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A preliminary whole-farm economic analysis of perennial wheat in an Australian dryland farming system

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Abstract

The development of perennial wheat could have a number of advantages for improving the sustainability of Australian dryland agricultural systems. The profitability that might be expected from perennial wheat of different types was investigated using MIDAS (Model of an Integrated Dryland Agricultural System), a bioeconomic model of a mixed crop/livestock farming system. Although perennial wheat may produce a lower grain yield and quality than annual wheat, it is expected inputs of fertiliser, herbicide and sowing costs will be lower. Perennial wheat used solely for grain production was not selected as part of an optimal farm plan under the standard assumptions. In contrast, dual-purpose perennial wheat that produces grain and additional forage during summer and autumn than annual wheat can increase farm profitability substantially (AU$20/ha over the whole farm) and 20% of farm area was selected on the optimal farm plan under standard assumptions. Forage from perennial wheat replaced stubble over summer and grain supplement at the break of season and increased farm stock numbers. The additional value added by grazing also reduced the relative yield required for perennial wheat to be profitable. This analysis suggests perennial wheat used for the dual purposes of grain and forage production could be developed as a profitable option for mixed crop/livestock producers.

Keywords: dual-purpose, perennial crop, MIDAS, profitability, sustainability, benefit/cost

Introduction

Increasingly, agricultural systems around the world are facing pressure to improve their sustainability. Environmental problems such as dryland salinity, soil erosion and degradation, nutrient leaching and eutrophication have arisen in conventional farming systems relying on annual crops and pastures (Hatton and Nulsen, 1999; Tilman *et al.*, 2001). Reintroduction of productive and profitable perennial plants in agricultural systems that more closely mimic the original vegetation can reduce many of these problems (Dunin *et al.*, 1999; Jackson 2002). Agroforestry and perennial forage plants can be used in many areas (Cransberg and McFarlane, 1994; Lefroy and Stirzaker,1999), but perennial grain crops could also provide a major opportunity to improve the sustainability of agricultural systems without the need to discontinue grain production (Wagoner, 1990; Scheinost *et al*., 2001; Bell *et al*., 2007).

Perennial grains might be developed from either domestication of wild species with potential or hybridization of currently grown crops with perennial relatives (Cox *et al*., 2002). Given that the majority of grain production worldwide is based on the cereals, wheat, rice and maize, the development of a perennial cereal would have the greatest impact. Some wild perennial grass species, such as *Thinopyrum intermedium* (intermediate wheatgrass, syn. *Elytrigia intermedia*) in central-west of the USA and *Microlaena stipoides* L. (weeping rice grass) in southern Australia, have been identified as candidates for direct domestication (Wagoner, 1995; Davies *et al.*, 2005). While efforts have been made to develop perennial versions of other cereal crops (e.g. rye, maize, rice and sorghum) (Wagoner, 1990), breeding perennial wheat has received the most attention and is a logical priority for dryland (non-irrigated) agricultural regions. Hybridization between wheat and its perennial relatives to produce a commercially suitable perennial wheat has remained elusive (Wagoner, 1990), but has provided useful breeding material for disease tolerance, winter hardiness, drought tolerance and earlier maturity in annual wheat (Friebe *et al.*, 1996). Some progress towards perennial wheat has continued in small breeding programs in the United States of America (Cox *et. al.*, 2006).

While a number of sustainability benefits from perennial wheat are predicted and cost savings such as reduced tillage and energy use are anticipated (Bell *et al.* 2007), the relative profitability of perennial grain crops compared to traditional annual systems will greatly affect its attractiveness to farmers and the scale of adoption that could be achieved. To our knowledge, only one documented investigation of the economic feasibility of a perennial grain crop has been previously carried out. Watt (1989) evaluated the break even price of intermediate wheatgrass (*Elytrigia intermedia* syn. *Thinopyrum intermedium*) for grain production in North Dakota. He found that a similar grain price would be needed to penetrate the current cereal grain market and at this price average yield would have to be >560 kg/ha over 8 years to compete with spring wheat. It was suggested that a combination of hay/forage and grain as a dual product would have added incentive. However, he suggested that subsidisation of perennial grains for provision of added conservation and environmental values might be required to make it competitive with current best options.

This study aimed to investigate how the economics of perennial wheat might compare to traditional dryland wheat-based cropping systems in a region of southern Australia and to evaluate the feasibility of investing in the development of perennial wheat in Australia. Two perennial wheat options were considered. Firstly, a perennial wheat that only produces grain, either feed or milling quality. Secondly, a dual-purpose perennial wheat that provided grain and additional forage for grazing. Bioeconomic interactions at a paddock and whole-farm level were investigated using MIDAS (Model of an Integrated Dryland Agricultural System), a steady-state, mathematical programming model, that jointly emphasizes the biology and economics of the farming system (Morrison *et al.*, 1986; Kingwell and Pannell, 1987; Pannell, 1996). The model's objective function is profit maximisation, subject to managerial, resource and environmental constraints (Bathgate and Pannell, 2000). Profit is defined as net cash returns minus non-cash costs (depreciation) minus the opportunity cost of capital (7%), exclusive of land. MIDAS output is based on production associated with average climatic conditions and does not consider climate variability. Interactions between enterprises are included in the model and past analysis has shown that interactions (both synergies and competition) play an important role in the selection of optimum strategies (Pannell 1987). Outputs from the MIDAS analysis are used to investigate a cost/benefit analysis for an ongoing research and development program on perennial wheat in Australia. **Methods and assumptions** *Standard assumptions used in MIDAS analysis* This analysis used the central wheatbelt version of MIDAS, which is based on a typical dryland farm in this region of Western Australia. The model assumes a farm size of 2000 hectares made up of 8 land management units (LMU), or soil types with different production capabilities. A description of each LMU and its size is shown in Table 1. The central wheatbelt region has a Mediterranean-type climate and receives 350 - 400 mm of rainfall annually; 75-80% falls in the winter-spring growing period (May – October). The model has 9 periods through the year, beginning on the 10 May with the start or 'break' of the growing season, and finishing with 2 periods over summer and autumn after crop harvest. Farms in the region generally run a mix of crop and livestock enterprises, with up to 70% of the farm area cropped (Kingwell 2003b). The predominant livestock enterprise in the region is Merino sheep for wool production based on annual pastures. Cropping systems are currently based on rotations involving pastures and annual crops including wheat, barley, lupins, canola and alternative grain legumes, such as field peas. The model identifies approximately 70 of these different rotational sequences. Emerging farming systems, such as lucerne/crop rotations have been previously investigated using the MIDAS model, but were omitted from this analysis (Flugge *et al.* 2004). Production parameters include grain yield, grain quality, grain protein levels (in the case of wheat) and germination and growth rates of pasture. Costs are specified for a full range of inputs, including fertiliser, chemicals for weed and pest control, machinery costs, labour, crop insurance and seed costs. Five additional rotations involving perennial wheat were added to the model (Table 2). These included: perennial wheat followed by annual pasture, perennial wheat followed by lupins and wheat and continuous perennial wheat. Changes to grain yields, grain prices, and input costs were made for perennial wheat, based on the following assumptions and expectations (Table 3 and 4).

Grain yield

A realistic assumption is that grain yield from perennial wheat will be lower than conventional wheat due to a greater allocation of resources to plant biomass other than grain and to mechanisms needed for survival (Cox *et al*. 2002, DeHaan *et al*. 2005; Table 3). Breeding will also be less advanced meaning that early released cultivars will be lower yielding. Due to the assumption of lower yield of the perennial wheat, insurance and seed cleaning costs are lower. Analyses were based on constant grain yields between years for perennial wheat, but should yield vary this would be captured in the total yield from a cycle of the perennial wheat rotation.

Grain price

Perennial wheat will be developed from breeding with plant species which are likely to possess less desirable grain characteristics than conventional wheat (Becker *et al.* 1992). Grain from perennial wheat could be used to feed livestock and would therefore attract a lower price for this less valuable end use. The model assumes a milling wheat price of AU$200 per Mg and a feed wheat price of AU$165 per Mg was used for perennial wheat, making the standard price differential between perennial and annual wheat AU$35 per Mg (Table 4). Nonetheless, perennial wheat grain could eventually have potential for human consumption and attract an equivalent price. This scenario is also investigated.

Fertiliser

The analysis made the assumption that perennial wheat would require less applied fertiliser compared to annual wheat (Table 4). Crews (2005) asserts that perennial cropping systems should have improved synchrony of crop nutrient demand and nutrient supply. Higher retention of nitrogen and other essential nutrients are expected in perennial wheat due to more extensive root systems, greater retranslocation within plants before senescence, and reduced nutrient removal from lower crop yields (Crews 2005).

Pesticides

For perennial wheat, pre-sowing herbicide application would still be required in year 1, but this would be a cost saving in subsequent years (Table 4). Competition from perennial wheat with weeds (especially during summer) might also reduce weed control costs. Some other pesticide applications, especially to control diseases or insects, may still be required.

Seeding and harvesting costs

Seeding costs (i.e. seed, machinery) would only be incurred at sowing in year 1, but harvesting costs are included in all years (Table 4). Higher cost pedigree seed may be needed, at least initially. However this higher price would be offset by lower seeding rates for perennial wheat; thus equal seed costs are assumed for annual and perennial wheat.

Assumptions for grazing benefits of perennial wheat

Perennial wheat may also offer advantages to livestock production over annual wheat in mixed farming systems. In addition to the same amount of stubble available from annual wheat crops, extra green forage for grazing was made available for perennial wheat in the MIDAS analysis in autumn before and after the start of the growing season (Table 5). Perennial wheat, like other perennial grasses, would be able to access additional water and maintain growth and green leaf for longer than annual wheat (DeHaan *et al*. 2005) and may also respond to out-of-growing-season rain events to provide additional green forage during summer and autumn (Ridley *et al*., 1997). An earlier response to rain after the break of season was assumed and additional forage available for grazing calculated based on a growth rate of 25 kg DM per day from 10 May – 13 June. In the analysis we assumed that the metabolisable energy of the additional green perennial wheat forage was 10.75 MJ/kg (approximately 75% dry matter digestibility) (Akin *et al*., 1995; Lippke *et al*., 2000), and the remainder of the stubble had the same quality parameters as annual wheat. We assumed that there was no effect of early season grazing (prior to 13 June) on grain production, and later grazing was not allowed to reduce any detrimental impact on grain yield (Winter and Thompson, 1987; Virgona *et al*., 2006).

Biological and economic outcomes

The model was used to investigate the allocation of activities across the farm, changes to crop and livestock enterprises, shadow costs (opportunity cost or the profit difference between a particular activity and the most profitable option), and changes to whole-farm profit when either perennial wheat for grain production only or dual-purpose perennial wheat were offered. The sensitivity of these results to changes in assumptions of grain yield and the amount and timing of forage availability were explored.

Benefit-Cost Analysis

A benefit-cost analysis was conducted to compare the potential economic return from perennial wheat to the expected capital that would be invested in its research and development. The net present value (NPV) and benefit-cost ratio (B/C) were calculated according to equation 1 and 2 with costs and revenue discounted at a rate of 5% per annum. Research costs assumptions were based on 3 years of AU\$150 000 per year as an initial feasibility study and AU\$1 M per annum for subsequent years (Equation 3). Three scenarios of varying lengths of the research and development program were considered (r = number of years of research); 3+10 years, 3+15 years and 3 +20 years.

$$NPV(AU\$) = \sum Revenue - \sum Costs \tag{1}$$

$$B/C = \frac{\sum Revenue}{\sum Costs} \tag{2}$$

$$\sum Costs(AU\$'000) = \sum_{r=1}^{r=3} 150 \times 0.95^{r-1} + \sum_{r=4}^{r} 1000 \times 0.95^{r-1} \tag{3}$$

$$Area_n\ (\text{‘000 ha}) = \%Area \times \%Adopted_n \times 20000 \tag{4}$$

$$\sum Revenue(AU\$'000) = \sum_{n=1}^{n=25} 21 \times Area_n \times \%Success \times 0.95^{r+n-1} \tag{5}$$

The economic return for perennial wheat was calculated using the MIDAS outputs based on the standard assumptions for dual-purpose perennial wheat (i.e AU$ 21/ha of farm area). While the central-wheatbelt MIDAS model only represents an average farm in this region of Western Australia, similar whole-farm benefits from perennial wheat were expected in other mixed crop/livestock regions of southern Australia. Scenarios of various scale of adopted area of perennial wheat were calculated using 4 levels of maximum adoption (20%, 40%, 60%, 80%) and applicability across 10%, 25% and 50% of the 20 million hectares that are sown to winter crops in southern Australia (*%Area*) (ABARE, 2006) (Equation 4). In the years after the completion of the research phase (*n*), adoption rate ($\%\mathrm{Adopted}_n$) was assumed to be 10% initially (*n*=1); maximum adoption occurred 5 years after the completion of research and declined at 5% per year thereafter. The potential additional revenue generated by perennial wheat was calculated over 25 years for the various areas of farm adoption ($Area_n$) and for 25%, 50% and 75% likelihood of achieving these outcomes (*%Success*) (Equations 5). **Results and discussion** *Economics of perennial wheat solely for grain production* Under the standard assumptions and without grazing value, the perennial wheat rotations were not optimal on any of the land management units (Table 6). The three sandier soils (LMU 1-3) and the medium-heavy soil (LMU 5) are allocated to continuous pasture, and the remaining four soils are allocated to continuous cropping rotations which include wheat, legumes and canola. Shadow costs (i.e. the profit difference between an activity and the most profitable activity) for perennial wheat rotations are shown in Table 5. Perennial wheat rotations were between AU$25 to AU$123 per year less profitable than the best alternative, depending on land management unit and the proposed perennial wheat rotation. The difference in profitability between perennial wheat and the selected activity was least on LMU’s 1, 4 and 7, where overall profitability was lower. Conversely, perennial wheat had a larger profit deficit on the more profitable LMU’s 3 and 5. Using the initial assumption of a AU$35/Mg price differential, perennial wheat would need to yield 85% to 135% of annual wheat, depending on soil type, for it to be selected (Table 7). If perennial wheat received the same price as conventional wheat (i.e. AU$0/Mg price differential) then it would be selected on LMU 7 under the assumption of 60% of yield for annual wheat (Table 7). On other soil types, yield would need to increase to between 65% and 100% of annual wheat (Table 7). It seems questionable that the development of a perennial wheat solely for grain production purposes will obtain significant short-term profit advantages for growers. Perennial wheat is most likely to achieve the grain yield required to be profitable on the parts of the farm where profitability of current cropping rotations is lowest.

Under the scenario where a required area of perennial wheat is imposed on the model, farm profit declines with increasing perennial wheat area, as was indicated by the shadow costs of perennial wheat compared to the optimal combination of enterprises (Table 8). In the case where 100 ha of perennial wheat were required, the farm suffers a reduction in profit of AU$2500 (Table 6). As the area of perennial wheat was increased the model selects a continuous perennial wheat rotation on the LMU with the lowest shadow costs (LMU 4 and 7). To be profitable for grain production only, perennial wheat would need to deliver greater than AU$ 25/ha of additional income from other sources to be maintain farm profitability. Accounting for benefits to farm sustainability (e.g. improved soil health, erosion or salinity control) and/or carbon credit or other payments for ecosystems services may compensate for some of this deficit. For example, perennial wheat that increases soil carbon levels a similar amount to grazed forages could attract as much as US$17/ha for carbon credit payments (Belcher, 2003).

Economics of perennial wheat integrating additional forage grazing

The inclusion of grazing value from perennial wheat greatly increases its profitability and results in its selection of 400 ha of perennial wheat as part of the optimal farm plan (Table 9). Including the additional grazing value of perennial wheat, whole-farm profit is increased by nearly AU$42,000 (38%) or AU$21/ha (Table 9). The inclusion of perennial wheat grazing makes the sheep enterprise relatively more profitable, as the number of sheep carried increases. There is a 1.3 dry sheep equivalent (dse)/ha increase in stocking rate, while there is only a small decrease in supplementary feed used (1 kg/dse) with 20% perennial wheat in the farming system. Perennial wheat replaces a wheat/lupin rotation on LMU 4 and part of LMU 7, where previously the shadow costs were lowest (Table 10). These changes result in a decrease in the percentage of the farm in crop (including perennial wheat) from 55% to 45% (Table 9). The optimal rotation on LMU 8 changes from 390 hectares of wheat-canola-wheat-lupin (WNWL) (Table 6) to only 190 hectares of WNWL and 200 hectares of continuous annual pasture (PPPP) (representing the 10% increase in pasture area) (Table 10). The extra annual pasture is needed to support the additional sheep through the winter and spring months with the less productive soils allocated to pasture and cropping continues where it is most profitable.

The addition of the perennial wheat grazing to the farm feed base changes the pattern of livestock forage sources (Table 11). In period 9, perennial wheat replaces some stubble and all grain supplements. Cereal stubble is typically chosen for grazing and has low nutritional quality, around 7.2 MJ/kg. In contrast, the additional forage from perennial wheat is assumed to be around 10.75 MJ/kg. Thus, replacing cereal stubble with the higher quality feed source from perennial wheat results in greater numbers of sheep carried during this period and an increase in farm profit. In periods 1 and 2, perennial wheat reduces grain supplement requirements which are usually chosen as the main feed source to allow better pasture growth later during the season and more sheep to be carried. The saved grain supplements are then fed in period 3 to provide a longer period for deferring grazing pastures, while without perennial wheat it would be too expensive to continue feeding at this time.

Effects of timing and amount of forage offered by perennial wheat

A sensitivity analysis was conducted to test the effects of the amount and timing of forage availability. The quantity of forage available was reduced to 25% of assumed values (see Table 5), and also the time of availability was limited to either before the break of season (periods 8, 9 and 10) or after the break of season (periods 1 and 2) (Table 12). If only 25% of the amount of forage is offered both before and after the break of season it is still profitable to include 210 hectares (11% of farm area) of perennial wheat in the farming operation. This is chosen on LMU 4 (Table 9) and this additional forage value represents as little as 170 kg/ha of feed in period 8 and 9, 53 kg/ha in period 10, 64 kg/ha in period 1 and 105 kg/ha in period 2. When grazing is restricted to after the break of season (periods 1 and 2) perennial wheat is chosen on 10 13% of the farm, irrespective of the quantity of additional feed available (Table 12). In contrast, when 50% or less of assumed additional forage is available only before the break of season (periods 8–10), then perennial wheat is no longer selected. These results indicate that the greatest grazing value from perennial wheat would be provided at the break of the season in late autumn and early winter, as a means of deferring grazing of annual pasture. Thus, the capacity of perennial wheat to respond to rain at this time and be tolerant of grazing will be an important driver of the profitability and a key selection criterion for dual-purpose perennial wheat.

While grazing dual-purpose perennial wheat provides a significant profit advantage, emphasis on both forage and grain production may reduce the potential grain yield of perennial wheat (DeHaan *et al*. 2005). In some cases, early season grazing can also reduce crop grain yield at harvest (Virgona *et al.* 2006). The sensitivity of perennial wheat profitability to reductions in grain yield as a result of various amounts of additional forage (including before and after the break) was investigated (Table 13). As expected, when the grain yield is lower, perennial wheat becomes less profitable and a smaller area is selected. However, if ≥ 50% of the assumed additional forage is available then perennial wheat is still included on 12% of the farm. Dual-purpose perennial wheat could offer a yield as low as 40% of annual wheat and provide 800 kg of additional forage and still provide profit economics benefits to mixed farmers.

Cost-benefit analysis

While it appears that perennial wheat might offer some profit advantages to farmers in the central-wheatbelt of Western Australia, the feasibility of a perennial wheat research and development program in Australia was evaluated via a cost-benefit analysis of the potential revenue and costs involved. This assumed a similar economic benefit would be achieved in other mixed farming regions of southern Australia. The benefit-cost analysis identifies that the size of the applicable area for perennial wheat will have a large influence on the rate of return on a perennial wheat development program (Table 14). For example, if perennial wheat is only applicable across 10% of the winter cropping area of southern Australia (i.e. 2 million ha), then the B/C is less than 5, irrespective of the level of adoption by farmers. A target of greater than 600 000 ha of perennial wheat at maximum adoption would result in an attractive return on research investment (B/C >

10) (Table 14). The likelihood of achieving this outcome is also an important matter for the feasibility of a research program (Table 15). A low probability of success greatly reduces the viability of an extended research program, but low initial certainty of success can be managed by a low initial strategic investment in a proof-of-concept phase, especially to determine the potential scale of application for perennial wheat. Longer-term research investment intensity could be matched to emerging results, especially if the risk of failure is reduced by promising outcomes (Table 15).

Residual uncertainties This analysis has considered the production benefits that perennial wheat could offer in a conventional dryland farming system, but a number of residual uncertainties exist that could impact on the future adoption of perennial wheat. First, emerging technologies that provide forage either before or after the break of season, such as lucerne, dual purpose winter wheats or other perennial forages are likely to adjust the farm feedbase in a way that reduces the value of grazing from perennial wheat. Secondly, this analysis has not considered the transition costs of changing to the optimal farm plan that incorporates perennial wheat. As sheep flock size need to increase to make the most of perennial wheat, income from sales of livestock would be foregone or additional purchases would be required. A similar case occurs for the integration of lucerne pastures in farming operations, which reduces farm cashflow and profit for the first 2 years, but these losses are recovered and farm profitability is increased in the longer term (Flugge *et al*., 2004). Thirdly, changes in grain yield and forage production would be expected over the life of a perennial wheat crop. As is frequently observed in other perennial crops such as lucerne, it would be expected that productivity would decline as the age of the perennial wheat stand increases (Lodge 1991). Dry seasonal conditions combined with depletion of reserves of sub-soil moisture, or the accumulation in disease pressure would reduce plant productivity and persistence. Thus, perennial wheat may be limited to rotations of a number of years and the permanent areas chosen in the optimal farm plan in the present analysis may not be suitable in all areas. In drier environments plant densities may decline below viable levels in the second or third year after the completion of the first harvest. If persistence and productivity is low in the first year then perennial wheat provides little or no additional value over annual wheat. Finally, productivity of perennial wheat in response to climate variability, and in different climatic zones has not been considered. An analysis of these factors would provide an indication of risk and protection from rainfall variability for grain and forage production from perennial wheat.

Uncosted benefits While we have assumed a number of cost savings from perennial wheat other uncosted benefits could be envisaged that were not included in this study. (1) Because of the reduced area that needs to be replanted each year, labour costs would be reduced and by overcoming restrictions on the availability of planting equipment at sowing time, greater areas could be planted each year and larger farming operations could be achieved. (2) Predictions of increased costs of petroleum and many fertilisers in the future would also favour a low input perennial wheat system, by increasing nutrient use efficiency and reducing tillage/sowing costs (Kingwell, 2003). (3) The potential for dual-purposes of perennial wheat may also provide flexibility in response changes in the relative value of commodity prices for livestock and grain. (4) Perennial wheat is an escalation of the concept of reduced or no-till practices and could provide many of the economic and environmental benefits these operations have contributed to cereal production systems.

(5) Furthermore, considering the external environmental benefits, such as control of recharge of groundwater or enhancement of biodiversity is often difficult. Phase

rotations of perennial wheat similar to lucerne could be successful at reducing drainage below the root-zone by up to 90% on duplex and loamy sand in lower rainfall regions in Australia (<380 mm annual rainfall), but permanent stands or longer rotations may be necessary in wetter regions or on coarser textured soils (Ward 2006). Perennial wheat could also provide other ecosystem services such as carbon sequestration, benefits to soil biology and shelter and/or habitat for biodiversity. Accounting for these potential long-term sustainability benefits would also further improve the value of perennial wheat.

Conclusions

This preliminary analysis suggests that development of perennial wheat has significant economic merit, but it also has a number of biological and breeding implications. Firstly, forage qualities, growth pattern and grazing tolerance of perennial wheat will be important characteristics to offset lower grain yield and quality than annual wheat. Alternatively, perennial wheat for crop-only production systems would require comparatively higher grain yields and/or grain qualities to attract premium grain prices or alternatively would need to be subsidised by payments for other services. Perennial wheat would be most valuable on poor or intermediate soil types or in circumstances where profit from current crop rotations is lower. Greatest benefits would also be expected in medium to high rainfall environments where mixed crop/livestock enterprises are more common and greater benefits from an extended growing season would be attained. This study suggests that further research into perennial wheat has significant merit, especially as a concept for examination in the short-term, as a dual purpose crop with grazing value in the medium-term, and even as a grain crop in the longer-term if suitable grain yield and quality can be attained.

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Tables

Table 1. Area and description of soil types associated with land management units (LMU) used in MIDAS.

LMU	Description	Area (ha)
LMU 1	Poor sands: deep pale sand	140
LMU 2	Average sandplain: deep yellow sand	210
LMU 3	Good sandplain: yellow loamy sand	350
LMU 4	Shallow duplex soil: sandy loam over clay	210
LMU 5	Medium heavy: red brown loamy sand/sandy loam	200
LMU 6	Heavy valley floors: red brown sandy loam over clay	200
LMU 7	Sandy surfaced valleys: sandy surfaced valley soil	300
LMU 8	Deep duplex soil: loamy sand over clay	390
Total Farm Area		2000

Table 2. Perennial wheat rotations that were designed for inclusion in MIDAS.

Rotation[A]	Description
3E3P	3 years continuous perennial wheat; 3 years continuous annual pasture
3EL^1WW	3 years continuous perennial wheat; 1 year grain legume; 2 years wheat
2EL^1WL^1W	2 years continuous perennial wheat; 1 year grain legume; 1 year wheat; 1 year legume; 1 year wheat
4EL^1W	4 years continuous perennial wheat; 1 year grain legume; 1 year wheat
6E	6 years continuous perennial wheat

[A] E = perennial wheat; P = annual pasture; W = annual wheat; L^1 = grain legume - field peas on valley floor and sandy surfaced valley, lupins on all other soil types

Table 3. Assumptions of grain yield for annual and perennial wheat on each LMU in MIDAS..

	Grain yield (Mg/ha)	
LMU	Annual wheat	Perennial wheat
1. Poor sands	1.0	0.6
2. Average sandplain	1.7	1.0
3. Good sandplain	2.4	1.4
4. Shallow duplex soil	2.0	1.2
5. Medium heavy soil	2.0	1.2
6. Valley floor soil	2.3	1.4
7. Sandy surfaced valley soil	2.1	1.2
8. Deep duplex soil	2.1	1.3

Table 4. Comparison of variable input costs (AU$/ha) assumed for annual wheat and first and subsequent years of perennial wheat in the medium rainfall central wheatbelt MIDAS model.

Annual wheat		Perennial wheat	
		Year 1	Year 2 onwards
Fertiliser	90	45	45
Pesticides	37	37	18
Seeding	24	24	-
Seed	10	10	-
Harvesting	29	29	29
Insurance	2	1	1
Seed cleaning	3	2	2
TOTAL	195	148	95

LMU	Period 8: 5 Dec – 25 Apr	Period 9: 26 Apr – 9 May	Period 1: 10 May – 23 May	Period 2: 24 May – 13 Jun
1. Poor sands	330	105	125	205
2. Average sandplain	575	180	215	360
3. Good sandplain	800	250	300	500

Table 5. Assumed amount of additional green forage grown by perennial wheat (in addition to equal amounts of stubble for annual wheat) during summer and autumn on each LMU under average climatic conditions for the region.

	Annual wheat	Perennial wheat	
		Year 1	Year 2 onwards
Fertiliser	90	45	45
Pesticides	37	37	18
Seeding	24	24	-
Seed	10	10	-
Harvesting	29	29	29
Insurance	2	1	1
Seed cleaning	3	2	2
TOTAL	195	148	95

LMU	Additional feed available (kg DM/ha)			
	Period 8: 5 Dec – 25 Apr	Period 9: 26 Apr – 9 May	Period 1: 10 May – 23 May	Period 2: 24 May – 13 Jun
1. Poor sands	330	105	125	205
2. Average sandplain	575	180	215	360
3. Good sandplain	800	250	300	500
4. Shallow duplex soil	675	210	255	420

Table 6. Optimal rotation selected on each land management unit (LMU) and shadow costs (the opportunity cost i.e. the profit that would be forgone by adopting one hectare of that rotation) for rotations of perennial wheat used solely for grain production.

	selected[A]	Shadow cost (AU$/ha)				
		3E3P	3ELWW	2ELWLW	4ELW	6E
1. Poor sands	PPPP	31	57	65	47	25
2. Average sandplain	PPPP	48	43	40	41	40
3. Good sandplain	PPPP	84	90	90	99	104
4. Shallow duplex soil	WWL	36	40	53	41	26
5. Medium heavy soil	PPPP	84	114	123	114	103
6. Valley floor soil	WWL	40	40	48	52	45
7. Sandy surfaced valley soil	WWL	33	30	42	32	28
8. Deep duplex soil	WNWL	48	40	40	44	45

[A] P: pasture; W: wheat (conventional); L: legume N: canola; E: perennial wheat.

Table 7. Relative perennial wheat yield (% of annual wheat) required to be selected on each LMU at various grain price differentials (perennial wheat minus annual wheat) when additional forage grazing was not included.

LMU	Grain price differential between perennial wheat and annual wheat (AU$/Mg)			
	-45	-30	-15	0
1. Poor sands	130%	126%	105%	70%
2. Average sandplain	105%	100%	85%	75%
3. Good sandplain	115%	110%	95%	85%
4. Shallow duplex soil	95%	90%	70%	65%
5. Medium heavy soil	140%	135%	115%	100%
6. Valley floor soil	100%	95%	80%	75%
7. Sandy surfaced valley soil	95%	85%	75%	60%
8. Deep duplex soil	95%	90%	80%	70%

Annual wheat		Perennial wheat	
		Year 1	Year 2 onwards
Fertiliser	90	45	45
Pesticides	37	37	18
Seeding	24	24	-
Seed	10	10	-
Harvesting	29	29	29
Insurance	2	1	1
Seed cleaning	3	2	2
TOTAL	195	148	95

LMU	Period 8: 5 Dec – 25 Apr	Period 9: 26 Apr – 9 May	Period 1: 10 May – 23 May	Period 2: 24 May – 13 Jun
1. Poor sands	330	105	125	205
2. Average sandplain	575	180	215	360
3. Good sandplain	800	250	300	500
4. Shallow duplex soil	675	210	255	420

Table 8. Impact on farm profit of including an increasing area (% of farm) of perennial wheat and the land management units that are selected.

Table 9. Comparison of 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 dual-purpose perennial wheat (DPW).

Annual wheat		Perennial wheat	
		Year 1	Year 2 onwards
Fertiliser	90	45	45
Pesticides	37	37	18
Seeding	24	24	-
Seed	10	10	-
Harvesting	29	29	29
Insurance	2	1	1
Seed cleaning	3	2	2
TOTAL	195	148	95

Table 10. Rotations selected on farm land management units when dual-purposes of grazing and grain production are included for perennial wheat.

LMU	Rotation[A]
1. Poor sands	PPPP
2. Average sandplain	PPPP
3. Good sandplain	PPPP
4. Shallow duplex soil	6E
5. Medium heavy soil	PPPP
6. Valley floor soil	WWL
7. Sandy surfaced valley soil	WWL / 6E
8. Deep duplex soil	WNWL / PPPP

[A] P: pasture; W: wheat (conventional); L: legume N: canola; E: perennial wheat.

Table 11. Comparison of the allocation of feed sources with and without the integration of dual-purpose perennial wheat in the optimal farm plan.

	Annual wheat	Perennial wheat	
		Year 1	Year 2 onwards
Fertiliser	90	45	45
Pesticides	37	37	18
Seeding	24	24	-
Seed	10	10	-
Harvesting	29	29	29
Insurance	2	1	1
Seed cleaning	3	2	2
TOTAL	195	148	95

Table 12. Area of perennial wheat (% of farm) selected in the optimal farm plan when the amount of feed available is reduced (% of standard assumptions, Table 5) and when the accessible periods for grazing was restricted.

LMU	Period 8: 5 Dec – 25 Apr	Period 9: 26 Apr – 9 May	Period 1: 10 May – 23 May	Period 2: 24 May – 13 Jun

Table 13. Area of perennial wheat (% of farm) selected at grain yields relative to annual wheat when various amounts of additional forage (% of those presented in Table 5) is provided both before and after the break of season.

Relative feed available (% of standard assumptions)	Relative perennial wheat grain yield (% of annual wheat)		
	60%	50%	40%
100%	20%	19%	14%
75%	16%	16%	14%
50%	13%	13%	12%
25%	11%	0%	0%

Table 14. Net present value (NPV) and benefit/cost ratio (B/C) for dual-purpose perennial wheat under different scenarios of extent of applicability and years to maximum adoption. Whole farm economic benefit from MIDAS was based on standard price and production assumptions (Table 9), and research costs were for 18 yrs (Table 15) with a 50% likelihood of success.

Table 15. Net present value (NPV) and benefit/cost ratio (B/C) for dual-purpose perennial wheat with different length periods of research and likelihoods of achieving peak adoption on 600 000 ha (i.e. 20% of farm area over 25% of Australia's winter cropping area with 60% maximum adoption after 5 years). Whole-farm economic benefit of AU$21/ha (Table 9) was based on standard price and production assumptions.

Annual wheat		Perennial wheat	
		Year 1	Year 2 onwards
Fertiliser	90	45	45
Pesticides	37	37	18
Seeding	24	24	-
Seed	10	10	-
Harvesting	29	29	29
Insurance	2	1	1
Seed cleaning	3	2	2
TOTAL	195	148	95

LMU Period 8: 5 Period 9: Period 1: 10 Period 2:

Research costs NPV (AU$ M) B/C Years Discounted Likelihood of success Likelihood of success

n) Costs 75% 50% 25% 75% 50% 25% (AU$ M) 3 + 10 7.4 211 138 65 28 19 9

3 + 15 9.8 159 103 47 16 10 5

3 + 20 11.7 119 76 32 10 6 3