47 years of Plant Breeding

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Introduction

It is an honour to be recognised by my peers for this prestigious award and to have this opportunity to give the Levy Oration. I have now completed 47 years of my plant breeding career in pastures.

I was among the first wave of breeders employed in New Zealand after the Plant Varieties Rights Act was passed into law 1973. I was employed in Pyne Gould Guiness (PGG), a small regional company but fortunately with the advice of Dr Corkill a former breeder and Director of Grasslands DSIR. Lionel Corkill was the first forage breeder employed by DSIR Grasslands in 1931 and breeder of many widely used cultivars.

For 25 years in PGG I had plenty of freedom to explore germplasm, read papers, and do field breeding, budgets were small and the structure informal. It was a classical individual approach with little support. After 2006 in PGG Wrightson Seeds the next 15 years were much more structured and formal with a larger support team. More recently with DLF ownership we have become much more global in our approach.

I have been very fortunate in having the opportunity to travel to international conferences, visit international universities, undertake pasture consultancies, and visit seed companies mostly in trips of 2 weeks to almost all the grassland regions of the world. Amazingly these trips add up to a over 5 and a half years of my 47 years.

Grasses

When I commenced breeding work in 1979 almost all cultivars were bred by DSIR or overseas institutes. Today breeding has transitioned almost entirely to private companies, many of which are international. Farmers had access to only a few cultivars, and of very limited types. Almost all the cultivars had originated from NZ ecotypes, originally from early English origins. Endophytes were unheard of but present and problematic at times. Since then, yields have improved considerably with a very significant gains in winter growth by the incorporation of Mediterranean germplasm.

We now have a range of productive cultivars which better match our climate - and we have effective endophytes for insect control (Table 1). Many species, such as Tall fescue, Prairie grass, Grazing Brome, Phalaris, Meadow fescue were not available in the 1970s while today these contribute to many improved farm systems.

This series of cultivars is a real achievement for New Zealand, but what is not always apparent is that we have also dominated temperate grass breeding in the southern hemisphere.

Table 1 Grasses

Grasses	Cultivars in the late 1970s	Cultivars 2025
Perennial ryegrass	Early diploid only	Diploids & tetraploids
	Mid-flowering only	Mids, lates, very lates
	endophyte effects not discovered	Novel Endophytes
Hybrid ryegrass	2 diploid cultivars	Wide range diploids and tetraploids
		Novel Endophytes
Italian ryegrass	2 cultivars, diploid and tetraploid	Wide range diploids and tetraploids
		Novel Endophytes
Annual ryegrass	1 tetraploid cultivar	Wide range diploids and tetraploids
Tall fescue	No commercial cultivars	A number of softer leaf cultivars with novel endophytes
Cocksfoot	1 cultivar	Many cultivars, including finer grazing tolerant types
Prairie grass, Grazing Brome, Phalaris, Meadow fescue	No cultivars	Cultivars available

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Table 2 Clovers

Clovers	Cultivars in the late 1970s	Cultivars today
White clover	2 cultivars	Many small, medium and larger leaf types
Red clover	2 cultivars	Many cultivars including grazing tolerant types
Lucerne	1 cultivar	Many cultivars including grazing tolerant types, pest and disease resistant, range of dormancies

Clovers and lucerne

Clovers are no different. Today we have a wider range of well adapted clovers (Table 2). White clovers with higher stolon density and persistence. Grazing tolerant red clovers, a concept developed in New Zealand.

The developments internationally of disease and insect tolerant lucernes have also been valuable as have the grazing tolerant types from Australia.

Forage Herbs

The herbs chicory and plantain are an innovation developed in New Zealand in the last 30-40 and now used widely (Table 3).

Table 3 Herbs

Herbs	Cultivars in the late 1970s	Cultivars today
Chicory	none	Many cultivars
Plantain	none	Many cultivars

One of the most interesting projects I was involved in was the breeding and commercialisation of plantain. I could see plantain was productive, but it took us many years to begin to understand how best to use it on-farm and to understand some of the positive environmental effect it can provide. Today the widespread adoption of both chicory and plantain makes it hard to imagine a world when they weren't available.

Forage Crops

Forage crops are a very important supplement to pastures and without them our grazing systems would not be as efficient. A particular New Zealand innovation in forage brassicas is that of cultivars able to be grazed multiple times, a concept providing enormous flexibility on-farm (Table 4).

The development of herbicide tolerant cultivars to enable simple effective weed control has also been a valuable breakthrough. More recently the development of raphanobrassica has provided a resilient multiple grazed option for hotter drier conditions. This is truly revolutionary crop for which we can thank Andrew Dumbleton.

The improvements in fodder beets, maize and forage cereals have also been very significant with a wider range of material available.

Overall, the broader range of pasture cultivars and fodder crops enables very smart farm systems not possible in the 1970s.

Capturing production gains

There has been much debate about progress in breeding for yield and persistence in pastures but over time it is apparent from trials that there has been a steady improvement in both yield and persistence, as well as the wider range of cultivar types with different growth habits, flowering times and seasonal growth patterns.

Table 4 Fodder Crops

Fodder crops	Cultivars in the late 1970s	Cultivars today
Turnips	A number of cultivars	A number of cultivars, including herbicide tolerant cultivars
Leaf turnips	No cultivars	Cultivars available
Rape	A number of cultivars	A number of cultivars, including herbicide tolerant cultivars
Kale	A number of cultivars	A number of cultivars, including herbicide tolerant cultivars
Swede	A few cultivars	A number of cultivars, including herbicide tolerant cultivars
Raphanobrassica	Unknown in the 1970s	A multigraze cultivar
Radish	Little value for grazing	A number of grazing types
Fodder beet	One open pollinated cultivar	Many F1 hybrids available
Forage cereals	few cultivars	Many oats, ryecorn, barley and triticale
Maize	Few hybrids	Wide range of F1 hybrids, many with improved quality and colder temperature tolerance

Genetics enables – it sets the limits
Management delivers - how much is produced on farm
Not only has breeding contributed to NZ farming it has had a significant impact globally

Turf grasses
Although not usually discussed at our NZ Grasslands Conferences the use and value of turf in our urban grasslands is substantial, potentially 2-4% the area of pasture in NZ depending upon what is included.
When I started work many sports fields were sown with pasture ryegrasses mixed with white clover and were often substandard for players and spectators. Home lawns were from ecotypes harvested of Browntop, Chewings fescue and crested dogstail (Table 5).

Today the range of top-quality cultivars enables stunning sports fields to be presented. I have been involved in breeding turf cultivars, particularly ryegrass, incorporating endophytes and winter activity for winter wear recovery. New Zealand has very successful in Browntop breeding and today we have substantial seed exports.

Germplasm
Germplasm is an essential source of new material for any breeder; - absolutely essential for a country with no suitable native pasture plants for farming.
For me germplasm discovery has been very valuable and interesting. Almost all the species we use in pastures originate from the European region, the key exceptions being Prairie grass and paspalum from South America and Kikuyu from highland Africa. Each species though has a different evolutionary history and understanding these is crucial to understanding the genetic resources available.

This diversity of germplasm and endophytes we use today is thanks to our "Margot Forde Genebank" and other international collections. For many breeders the Margot Forde Genebank is a national goldmine.

I discovered recently after ordering samples from the Swiss Genebank that not all breeders are like me. I was told I was the first person outside Switzerland who had ordered samples.

One of the many interesting evolutionary studies I have been involved in was that on cocksfoot. The European species have an amazing history of migrating during glaciation events and reinvasion of northern Europe from glacial refugia (Figure 1).

I have been fortunate in being able to collaborate with researchers using molecular tools to understand the history of the many species we breed. After taking over 10 years to obtain germplasm samples of diploid cocksfoot's we were able to use chloroplast and ITS molecular sequences to show migration events.

Commercial cocksfoot is a tetraploid evolving naturally from adjacent diploid populations. Knowing this we can design other novel tetraploid combinations.

What happens when we develop tetraploids from hybrids of distant populations, Spain with material from the China or Moroccan and the Himalayas? And how do we use this new novel material?

Endophyte
I first heard of ryegrass staggers at Lincoln University in a passing comment by one of our lecturers and thought it rather odd that no-one could explain it. In the 1970s we had no knowledge of endophyte and with ryegrass pasture then it was hit and miss whether endophyte was present. We had to wait a few years to learn more about this.

Today of course it is a major area of science, and we have the International Conference here this week. The discovery in the early 1980s that the common ryegrass endophyte in pastures could cause both ryegrass staggers and insect resistance was a major breakthrough in our understanding of pastures in New Zealand.

I ended up doing my PhD on endophyte, one of the first in the world on this topic. It absolutely fascinated me that although ryegrass came from the European region there didn't appear to many major insect problems there, some yes but nothing like New Zealand. Why?

New Zealand is quite different to many other continental regions. New Zealand is typical of many islands with very limited range of natural flora and fauna, - few natural predators to our insect pests.

New Zealand's isolation has led to a distinct and vulnerable ecosystem, while larger continents have

Table 5 Turf

Turf grasses	Cultivars in the 1970s	Cultivars 2025
Perennial ryegrass	Forage types only	Many improved turf types with endophyte Winter activity for sports fields
Turf tall fescue	Turf types unknown	Many improved turf types with endophyte
Browntop	Ecotypes only	Many improved turf types exported to UK, Europe
Fine fescue	Ecotypes and a few imported cultivars	Many improved turf types

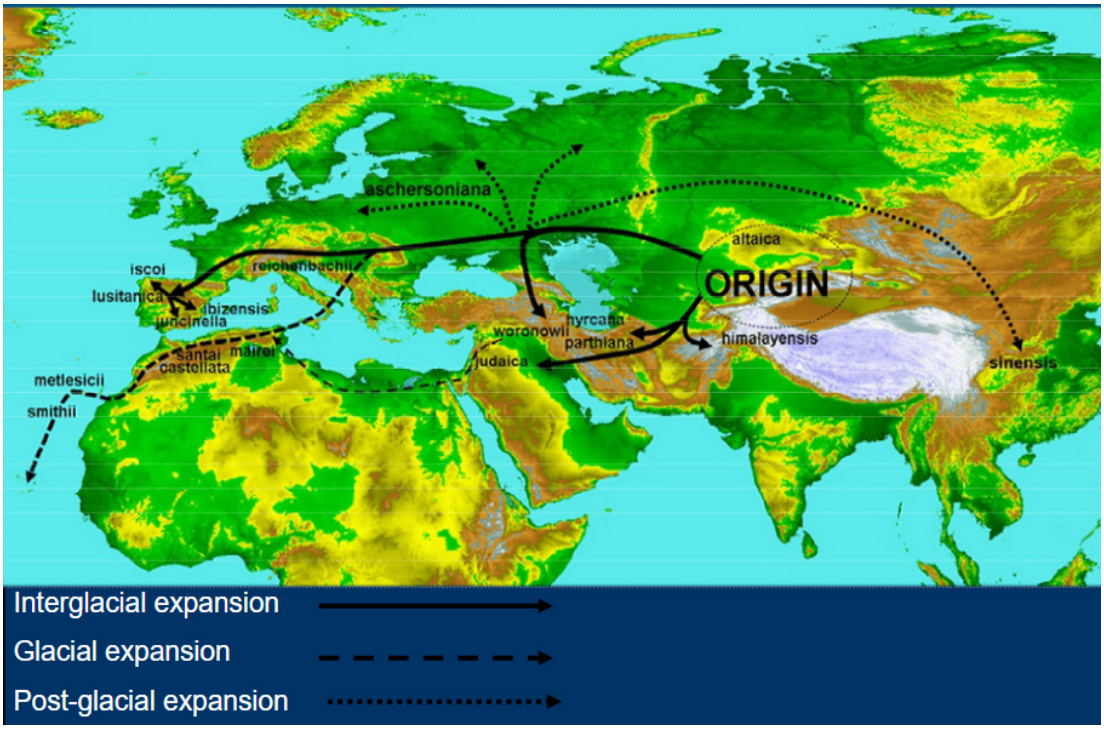


Figure 1 Evolutionary history of cocksfoot.

more diverse and established insect communities with more natural biocontrol's.

Today, we have consistent delivery of selected endophytes in seed, offering tailored insect resistance with reduced livestock toxicity —a remarkable transformation in pasture science. However, finding ryegrass endophytes which can control root feeding grass grub still remains elusive.

Molecular breeding

To date the molecular technologies have generated an enormous amount of knowledge about genes, genetic pathways, germplasm relationships, and enabled the development of genomic selection in many species and allowed large advances in animal and crop breeding. But surprisingly few improved pasture cultivars anywhere in the world.

Looking at major crops, we see a predominance of simpler single gene GMO traits such as herbicide resistance. Most of the traits we are dealing with in pastures are controlled by multiple genes and aren't simple, in addition, our grasses and legumes are crosspollinated populations and the complexity of breeding and dealing with these has been ***seriously underestimated by everyone involved***.

On the other hand, molecular technology has been very helpful in our endophyte world of simpler clonal genotypes.

There is considerable potential for success, but it will require close cooperation of molecular breeders and field breeders and probably 20 years or more of strong funding and collaboration.

Easing of New Zealand's regulatory environment should help, but in reality; the issue may be the large cost of such programs in a world of relatively low value forage; particularly compared to major crops.

Environment

Our pasture industry gets a lot of criticism from an environmental perspective, both for Nitrate leaching and greenhouse gases. However, I want to remind everyone of the unique nature of our clover-based pasture systems. New Zealand leads the world in these. Many countries aspire to use legume-based systems but only a few other countries effectively achieve it. Almost all other grass-based systems rely upon Nitrogen fertiliser and to manufacture 1kg Nitrogen fertiliser requires around 1.5kg of natural gas with corresponding CO_2 emissions.

We are in the game of converting **sunlight to food not Oil to food**.

We should be proud of our clover base grazing systems; very few farming systems overseas use clovers as effectively.

Never-the-less! we do get Nitrate leakage and greenhouse gas emissions from our high fertility farm

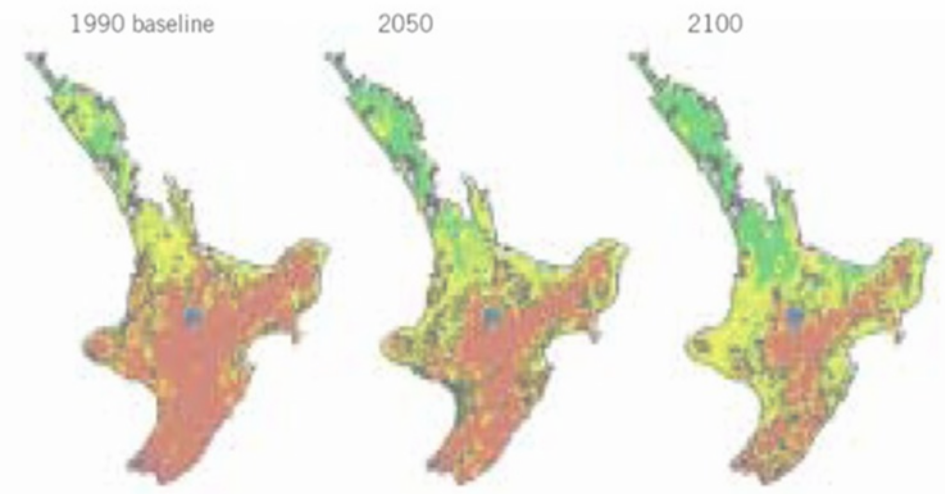


Figure 2 Projected range of Paspalum dilatatum in New Zealand
Ministry for the Environment. 2001.

systems, and we are challenged with reducing them.

We are learning a lot about Nitrogen leaching from many recent trials and the unique effects of plantain and other species. In the future we hope be able to breed improved ryegrasses with less nitrate leaching or nitrous oxide emissions

Approximately 50% of NZs greenhouse gas emissions come from ruminants and this looks bad. While in industrial countries their ruminant emissions are equally bad but pale into insignificance compared to their industrial emissions. Breeding plants that can reduce emissions on-farm will become essential.

A number of plants offer potential reductions in methane, including AgResearch's genetically modified high condensed tannin white clover and their high lipid perennial ryegrass.

An over-arching question though is: Can farmers get a premium price for reduced greenhouse gas emissions?

Climate change

Already many of our temperate grasses and clovers are becoming less suited to northern New Zealand as kikuyu and other low quality subtropical grasses spread further south.

In figure 2 you can see the expected expansion under one climate scenario of the subtropical grass Paspalum up to 2100 (the area in green). We expect the expansion of Kikuyu to be similar.

Grasses are not alone in this expansion as a number of serious insect pests are moving south too, particularly African black beetle but numerous others. This pest expansion may be even more serious than that of the grasses.

There are a range of subtropical grasses we can look at and looking at farming systems where these occur overseas provides some perspective. Many are productive plants in summer, but all will need additional winter pastures to provide a year-round supply.

This probably means sowing annual or short-lived ryegrass or forage crops to get the desired amounts of fodder through the year. Unfortunately, this also means higher cost farm systems than a productive ryegrass clover system grazed all year.

Also, with many tropical grasses it is not easy to develop mixed legume-based systems.

International breeding companies are in a good position to breed for climate change as they already breed overseas and can introduce cultivars locally.

Future

I am very confident that yield gains will continue to occur in plant breeding of our many species and that endophytes will be further improved. The use of molecular tools such as genomic selection should become applied in the major species, but unlikely in many minor low value forage species. The challenge will be to develop innovative and valuable traits, via mutations, gene edits or GMO. This will be particularly difficult for multigenic traits

For sure we will see a few major projects with gene editing and GMOs, but the politics, regulatory requirements, complexity and funding will limit these to only a few very significant projects.

We have the challenge of breeding to reduce environmental impacts, and we are only now learning about the genetic variation available and potential for selection.

Climate change effects are occurring relatively slowly, and the plant breeding process should be able to keep up. Never-the-less many impacts will be

disruptive.

We have yet to see what the impact of Artificial Intelligence is on plant breeding and on our agricultural industries in general. This is hard to imagine.

Many agrichemicals will become restricted and pest control options may become very limited. A situation where endophytes are likely to become even more important.

New Zealand land use patterns are likely to change in ways we can't foresee today. Much of the arable land in New Zealand may be in demand for dairying, international seed crops or other uses. Production of grass and clover seed may struggle to be price competitive, and seed may have to be grown elsewhere in NZ or even overseas. We are likely to see markets and farm systems change in ways we never expected.

I am now approaching retirement after 47 years of a wonderfully interesting plant breeding career. What could have been better for someone growing up on a farm than to get into a creative side of agriculture in plant breeding. It has allowed me to develop many significant cultivars in New Zealand and internationally, and it has taken me around the world many times.

I can assure you that although I may retire: my childlike curiosity of everything will continue!