Economics of Increasing Wheat Competitiveness as a Weed Control Weapon

John P. Brennan[A], *Deirdre Lemerle*[AB] *and Peter Martin*[A]

[A] Senior Research Scientist (Economics), Principal Research Scientist (Weeds) and Senior Wheat Breeder, respectively, NSW Agriculture, Wagga Wagga Agricultural Institute, Wagga Wagga, NSW 2650
[B] CRC for Weed Management Systems

Abstract

Crop varieties that are more competitive with weeds offer a means of reducing dependency on herbicides. On the basis of trial results, economic analysis indicates that choosing crop varieties that have stronger competitive ability against weeds can provide a clear economic advantage for farmers. In this paper, the effect of changes in seeding rate on this economic advantage is explored. The question if whether it is economic to breed for greater competitive ability is addressed by examining the economic implications for the breeding program, in terms of costs and impacts on other selection traits, of selection for competitive ability. The results of the analysis indicate that more competitive varieties can be an important tool in an integrated weed management package. However, while breeding for increased competitive ability can produce benefits for weed control, in some cases the most appropriate option is agronomic practices such as increased seeding rates. Selection for increased competitive ability in a breeding program can reduce the rate of progress with other important characteristics such as yield. Only in particular circumstances is it economic to increase selection for competitive ability within a breeding program.

Key Words: variety/competitive/weed control/benefit/cost

Contributed paper presented to the 45th Annual Conference of the Australian Agricultural and Resource Economics Society, Adelaide, January 2001. The views expressed in this paper are those of the authors and do not represent those of NSW Agriculture.

Economics of Increasing Wheat Competitiveness as a Weed Control Weapon

1. Introduction

Differences have long been observed in the competitive abilities of crops and varieties against weeds. More recently, there has been interest in developing further the understanding of the nature of that competitiveness, and exploring its use as a means of weed control that does not rely on herbicides (Lemerle *et al.* 1995; Lemerle *et al.* 2000). The development and spread of herbicide resistance in weeds has reinforced the need for integrated weed management with more reliance on non-chemical control methods (Lemerle *et al.* 2000).

The competitive ability of a crop has two distinct, but broadly correlated, elements (Lemerle *et al.* 1996):

- ability to compete with weeds for nutrients, moisture and light ("crop tolerance");
- ability to suppress weeds.

The benefits of strongly competitive varieties are (Lemerle *et al.* 2000):

- reduced need for post-emergence herbicides;
- less selection pressure for herbicide resistance;
- less herbicide in the environment;
- reduced risk of herbicides contaminating food;
- more reliable performance of herbicides in adverse environmental conditions;
- less emphasis on cultivation for weed management and the associated risk of soil erosion; and
- reduced weed densities in future weed populations.

The corresponding costs of competitive varieties are:

- additional seed and sowing costs;
- research needed to breed a new competitive variety; and
- the identification and removal of any penalties associated with high competitiveness in wheat (e.g. loss in wheat grain yield or quality, disease susceptibility).

There is increasing evidence that modern semi-dwarf wheat varieties are less competitive with weeds than the older, taller varieties they replaced (Lemerle *et al.* 1996). However, among the current set of commercial varieties, there is only a small range of competitive ability. Therefore, there is potential for breeders to select varieties that have more competitive ability, particularly early vigour (Lemerle *et al.* 2000), but little opportunity for farmers to make much progress with current varieties. An alternative management strategy to ensure that the crop is more competitive with weeds is to increase the seeding rate, since higher seeding rates increased weed suppression (e.g., Medd *et al.* 1985, Lemerle *et al.* 1996).

The options for increasing the competitive ability of crops against weeds can be classified as:

(a) Management:

- Grow most competitive varieties from currently available set of varieties
- Increase seeding rates for current varieties

(b) Develop more competitive varieties through breeding:

- Screen current and new varieties for information on competitive ability
- Late stage screening with limited selection
- Early generation selection for competitive ability
- Development of more highly competitive parental materials

The economic costs and benefits of these strategies can be very different, as can the time period involved in their research and development. For example, there is an opportunity cost of the resources used in wheat breeding programs to pursue the selection for competitive ability. Given the increasingly limited resources available to breeders, introducing additional selection criterion means that progress over time in improvements in other selection characteristics will be reduced.

The aim in this paper is to identify the economic issues associated with increasing the competitive ability of wheat. The analysis in this paper addresses several questions that relate to the use of competitive crop varieties as a means of weed control. Is it economic to use the more competitive varieties as a means of weed control, and in what circumstances? Is it economic for breeders to seek increased competitiveness in new varieties? What degree of selection should the breeders use for competitive varieties? The management options are addressed in the following section, and the breeding options are analysed in section 3. Consideration is then given to determining the most appropriate strategies. Some conclusions are drawn in the final section.

2. Economics of Management Options for Increasing Competitiveness

2.1 Analysing Value of Competitive Ability

The following management options are compared in the analysis:

(a) Competitive ability of crop is rated as Low, Medium, High

(b) Two seeding rates: Standard and High

(c) Comparisons are made of outcomes with and without ryegrass control, using the herbicide Hoegrass®

In assessing the relative economic merits of each option, the main input assumptions are based on Faour (1999). The key data assumptions are shown in Table 1. The analysis is carried out on the basis of potential weed-free yields of 4.0 t/ha, though sensitivity analysis is also carried out at different levels of potential weed-free yields (2.0 t/ha and 6.0 t/ha).

Table 1: Assumptions for Economic Analysis of Management Options

	Standard seeding rate	High seeding rate
Seeding rates (kg/ha):	60	100
Yield reduction without herbicides:		
- Low competitive crop	50%	30%
- Medium competitive crop	35%	20%
- High competitive crop	20%	5%
Yield reduction after herbicide control	5%	3%

	Values used	
Seed cost	$0.50	per kg
Herbicide (Hoegrass®):		
- Herbicide cost ($/L)	$23.90	
- Application cost ($/ha)	$2.32	
Herbicide application rate (L/ha)		
- Low competitive crop	1.5	litres/ha
- Medium competitive crop	1.0	litres/ha
- High competitive crop	1.0	litres/ha
Crop production costs:		
- Other herbicide costs ($/ha)	$30.00	(Roundup®, Igran®, MCPA)
- Other growing costs ($/ha)	$95.00	
Contract harvest costs ($/tonne)	$14.00	
Levies, insurance		
- Levies	3.02%	of on-farm value
- Crop insurance	2.22%	of on-farm value

2.2 Single-Year Gross Margin Analysis of Competitive Varieties

Using single-year gross margin analysis, the direct cash consequences of the technologies can be compared. These comparisons do not incorporate the implications for the weed seed bank of the alternative forms of weed control, which are accounted for later.

(a) Value of increased competitive ability

In the gross margin analysis, two comparisons are made initially of the different levels of competitive ability of the variety (with standard seeding rates):

(a) Where herbicides are used for weed control

(b) Where no herbicides are used for ryegrass control.

These options are compared for differences in competitive ability of varieties.

On the basis of the above assumptions, the situation where herbicides are used for weed control in conjunction with competitive varieties is illustrated in Table 2. Where these herbicides provide a generally effective means of weed control, the advantage of the competitive ability of the variety is relatively minor. Where the competitive ability of the varieties is low, higher rates of herbicide have to be used for the same level of weed control. Thus, there is no advantage in using the highly competitive varieties rather than those with medium competitive ability. The benefit of the more competitive varieties is $12 per hectare, or about 5% of the gross margin.

Table 2: Value of Competitive Ability: Herbicide Weed Control

	Standard seeding rate			Higher seeding rate		
Competitive Ability of Variety:	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Weed-free yield (t/ha)	4.00	4.00	4.00	4.00	4.00	4.00
Yield loss from weeds	5%	5%	5%	3%	3%	3%
Yield achieved (t/ha)	3.80	3.80	3.80	3.88	3.88	3.88
- Income per ha	*$513*	*$513*	*$513*	*$523*	*$523*	*$523*
Seed costs ($/ha)	$30	$30	$30	$50	$50	$50
Ryegrass control costs ($/ha)	$38	$26	$26	$38	$26	$26
Other herbicide costs ($/ha)	$30	$30	$30	$30	$30	$30
Other costs ($/ha)	$175	$175	$175	$177	$177	$177
- Total variable costs per ha	*$273*	*$261*	*$261*	*$295*	*$283*	*$283*
Gross Margin per Ha	**$240**	**$252**	**$252**	**$229**	**$241**	**$241**

The situation where no herbicide is used for ryegrass control, and with standard seeding rate, is shown in Table 3. Because yields increase with the competitive ability of the variety, costs such as harvest and levy costs rise also, but the gross margins are still markedly higher with highly competitive varieties than for less competitive ones. Therefore, for farmers who are faced with herbicide resistance (or who prefer not to use herbicides), competitive varieties offer an economic alternative. Gross margins for low competitive varieties are approximately one-third of those with high competitive ability, while the medium competitive varieties are approximately mid-way between the two.

It is apparent that the advantage of the competitive ability of the variety is markedly less where herbicides have been used than where they were not used. However, it is also evident that whichever variety is used the gross margins are higher when herbicides are used. Another clear message from a comparison of Tables 2 and 3 is that growers who use varieties with low competitive ability have a greater economic need for herbicides to maintain incomes, and a correspondingly higher probability of herbicide resistant varieties developing. Therefore, competitive varieties provide a means of reducing the chance of developing herbicide resistance.

In environments where the weed-free potential yield is lower, the general level of returns is lower for all options. However, the dollar value of increased competitive ability where no herbicides are used is reduced. Where herbicides are used, the difference in gross margins between varieties with different competitive ability is unchanged by the yield level.

Table 3: Value of Competitive Ability: No Herbicide Use

	Standard seeding rate			Higher seeding rate		
Competitive Ability of Variety:	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Weed-free yield (t/ha)	4.00	4.00	4.00	4.00	4.00	4.00
Yield loss from weeds	50%	35%	20%	30%	20%	10%
Yield achieved (t/ha)	2.00	2.60	3.20	2.80	3.20	3.60
- Income per ha	*$270*	*$351*	*$432*	*$378*	*$432*	*$486*
Seed costs ($/ha)	$30	$30	$30	$50	$50	$50
Ryegrass control costs ($/ha)	$0	$0	$0	$0	$0	$0
Other herbicide costs ($/ha)	$30	$30	$30	$30	$30	$30
Other costs ($/ha)	$137	$150	$162	$154	$162	$171
- Total variable costs per ha	*$197*	*$210*	*$222*	*$234*	*$242*	*$251*
Gross Margin per ha	**$73**	**$141**	**$210**	**$144**	**$190**	**$235**

(b) Impact of increasing seeding rates
Another weed control option for farmers is to increase the seeding rate. While increasing the seeding rate increases the yields achieved with uncontrolled weeds, costs were increased. The resultant gross margins are higher for all levels of competitive ability when no herbicides are used (Table 3). However, where herbicides are used (Table 2), the yield gains from the more competitive varieties (approximately $10 per hectare) are less than the costs of the additional seed used. Therefore, higher seeding rates only increase gross margins where herbicides are not used, and provide the largest benefit for the less-competitive varieties. Nevertheless, gross margins are still higher where herbicides are used. For a variety with medium competitive ability, herbicides increase the gross margin by $111 per hectare (or 79%), while increasing the seeding rate increases the gross margin by $49 (or 35%). Thus higher seeding rates are only a partial substitute for herbicides, and when they are used together can cause a reduction in gross margin. Where herbicides cannot be used, a highly competitive variety and a higher seeding rate give the highest gross margin.

The benefits from increased seeding rates are reduced in environments where the potential weed-free yield levels are lower.

2.3 Accounting for Longer-term Implications of Competitiveness
To properly assess the true economic impacts of competitive varieties, the analysis needs to incorporate the impact of the various weed control options on the weed seed bank, and therefore on the longer-term weed consequences (Jones and Medd 2000; Jones and Cacho 2000). Improved weed control not only reduces immediate yield losses from weeds, but also reduces the need for weed control in the future if the weed seed bank is reduced. That requires analysis that is beyond the scope of this paper, but remains a significant challenge for analysts to address.

3. Economics of Breeding Competitive Varieties

3.1 Economic Issues with Breeding More Competitive Varieties

The important economic issues that relate to the breeding of more competitive crop varieties as a means of weed control are:

(a) Is it economic for breeders to seek increased competitiveness in new varieties?
(b) What degree of selection should the breeders use for competitive varieties?
(c) At what stage should selection for competitiveness be made?
(d) How much selection pressure is appropriate?

In assessing these issues to determine whether it is economic to breed for competitive ability rather than using agronomic means to bring it about, key factors are:

(a) the relationship between competitive ability and other significant economic characteristics such as yield;
(b) the costs of evaluating and selecting for competitive ability;
(c) the resources available to the breeding program; and
(c) the impact on progress with other characteristics of increasing selection for competitive ability.

An important issue is whether there are biological trade-offs between competitive ability and other economically important characteristics. For example, more competitive wheats may use more water in early growth stages that result in problems in drier areas at grain fill. Although strongly competitive wheats have increased height, high tillering, early vigour, and wide and long leaves, Lemerle *et al.* (2000) found that there was no relationship between wheat varieties in their competitive ability and their weed-free yield[1]. Thus they concluded that it is technically feasible to select for competitive ability without compromising yield potential. However, where there are limited resources available to a breeding program, there is still an economic trade-off between progress in yield and selection for competitive ability.

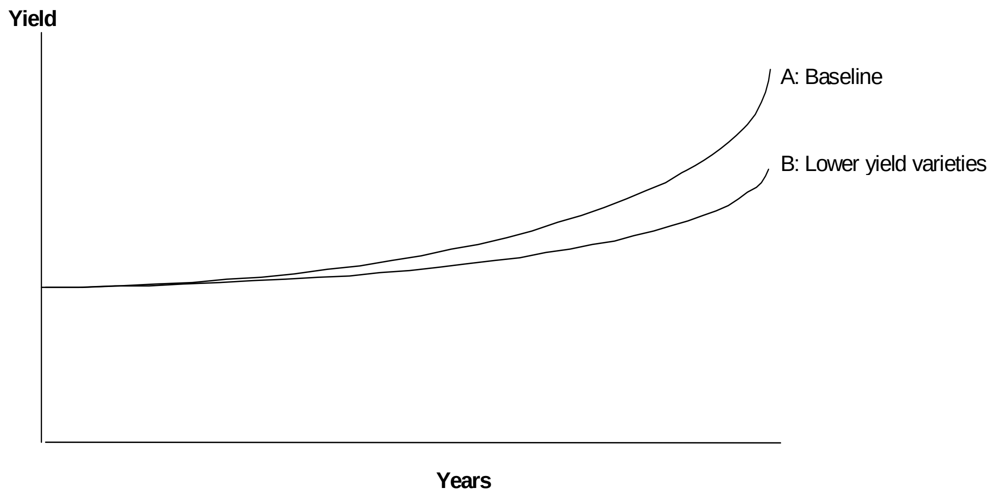
Progress in plant breeding depends on the numbers of lines and the probabilities of identifying a line with superior yield (or other characteristics) to the current varieties. Any reduction in numbers caused by selecting for another characteristic will reduce the probability of finding such a superior line for release, unless additional resources are made available to expand the number of lines in the earlier stages of the program. As the lines are brought through the stages of the program, any reduction in numbers at one stage of the program impacts on the likely numbers and the characteristics of the materials flowing through to the subsequent stages of the programs in the following years. Thus, the impact of adding another selection character will be felt through the impact on the release of new varieties over a number of years, even if it is biologically independent of characteristics such as yield and quality.

The impact of a slowing of the rate of varietal yield improvement is illustrated in Figure 1. Without the additional selection for competitive ability, the value of production would progress along line A. With the additional selection, the slower rate of progress (line B) is followed. The cost to the industry in terms of the loss of progress in yield is the difference between the two lines.

---

[1] Across a wide range of environments, Lemerle *et al.* (2001) also found that weed-free yields in current Australian wheat varieties were highly correlated with weedy yields.

Figure 1: Impact of Slowing in the Rate of Varietal Improvement



The benefits of selection for competitive ability need to be compared with those costs. As selection is made for increased competitive ability, costs fall because of the saving in weed control costs. If nothing were done to improve competitive ability, real costs would be likely to increase in future with the probable development of herbicide resistance in weeds. When herbicide resistance does develop, returns are likely to fall, as the highest-return option is likely to unavailable. Even with competitive varieties, herbicide resistance may still develop if there were no other changes to farm operations, but over a longer time frame.

3.2 Analysis of breeding options

The options that a plant breeder faces in increasing competitive ability of new varieties include (Lemerle *et al.* 1996):

- (a) Late stage screening for information on competitive ability
- (b) Late stage screening with limited selection for competitive ability
- (c) Early generation selection for competitive ability
- (d) Development of especially competitive materials for use as parent lines, using indirect selection for desirable morphological traits

In assessing these options, the breeder must be conscious that where selection is imposed later in a breeding program, there will be less variation for competitive ability, and therefore less chance of combining it with other suitable characteristics such as yield. On the other hand, the earlier the selection is made the more lines that need to be evaluated (and therefore the higher the costs). Also, the earlier the selection is made the greater the chance that selecting for competitive ability will affect the rate of progress with other important characteristics, unless the number of lines involved is increased to compensate.

An analytical model of a wheat breeding program that can evaluate the impact on breeding outcomes from changes in breeding operations (Brennan 1989) was used to determine the impact of a breeding response to the issue of increasing competitiveness of varieties. In this study, analysis was made of the impact of the first three of these options for the breeder. The program analysed is based on the wheat-breeding program at Wagga Wagga Agricultural Institute, Wagga Wagga, and the number of lines at the different stages of the program in a "normal" breeding cycle is shown in Table 4.

In the analysis of selection for competitive ability, the case analysed was of applying 50% selection pressure for competitive ability at the relevant stage of the program. Thus in the S2 selection option, the 50% of lines in the S2 trials with the lowest competitive ability were discarded, so that the number of lines in the subsequent stages of the program were accordingly reduced. The reduced number of lines in the program

Table 4: Lines in Wheat Breeding Program

Year	Generation/Stage	No. of lines
1	Crossing/F1 Generation	50
2	F2 Generation	3500
3	F3 Generation	14000
4	F4 Generation	5500
5	F5 Generation	2600
6	F6 Generation	5000
7	S1 trials	1800
8	S2(1) trials	400
9	S2(2) trials	200
10	S3(1) trials	35
11	S3(2) trials	15
12	S4(1) trials	5
13	S4(2) trials	1
14	Release	1

In assessing the impact of the screening or selection for competitive ability, in each case the rate of varietal improvement from the program was compared to that without such selection. For the case of yield improvement, the "base-line" case was of an increase of 0.8% per year. The "base-line" rate of increase in quality from the program is 0.5% per year, so the rate of increase in "value", where value incorporates both yield and quality increases, is 1.3% per year. In the analysis, the costs of the program and the expected outcome of the breeding program were determined and compared with that of the base case.

(a) Late stage screening for information on competitive ability

The key issue here is the provision of information for growers. The activities involve screening all advanced lines and current varieties so that information on competitive ability would be made available to growers on any newly released varieties. Growers could then use that information in making decisions on which varieties to grow in particular situations.

In analysing this option, the costs of evaluating the competitive ability at 4 of the 25 sites used in the S4 testing were estimated. The output of the program was unchanged, as the same varieties were released, but more information regarding its competitive ability compared to other varieties was provided at the time of its release.

The advantage of this option is that it would be relatively low cost. To grow the advanced lines in the S4 trials in weedy and weed-free comparative trials at four sites would increase breeding costs by $6,000 per year. The comparison of the yields under each option would then provide information on the competitive ability (as measured by its relative yield difference) for farmers to use in their variety-choice decisions.

The main disadvantage of this approach are that there is likely to be a more limited range of competitive abilities in advanced lines than in earlier-generation materials, so that the size of the possible gains made from this screening are likely to be generally small. While some progress could be expected over time in the competitive ability of varieties grown, that improvement is unlikely to be sufficient to result in a reduction in herbicide costs.

Because this evaluation takes place at the very late stage of the breeding program, the benefits from it are available to growers almost immediately. Growers would expect a lag of only 2 years before they obtained some benefits from the additional varietal information..

In summary, this would be a relatively low-cost option, but the benefits are also likely to be relatively small.

(b) Late stage screening with limited selection
This option involves carrying out limited selection for competitive ability at an earlier stage (at S2 or about 5 years prior to release). The advantages of this approach are the increased competitive ability of all varieties released from the program over time. The benefits of that would depend on the impact of the variety, but ultimately one herbicide application could be avoided at a cost of $38/ha in 50% of the crops of the new varieties. However, progress towards that improvement in competitive ability could be slow, given the relatively late stage at which selection for competitive ability is incorporated and that competitive ability is only broadly genetically controlled.

The costs of this approach include:

(i) Costs of conducting weedy and weed-free trials at 2 of the 5 sites for the S2 stage of testing in the breeding program. Those costs are estimated to be approximately $44,000 per year, after allowing for the savings in subsequent stages of the program because of reduced numbers.

(ii) Loss of progress with other traits (notably yield and quality) as a result of selection pressure for competitive ability. With selection pressure of 50% at S2 stage (that is, the least-competitive 50% of lines would be discarded from the program), the result is an estimated reduction in yield progress from 0.80% to 0.12% per variety, but with no reduction of progress in quality from 0.50%. Given average adoption of new varieties, the economic cost of these options would be significant, and is estimated at $7 per ha per year over the whole target region for the varieties produced by the breeding program.

Because this selection occurs about five years before the end of the breeding cycle, the benefits for growers will be lagged. The lag is taken as five years in the analysis.

Thus, both the costs and the gains are likely to be greater than for the previous option. On balance, it is unclear whether there are net gains from this option.

(c) Early generation selection for competitive ability
Under this option, selection for competitive ability is incorporated into the breeding program at the earlier F5 generation stage (or 8 years before release). Progress from the early-generation selection for competitive ability is likely to be more rapid, since selection is made in a breeding population with greater variability for competitive ability. Also, the earlier stage means that there is likely to be less effect on other traits than if the selection is made at the later S2 stage, because the remaining population of lines will have greater variability for other traits such as yield..

The costs of this approach include:

(i) Costs of conducting weedy and weed-free trials for the F5 stage of testing in the breeding program. Those costs are estimated to be approximately $24,000 per year, after allowing for the savings in subsequent stages of the program because of reduced numbers.

(ii) Loss of progress with other traits (notably yield and quality) as a result of selection pressure for competitive ability. With selection pressure of 50% at F5 stage (that is, the least-competitive 50% of lines would be discarded from the program), the result is an estimated reduction in yield progress from 0.8% to 0.39% per variety, but with no reduction of progress in quality from 0.50%. Given average adoption of new varieties, the economic cost of this lower rate of varietal improvement is estimated at $5 per ha per year over the whole region.

Because this selection occurs about 8 years before the end of the breeding cycle, the benefits for growers will be lagged. The lag is taken as 8 years in the analysis.

The direct costs of this option and the indirect costs in terms of lower yield increases are both lower than the previous option. The benefits are greater because the increase in competitiveness in varieties produced by the program is likely to be greater. Overall, the benefits of the increased competitiveness are greater than the costs of the reduction in improvement.

(d) Development of competitive parental materials
The development of special breeding materials for use as parents in the breeding programs provides a basis for raising the competitive ability of all the material in the breeding programs. For example, Richard Richards at CSIRO has been using backcrossing to incorporate greater competitive ability into current leading varieties that are being used as parents in the breeding programs. This involves indirect selection for desirable morphological traits. Early vigour incorporated into parental lines by this means provides a valuable resource for breeders wishing to improve the overall competitive ability of their varieties.

If the competitive ability can be incorporated without losing important traits, then the competitive ability could effectively come into the breeding program with no costs attached (other than the costs of developing the materials). In that case, the eventual outcome from the breeding programs would be the same for all other traits, but with a generally higher level of competitive ability. However, if the lines developed with higher competitive ability lose some of their yield or quality, or there are linkages to other undesirable genes, then overall breeding progress will be slowed and substantial costs could be imposed on the industry. The economic benefits and costs of this approach are not clear at this stage.

4. Determining and Developing Appropriate Strategies

Based on the above analyses, the outcomes of the various options involving competitive varieties for wheat grown in a monoculture is shown in Table 5. For each of the options, the likelihood of herbicide resistance developing is estimated. When herbicide resistance develops, farmers need to undertake expensive operations or need to change to less profitable enterprises. In this analysis, that cost is estimated at $100 per ha until the problem is overcome. In each case, the adjustment period is taken as 5 years once herbicide resistance develops. Depending on the strategy adopted, herbicide resistance takes different lengths of time to develop.

In the base case where there is no attempt to use more competitive varieties or to increase competition through agronomic means, the expected rate of yield improvement is 0.8% per year. However, herbicide resistance is expected to develop in five years, given the strong reliance on herbicides for weed control. On the basis of these parameters, the Present Value of the net income over the next 25 years is estimated as $2009 per ha.

Where a higher seeding rate is used with current varieties, there is likely to be no impact on the expected rate of yield improvement from the program. There is a saving of a herbicide application in 50% of crops, and the reduction in reliance on herbicides means that herbicide resistance would take 15 years to develop. The Present Value of the net income over the next 25 years is estimated as $2151 per ha, $6 per ha per year higher than the base case.

Where selection for competitive ability was incorporated at the F5 stage, the rate of genetic yield improvement fell to 0.39% per year, because of the reduced selection pressure for yield. However, the savings in herbicide application are estimated to be three crops in four (or 75%) because of the increased competitiveness of the varieties produced. The reduction in reliance on herbicides means that herbicide resistance is estimated to take 20 years to develop, so that the Present Value of the net income over the next 25 years is estimated at $2297, or $12 per ha per year higher than the base case.

Where selection for competitive ability was incorporated at the S2 stage, the rate of genetic yield improvement fell even more to 0.12% per year, because of the reduced selection pressure for yield. In this case, the savings in herbicide application are estimated to be the same as when increased seeding rates are used (50%) due to the more limited increase in competitiveness of the varieties produced. The reduction in reliance on herbicides means that herbicide resistance is estimated to take 15 years to develop, so that the Present Value of the net income over the next 25 years is estimated at $2115. This is $5 per ha per year higher than the base case, but markedly lower ($7 per ha per year) than where selection takes place at F5.

Table 5: Comparison of Options involving Competitive Varieties

	Without competitive varieties	Agronomy (higher seed rate)	Breeding to increase competitive ability		
			F5 selection	S2 selection	S4 evaluation
Yield growth (% per year)	0.80	0.80	0.39	0.12	0.80
Lag to benefits (years)	0	0	8	5	2
Saving in ryegrass post-emergent herbicide application (%)	0	50	75	50	0
Years for resistance to develop	5	15	20	15	10
Years of adjustment to herbicide resistance	5	5	5	5	5
Costs of adjustment to herbicide resistance	100	100	100	100	100
Present Value of income over 25 years ($/ha)	2009	2151	2297	2115	2099
- Average PV per year ($/ha)	80	86	92	85	84

Screening advanced lines for competitive ability at the S4 stage means that the rate of genetic yield improvement is unaffected, because there is no change to the selection pressure for yield. In this case, there are not expected to be any savings in herbicide application, but the increased use of competitive varieties means that herbicide resistance is estimated to take 10 years to develop. The resultant Present Value of the net income over the next 25 years is estimated at $2099 per ha, marginally higher than the base case but lower than the other options.

Overall, the comparisons indicate that “doing nothing” towards increased competitiveness is the lowest-return option. Unless selection in the breeding program is made at the early stage of F5, the net benefits are lower than the use of the agronomic solution of increasing seeding rates. Thus, there are significant benefits that can be obtained from farmers adopting the agronomic solution, with further benefits available in the medium to longer term if the breeding program is changed to increase selection for competitive ability.

The sensitivity of the results shown in Table 5 to the parameters used was examined. For the preferred solution of selection at F5 for competitive ability, it would still be the highest-return option as long as a herbicide application was saved in at least 12% of crops. Alternatively, if the reduction in the onset of herbicide resistance were delayed by only 3 years rather than 15, selection at F5 would still remain the preferred option over the alternatives. The agronomic solution is superior to the do-nothing option if it leads to a saving of herbicides on 18% of crops or delays herbicide resistance by only one year. Thus, the main results are relatively robust to the values of the key parameters in the analysis.

5. Conclusions

A key issue for farmers is the question of weed control and the extent to which the current higher reliance on herbicides leads inevitably towards problems with herbicide resistant weeds. Increasing efforts are being made to develop integrated weed management systems (IWM) to reduce the dependence on herbicides. One of the tools in that move towards IWM is the to increase the competitive ability of the crops against weeds.

On the basis of trial results and standard costs and prices, choosing wheat varieties that have stronger competitive ability against weeds can provide an economic advantage for farmers. Those farmers who would otherwise be unable to control ryegrass get particular advantages from more competitive varieties, particularly when sown at a high seeding rate. However, where herbicides are used for ryegrass control, the economic advantage of competitive varieties is markedly lower. Nevertheless, the highest gross margins are obtained when varieties have at least a medium level of competitive ability. Where increased seeding rates can be used to reduce the dependence on herbicides, the benefits are significant.

The economic implications for the breeding program, in terms of costs and impacts on other selection traits, of selection for competitive ability have been analysed. Those implications have been compared to the alternative of obtaining greater competition through agronomic means such as increased seeding rates. It is apparent from the analysis that in some breeding options the farmers pay a high price for the increased competitive ability through lower rates of yield increase. In some cases, the benefits from such an approach are limited in relation to their costs, and the preferred option would be to use agronomic rather than genetic means to improve competitive ability.

However, the analysis indicates that the introduction of selection for competitive ability in the early stages of a breeding program can provide overall benefits to farmers in their fight against weeds. While there would be a slowing in the rate of genetic improvement in yield, the benefits from the increased weed control are sufficient to outweigh the costs of that slower rate of improvement. The precise means of making that selection and the degree to which the competitive ability can be improved from the current genotypes within the breeding program need to be further evaluated to ensure that those potential benefits for farmers can be achieved.

The results of this study indicate that more competitive varieties can be an important tool for those who are developing integrated weed management systems for the future.

References

Faour, K. (1999), *Winter Crop Budgets, Southern Zone 1999*, NSW Agriculture, Yanco.

Jones, R. and Cacho, O. (2000), “A dynamic optimisation model of weed control”, Contributed paper presented to the 44th Annual Conference of the Australian Agricultural and Resource Economics Society, Sydney.

Jones, R.E. and Medd, R.W. (2000), “Economic thresholds and the case for longer term approaches to population management of weeds”, *Weed Technology* 14(2), 337-350.

Lemerle, D., Verbeek, B. and Coombes, N.E. (1995), “Losses in grain yield of winter crops from *Lolium rigidum* competition depend on cultivar and season”, *Weed Research* 35, 503-509.

Lemerle, D. Verbeek, B., Cousens, R.D. and Coombes, N.E. (1996), “The potential for selecting wheat varieties strongly competitive against weeds”, *Weeds Research* 36, 505-513.

Lemerle, D., Gill, G.S., Murphy, C.E., Walker, S.R., Cousens, R.D., Mokhtari, S., Peltzer, S.J., Coleman, R, and Luckett, D.J. (2000), “Genetic improvement and agronomy for enhanced wheat competitiveness with weeds”, *Australian Journal of Agricultural Research* (in press).

Medd, R.W., Auld, B.A., Kemp, D.R. and Murison, R.D. (1985), “The influence of wheat density and spatial arrangement on annual ryegrass, *Lolium rigidum* Gaudin, competition”, *Australian Journal of Agricultural Research*, 36, 361-371.