More to perennial cereals than yield

GRAEME JENNINGS

Researchers involved in a global project to develop perennial wheat and other grains have registered strains of perennial wheatgrass as Kernza, but this new crop, which is being grown commercially in the US, is a long way from wheat in every way.

Growing perennial wheat – or any perennial grain crop – would require a farming system dramatically different from current dryland cereal production systems; a fact acknowledged by those involved in the perennial grains initiative.

While plant breeders are striving to develop commercially viable perennial grains, others are working on ways to integrate perennial cereals into farming systems.

Perennial wheat has attracted attention in Australia but efforts are underway to also develop perennial forms of rye, sorghum and rice. Much of this work involves crossing annual commercial cultivars with closely related wild perennial relatives, mostly wheat grasses, in the case of wheat; a process similar to that used in the development of triticale.

There is also a parallel, complementary strategy of domesticating wild perennial plant species with the potential to become grain crops. Species in this program include ***Helianthus maximiliani*** and ***Silphium integrifolium,*** two relatives of common sunflower, and intermediate wheatgrass, a perennial relative of wheat reported to be good pasture and produce high-protein grain.

Improved lines of intermediate wheatgrass have been registered as Kernza® and grain from this new crop is being used commercially in US restaurants, bakeries and for brewing.

The global interest in perennial grains, and Australian work with perennial pastures and forage shrubs, is driven largely by concerns about soil degradation associated with intensive cropping practices based on shallow-rooted, annual species that have displaced the predominantly deep-rooted, perennial vegetation that existed before the land was cleared for farming. Specific issues include salinity, groundcover maintenance and seasonal feed gaps.

In the US, where farmers are facing much the same environmental issues as Australian producers for much the same reasons, the Kansas-based Land Institute is a major player in the effort to develop perennial grains as part of its goal of developing Natural Systems Agriculture 'with the ecological sustainability of the prairie and grain and seed yield comparable to that of annual crops'.

NSW DPI RESEARCHERS MATTHEW NEWELL (LEFT) INSPECTING PERENNIAL WHEAT PLOTS AT COWRA WITH DR THARCILLA ARVARENGA AND DR GORDON REFSHAUGE.

As with any cross-breeding program using genetics from wild species to alter the characteristics of commercial crops, achieving acceptable grain characteristics, yield and quality in perennial cereals is proving a major challenge, with the annual yields from current wild x domestic crosses and wild species undergoing domestication lower than those from annual grain crops. However, according to NSW Department of Primary Industries Senior Research Scientist Richard Hayes, there are indications that yields of perennial wheat increase as a stand matures and researchers are optimistic that yields of perennials will compare more favourably with those of current annual varieties once better-adapted material is available and yield performance can be compared over multiple years.

Australia has been exploring the potential of perennial wheat for some years. Current Australian work is being co-ordinated from Cowra, in NSW, with NSW DPI researchers having trialled more than 200 perennial lines, some grass x wheat crosses and some improved wheatgrass lines including several registered Kernza selections from the US.

Under Australian conditions Kernza lines have proved to be longer-lived than hybrid wheats but much less vigorous during the establishment year, with grain that is only a sixth the size of wheat.

The Cowra work is largely focused on the potential of perennial wheat as a 'dual purpose' crop providing grazing and opportunistic grain production; an approach being increasingly adopted with annual winter wheats in higher-rainfall areas of NSW.

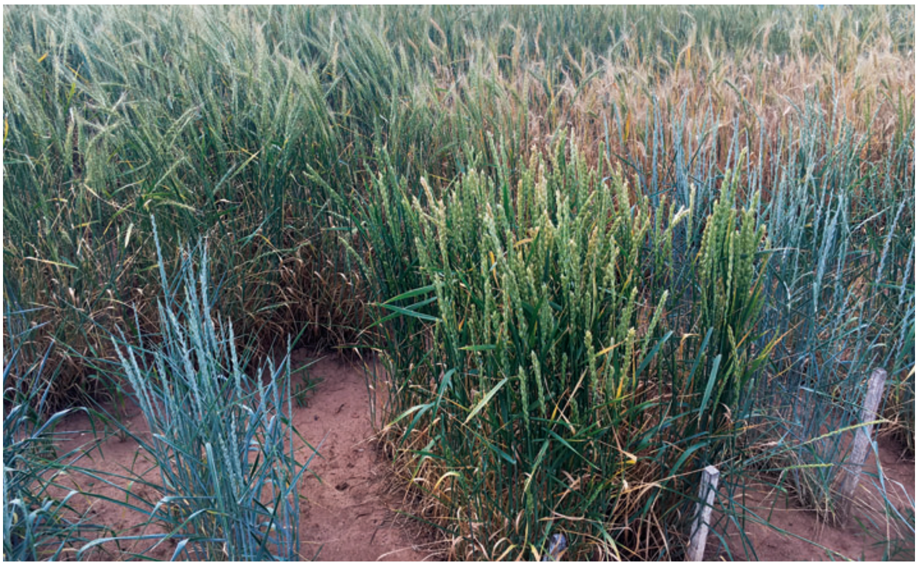
Matthew Newell, one of the NSW researchers involved in the project, suggests that 'dual-purpose' cropping systems based on perennial varieties could help farmers better manage climate variability by making farming systems more flexible and easier to adapt to changing environmental conditions. In marginal cropping areas, perennial cereals could enable farmers to reduce inputs and costs, improve water-use efficiency and use out-of-season rain while providing environmental benefits such as reducing acidification, salinisation and soil erosion.

Cornell University scientist Matthew Ryan, in a paper titled 'Managing for Multifunctionality in Perennial Grain Crops', places more importance on the environmental and ecosystem benefits of having perennials in farming systems than on their grain yield potential.

For example, growing perennial grains for several years before growing annual crops, a concept similar to the well-established practice in parts of southern Australia of alternating phases of grass-based pasture and cropping, could improve soil health, he suggests, and where erosion or water quality is an issue perennial grain crops can be grown on slopes or as a buffer crop along field edges to reduce soil erosion and nutrient losses.

In annual cropping systems it is common to rotate crops to manage weeds, pests and disease and to improve soil, while planting cover crops between commodity grain crops can have beneficial effects on soil biology and soil physical properties. Planting areas to perennial grains and inter-cropping with annuals has the potential to provide many of the benefits gained from wide seasonal rotation of annual crops, while harvesting or grazing vegetation from perennials can reduce certain pest problems as well as generate income.

In SA and Victoria, Mallee Sustainable Farming [MSF] is exploring how to



PERENNIAL WHEATS, AND OTHER PERENNIAL CEREALS, COME IN MANY SHAPES, SIZES AND COLOURS. ONCE PLANT BREEDERS DEVELOP OR SELECT A LINE WITH ADEQUATE COMMERCIAL AND CULTURAL CHARACTERISTICS THE NEXT CHALLENGE WILL BE HOW TO INTEGRATE IT INTO FARMING SYSTEMS.

reduce the risk posed by saline scalding from 'seeps' caused by water draining off sandhills, an issue projected to impact more than 20,000 ha in the SA and Victorian Mallee within a decade unless it is addressed.

This four-year initiative aims to identify areas at high risk of saline degradation due to sub-surface drainage down slopes, devise a method to predict where seeps might develop and determine how best to remediate established seeps and prevent new ones developing.

Much of the work around prevention and remediation of salinisation involves use of plants to intercept and use water moving down slopes before it reaches the surface and begins to cause problems. Some of the most successful perennial lines in the Australian perennial wheat trials are derived from tall wheatgrass, ***Thinopyrum ponticum,*** a perennial relative of wheat that is commonly used to reclaim saline land.

In his paper Dr Ryan, an assistant professor in the Cornell School of Integrative Plant Science, identifies potential agronomic and commercial benefits of perennial grain crops as including no or lower annual seeding costs and lower fuel, fertiliser and pesticide inputs than required for comparable annual grain crops and suggests there could be price premiums for grain from perennial crops driven by consumers searching for more 'sustainable' products or characteristics of the grain or seed.

Perennial grain cropping systems will need to be multifunctional, he suggests, a position supported by Dr Hayes, who says multi-functionality will be important in maximising resource-use efficiency because it increases the likelihood of resources such as rainfall being channelled into agricultural product.

Both men identify potential to graze perennial cereals early in the growing season prior to stem elongation and grain development, just as is done with dual-purpose annual wheat. Results from NSW field work show that some perennial wheat hybrids and IWG can withstand early defoliation with only a modest reduction in grain yield. Defoliation prior to the first grain harvest, in the first year after establishment, reduced IWG grain yield by 13.3%, the average yield of four perennial wheat

IDENTIFYING PERENNIAL BENEFITS

Visions of a perennial crop that will generate direct income, improve the resilience and sustainability of farming systems and provide environmental benefits ensure the idea of perennial cereals continues to attract considerable interest and research effort.

However, Australian research suggests that perennial pastures and forage shrubs could be of at least equal and possibly greater value than perennial cereals in many farming situations.

Bio-economic analysis has shown that whole-farm profit can be increased by including perennial shrubs as a feed source because grazing of shrubs reduces the amount of supplementary feed needed in summer-autumn when the feed quality of crop residue has declined and allows grazing of annual pastures to be deferred.

Much of the recent work in this field has been done under the banner of EverCrop, a farming-system research project of the Future Farm Industries Cooperative Research Centre that operated from 2007 to 2014.

According to Michael Robertson and Clinton Revell, in a paper on perennial pastures, land degradation issues that have emerged over recent decades have stimulated a renewed effort to incorporate perennial forages into Australian crop-livestock systems.

Drivers for the inclusion of perennial forages in crop-livestock systems include their ability to use of out-of-season rainfall to produce green feed and so reduce the need for supplementary feeding, enable more productive use of marginal land and the possibility of sequestering carbon and enhancing biodiversity outcomes, they say.

Conversely, annual pasture species encourage weed build up, increase the rate of soil acidification and allow unused rainfall to increase deep drainage, leading to increased river and dryland salinity. Annual-based systems also often make it difficult to maintain sufficient cover to protect the soil from wind and water erosion, particularly if dry residues are grazed over summer and autumn.

The authors expect the need for perennials to grow as producers look to mixed crop-livestock systems to manage risk and achieve better natural resource management outcomes. However, despite the benefits of and opportunities for perennial forages in crop-livestock systems and the issues arising from on-going use of annual pasture species, the use of perennials has been constrained by a lack of well-adapted species and perceived difficulty in establishing and removing perennial species from cropping paddocks.

A large range of alternative perennial legumes has been evaluated in Australia but few have proved as productive as lucerne; currently the only perennial legume widely grown in the crop-livestock zone, predominantly in phase rotations in eastern Australia.

Short-lived perennial herbs such as chicory and plantain are recognised as valuable species for finishing livestock, they say, but have rarely been considered as serious options for the mixed crop-livestock zone. However, the performance of these two species in field evaluations suggests their role in mixed farming systems should be reconsidered by growers in temperate regions.

Saltbush *(Atriplex spp)* is the most widespread browse shrub used on mixed farms in southern Australia but recent research has focused attention on the potential of other Australian perennial native shrub species including *Acacia* and ***Rhagodia***, another saltbush species, in medium to low rainfall districts.

Integration

Australian mixed farming systems are typically dominated by annual species but perennial forages and shrubs are used in a variety of roles and the EverCrop team identified a variety of approaches that can minimise the apparent conflict between increased use of perennials and the dynamics of an annual-based cropping system and enable integration of perennials into mixed crop-livestock enterprises.

These approaches are characterised as rotate, separate or integrate.

In this context 'rotation' involves sequences or 'phases' of pasture and crop production on the same area of land, such as a multi-year stand of lucerne followed by several years of grain crops or grain-canola rotation.

The authors identify several potential trade-offs between cropping systems when growers rotate perennials and annuals. These include drier soil profiles at the end of the perennial phase, which can result in lower yields of following crops, and the expense of removing perennial forages at the end of that phase. There is greater risk of poor establishment and out-of-season growth of perennials is generally difficult to predict, they require a higher level of grazing management than annual pastures or cereal stubbles and the residues of many perennials, including lucerne, are slow to break down and can tie up soil N needed by a following crop for early growth, they say.

Shrubs such as tagasaste and saltbush are not options for phase farming but are well suited to a 'separation' approach. They are best used as permanent forages and are often grown in strategically positioned block plantings, frequently on moderate- or poor-yielding cropping soils, to achieve environmental objectives such as disrupting rainfall runoff to prevent erosion or intercepting and using sub-surface water to avoid development of saline seeps.

Tagasaste and saltbush are also suited to use in wide-spaced alley systems with annual crops grown between them; technically a hybrid form of incorporation between separation and integration.

Integration, also categorised as synchronisation, involves growing a perennial and annual simultaneously on the same land, typically by 'pasture cropping', which usually involves under- or over-sowing with an annual species or relay sowing forages with crops.

All this suggests growers calculating the benefits of having perennials as part of their farming system should take a holistic approach and look beyond immediate cash returns from grain and grazing to take account of indirect or deferred benefits such as soil improvements, management benefits like weed control opportunities, wider environmental benefits, eco-system services and risk management.

hybrids by 8.1% and the yield of annual wheat by 30.3%. However, the grain yields of the perennial lines were still considerably less than the yield of the annual wheat. Dr Hayes points out that these results were achieved with young stands of poorly-adapted perennials.

In addition to producing grain, perennial crops offer unique opportunities for multi-functional agriculture that combines production of agricultural products and non-market goods and services including ecosystem services, Dr Ryan says. Year-round vegetative cover can help regenerate soil health, provide a buffer to reduce soil erosion or protect water quality and reduce fertiliser nitrogen (N) requirements. Soils in perennial cropping systems also typically have good water infiltration and retention rates, which decreases runoff and soil erosion.

Increasing diversity by intercropping or growing a mixture of different species can increase yield stability, enhance biological control of pests and provide habitat for wildlife.

Mixed-species stands maximise the use of resources by crop plants and make it more difficult for weeds to access light, nutrients and water but competition can result in resources being diverted away from the primary crop, which highlights the importance of multi-functionality. Mixed stands also support greater populations of natural enemies that help keep pest insects in check, with predators and parasitoids often present at higher densities in mixed intercropping systems than in monocultures because a diverse mix of plants is more likely to provide floral resources, egg-laying sites, refuges, alternative prey and non-prey food sources.

In-field plant species diversity can also increase production due to greater resource use efficiency and help reduce losses from insect pests through processes such as altered chemical signalling or lower insect feeding efficiency due to increased search time. Grazing or harvesting perennial grain crops for forage can help further suppress pests, with removal of growing vegetation able to help reduce weed populations and removal of residue after grain harvest having the potential to limit disease and insect pest pressure in the following year.

However, there are questions about the performance and productivity of individual species in multi-species stands and the management challenge posed by highly diverse mixed-species stands could limit adoption of this approach, Dr Ryan says.

PERENNIAL RISK MITIGATION

Perennials can contribute to the enterprise diversity that is increasingly being recognised as key to mitigating the seasonal and price risks facing farmers, say Michael Robertson and Clinton Revel in a paper on perennial pastures.

The ability of perennial plants to extract soil water and nitrogen (N) from below the root zone of annual plants, convert rainfall falling outside the annual growing season to green feed and provide more stable groundcover means they have a key role in risk mitigation, they say.

Perennials have the potential to improve surface cover and soil biological activity and reduce groundwater recharge, so they can be used to reduce negative impacts of farming on the natural resource base and enable farmers to better match land-use activities with land capability. There are also indications that perennials can improve nutrient cycling, soil surface condition, water infiltration and the subsoil environment.

Emerging precision-agriculture technologies such as high-accuracy auto-steer guidance systems and remote monitoring capabilities will facilitate the management of livestock in cropping systems and reduce demands on labour and complexity of management decisions, the authors say.

For example, high-accuracy auto-steer will enable fine-scale design and management of planting arrangements for perennial-annual combinations, while remote monitoring of pastures will facilitate feed budgeting and grazing management, enabling more effective management of the feed base.

Similar technologies will also play into livestock management and reduce labour demands for moving livestock and monitoring livestock condition, they predict.

PERENNIAL CEREALS NEED TO GROW WELL ENOUGH TO PRODUCE A GRAIN CROP – OR FORAGE FOR LIVESTOCK – AND STORE ENERGY RESERVES IN ROOTS OR CROWNS FROM WHICH TO REGENERATE THE FOLLOWING SEASON.

Management issues raised by the concept of functionally diverse perennial grain polycultures include how complex a mixture might be to manage, profit stability and the possible need to re-seed or take other action to increase the relative competitive ability of weaker species. Greater diversity of species could potentially restrict herbicide options and require harvesting equipment that can handle multiple grains or green vegetation along with dry grain, he says. However, because farmers can strategically select species based on agronomic compatibility as well as what they offer in a polyculture or intercropping system, it is possible to achieve a high level of ecosystem services while minimising increases in management complexity.

Phase farming - growing a perennial grain crop for several years then a sequence of annual grain crops - is one of the options suggested as a way to integrate perennial crops into modern cropping systems. This approach, which is already widely used with perennial pastures in much of S-E Australia, has the potential to regenerate soils degraded by annual grain crop production because a stand of perennial vegetation can increase soil organic matter content, enhance soil porosity and water infiltration rates, reduce soil bulk density, improve soil biology and increase N cycling.

Over-sowing perennial cereals with legume forages will reduce nitrogen requirements, as will growing a perennial legume such as lucerne and over-sowing with a cereal or other annual crop, Dr Ryan suggests, but Dr Hayes favours establishing a self-regenerating annual legume to coexist with the perennial cereal as the best approach in Australian conditions.

THE 6HA EVALUATION EXPERIMENT AT COWRA LAST YEAR IN WHICH RESEARCHERS COMPARED THE MOST PROMISING LINES OF PERENNIAL WHEAT FROM AROUND THE WORLD IS BELIEVED TO HAVE BEEN THE LARGEST PLANTING OF PERENNIAL WHEAT ANYWHERE ON THE PLANET.

Growing legume forages with perennial cereals, whether in strips or intermixed within rows, can also provide N for the grain crops, facilitate the accrual of soil organic matter and increase forage quality.

However, growing two crops in the same space at the same time is likely to impact the performance of one or both.

Grasses and legumes are compatible functional groups and are often seeded together in perennial pasture systems and for forage production, but in an Australian trial exploring seeding arrangements for experimental perennial wheat lines intercropped with sub clover, clover sown in its own rows beside rows of the perennial persisted better than clover sown with perennial wheat in the same row. Conversely, in an Iowa experiment comparing the performance of three legumes and four grasses, including a forage variety of IWG, as monocultures and in perennial forage crop mixtures, the polycultures were on average 73% more productive than the monocultures.

Replacing annual grain crops with perennial crops can reduce nitrate leaching and nutrient transport throughout the year because perennials generally have larger root systems than the annuals and are in place year round. One 2013 experiment found that total nitrate leaching under IWG was almost half that under annual wheat when both systems were fertilised with 90 kilograms of N per hectare.

Other work suggests that perennials are less likely to require fertiliser N to ensure a good start to the growing season.

In a 2016 paper on plant succession Tim Crews, Director of Research with The Land Institute, points to storage and subsequent internal translocation of N as an important mechanism for maintaining productivity in perennial systems under variable environmental conditions. The ability to take up and store N until it is needed by the plant is key to the ability of perennials to emerge and regrow after a period of dormancy, he says, with mobilisation of stored N providing as much as 50% of the N required for above-ground growth in a full growing season.

This storage of N also limits N losses, a substantial inefficiency in annual cropping systems, which has environmental benefits and is another reason perennial-based systems are expected to need lower fertiliser inputs.

Approximately half the N remaining in the foliage of a perennial at senescence is recycled to support new growth by translocation to roots and crowns that persist through dormancy, Dr Crews says, with N translocated internally from these reserves important in enabling perennials to achieve rapid, early season growth and rapid regrowth following defoliation events.

Biomass harvest prior to senescence, whether by grazing or cutting, or limited soil N availability can reduce the N available for translocation to roots and crowns and so impact on spring growth, so in perennial grains there may be a trade-off between grain harvest and the development of N reserves to support the following year's growth.

Growing a second crop with a perennial cereal can reduce the availability of resources for the primary grain crop and will likely lead to reduced grain yield, according to Dr Ryan. However, if vegetation from the perennial cereal is grazed or harvested for forage, the gains in forage production and quality might offset the losses in grain yield.

Perennial crops are often active for longer than annual crops so perennial grains can use sunlight and rainfall at times when annual grain crops cannot, he says.

Comparisons of perennial and annual forage and bioenergy crops suggest perennial grain crops are likely to extract more water from deeper in the soil profile than annual grain crops because of their extensive root systems, greater primary productivity, longer growing season and greater longevity. In one experiment comparing water use in IWG and annual wheat, moisture levels under the IWG were lower than under annual wheat at depths of up to a metre, suggesting that in medium to low-rainfall areas where growers rely on soil moisture stored over summer to grow winter grain crops, perennial grains could deplete soil water reserves and limit crop persistence and future yields.

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