groundwater challenges have a limited range for dating old groundwater, are often not geochemically inert and provide limited information on recharge conditions, for example the temperature at the time the water entered the underground system.

Noble gases – helium, neon, argon, krypton and xenon – can be used to quantify very small flow velocity through aquitards and can determine recharge temperatures, says Axel.

Noble gases are particularly useful in telling us about groundwater because they can be traced to show us how quickly, or slowly, water moves through underground aquifers; providing a better understanding of the connection between surface water and groundwater flow, and the replenishment of aquifers; and showing if water can move between shallow aquifers and deep underground aquifers through geological layers with low permeability.

Noble gases provide a unique contribution to characterising and understanding groundwater flow processes, surface water–groundwater interactions, groundwater-seawater interactions, aquitard permeability and inter-aquifer connectivity.

Specifically, some of their isotopes allow estimating flow velocities on time scales from years (85Kr), centuries (39Ar), millennia (4He), up to one million years (81Kr) and beyond (4He, 40Ar, 21Ne, 134Xe, 136Xe).

"Because Australia is dry and flat, groundwater in many deeper aquifers moves very, very slowly and that means we need tracers for old water," he says.

"Knowledge of flow velocities is indispensable when managing groundwater as a resource for drinking water, agriculture, industry and mining. Infiltration processes, such as recharge after flooding a dry riverbed or constant infiltration from a permanently losing stream, can also be identified using noble gases.

"We need a better understanding of the nature and extent of our groundwater systems and how they are recharged to ensure that, as we continue to use this valuable resource and with a changing climate, we also protect it from overuse or contamination."

Sampling groundwater from an artesian stock bore screened in the Poole Sandstone aquifer of the Fitzroy catchment.

Taking samples from the surface water of the Fitzroy River was an important element in understanding the connectivity between groundwater and surface water.

A bigger regional picture

Among the first water samples to be tested at the new Noble Gas Facility came from the Fitzroy catchment in Western Australia's Kimberley region. It was part of groundwater analysis done for the Northern Australia Water Resource Assessment and aimed to identify the potential for, and risk of, increasing water-related development opportunities in northern Australia.

Groundwater hydrologist Andrew Taylor explains that in the Fitzroy catchment, the Kimberley plateau in the far north of the catchment receives high precipitation in the wet season which runs off the land surface draining into ephemeral rivers and flows downstream to flood the Fitzroy valley where it's quite flat. The river eventually bursts its banks and comes out on to the flood plain where it saturates large parts of the landscape before a portion of the flood water infiltrates into the groundwater systems of multiple aquifers.

When the wet season subsides, the river flows also subside. But large reaches of the river, as well as persistent instream water holes are sustained by the inflow of groundwater, discharging from aquifers.

The hydrogeology and groundwater systems of the Fitzroy catchment is largely a greenfield region which has never been properly characterised.

Taylor describes the aquifers and groundwater systems as a cake with different layers: Alluvial aquifers occur at the surface in association with the rivers, their tributaries and their flood plains, while underneath this there are multiple layers of sandstone, mudstone, siltstone and limestone, some of which allow water to flow (aquifers) and some which don't (aquitards).

He has travelled across the Kimberley taking water samples from bores, as well as surface water from persistent water holes and reaches of the Fitzroy River to better understand the nature of groundwater systems in different aquifers and how hydrologically connected they are to the Fitzroy River.

"Groundwater resources occur over vast geological areas but information is sparse because there is only a certain number of bores associated with the occasional pastoral lease, mining operation or community water supply," he says.

"First, we needed to review all of the available data, then get out and do some sampling from existing bores, as well as drilling in areas with no bores to gain a better understanding of the nature and extent of aquifers.

"Then we wanted to know how the groundwater systems in different aquifers interacted, particularly those aquifers that are deep.

"We also wanted to know where and how the groundwater systems are connected to the river itself."

Taylor took a helicopter and flew the length of the Fitzroy River taking surface water samples for tracers.

Comparing those samples from bores and also from the river, they were able to test those samples using the Noble Gas Facility and conceptualise the groundwater systems of the region.

"Environmental tracers allow us to fingerprint the history of that water and that's what you need to know in an area where you don't have much groundwater level information. If you can't see where its water levels are going up and down – it's hard to understand groundwater recharge, water that's replenishing the groundwater, and whether is it coming from rainfall or flooding of rivers.

"We know, for example, in the Fitzroy where we did the helicopter survey, there are high levels of noble gases in the deep regional aquifer which we then found in the river itself. That showed us that groundwater from deep aquifers is discharging up into the river where regional faults cut through overlying aquitards.

"We take a lot of care in trying to conceptualise how things are behaving and using multiple lines of evidence to validate if that is real or not. Every time we do a new study, it tells us a different story, sometimes you get a nice story coming out of environmental tracers.

"We have now used this new conceptualisation to underpin a regional groundwater model which covers more than the Fitzroy River catchment and which is used to estimate the inflows and outflows of the deep regional sandstone aquifers (Grant Group and Poole Sandstone). It can also be used to assess the volume you can extract from the aquifer without affecting existing users and environmental assets like the river itself."

Clues to paleoclimate

Axel Suckow points out that for the Great Artesian Basin the flow time from the site of infiltration to the springs in South Australia is roughly considered to be two million years.

"Helium, for instance, increases due to radioactive decay of uranium in the rocks and that means the higher the helium content in the groundwater the older the groundwater is," he says.

"The other noble gases tell us about the infiltration conditions. If you give me a water sample that is 10,000 years old then, from the concentration of argon, krypton and xenon, I can tell you the ground surface temperature 10,000 years ago which is very valuable information for paleoclimate studies inland.

"We can reconstruct infiltration conditions such as temperature, salinity and altitude."

With the new facility, it's anticipated that data from groundwater systems across the country will progressively paint a picture of the continent's paleoclimate. As such, the facility also stands to contribute to a better understanding of climate change.

"Everyone sees the Murray Darling. With groundwater you can't do that, it's hidden in the ground but no less important. It's much more difficult and challenging to investigate and I love that."

The Science and Industry Endowment Fund (SIEF) awarded $550,000 to CSIRO for the acquisition of the noble gas spectrophotometer as part of the Noble Gas Facility. ■

Profitable legumes for WA's difficult soils

By Alana Hartley, Research Agronomist & Coordinator – Liebe Group

Results at a glance…

- Adequate pre and post emergent weed control is critical for maintaining yield potential and quality of grain legume crops.
- Canola remains the most profitable non-cereal crop type demonstrated at this site in 2018.
- Where vetch grain is not harvested and sold as feed, consideration of this legume crop type for its grazing value may be advantageous for a mixed farming system.
- Results reported here are for Dalwallinu which is one of four sites within the Liebe region. The other sites being Kalannie, Carnamah and Koorda.

Why do the trial?

The Liebe Group is investigating the suitability and profitability of alternative legume crops in the Western Region of the WA wheatbelt.

Previous research has suggested that most legume and pulse crops are best suited to fine textured soils of neutral to alkaline pH. While previous attempts to grow legumes and pulses on 'un-preferred' soil types have had varied success, there has been limited adoption of these crop types. This is in part due to suitability of soil type, weed competition and weed control options, yield, market access and overall profitability of legume crops.

This two year GRDC-funded project, aims to demonstrate how – and if – certain grain legumes are a suitable and profitable alternative crop choice for the farming systems of each region in which the project will be implemented. The four trial sites (Dalwallinu, Kalannie, Carnamah and Koorda) cover a vast range of soil types, rainfall zones and farming systems (cropping and mixed farming).

Dalwallinu Legume Demonstration Trial details, 2018

Location	Ian and Ainsley Hyde, Bell Rd, Dalwallinu, Western Australia. The 2018 Growing Season Rainfall measured at the Dalwallinu site was 300 mm.			
Plot size & replication	18.28 m x 300 m x two replications			
Soil type	Heavy red loam			
Soil pH (CaCl2)	0–10 cm depth: 6.1; 10–20 cm depth: 6.8; 20–30 cm depth: 7.7			
Paddock rotation:	2015: Wheat 2016: Wheat 2017: Barley			
Sowing date	Canola, Vetch, Chickpeas – 25/05/2018, Field peas – 11/06/2018			
Sowing rate	Striker chickpeas: 90 kg/ha Twilight field peas: 100 kg/ha Volga vetch: 40 kg/ha Bonito canola: 3 kg/ha			
Fertiliser	22/05/2018: NPK CZ 60 kg/ha (canola, vetch, chickpeas) 11/06/2018: Double-Phos 60 kg/ha (field peas)			
Pre-emergent sprays	**Canola** Trifluralin 2 L/ha Simazine 1.1 kg/ha Chlorpyrifos 200 ml/ha	**Chickpeas** Trifluralin 2 L/ha Simazine 1.1 kg/ha Chlorpyrifos 200 ml/ha	**Field peas** Metribuzin 150 g/ha Diuron 600 g/ha Glyphosate520 1.5 L/ha Chlorpyrifos 150 ml/ha	**Vetch** Trifluralin 2 L/ha Simazine 1.1 kg/ha Chlorpyrifos 200 ml/ha
Post-emergent sprays	**13/06/2018** Atrazine 1.05 kg/ha Enhance 0.5%	**18/07/2018** Clethodim360 330 ml/ha Verdict520 50 ml/ha Chlorpyrifos 250 ml/ha Hasten 1%	**18/07/2018** Clethodim360 330 ml/ha Verdict520 50 ml/ha Chlorpyrifos 250 ml/ha Hasten 1%	**18/07/2018** Clethodim360 330 ml/ha Verdict520 50 ml/ha Chlorpyrifos 250 ml/ha Hasten 1%

Treatment details

Plot	Replications	Treatment #	Treatment	Plot	Replications	Treatment #	Treatment
1	1	1	Chickpeas	2	1	C	Canola
3	1	2	Field peas	4	1	3	Vetch
5	2	C	Canola	6	2	2	Field peas
7	2	1	Chickpeas	8	2	3	Vetch

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Region: The Liebe Group is a dynamic, grower-driven, not for profit organisation that operates within the Dalwallinu, Coorow, Perenjori, Moora and Wongan-Ballidu Shires in the West Australian wheatbelt. As a leading 'grass roots' group, the Liebe Group provides its members with access to innovative, timely and relevant research along with grower and industry network opportunities from all over Australia. The Liebe Group was established by progressive local farmers in 1997 due to concern of the local area being isolated from existing agricultural research and development. The group was founded to ensure research and development remained local, innovative and relevant to a whole farm systems approach to agriculture.

Commercial sponsors: Rabobank, CSBP, CBH Group, RSM, AFGRI, Farmanco, Imtrade Australia, Elders Scholz Rural, Bayer, Precision SoilTech, Syngenta, Pacer Legal, Agrimaster, AGT, Scott's Watheroo Dolomite, Pacific Seeds, Refuel Australia, Landmark, Grain Growers, Nufarm, Adama Australia, Intergrain, Boekemans Machinery Dalwallinu.

This article reports on results from the Dalwallinu Legume Demonstration site where three legumes – chickpeas, field peas and vetch – were compared to canola. Canola is the current break crop option of choice in the area.

Trial and treatment details for the Dalwallinu site in 2018 are detailed in the accompanying chart.

Table 1: Baseline soil nutrition status, Dalwallinu, February 2018

Depth	pH	PBI	Col P	Col K	KCl S	NO_3N	NH_4N	EC	OC
0–10 cm	5.7	80.4	37	430	16.6	51	6	0.182	1.30
10–20 cm	7.4	157.3	9	258	4.8	9	1	0.047	0.90
20–30 cm	7.7	204.8	7	118	3.4	4	1	0.069	0.50
30–40 cm	7.7		5	94		4	2	0.133	
40–50 cm	8.3		3	96		3	1	0.179	

What we found

Soil analysis

A soil analysis was conducted at the beginning of the project, to measure base line nutrients (Table 1). Further soil testing was conducted prior to seeding in 2019, to determine the change in N status from the baseline results.

PreDicta B was conducted prior to the trial being sown, to determine the disease profile and risk at the beginning of the project (Table 2).

The results indicated that there was a low presence of disease at the site. PreDicta B was conducted again prior to the 2019 season – and entering into the wheat phase – to determine if the legume crops have had an impact on the disease profile.

Plant and weed counts

Weed and plant counts were taken at establishment (four weeks after sowing) and again at late establishment, when the legume crops were at branching.

Table 2: PreDicta B soil-borne disease rating, 2018

Test	Result
Cereal Cyst Nematode (CCN)	Nil
Take All (Wheat & Oat race)	0.9
Rhizoctonia solani	1.1
F. pseudograminaerum (test 1)	3.4
F. pseudograminaerum (test 2)	Nil
Pyrenophora tritici-repentis (YLS)	1.3
Bipolaris	0.8
Pythium	1.4
Macrophomina phaseolina (collar rot/stem rot)	2.0
Disease detection rating	Low
	Medium
	High

Table 3: In-crop plant and weed counts, August 2018

Crop type	Average plants per m²	Log weeds per m²
Canola	37	5
Chickpeas	41	38
Field peas	41	54
Vetch	38	25
P value	*0.982*	*0.247*
Lsd	NS	NS

There were no significant differences in plant numbers between crop types in these early counts. A log transformation of weed counts suggest that there was some influence of weeds on crop establishment, but this was not highly significant. Counts were not taken for field peas, as they had only just been sown at the time the establishment counts were taken.

Later plant and weed counts in August (Table 3), showed no significant difference between crop type, and weed counts by crop type.

But there was a significant difference between weeds in the canola plots compared to other crop types. Canola had the lowest average weed counts of all crop types, due to crop competition and shading of weeds and the addition of a post emergent herbicide.

Only a grass selective was applied to the legume crops, meaning broadleaf weeds and some grass weed survivors and late germinations remained uncontrolled. This had some influence over the reduction in plant numbers from early establishment to late counts. Weed burden also has an influence on crop yield.

Harvest yield

This demonstration was harvested using grower equipment, with yield being measured by weigh trailer. Crop yield by replicate (Figure 1) illustrates a downward trend in yield from replicate one to replicate two. This is due to a slight soil type change at depth across the site.

Figure 1: Crop yield (t/ha) by replicate

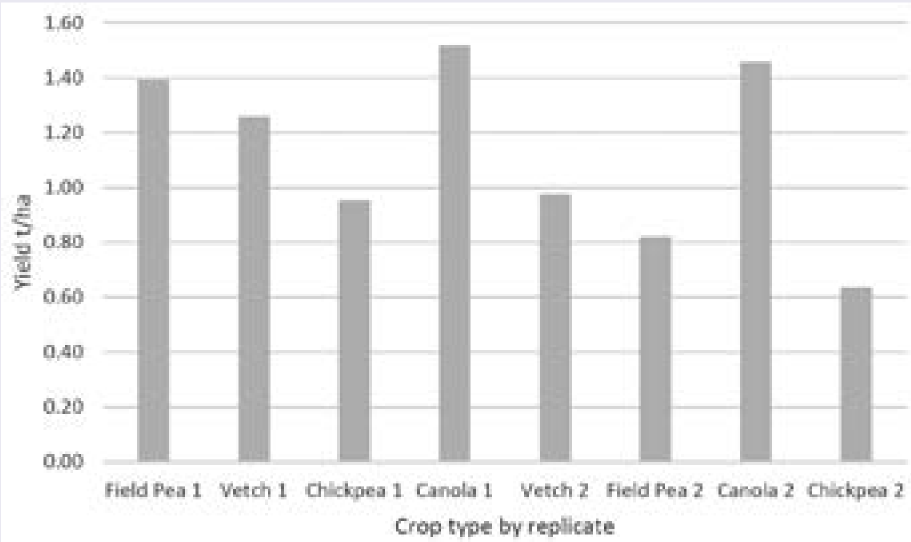

Figure 2: Combined average yield (t/ha) by crop type