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ECONOMICS AND SYSTEM APPLICATIONS FOR PERENNIAL GRAIN CROPS IN DRYLAND FARMING SYSTEMS IN AUSTRALIA

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ABSTRACT

The development of perennial grains could provide a number of sustainability and farm management benefits for Australian dryland crop-livestock farming systems. Whole-farm bio-economic modelling has shown that perennial wheat would have greatest economic feasibility if it had dual-purpose attributes by providing additional forage post-harvest (during summer) and early in the winter growing season. This accrued from the ability to increase livestock numbers without a proportionate reduction in returns from grain production. Grain-only perennial wheat achieving similar prices would require yields of 60-100 percent of annual wheat to compare with current systems, while dual-purpose perennial wheat was still economically favourable with grain price AU$35/tonne less and grain yields 40 percent of annual wheat. In all cases perennial wheat would be most attractive on soils or situations where current annual cereal systems are most marginal. Cost-benefit analysis based on modelled increase in farm profit (AU$20/ha farm area), suggests that a 20 year investment in perennial wheat would result in a 10-fold return if it was adopted on 450 000 ha assuming 75 percent chance of success. While perennial wheat would have the largest impact in Australian farming systems, the development of perennial legumes for dual-purpose grain-grazing could also offer some potential. Several native Australian legumes have been assessed for their suitability and there are several short-lived perennial legumes that could have potential in such a system both in Australia and elsewhere (e.g. *Lablab purpureus*). Finally, perennial grain crop development should consider the range of farming systems where they might be used including facultative perennial systems, phase rotations (e.g. 2-4 year long rotations), companion or relay cropping (oversowing them with other crops/pastures) or polycultures involving a range of perennial species.

Keywords: dual-purpose, modelling, rotations, polyculture, companion cropping, cost-benefit

INTRODUCTION

Annual cereal crops, mainly wheat, in rotation with annual pastures have dominated grain production systems in Australia. This reliance on annual species has caused environmental problems such as dryland salinity, soil erosion and degradation, nutrient leaching and eutrophication. Reintroduction of productive and profitable perennial plants into agricultural landscapes to more closely mimic the original vegetation by increasing ground cover and annual water use can address many of these problems (Hatton and Nulsen, 1999). Farming systems incorporating agro-forestry and perennial forage plants are being utilised in many areas (Bell *et al.* 2013), but perennial grain crops could also provide a major opportunity to improve the sustainability of agricultural systems without the need to discontinue cropping activities (Glover *et al.* 2010; Bell *et al.* 2010b).

Perennial grain crops might be developed from either domestication of promising wild species or via hybridization of current annual crops with their perennial relatives (Cox *et al.* 2002). Both these avenues hold promise for developing perennial grain crops suitable for Australian conditions, but significant breeding effort would be required (Larkin, 2013). While breeding a genetically stable, productive and persistent perennial crop holds many challenges it is vitally important to consider how a perennial crop might be used in a farming system. This can provide insights that will guide the characteristics required in the crop and their relative importance for breeding efforts. While a number of sustainability benefits from perennial wheat are predicted and cost saving such as reduced tillage, fertiliser requirements and energy inputs are anticipated, the relative profitability of perennial grain crops compared with conventional annual systems needs to be analysed to justify investment in perennial crop development. This can also potentially expose the economic trade-offs between different attributes and help identify diverse crop ideotypes that might be valuable in different farming systems. This paper will provide a summary of some whole-of-system economic analysis conducted in Australia and consideration of diverse options for integrating perennial grain crops into farming systems. This provides some useful insights into priorities and strategies, and identifies opportunities for perennial grain crop development more widely. In particular, much attention has been applied to perennial wheat hybrids, yet there may be opportunities for complementary perennial grain legumes or other cereals either from direct domestication of native species or targeted breeding of other species.

PRELIMINARY ECONOMIC ANALYSIS OF PERENNIAL CEREAL CROPS IN AUSTRALIAN FARMING SYSTEMS

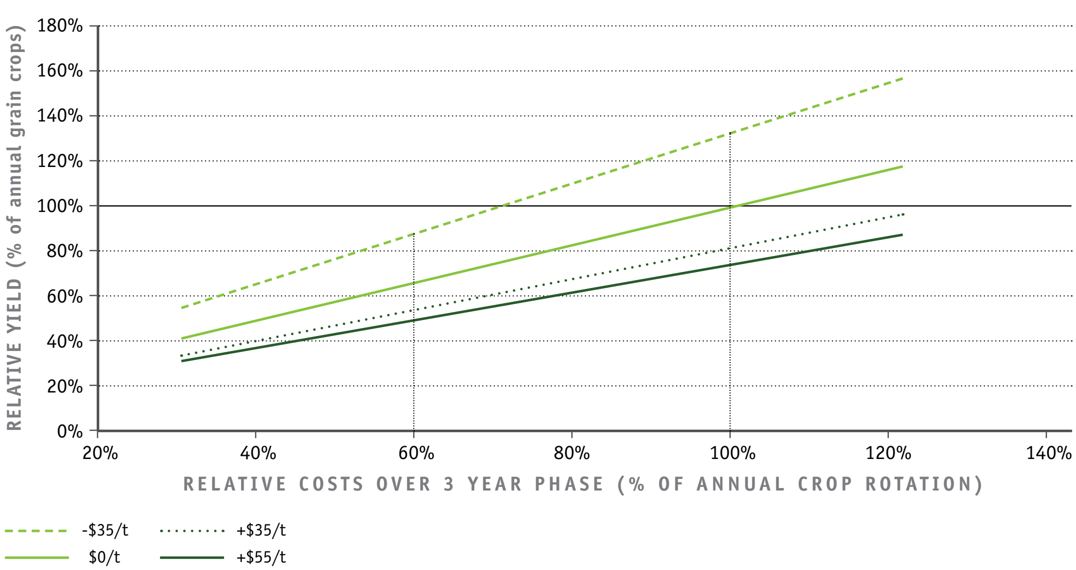
Grain-only production

Gross margins and whole-farm economics of a perennial cereal utilised for grain production were only compared with returns from conventional annual crop-based systems (based on a wheat-wheat-grain legume rotation). Yield, price and costs for the annual crop rotation were drawn from data for the medium rainfall regions of south-western Australia (350-500 mm mean annual rainfall) (more details are available in Bell *et al.* 2008). Because the income and costs for a perennial cereal system are uncertain, the sensitivity of break-even profitability was explored across a range of relative grain price, yield and variable production costs between the perennial and annual crop phases.

Figure 1 depicts the relationships between relative grain yield, growing costs and grain price on the relative profitability of a perennial crop compared with a typical annual crop rotation. This demonstrates the importance of the likely market for grain products on the cost-price requirements for a perennial grain crop. For example, if a grain-only perennial crop received a price premium or incentive payment of >US$35/tonne then it would achieve equal economic returns with grain yields 70-80 percent of annual crop yields at the same production cost per hectare. On the other hand, a lower quality grain product, similar to an animal feed grain receiving US$35 less per tonne than a milling grade product would require significantly higher grain yields than an annual grain crop system; an unlikely scenario for a perennial grain crop. One claim is that perennial grain crops will have lower production costs due to savings from less frequent sowing, herbicide applications and lower fertiliser replacement requirements (Crews 2005). Bell *et al.* (2008) estimate this could be 60 percent of an annual crop system. This would enable grain yields to be 50 percent and 65 percent of annual crops if a perennial cereal received a US$35/tonne price premium or the same price as an annual cereal crop, respectively. A perennial cereal receiving a lower price differential would require grain yields of >80 percent of an annual crop rotation to obtain a similar return.

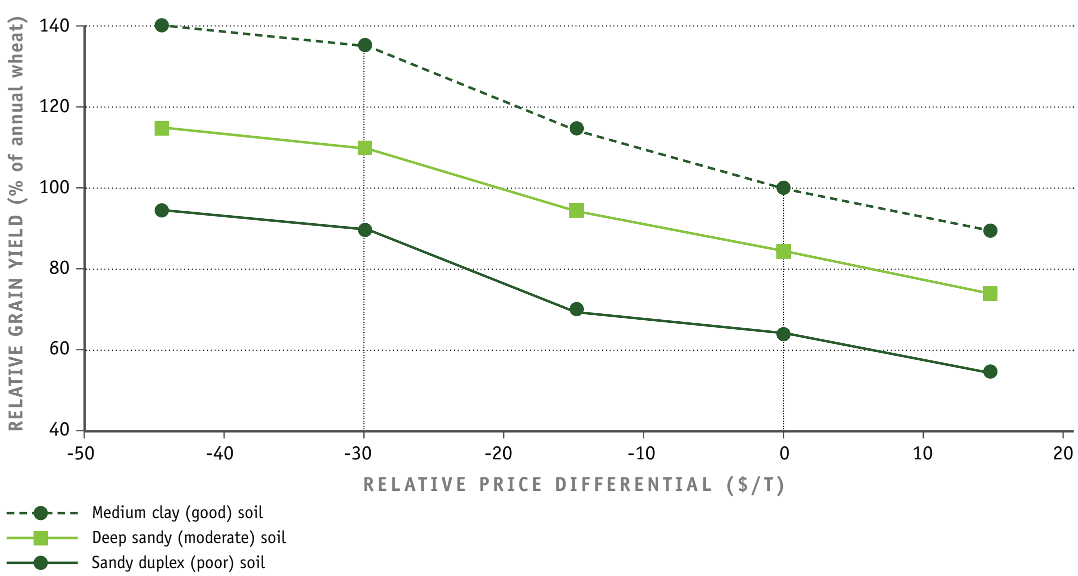
This analysis in Figure 1 was based on a 3-year phase of a perennial crop but the longevity of a perennial crop phase is also a factor that may impact on its relative profitability compared with annual crop systems. The yield required for a perennial crop to compare with an annual crop system declines with the duration of a perennial crop phase, as establishment costs are spread over more years. However, this reduction in grain yield required is small (<3 percent) once the duration of the perennial crop rotation is greater than three years because annual production costs (i.e. replacement fertiliser, harvesting costs) remain consistent. This suggests that unless perennial wheat yields are stable or increase with age of the stand, then there is little direct economic advantage in long-lived perennial crops. This is especially pertinent when considering potential trade-off that may exist between plant grain yield and longevity (see DeHaan *et al.* 2005).

FIGURE 1. GRAIN YIELD REQUIRED BY GRAIN-ONLY PERENNIAL CEREAL TO OBTAIN SIMILAR 3-YEAR GROSS MARGIN RETURNS TO AN ANNUAL CROP ROTATION (WHEAT-WHEAT-GRAIN LEGUME) ACROSS A RANGE OF RELATIVE GROWING COSTS AND GRAIN PRICE DIFFERENTIALS FOR PERENNIAL WHEAT COMPARED WITH THE ANNUAL CROPS



A perennial grain-only cereal crop that yielded 60 percent of an annual wheat crop with 60 percent of the variable costs but receiving US$35/tonne lower price was made available in a whole-farm bio-economic profit optimising model (MIDAS) (Morrison *et al.* 1986). The whole-farm model captures many of the biological and economic interactions that occur across a whole farm including variation in soil capabilities (denoted by different land management units with specific production and cost structures), rotational impacts and farm overheads (for more detail refer to Bell *et al.* 2008). Using the standard production/cost assumptions, a perennial grain crop producing only grain was not chosen on any land management units. The shadow or opportunity cost for a perennial cereal to be adopted on the farm was lowest on the less productive soil types (around US$25/ha), but was much higher on land management units where other annual crop and pasture systems were more profitable (US$40-100/ha). Subsidisation or other additional systems benefits would have to be larger than this to encourage adoption of a grain-only perennial cereal. Figure 2 demonstrates the relative grain yield and price required by a perennial cereal crop for it to be adopted across soil types differing in their productivity on a profit-maximising farm. This indicates that a grain-only perennial cereal is most likely to be adopted if it can be used on poorer or more marginal soil types for annual crop and pasture systems. On the most productive and profitable soil types grain returns similar to annual cereal crops would be required to displace current systems.

FIGURE 2. RELATIVE GRAIN YIELD REQUIRED FOR GRAIN-ONLY PERENNIAL CEREAL AT DIFFERENT PRICE DIFFERENTIALS COMPARED TO ANNUAL BREAD WHEAT TO BE PROFITABLY INCORPORATED ONTO DIFFERENT SOIL TYPES OF A DRYLAND FARM IN SOUTH-WESTERN AUSTRALIA



Dual-purpose graze and grain option

Because of the longer growing season, the potential to maintain green leaf for longer than an annual crop and respond to out-of-season rainfall, a perennial crop is likely to provide some additional forage compared with annual grain crops. This opportunity is likely to be similar, but perhaps larger than where long-season wheats are currently grazed during their vegetative growth period early in the growing season and allowed to regrow to produce grain later in the season (Bell *et al.* 2013). Whole-farm bio-economic modelling was necessary to determine if such a dual-purpose perennial crop may offer advantages to livestock production and whole-farm productivity over annual crops in mixed crop-livestock farming systems. This approach enables many of the complex interactions between crop and livestock enterprises, timing of livestock feed supply and the economics of the whole farm system to be analysed concurrently. In addition to standard production and price assumptions described previously, high quality green forage was made available for grazing early in the growing season following the break of season (i.e. start of the rain prior to sowing annual crops) and/or additional green forage was available after harvest in addition to the crop residue or stubble from the annual crops. No yield penalty from grazing was assumed.

Additional grazing obtained from a perennial cereal crop greatly improved its profitability and resulted in 20 percent of the profit-maximising farm plan being allocated to the perennial crop under standard assumptions. Again this was mainly on the soil types where other crop and pasture systems were least profitable even though lower production of grain and forage was assumed on these soils for the perennial cereal crop. Hence a perennial cereal crop was found to be a profitable addition to a mixed crop-livestock enterprise in southern Australia when it provided an additional 900 kg/ha post-harvest forage and 700 kg/ha early season forage, a yield 60 percent of annual wheat at a AU$35/tonne lower grain price and 60 percent of the production costs.

Modelling suggested that the dual-purpose perennial cereal crop could increase farm profit by 38 percent or AU$21 per farm hectare (Table 1), which equates to a net gain of AU$105/ha of perennial cereal sown (i.e. change in farm profit per unit area sown to the perennial cereal in the optimal scenario). This mainly came about through the ability to increase livestock numbers by providing forage at key times of the year. This also brought about structural changes in farm allocation between crops and pastures by enabling improved utilization of pastures by deferring the use of supplements, and an increase in pasture area on the farm to support this higher potential stocking rate. The dual-purpose crop also reduced the grazing of crop residues or stubbles which may also have other environmental and production benefits on other parts of the farm.

TABLE 1. FARM PROFITABILITY, ALLOCATION OF LAND TO CROP AND PASTURE, AND LIVESTOCK NUMBERS AND SUPPLEMENTATION UNDER AN OPTIMAL FARM PLAN WITH AND WITHOUT THE INTEGRATION OF A DUAL-PURPOSE PERENNIAL CEREAL

	WITHOUT GRAZING	WITH GRAZING	CHANGE (%)
FARM PROFIT (AU$/HA)	$55.6	$76.5	+ $21 (38%)
PERENNIAL CEREAL AREA (%)	0	20	+ 20
CROP AREA (%)	55%	45	- 10
PASTURE AREA (%)	45%	55	+ 10
STOCKING RATE (DSE/HA)	7.6	8.9	+ 1.3 (17%)
SUPP FEED (KG/DSE)	59.4	58.4	- 1.0

Adapted from Bell *et al.* (2008).

Due to uncertainty about the amount and timing of additional forage that might be provided by a dual-purpose perennial grain crop, a sensitivity analysis to these factors showed that a perennial grain crop providing even less additional forage could still be valuable and there is capacity to trade-off between forage and grain yield. Table 2 shows that forage provided early in the growing season before other feed sources are available is particularly valuable. Even small amounts of forage, as little as 175 kg/ha, provided at this time would increase farm profit and see 10 percent of farm allocated to perennial wheat. Providing forage after harvest was less valuable, but perennial wheat was still a profitable addition to the farm when only 500-1 000 kg of additional forage was provided after harvest only.

TABLE 2. SENSITIVITY OF AREA OF PERENNIAL CEREAL SELECTED (% OF FARM) IN THE OPTIMAL FARM PLAN TO THE TIMING AND AMOUNT OF FORAGE SUPPLIED FROM A DUAL-PURPOSE PERENNIAL CEREAL

EARLY GROWING SEASON		AFTER HARVEST ONLY		BOTH AFTER HARVEST AND EARLY SEASON	
Additional forage (kg/ha)	% perennial wheat	Additional forage (kg/ha)	% perennial wheat	Additional forage (kg/ha)	% perennial wheat
700	12	900	11	1600	20
525	10	675	13	1200	16
350	13	450	0	800	13
175	11	225	0	400	11

Adapted from Bell *et al.* (2008).

Table 3 also shows a further sensitivity analysis showing the area of the farm that would be sown to a perennial cereal under the optimal farm plan where lower levels of additional forage are supplied and lower relative grain yields were provided by a perennial cereal crop. This demonstrates that there is potential to trade-off between the grain yield and forage provided by a dual-purpose perennial grain crop. For example, if 800 kg/ha of additional forage was provided (350 kg/ha early in growing season and 450 kg/ha after harvest), perennial grain yields could be as low as 40 percent of annual wheat and still make a positive economic impact and would be included in an optimal farm plan on mixed crop-livestock farms. This shows that grain yields as low as 40 percent of an annual wheat might be feasible in a perennial cereal crop if it provides modest levels of additional green forage at key times of year. This also has significant implications for the attributes that might be targeted in developing perennial grain crops; revealing that forage production may be a vital attribute to consider and that lower grain yields could be profitable if additional forage for livestock at key times could be obtained from a perennial grain crop.

TABLE 3. SENSITIVITY ANALYSIS TO LOWER AMOUNTS OF ADDITIONAL FORAGE SUPPLY AND LOWER RELATIVE PERENNIAL CEREAL GRAIN YIELD ON THE AREA OF PERENNIAL WHEAT (% OF FARM AREA) UNDER THE OPTIMAL FARM PLAN

Standard assumptions were a relative grain yield of 60 percent and 1600 kg/ha of additional forage supplied.

FORAGE SUPPLIED AFTER HARVEST AND EARLY GROWING SEASON (kg/ha)	RELATIVE PERENNIAL WHEAT GRAIN YIELD		
	60%	50%	40%
1600	20%	19%	14%
1200	16%	16%	14%
800	13%	13%	12%
400	11%	0%	0%

Source: Bell *et al*. 2008.

Residual indirect production and environmental implications

It is important to point out that the above economic analyses considered only the direct production implications of a perennial cereal in a conventional dryland farming systems. This did not consider the implication of other technologies such as perennial pastures or dual-purpose annual crops which might diminish the relative benefit obtained from forage provided by perennial wheat. There are also several other indirect and sustainability factors are also important. No value was attributed to environmental benefits that a perennial crop might provide, whether this is an impact on the long-term condition of the land where a perennial crop is grown (e.g. soil carbon, soil erosion) or off-site external impacts (e.g. water eutrophication, sediment flow, greenhouse gas emissions). While the maintenance of land condition may directly influence a farmer's intention to adopt a perennial crop, without policy or economic incentives it is unlikely the off-site externalities would play a major part of farm decision making. However, a perennial crop may also offer several whole-farm management benefits that might prove attractive to farmers (Bell *et al.* 2010b). Firstly, because seeding frequency would be reduced, farmers could adjust or reduce their capital investment in seeding and spraying equipment, or alternatively farm a larger area without the need for more machinery. This would also be beneficial by reducing labour requirements at peak times of the year such as sowing. Secondly, the possibility of utilising perennial wheat for either grain or grazing purposes would enable greater enterprise flexibility where producers could delay their decision beyond the time of planting in response to climatic and economic conditions. Because of lower external inputs such as crop establishment costs, fertilizer and herbicides (as discussed previously), the risk exposure to climatic and market fluctuations is also reduced.

INTEGRATING PERENNIAL CEREALS INTO FARMING SYSTEMS

In addition to the economic and agronomic characteristics outlined above, perennial cereals could be utilised in a range of different ways in a farming system which may require different attributes (Bell *et al.* 2010b). One of the most important of these is the persistence or stand longevity of a perennial cereal which will influence the permanency, or length of time the perennial crop remains in the system. Hence, depending on the capacity of a perennial crop to persist or maintain productivity in different agro-climatic zones or conditions, different uses of perennial wheat may be appropriate. Below some likely systems are discussed where a perennial cereal could conceivable fit into a farming system

Perennial grain polycultures

In North America, the ultimate system for perennial grain production proposed by some would involve a permanent 'polyculture' mixture including warm- and cool-season perennial grasses, perennial legumes and composites that mimic their natural prairie systems (Piper, 1998)(Figure 3a). Perennial mixtures are thought to be more sustainable than pure stands, and have been shown experimentally to produce more grain yield and biomass from mixtures compared with monocultures of each species (Piper, 1998). This is because there were synergies between the functional groups, such as legumes compensating for low N supply. However, realizing successful perennial crop polycultures would require species that complement one another spatially, seasonally or in nutrient requirements, so that (a) land, labour or resources are used more efficiently; (b) yield is increased; (c) losses to insects, diseases, and weeds are reduced; or (d) yield variation is reduced (Piper, 1998). The development of such a system is an ambitious undertaking and its complexity would bring challenges. Water limitations during the wheat growing season in many Australian cropping systems, may impose significant competition between components of a mixture, especially among competitive perennial species. Many Australian environments also have short growing seasons and hence it would be difficult to time the growth, development and harvest of diverse grain crops into such a short period.

Companion or relay cropping

It is likely that in Australian systems, much simpler mixtures of perennial cereals would be more suitable. Companion or relay of other crops (e.g. grain legumes or cereals) into existing perennial crop stands may provide several of the benefits of mixtures (e.g. N inputs, enable competition to be managed and increased system productivity). Inputs of nitrogen might be obtained by growing an annual pasture legume (e.g. medic or clover) under a perennial cereal to provide a cheap source of N, as well as to compliment grazing from a perennial cereal (Figure 3b). Similar systems involving perennial pasture grasses in mixtures with annual legumes already exist in many environments (see Hayes *et al.* 2013, this conference). In more arid environments, where lower densities of perennial plants persist, companion cropping during periods favourable for growth could be a good strategy for increasing productivity (Figure 3c). In higher rainfall regions of southern Australia, a companion crop could be grown at the same time as the perennial cereal during the moist winter-growing period without excessive competition for water. For example, in some regions in the uniform rainfall zone of southern NSW, annual cereal grain crops are sown into permanent perennial grass pastures (pasture cropping) which is being found to increase water utilization, and enable fertilizer inputs that benefit the productivity of the perennial system (Miller and Badgery, 2009). Where longer growing seasons or summer rainfall is higher, relay systems might enable a crop or forage to be sown or regenerate after the harvest of the perennial wheat. Annual decisions on whether or not to companion or relay crop the perennial wheat could be made tactically based on seasonal prospects, the requirements for nitrogen inputs, disease pressures and perennial crop densities.

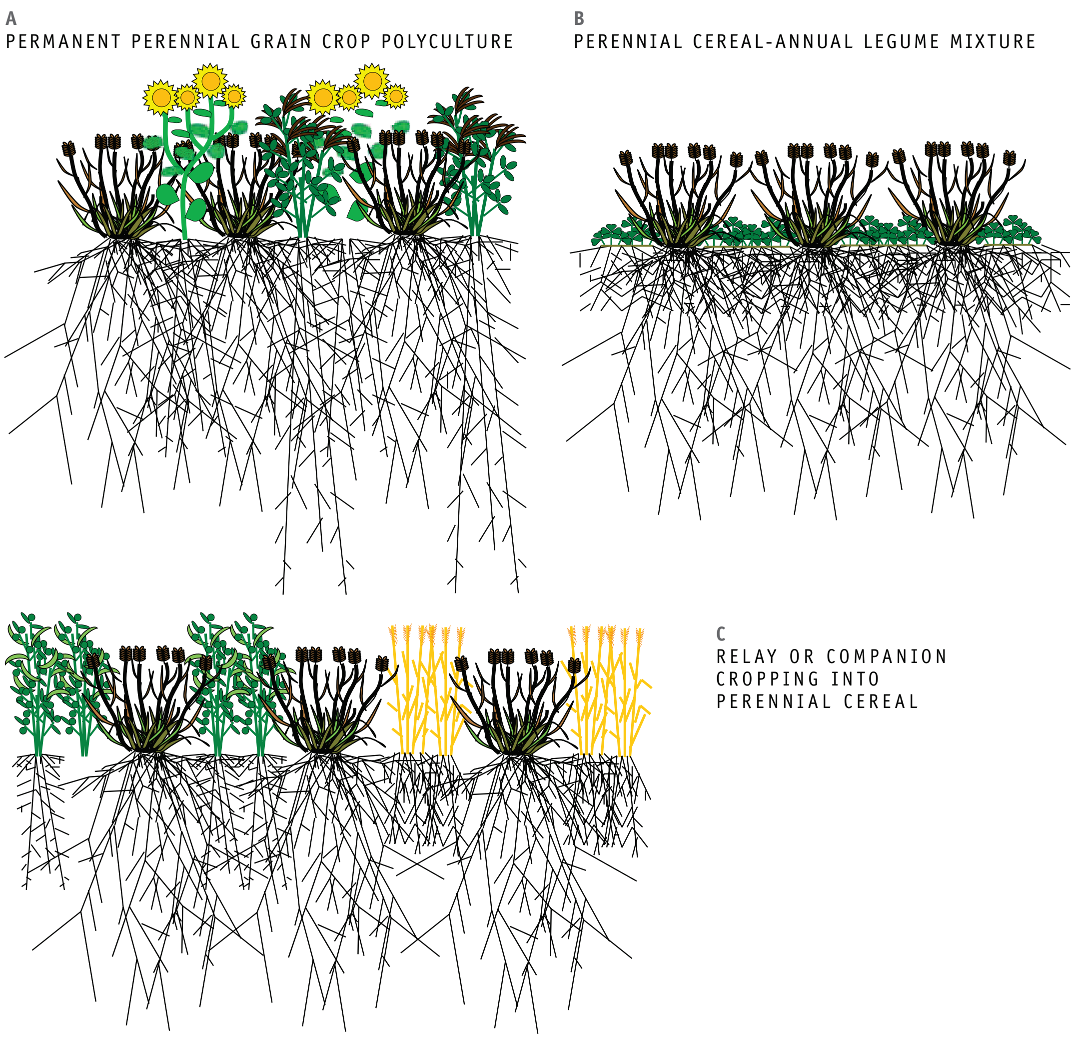
Phase rotations

A perennial crop might be used in a similar way to perennial pasture legumes and some grasses (e.g. alfalfa) as a phase of 2-4 years followed by a phase of annual crops or pastures (Figure 4). In this system, a perennial crop does not need to be long-lived and the perennial crop could be removed once plant populations or productivity decline. Alfalfa and other perennial pastures used in this way provide hydrological benefits by depleting subsoil water content and then allowing this dry soil buffer to refill during subsequent years of annual crops or pastures (Ridley *et al.* 2001; Ward 2006). The annual crop and pasture phase would also enable soil nutrient reserves to be replenished, provide disease break benefits should soil borne or foliar diseases build up and enable weed control options to be diversified.

Such a system is also self-regulating. In low rainfall environments, the length of the perennial phase would be shorter because subsoil water reserves are depleted and productivity of perennials decline more quickly, but in these environments drainage events below the annual crop root zone are less frequent, and longer phases of annual crops can be accommodated before dry subsoils are refilled (Ward, 2006).

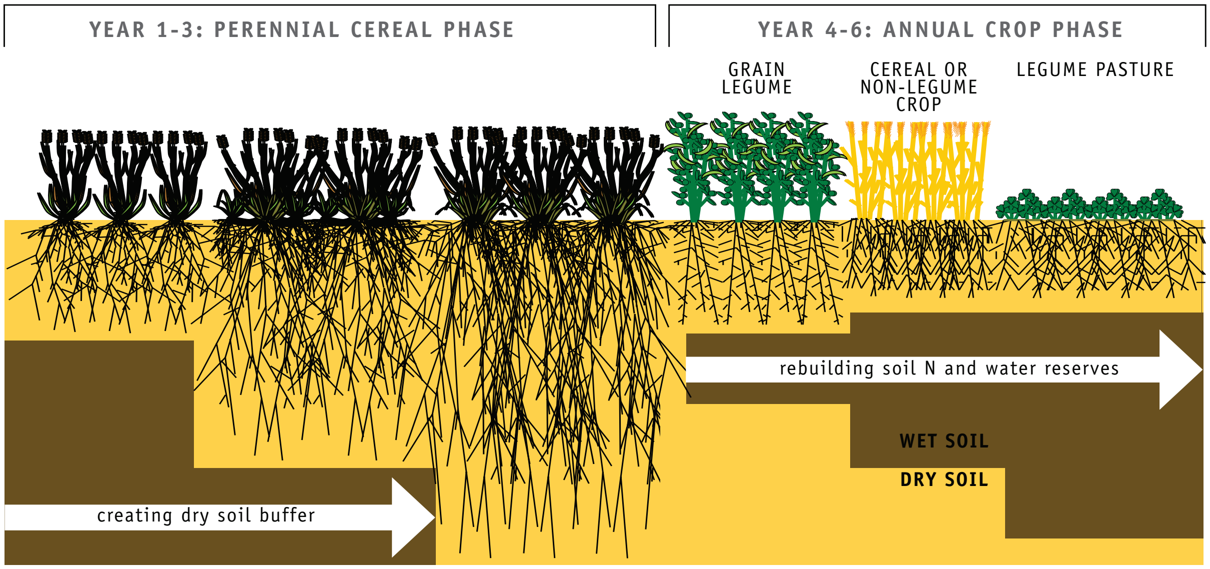
FIGURE 3. DEPICTIONS OF ALTERNATIVE FARMING SYSTEMS INVOLVING PERMANENT PERENNIAL CEREAL CROPS

(a) polyculture mixture with perennial legume and composite as proposed by Piper (1998), (b) annual legume understory to provide N inputs and minimal competition for water during the growing season, (c) relay or companion cropping of annual grain legumes or cereals.



On the other hand, like perennial pastures, perennial cereal persistence may be better in higher rainfall zones, and hence, allow longer rotations where a greater proportion of perennial is needed in crop rotations to reduce the higher drainage and runoff rates in these environments (Ward, 2006). Perennial wheat suitable for these phase rotation systems would need to produce grain in the first year, and be cheap and reliable to establish and remove.

FIGURE 4. DEPICTION OF A PHASE ROTATION INVOLVING A THREE YEAR PHASE OF A PERENNIAL CEREAL CROP WHERE SUBSOIL WATER AND MINERAL N IS DEPLETED FOLLOWED BY THREE YEARS OF ANNUAL CROPS AND PASTURES WHERE SOIL NUTRIENTS AND SUBSOIL WATER RESERVES ARE REPLENISHED



Facultative perennial crop systems

Even in situations where a perennial cereal has uncertain year-to-year persistence (e.g. low rainfall environments) there may still be a fit and advantages in farming systems. Such a perennial wheat genotype would require cost and ease of establishment and management, and grain yields similar to annual wheat and, in most years, would be analogous to using a long-season dual-purpose wheat. However, in favourable years when the perennial wheat was able to persist adequately, this may allow an opportunistic crop or may be used as a pasture in the subsequent year. By reducing the requirement for longevity and/or allocation of resources to survival strategies, higher grain yields might also be achievable more immediately.

PROSPECTS FOR OTHER DUAL-PURPOSE PERENNIAL GRAINS

While perennial cereals, based on wheat hybrids, would have the largest market opportunity in Australia, a range of other perennial cereals and non-cereal grain crops might have significant value in Australian farming systems. This is particularly the case if perennial crops have greatest opportunities on marginal or challenging soils to provide dual-purpose grazing and grain production opportunities.

Perennial grain legumes

The development of perennial legumes for dual-purpose grain-grazing could also offer some potential by providing high quality forage, in particular protein, for livestock at key times, provide inputs of N and disease management options in rotations, as well as potentially fitting on soil types where few grain legumes are well adapted. A perennial grain legume providing its own N needs would also reduce the need for the perennial crop to be grown in a mixture with other species, hence providing easier management of a monoculture.

A significant effort has been continuing in Australia to investigate the potential for a range of exotic and native perennial legumes as forage species but little attention has been applied to perennial grain legume options (Li *et al.* 2008). The native Australian legumes examined in this work were found to occur in areas with arid climates, and infertile and poor soils (Bennett *et al.* 2010; Pang *et al.* 2010) and hence were thought to be a good place to look for potential new grain crops adapted low-input agricultural systems in harsh growing conditions where other crop species may not be well suited. Australia's native legume flora is also largely unexplored for their potential as grain crops.

Examination of the natural distribution among a range of native legume genera found in semi-arid and arid regions of temperate Australia, together with information on traits linked to agronomic success as grain crops (i.e. harvestability, grain qualities and fecundity) revealed several species considered worthy of further evaluation for their grain production potential (Bell *et al.* 2010a). A range of these species have been grown under controlled conditions to compare their growth and reproductive traits, seed yield and composition with commercial annual grain legumes (Table 2; Bell *et al.* 2012). Seed yields of seven native perennial legumes were >40 percent of chickpea (*Cicer arietinum*), with grain protein, fat and fibre similar to the commercial grain legumes in the range desirable in food and feed industries. In several species the reproductive allocation were also similar to the annual commercial grain legume cultivars and much higher than might be expected from perennial species. These results are quite exciting for several reasons. Firstly, growing conditions were favourable to the annual species (well watered and fertilised in greenhouse), while under lower fertility and moisture limited conditions the relative productivity of the native perennials would be expected to be improved. Secondly, these results were based on only one accession of each taxon; undoubtedly there is substantial capacity to explore germplasm with greater productivity, larger seed size and phenological development. These species are also those that have been identified as having potential as forage plants and hence could have potential as dual-purpose options.

TABLE 4. SEED YIELD, HARVEST INDEX, SEED SIZE, CRUDE PROTEIN (CP) AND FAT CONTENT OF SEVEN UNDOMESTICATED AUSTRALIAN NATIVE LEGUMES COMPARED WITH TWO COMMERCIAL ANNUAL GRAIN LEGUMES (CHICKPEA AND FIELD PEA; HIGHLIGHTED IN GREY) WHEN GROWN IN A GREENHOUSE UNDER THE SAME CONDITIONS

SPECIES	SEED YIELD (g plant^{-1})	HI (g g^{-1})	SEED MASS (mg seed^{-1})	CP CONTENT (%)	FAT CONTENT (%)
Pisum sativa	9.9	0.50	258.9	26.3	1.2
Glycine species	4.8	0.54	11.2	32.2	5.2
*Cicer arietnum**	4.6	0.60	188.7	22.9	4.5
Lotus cruentus	3.4	0.65	1.5	32.0	5.9
Cullen tenax	2.8	0.30	5.2	32.1	11.3
Glycine canescens	2.7	0.35	16.9	34.0	6.2
Swainsona kingii	2.2	0.47	2.7	34.3	2.5
Cullen cinereum	2.1	0.30	5.2	36.2	11.8
Swainsona colutoides	2.0	0.21	3.1	27.5	2.1

* actual species is unknown

Adapted from Bell *et al.* (2012)

While this analysis examined potential in Australia's native herbaceous legumes adapted to temperate environments, there is also a range of tropically adapted perennial legumes that might have potential. For example, Australia possesses a large diversity of perennial legumes in the genera *Glycine*, *Crotalaria*, *Canavalia* and *Vigna* all which have close relatives which are grown as annual grain legumes (e.g. *Glycine max* – soybean, *Crotalaria juncea* – sunn hemp, *Vigna radiata* – mungbean) (Bell *et al.* 2010a). These perennial relatives of grain legume crops could provide a useful source of perennial germplasm adapted to arid conditions and infertile soils. Several tropical species such as lablab (*Lablab purpureus*) and pigeon pea (*Cajanus cajan*) are already used as annual dual-purpose crops in some countries (particularly in smallholder settings), but have germplasm that are short-lived perennials.

Other perennial cereals

A diverse range of other perennial cereal crops could have advantages over wheat in some situations. For example, perennial triticale could be produced from hybrids between *Triticum* species and *Secale montanum* with advantages over wheat due to its greater tolerance of acid soils (and high aluminium levels), low nutrient availability, drought and temperature stress (Jessop, 1996). Annual triticale is currently grown in Australia where wheat performance is reduced by these stresses and it is also widely used as a dual-purpose graze and grain crop. Hybridisation of *Triticum* with *S. montanum* should also be easier than with *S. cereale* (used to develop existing triticale), because the former is thought to be more closely related to wheat (Appels, 1982). Perennial grain rye using *S. montanum* has also been the target of some efforts internationally, and could improve the rooting depth, drought and heat tolerance of rye, but past efforts have encountered problems maintaining both perenniality and fertility (Reimann-Philipp, 1995). In Australia, *S. montanum* has been breed as a forage grass and hence adapted and agronomically suitable germplasm is likely to be available and may provide a useful starting point for any efforts to develop either a perennial rye or triticale (Oram, 1996). However, the increases in grain size above the commercial *S. montanum* forage variety would be required to produce a useful grain product and to increase grain yields (Hayes *et al.* 2012).

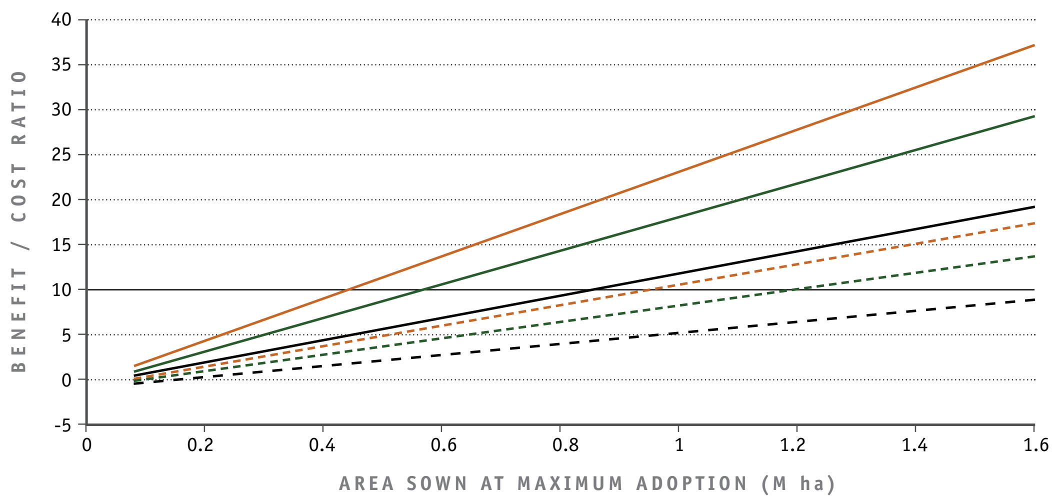
In addition, we should not discount direct domestication of already adapted native Australian grasses such as *Microleana stipoides* (Davies *et al.* 2005). This grass is an important forage species and has been shown to have many attributes suitable as a dual-purpose grain and graze crop. Warm season perennial cereals, such as sorghum and pearl millet, may also be better suited in Australia's northern grain growing zone where rainfall is summer dominant. In these environments, commercial sorghum crops regularly ratoon after harvest and sometimes survive for more than one year, unless they encounter severe frost. Hence, breeding a perennial sorghum suited to subtropical farming systems may involve selection from within the range of pre-breeding material already available and hence avoid challenges with wide hybridization.

VALUE PROPOSITION FOR INVESTMENT IN PERENNIAL CROP DEVELOPMENT

Despite the significant opportunities and benefits that development of a perennial grain crop could provide it is important to consider and establish the value proposition for investment in their development. That is, would breeding a perennial grain crop pay off economically? Based on the economic outcomes predicted from a dual-purpose perennial cereal in the whole-farm modelling described previously (i.e. AU$20/farm ha (as shown in Table 1) and AU$10/ farm ha (assuming smaller areas are adopted on farms; e.g. Table 3), Figure 3 shows the benefit-cost ratio (i.e. calculated cumulative economic return over 20 years divided by the cost of development, with a discount rate of 5 percent) across a range of scales of adoption and assuming investments of AU$1 million per year over 10, 15 and 20 years. This demonstrates that the likely scale of adoption is a key factor influencing the likely return on investment in a perennial crop. Successful peak adoption on 0.4-0.5 million ha would achieve a 10:1 minimum benefit/cost on a AU$20 million investment over 20 years with 75 percent probability of success. Lower probabilities of success even over shorter time-frames and/or lower returns per farm hectare challenge the capacity for a perennial cereal to produce such high returns on investment unless it was suitable for a large proportion of Australia's cropping zone.

FIGURE 5. RELATIONSHIP BETWEEN AREA ADOPTED AND BENEFIT/COST RATIO FOR AN INVESTMENT OF AU$1 M/YEAR IN THE DEVELOPMENT OF A PERENNIAL CROP ASSUMING 25 PERCENT LIKELIHOOD OF SUCCESS AFTER 10 YEARS (BLACK), 50 PERCENT LIKELIHOOD OF SUCCESS AFTER 15 YEARS (GREEN) AND 75 PERCENT LIKELIHOOD OF SUCCESS AFTER 20 YEARS (RED) ASSUMING A NET ECONOMIC ADVANTAGE OF AU$20/FARM HA (SOLID LINES) AND AU$10/FARM HA (DOTTED LINES)

For further details on assumptions refer to Bell *et al.* (2008).



CONCLUSION

This paper points out that it is important to consider the farming systems context into which a perennial grain crop might be introduced. This can help guide those qualities and attributes that might be most desirable and lead to greatest adoption and economic returns. In an Australian context is seems that a perennial grain crops with dual-purpose attributes providing grazing for livestock as well as grain yield and is adapted to the less productive parts of the landscape are likely to be the most advantageous in Australian farming systems. This can also offset initially lower grain yield and quality of a newly developed perennial cereal and provides an opportunity for a transitional genotype that might be developed based on forage grass that provides opportunistic grain production. While most of efforts so far have focussed mainly on wheat, there may actually be other perennial grain options which are easier to realize and could meet these requirements more easily (e.g. sorghum, triticale, perennial lablab or domestication of a native grass or legume). Similarly, a diverse range of farming systems could be developed in which a perennial crop might be used and wider consideration of these options should be taken in future breeding efforts.

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