.

I was elected to AAS in 1994. My first memory of being a Fellow was attending the Dining Club, which had been running for many years. It involved a lecture followed by a sumptuous meal in the Jaeger room.
I enjoyed those occasions greatly. When the organizer retired, in 1966, I offered to take over from him and I continued to do so for 15 years. Thereafter, Susanne von Caemmerer took over from me, though I then took on the role of MC. We continued for another few years but eventually we had to abandon these events because our clientele withered away. They were almost entirely long-standing Fellows who had maintained their broad interests and curiosity. Their numbers slowly fell as they aged. Fellows who were still in senior positions in Universities and Research Institutes were hard-pressed for time and were generally overworked, a reflection on the generational change. Hardly any were interested in taking an evening off.

In 1999 David Curtis asked me if I would take over from him as the Chair of the Board of HRAS *(Historical Records of Australian Science)*. This I did. It was an interesting though time-consuming task to find authors to write scientific obituaries, and to encourage them to do so in a timely fashion. I served on this Board for 9 years, until 2008, when Chris Dickman took over.

In 2015 I was asked to represent AAS on the National Library of Australia's Fellowship Advisory Committee (FAC). The NLA Fellowships (about 10) are for advanced research using the extraordinarily rich NLA archives; there are also Scholarships for Summer Students who are doing PhDs. This was a mind-expanding activity that took several days a year to sift through the hundred or more applicants to see whose proposals were seemingly the best.

JK The challenges of food production in the face of climate change seem to me to call on a whole new generation of John Passiouras to continue the search for physiological understanding of genetic and agronomic adaptations.

What is your advice to young people interested in a career in agricultural science focused on global food security?

The pressure on young scientists to publish in "High Impact" journals, is much too great. Many of these journals are HI because they allow scientists with trivial projects to review each other's papers. This they do enthusiastically without any idea of their papers' agricultural influence. Amongst laboratory scientists, "drought resistance" and "salinity resistance" are the most popular of their goals. Such work has led to at least 5000 papers that are irrelevant to what happens in the real world. Only two have so far been successful, and that because it took many years in the field to confirm that the novel plants did indeed produce higher yields.
Mark Neff has written a devastating criticism of this overwhelming irrelevance entitled "How Academic Science Gave Its Soul to The Publishing Industry".

How to make dents in the armour of most of the publishing industry is, however, beyond academic science, because publishing in HI journals is the best way of being promoted in academia. I believe that the only hope is for funding agencies like NAS and ARC not to be swayed by claims of utility in research proposals without such proposals being reviewed by other scientists who know what utility means.

For more information see John B. Passioura (2020-06-12). Translational research in agriculture. Can we do it better?. In Crop and Pasture Science. 71 (6), 517 - 528.

JK What would you like to share from your life outside work?
e.g. Have family or friendships shaped a particular element of your life? How have you or your work influenced them?

55 years in Canberra accumulates many diverse friends and colleagues. Of great importance is one's family. For example, my wife, Kay Johnston, was prominent in the *Women's Electoral Lobby* in the early 1970s, and also later, when she became a guide at the National Gallery and the Classics Museum at the ANU. She was also prominent in helping manage, and make costumes for, the *Canberra Dance Theatre* when that was active. I took interest in all of such activities which greatly expanded the number of my friendships.

Likewise, I have several friends who were heavyweights in politics and administration. Memberships of the *Australian Garden History Society* and of *the Botanical Gardens* has also created many friendships.

My work, I suppose, has influenced many of these friends when they have asked me about the roles and facets of agriculture, both in Australia and globally.

JK. Looking back on your career do you sense a unifying Theme?

In my scientific life I have been a soil chemist, a soil physicist, a biophysical chemist studying the polymer chemistry of cell walls in growing leaves, an agronomist, a pre-breeder, a substantial contributor in plant and soil water relations, a co-discoverer of inhibitory signals from roots that modulate the behaviour of the leaves, and an analytical philosopher.

Sounds bewildering?

But all these areas have concerned improving agricultural productivity. The transitions have been almost seamless, largely because of serendipitously chancing upon related phenomena that I thought I could usefully explore (Pasteur: "chance favours the prepared mind"). Similar stories applied to most of my colleagues. It is not the random bouncing around that inspires these transitions. Rather, it is curiosity about what other people are productively doing in one's scientific (or administrative) neighbourhood.

Finally, I would like to thank the many visitors that local colleagues and I have attracted over the years. These have had inspirational influences on our work. They include: Champ Tanner, John Boyer, Joe Ritchie, Paul Jarvis, Mark Westgate, Missy Holbrook, Ken Shackel, Wendy Silk, Grant Cramer, Thomas Gollan, and Ian Dodd.
Rana Munns's influence was especially important in attracting these scientists. The breadth of her plant-physiological understanding eventually resulted in her becoming the world's leading authority in research on salt-affected plants.

One of the visitors stayed. She was Margaret McCully, a superb microscopist who was invited to come to the Division of Plant Industry by the GRDC because of her great knowledge about roots and micro-organisms in undisturbed field soil. She decided to "retire" from Carleton University in Ottawa, her previous home, and thereafter stayed as an Honorary Fellow with CSIRO for many years. She became a great mentor in microscopy and encouraged many colleagues to become involved. During the first few years of her time here she organized excellent annual one-day meetings based on microscopy that attracted full houses, including many speakers from overseas.

JK No doubt you are still working on your next move?

I will be moving to the ANU within a few weeks. I plan to take my experimental equipment with me, which would otherwise have been put into a skip. COVID disrupted the experiments I was doing with that equipment, and I can now resume those experiments to find out why deep roots take up water so slowly from the subsoil.

JK John, good luck with your next project and thanks so much for sharing these insights into your career.

As one of the many who has benefited tremendously from your friendship and mentorship, I can assure you that your focus on rigour and relevance in science lives on in us all, as does your plea for us to find time for more scientific leisure from which creativity springs.