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An Economic Model Evaluating Competitive Wheat Genotypes for Weed Suppression and Yield in a Wheat and Canola Rotation

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Abstract: Recurrent selection for early vigour traits in wheat (*Triticum aestivum* L.) has provided an opportunity to generate competitive biotypes to suppress agronomically important weeds. Quantifying the potential benefits of competitive genotypes, including yield improvement and reduced frequency of herbicide application when incorporated into a long-term rotation, is vital to increase grower adoption. In this simple economic model, we evaluated a weed-suppressive early vigour genotype utilising on-farm experimental results and simulation analysis to predict gross margins for a seven-year wheat-canola rotation in southeastern Australia. The model applied a local weather sequence and predicted wheat production potential, costs and benefits over time. An early vigour wheat genotype was compared to commercial wheat cultivars for weed control, yield and actual production cost. With respect to weed control, three scenarios were evaluated in the model: standard herbicide use with a commercial cultivar (A), herbicide use reduced moderately by inclusion of an early vigour wheat genotype and elimination of the postharvest grass herbicide (B) or inclusion of an early vigour wheat genotype and withdrawal of both postharvest grass and broadleaf herbicides (C). Cost savings for the use of a competitive wheat genotype ranged from 12 AUD/ha in scenario B to 40 AUD/ha in scenario C, for a total saving of 52 AUD/ha. The model generated annual background gross margins, which varied from 300 AUD/ha to 1400 AUD/ha based on historical weather conditions, production costs and crop prices over the 30-year period from 1992 to 2021. The benefits of lower costs for each of the three scenarios are presented with rolling seven-year average wheat–canola rotation gross margins over the 30-year period. The limitations of this model for evaluation of weed suppression and cost benefits are discussed, as well as relative opportunities for adoption of early vigour traits in wheat.

Keywords: early vigour wheat; weed suppression; reduced chemical costs; savings for improved gross margins; bioeconomic simulation model

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1. Introduction

Many of the cultural and chemical strategies employed to manage weeds in broadacre crops have resulted in increased costs in recent years. Both surveillance and predictive analysis point to the continued development of herbicide resistance across the grain growing regions of Australia [1]. Therefore, cost-effective integrated approaches for weed management in cereals are receiving increased attention from both researchers and grain producers.

In recent years, several studies have assessed the ability of competitive or early vigour (EV) wheat genotypes to suppress weed growth following selection for traits associated with greater shoot vigour [2,3].

Historically, desirable biological modifications were achieved through recurrent selection for early vigour (EV) traits in wheat. Through this process, Commonwealth Scientific and Industrial Research Organisation (CSIRO) plant breeders in Australia aimed to improve photosynthetic capacity for enhanced biomass and yield while encouraging rapid formation of a closed wheat canopy, with wider leaf width and improved water use efficiency, consequently leading to successful competition with weed seedlings. EV characteristics were then evaluated in multiple field locations over a three-year period with varied environmental conditions [4]. In these replicated field trials, EV wheat proved highly competitive with weeds, suggesting that some herbicide applications may be withheld or scaled-back without sacrificing yields, and reduction in costs may later be estimated by development of a predictive model.

In Australia, EV wheat genotypes typically show superior early-season growth characteristics associated with significant canopy closure, leading to reduced light at the soil surface and weed suppression, as well as potential for production of similar grain yields to those of current commercial cultivars [4]. The incorporation of EV wheat into commercial wheat rotations could facilitate widespread EV adoption as there are no real requirements for modification of existing farming practices or management systems. We postulated that EV inclusion might also reduce total expenses associated with input costs, including the use of both pre- and post-emergent herbicides. Therefore, an economic model that considered EV performance and grain yield, along with local farm input costs and grain prices, could provide valuable insights impacting grower appeal and adoption.

Several similar studies have successfully used economics to inform and evaluate biological control programmes [4] or to develop biosecurity budgets [5]. A combination of on-farm experimental results and simulation analysis has also been used to guide the management of cereals across low-rainfall regions of southeastern Australia [6]. Similarly, a bioeconomic model was used to quantify the value of monoculture and mixed swards of under-vine species in wine grapes, which would otherwise rely on herbicides or cultivation. In South Australia's Barossa, Langhorn and Eden Valleys, mixed swards of legume/grass species as well as monocultures of ryegrass were shown to be profitable when compared to the use of herbicides for weed management. In the Riverlands district, the herbicide treatment was most profitable and was followed closely by a grass monoculture or a legume/grass mixed culture [7].

In previous field experiments performed in Wagga Wagga, NSW to evaluate the genetic basis for weed suppression in wheat, in-crop weed density was significantly and negatively correlated with early canopy closure and crop biomass [8,9]. Experimentation performed across Australia with EV wheat genotypes has shown that such competitive cereal genotypes offer considerable promise for sustainable and effective weed management without additional cost for establishment or management [8,10]. However, the potential value of a new agronomic tool, specifically the early vigour trait in commercial wheat genotypes offering improved weed control, most certainly requires further evaluation and consideration before widespread adoption can occur. The use of EV wheat genotypes can be likened at this stage of development to an uncompleted orchestral composition. Such unique innovations tend to progress with substitution, selection and elimination steps along the way.

At this time, private breeding firms as well as researchers continue to evaluate the integration of such traits in commercial wheat breeding lines. In recent 2020 wheat trials, we discovered that ample rainfall resulted in optimal wheat yields and significant weed establishment in wheat trials. Further assessment of weed seed dynamics at this site as impacted by long-term crop rotations revealed that weed propagule numbers were reduced over time due to less accumulation in numbers of propagules in cropping soils that were cereal-dominant or were in a wheat–canola rotation over a six-year period. In this case, highly significant reduction in weed propagules (by 70–80%) was observed with wheat–canola rotations in a mixed cropping rotational experiment and with incorporation of EV wheat genotypes [1,11].

This study aimed to use a simple economic model to more broadly evaluate the impact of early vigour wheat crops over various climatic conditions and grain prices in NSW. A series of data layers or assumptions based on historical weather patterns, grain prices and local farm management costs provided reference information to construct the economic model. Using the data obtained from replicated wheat genotype evaluations in 2020 that assessed the direct impact of genotype on weed suppression, we developed this simulation model to predict economic outcomes on weed management and gross margins as impacted by rotations of EV wheat with canola. With respect to weed control, three scenarios were evaluated in the model: standard herbicide use of pre- and post-emergent herbicides in a commercial wheat cultivar (A), moderate reduction in herbicide use by inclusion of an early vigour wheat genotype and elimination of the postharvest grass herbicide (B) or inclusion of an early vigour wheat genotype and reduction in use of both postharvest grass and broadleaf herbicides (C). We also compared the impact of standard herbicide treatments in this mixed cropping rotational experiment in contrast to the use of EV wheat biotypes for low-cost weed suppression. This study also assessed the value of EV traits through modelling costs and benefits associated with weed management and yield of both commercial and EV wheat genotypes.

2. Materials and Methods

The present study employed a simple numerical bioeconomic model to evaluate the impact of early vigour wheat genotypes in contrast to those of a conventional wheat cultivar over various climatic conditions encountered over a historical period in southeastern Australia, specifically Wagga Wagga, NSW. We combined on-farm experimental results using simulation analysis to predict gross margins for a typical seven-year wheat–canola rotation in southeastern Australia, based on local weather sequence, production potential, costs and benefits over time. A series of references provided historical weather patterns, grain prices, local farm management costs and field evaluations for wheat yield observed in our 2020 wheat genotype data set [11]. More specifically, the model was based on data obtained from replicated field evaluation results of EV wheat genotypes performed in 2020 in Wagga Wagga, NSW on the Charles Sturt University research farm [12]. Field evaluations included EV genotypes (herein referred to as genotypes with the prefix "W") developed by CSIRO (obtained from Dr. G. Rebetzke after recurrent selection in existing wheat genotype collection, CSIRO Black Mountain Science and Innovation Park, Building 101, Clunies Ross St, Black Mountain ACT 2601, Australia) and commercial or historic cultivars (Elders Ltd., 80 Grenfell Street, Adelaide, SA 5000, Australia) (Figure 1) [11,13]. A high-performing EV wheat genotype (W47) was compared to a commercial wheat cultivar (Condo) for weed suppression, grain yield (both at 6 t/ha) and production cost. With respect to weed control, three specific scenarios were included and evaluated in the model: standard herbicide use with Condo, the commercial cultivar (A), herbicide use reduced moderately by inclusion of an early vigour wheat genotype (W47) and elimination of the postharvest grass herbicide (B), or inclusion of an early vigour wheat genotype (W47) and withdrawal of both postharvest grass and broadleaf herbicides (C).

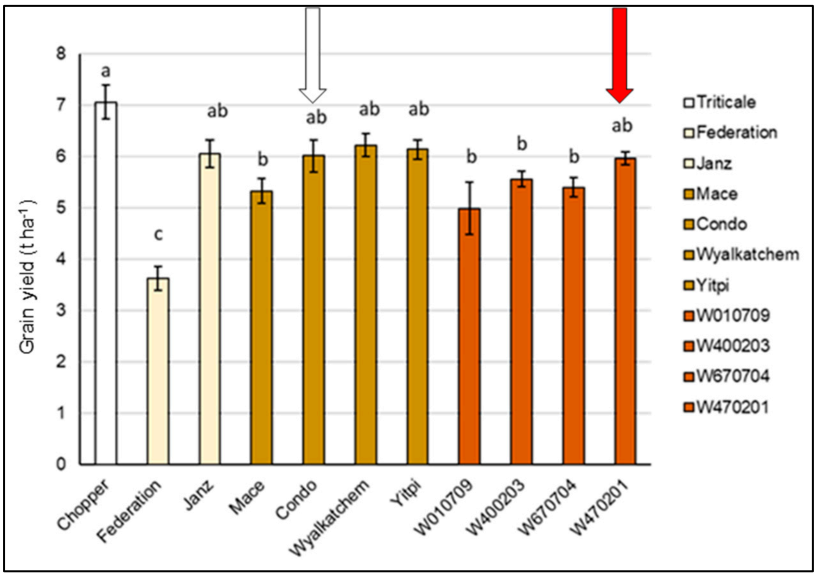

Figure 1. Comparison of grain yields of high-vigour lines (W010709, W400203, W670704 and W470201) with commercial cultivars (Condo, Wyalkatchem, Yitpi, Janz, Mace), historic cultivar (Federation) and the triticale control (Chopper) from experimental plots established in Wagga Wagga, 2020. The open arrow points to the commercial wheat cultivar "Condo" and the red arrow points to the early vigour genotype "W470201", each yielding 6 t/ha in 2020. This conjunction allowed the simple economic comparisons made in this paper. Error bars indicate standard error of the mean. Bars that share the same letters are not significantly different (p = 0.05). Adapted from Hendriks 2023 [11].

The model generated gross margins for the effects of the three scenarios through 24 overlapping seven-year wheat–canola rotations in a 30-year period from 1992 to 2021. Weed seedbank assessments at this site indicated a significant reduction in the weed seedbank following rotations of competitive cereals, and were used as the basis for our clear assumption of lower seedbank densities in scenarios B and C, when compared to the control, A [1,14].

As the model evaluated a typical Australian winter crop rotation of wheat followed by canola repetitively over seven years, the wheat and canola crops were assumed to be co-located in two separate paddocks, cropped in out-of-phase succession such that both crops were present on the farm every year, experiencing the same growing conditions. The context of NSW wheat and canola yields, prices and gross incomes per hectare was taken from 1992 onwards, when canola data were first published, through 2021, providing a reference base (ABARES annual wheat and canola production data and export prices; Australian Bureau of Agricultural and Resource Economics and Sciences; https://www.agriculture.gov.au/abares, accessed on 19 December 2024). A seven-year rotation was selected for modelling treatment effects as this timeframe allowed for significant weed seed reductions in the weed seedbank, as was also observed in the same field location [1], provided appropriate rotational and management choices are applied. A wheat–canola yearly rotation in this region is typical, and replaces wheat on wheat or canola on canola, due to less favourable production issues associated with pest and weed management [14].

We also applied a modified French–Schultz response function [7,15] in our model to depict reduced yield increments associated with the highest growing season rainfalls (GSRs), where waterlogging in the field continues to be a critical factor impacting crop productivity (Figure S1d; see French Schultz response). All bioeconomic model supporting data are presented graphically in Supplemental Figure S1. Figure S1 Panel a presents the history of fluctuating wheat and canola yields in New South Wales (NSW) from 1992 to 2021; Panel b is inflation-adjusted wheat and canola export prices (Panel a and b data were sourced from ABARES); Panel c shows growing season (Apr–Oct) rainfall at Wagga Wagga from 1900 to 2022 ((Lat −35.033708, Long 147.361481), from the Bureau of Meteorology employing spatial interpolation [16,17]); Panel d is the French–Schultz wheat yield response curve with water-logging [18]; Panel e presents simulated Wagga Wagga wheat and canola yields from 1991 to 2021 based on French–Schultz and local rains; Panel f is the calculated gross income per hectare of wheat and canola from 1992 to 2021 calculated using historical wheat and canola production costs and sale prices [14,19]. All modelling was conducted on Microsoft Excel (Microsoft Excel, 2024; Microsoft Corporation, Redmond, WA, USA) over time [20] with multiple iterations to generate costs and benefits in terms of cost savings.

An economic assessment of possible benefits builds on past field experimental results and use of historical rainfall information for the Wagga Wagga field location (Lat-35.033708, Long 147.361481) from the Bureau of Meteorology employing spatial interpolation [16,17], and local wheat and recent canola production costs and sale prices [14,19].

A key assumption of our model is the use of a typical wheat–canola annual crop rotation, which in fact is frequently performed in this region, the NSW Riverina. The economic analysis performed was thus designed with several key assumptions including and not limited to:

1. A seven-year winter annual crop rotation consisting of wheat and canola, cropped in succession.

2. Yield responses were taken to be very tightly aligned to rainfall received, as summarised in a modified French–Schultz potential yield model [8,15] that depicts reduced yield increments at the highest growing season rainfalls (GSRs) for a simulation across 30 years of variable weather, yield, total input costs and prices (adjusted for inflation, 2021) to determine potential economic outcomes. Yields as impacted by rainfall and other variables including EV were estimated in our model.

3. A seven-year crop rotation was modelled (by contrasting two paddocks of wheat–canola and canola–wheat with the assumption that both crops were exposed to the same climatic conditions). The two paddocks (of 1 ha each) represent each canola–wheat treatment out-of-phase over time; that is wheat in one paddock and canola in the other in a given year, with consecutive switching of crops through a seven-year rotation. A seven-year rotation was selected for modelling treatment effects as this time frame allows for significant weed seed reductions in the weed seedbank, provided appropriate rotational and management choices are applied.

4. We proposed and evaluated three individual wheat genotype treatments in our model: A. the commercial wheat cultivar "Condo", which was weed-suppressive but lacked early vigour traits; B. a high-performing, weed-suppressive early vigour (EV) genotype (W47), from which treatment postharvest grass herbicide was withheld in the wheat phase of the split rotation with canola; and C. the high-performing early vigour (EV) wheat genotype (W47) and, as for B, withholding the postharvest herbicide application for the control of early-emerging summer grass and broadleaf weeds. Treatments B and C were assumed to enhance crop competition with weeds using the EV genotype W47 [3] and through the production of increased crop residues postharvest, thereby, as previously observed, reducing the emergence of summer weeds that contribute to the seedbank over multiple growing seasons [1].

Details of these three treatments are presented (Table 1). The cost savings per hectare due to reduction in herbicide use are also presented in Table 1. Other standard costs for these rotations are summarised in Table S5, with respect to fixed costs per hectare (including seed, fertiliser, operations, insurance), variable costs per ton of grain harvested (including harvesting itself) and NSW state levies, and finally a modest Grains Research Development Corporation (GRDC) levy of 1% of the gross value of the crop.

Table 1. Herbicide and fungicide chemistry regimes adopted for the management of seven-year crop rotations. Canola and a commercial wheat cultivar rotation (**A**), canola and EV wheat genotype rotation with reduced herbicide applications (**B**,**C**). All cost calculations are presented in estimated 2021 AUD.

	Condo Wheet Chemistry Applications A.			**Canola Chemistry Applications**			**W47 Wheat Chemistry Applications B. and C.**			
Mix 1	**Summer fallow**	$/ha		**Summer fallow**	$/ha		**Summer fallow**	$/ha		
	Carfentrazone-ethyl	**$ 6.00**	0.075 L/ha	Carfentrazone-ethyl	**$ 6.00**	0.075 L/ha	Carfentrazone-ethyl	**$ 6.00**	0.075 L/ha	
	Glyphosate (450 g/L)	**$ 9.75**	1 L/ha	Glufosinate	**$ 9.75**	3.75 Lha	Glyphosate	**$ 9.75**	3.75 L/ha	
	Surfactant	**$ 1.31**	0.5 L/ha	Surfactant	**$ 1.31**	0.5 L/ha	Surfactant	**$ 1.31**	0.5 L/ha	
	Paraquat	**$ 21.00**	1.5 L/ha	Diquat	**$ 21.00**	3 L/ha	Paraquat	**$ 21.00**	3 L/ha	
Mix 2	**Pre-emergent**			**Pre-emergent**			**Pre-emergent**			
	Triasulfuron	**$ 42.00**	30 g/ha	Trifuralin + Triallate	**$ 20.80**	1.5 L/ha + 1.6 L/ha	Triasulfuron	**$ 42.00**	30 g/ha	
Mix 3	Post-emergence broadleaf control			Post-emergence broadleaf control			Post-emergence broadleafcontrol			
	Halauxifen-methyl +Florasulam	**$ 14.00**	25 g/ha				Halauxifen-methyl +Florasulam	**$ 14.00**	25 g/ha	
	Clopyralid 750 wG	**$ 7.20**	120 g/ha	Clopyralid 750 wG	**$ 7.20**	120 g/ha	Clopyralid 750 wG	**$ 7.20**	120 g/ha	
	LV MCPA570	**$ 7.50**	0.5 L/ha				LV MCPA570	**$ 7.50**	0.5 L/ha	
	Uptake	**$ 2.63**	@ 0.50%	Uptake	**$ 2.63**	@ 0.50%	Uptake	**$ 2.63**	@ 0.50%	
Mix 4	**Fungicide**			**Fungicide**			**Fungicide**			
	Epoxiconazole	**$ 15.00**	0.13 L/ha	Prothioconazole +Tebuconazole	**$ 15.00**	0.45 L/ha	Epoxiconazole	**$ 15.00**	0.13 L/ha	
Mix 5	**Post-emergence grass**	**-**		**Post-emergence grass**	**-**		**Post-emergence grass**	**-**		
Mix 6	**After-harvest Grass weed control**			**After-harvest Grass weed control**			**After-harvest Grass weed control**			
	Clethodim	**$ 12.00**	0.5 L/ha	propaquizafop	**$ 40.00**	0.5 L/ha	Clethodim	**$ 12.00**	0.5 L/ha	**not in B or C**
	Broadleafweed control-			Broadleaf weed			**Broadleaf weed control-**			
	2,4D	**$ 40.00**	1 L/ha	control-Saflufenacil	**$ 40.00**	0.09 L/ha	2,4D	**$ 40.00**	1 L/ha	**in B, not in C**
	Total	**$ 178.39**		**Total**	**$ 175.69**		**Total**	**$ 178.39**		
	A. Commercial Condo Wheat			**Canola**			**Early Vigour W47 Wheat**			
	A. has full chem regime @ $178.39/ha			**$175.69/ha**			**B. as A. but without Clethodim @$12.00**		**C. as B. but also without 2,4D @$40.00**	
							Totals: Chem Costs $166.39/ha		**Chem Costs $126.39/ha**	

The three treatments used in Table 1 are explained as follows: A. The commercial wheat cultivar "Condo" which is weed-suppressive but lacking EV traits, and assumed to receive the entire chemistry regime in Table 1, accompanied in rotation with canola; B. A high-performing EV genotype ("W470201") which has demonstrated weed suppression, and all chemicals applied for pest management, except for postharvest grass herbicide (Clethodim) application following EV wheat in the rotation with canola; and C. The high-performing EV wheat genotype ("W470201"), as in B above, withholding the selective postharvest grass herbicide Clethodim, but also the postharvest application of 2,4 D broadleaf weed control following EV wheat.

5. As the highest-yielding EV wheat genotype (6 Mt/ha) (W47, obtained after 3 cycles of recurrent selection for EV traits with parents Yitpi and Wyalkatchem), among several evaluated in a 2020 plot trial at Wagga Wagga, the W47 yield was observed to equal that of the commercial wheat cultivar "Condo" currently in use in this region (Figure 1). The model was developed on the assumption that wheat and canola costs in treatments A, B and C were identical except for the post-emergent herbicide application savings with W47 in contrast to the existing commercial genotype Condo.

6. For the present analysis, we have further assumed these specifications hold true through both optimal and sub-optimal growing seasons for wheat which are typically experienced in this region. We applied the 1992–2021 period for which yield records are published by ABARES for both wheat and canola (when the latter was established as a new crop in this region) [19]. Thus, this 30-year production sequence allowed the definition of 24 unique 7-year sequences of weather and prices (adjusted to 2021 AUD) for the expression of yields, costs and gross margins (Figure 2). Historic wheat and canola yields for the Wagga Wagga region, grain prices, and gross incomes used for economic modelling are provided in Figure S1.

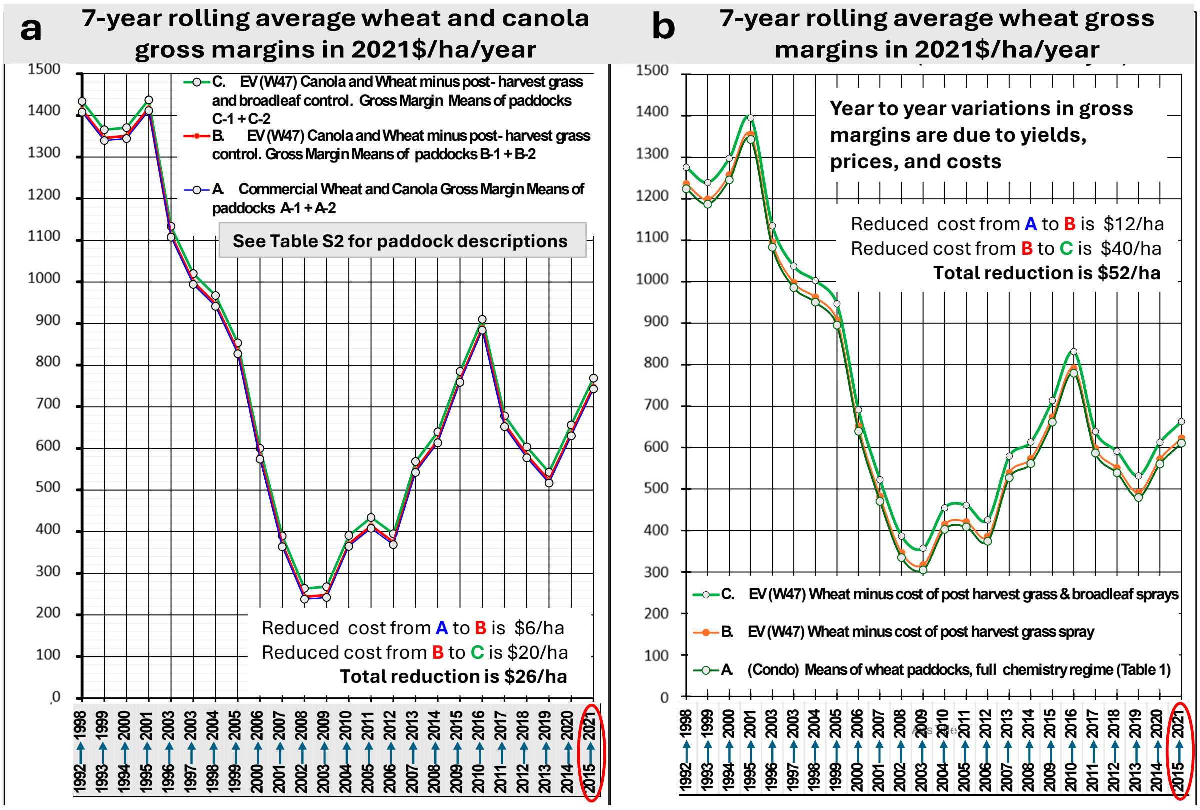

Figure 2. Wheat and canola in 24 seven-year rotations simulated for Wagga Wagga, NSW, under three weed control regimes, A, B and C from 1992 to 2021: (**a**) rolling annual average for wheat and canola gross margins, and (**b**) rolling annual wheat gross margins, all calculations are presented in 2021 AUD/ha/year.

3. Results

The growing season rainfall associated with the selected 7-year period of rotation in Wagga Wagga, NSW is included in Figure S1 and is consistent with the long-term trends in this area, beginning in 1900. Growing season rainfall was accessed from 1901 to 2021 and its presentation over 120 years clearly illustrates the major challenge of rainfed agriculture in Australia, the year-to-year variance in rainfall. The variation observed in rainfall over the

30-year study period accessed in this model was much like that observed over the longer historical period, and representative of this region.

The model incorporated Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) data on NSW wheat and canola yields and export prices (Figure S1a,b) for the 30-year period from 1992 to 2021, with prices adjusted for inflation to 2021 dollars. The growing season rainfalls and a French–Schultz wheat yield function (Figure S1c–e) allowed simulation of wheat yields over the 1992–2021 period [15,21]. Canola yield/ha was also included, based on proportion obtained in contrast to wheat yield, on a year-by-year basis (Figure S1a). Estimated gross incomes in 2021 dollars/ha for the two crops at Wagga Wagga (Figure S1f) were based on local rainfall and simulated yields multiplied by their respective export prices per ton (Figure S1b), all of which varied from year to year.

Figure 2a,b exhibit rolling 7-year average gross margins of the combined wheat and canola rotation of 26 AUD/ha/year comparing treatment C to treatment A, due to chemical cost savings in the EV wheat, assuming equal yields to the commercial wheat cultivar under all environments. The combined canola and wheat sales values per hectare were most frequently higher than those contributed per hectare by wheat alone due to higher prices for canola (see Figure S1b,f). Not surprisingly, all gross margins were greatest in cropping years that received optimal growing season rainfall or in years with high grain prices. Wheat gross margins alone were 52 AUD/ha higher for treatment C with the EV wheat genotype W470201 than for treatment A with the commercial wheat Condo due to opportunities provided by potential reductions in herbicide use for all seven-year crop sequences assessed.

The framework and results generated from this model were based largely on wheat yields from one well-controlled experiment of EV wheat genotypes and commercial cultivars at Wagga Wagga in 2020, a very good dryland crop season (with 447 mm growing season rainfall and high yields of >6 t/ha). Experimental plot yields exceeding 6 t/ha were only reported for wheat at Wagga Wagga once in the 1980—2024 period, for example, a 1-hectare plot yielding over 6.5 t/ha in 1983 [21]. We assumed the potential chemical cost reductions to be a constant across seasons with high and low background gross margins given the large variations in growing conditions, grain yields and prices (summarised in Figure 2), and input costs (summarised in Tables S1–S4).

Producers considering a wheat–canola rotation on a 1000-hectare farm (50% wheat and 50% canola each year) could weigh the possibility of herbicide cost reductions to boost gross margin (earnings) given the weed-suppressive qualities of an EV wheat. Two perspectives on this question are of interest: (a) the overall cost reductions for the 1000-hectare wheat–canola rotation are the differences in costs per hectare of the proposed chemistry treatments in wheat defined in Table 1 for combined wheat and canola phases, or (b) for the wheat phase alone. In other words, for the combined 500 ha of wheat and 500 ha of canola crops, the cost reduction from treatment A to treatment B was 6 AUD/ha; and from B to C, 20 AUD/ha (as illustrated in Figure 2a). Considering only the 500 ha wheat phase of the rotation, the cost reduction from treatment A to treatment B was 12 AUD/ha; and from B to C, 40 AUD/ha (Figure 2b). Source data for Figure 2 are derived from Table S2, collected in Table S3 and transformed in Table S4 to 7-year rolling averages for plotting in 2021 AUD/ha/year. These idealised cost reductions are shown as increases in gross margins of wheat and canola combined (Figure 2a) and increases only in wheat gross margins (Figure 2b).

Our model simplifying assumption, that there would be identical yields from the two genotypes of wheat, EV W47 and "Condo", despite the variability in growing conditions over a 30-year period of seasonal data, is indeed an assumption. This assumption of equal yield potential of both genotypes is based on actual 2020 observations for weed suppression, in a year in which very significant weed establishment was observed following on from several years of drought and reduced infestation (2018–2019). Based on previous trials and comparisons of EV and commercial wheat genotypes, our assumptions on the feasibility of reduced herbicide applications, in the context of seven-year crop rotations with canola for cost reductions without yield penalties, are supported by our data collected at multiple production locations across NSW. In contrast, we are assuming that yield will vary across rainfall and variable weather conditions, including soil and air temperature. Replicated field trials are actually critical in order to validate any model results obtained.

4. Discussion

We developed a simple spreadsheet software model using Excel as a natural choice platform to explore a unique bioeconomic model investigating the use of competitive wheat genotypes for weed suppression in an Australian wheat and canola rotational system. This spreadsheet software platform is flexible, cost-effective and, while requiring time to learn, is relatively simple to use, as suggested by Cahill and Kosicki in 2020 [20]. Specifically, we generated a unique bioeconomic model that reflects rainfall, crop pricing, and cost of crop establishment and pest management while evaluating the potential for adoption of weed-suppressive early vigour wheat genotypes for stakeholders wishing to test the advantages of a novel weed management tool involving competitive genotypes. In this model, we examined strategic reductions in the frequency of application of key postharvest herbicide applications as projected in a competitive wheat crop, providing savings of up to 52 AUD/ha/year, given the weed suppression afforded by an EV wheat genotype in a 7-year wheat and canola alternating crop rotation.

Competitive wheat crops may also provide additional season-long protection against key agronomic weeds that have adapted to germinate in winter months as well as late spring and summer [22]. The addition of an integrated weed management strategy that incorporates crop competition with EV wheat genotypes as a tool for weed suppression may also contribute to the reduction in incidence of herbicide resistance and weed seed-bank density [23,24]. The use of competitive crops may also reduce the burden of using increasingly complex herbicide mixtures by reducing frequency of application in those situations that experience lower weed burden [25].

Our results, based on one year of data in an optimal southern Australian growing season with ample rainfall and weed pressure, demonstrate that crop performance, EV-driven weed suppression and seedbank characteristics, along with climatic variables including rainfall, can provide valuable inputs for generation of a bioeconomic model projecting the value of EV trait use in commercial wheat production. However, it is clear that model validation by field assessment across several growing seasons with diverse environmental conditions is subsequently important.

Not surprisingly, gross margins generated by this model were predicted to be greatest in cropping years that received optimal growing season rainfall and/or in years with high grain prices. Gross margins were 52 AUD/ha higher for treatment C when compared to treatment A using the EV wheat genotype W47 due to the significant reduction in frequencies of herbicide use with EV wheat in all seven-year crop sequences assessed. The framework and results generated from this model were based largely on wheat yields from one well-controlled trial of EV wheat genotypes and commercial cultivars at Wagga Wagga in 2020 with an optimal dryland crop season (with 447 mm growing season rainfall), and were predicated on that year’s data and results. Experimental plot yields over 6 t/ha were earlier reported for wheat at Wagga Wagga in 2020 and previously in the 1980–84 period;

for example, a 1-hectare plot yielded over 6.5 t/ha in 1983, while typical yields and weed infestations are reduced due to lower rainfall [21].

Our simulation assumed yields of the two wheat genotypes would be equal under different treatments and across both wet and dry seasons. This simplifying assumption, that there would be identical wheat yields from the genotype EV W47 and the cultivar "Condo" in all years, despite the variability in growing conditions over a 30-year period of seasonal data, is indeed heroic, given the different genetic backgrounds of both genotypes. However, our assessment of equal yield potential of both wheats is based on 2020 observations for weed suppression, in a year when significant weed establishment was observed before and after crop sowing, following on from several years of drought and reduced weed infestation (2018–2019). In addition, data from other years of production under some drought conditions also supported similarity in yield outputs with EV and commercial genotypes, particularly W47.

Based on previous trials and comparisons of EV and commercial wheats, our assumptions on the feasibility of reduced herbicide applications, in the context of seven-year crop rotations with canola for cost reductions without yield penalties, are predictions, due to our reliance on several years of supporting data at multiple locations. Again, further plot and field trials are required to test the model assumptions and results to date. Our estimates of past wheat yields, based on water-limited "growing season rainfalls" alone, were also dependent on several simplifying assumptions.

Many, if not most, hazards to crops such as frost or heat at flowering, nutrient deficiencies, and pest burdens (such as insects, weeds or pathogens) can be accounted for in a yield and gross margin model such as CSIRO's APSIM Model withreasonable accuracy [6,24] while the French–Schultz method has limitations associated with waterlogging at the highest rainfalls [18], and the effect of latitude on daylength. The latter only indicates maximum yields for a given growing season rainfall. However, actual yields often fall short of this due to the afore-mentioned reasons, among others. Our simple approach can only be considered to capture the very wide range of water-limited yields and values of modern wheat and canola rotations over the 1992–2021 rainfall sequence at Wagga Wagga, as estimated with that period's input prices and yields.

Further validation of economic benefits predicted in our model by field experimentation under commercial on-farm conditions over a longer duration (5 to 7 years) should logically be followed up to fully assess the impact of crop-rotational choices that include W47 and other EV wheat genotypes. The impact of EV wheat genotypes on the depletion of the soil weed seedbank and/or soil moisture over time under various growth conditions should also be physically quantified to better guide herbicide mode-of-action choices and rates appropriate for such crop rotations. One key challenge would be to estimate the economic effects of differences in levels of weed-seed suppression over time due to implementation of EV genotypes in a long-term rotation in the field, and the potential for significant resulting impacts on the weed seedbank. This is the logical next step for research proposed from the work performed and reported in this study.

The strategic reductions in key postharvest herbicide applications (on the order of AUD 26 savings/ha/year from a combined wheat–canola rotation (Figure 2a); or 52 AUD per wheat-year in the rotation (Figure 2b), given the weed suppression afforded by an EV wheat in a 7-year crop rotation sequence, would undoubtably prove attractive to many growers. This is especially true if the practice also resulted in reduced progression of herbicide resistance and reduced weed seedbanks, both of which are possible, based on supporting data in our model. However, there is no doubt that replication of plot trials and field trials over several seasons with diverse growing conditions would allow a much more confident assessment than is currently possible.

Water use efficiencies are expected to be greater on Australian farms further south than those closer to the equator [17]; this is a significant factor, for example, with experimental sites at Wagga Wagga (Lat −35.03), Narrabri (Lat −30.27) and Kingaroy (Lat −26.59). It is possible that some EV genotypes can make more effective use of soil water than others, when compared to popular commercial cultivars [26]. Evaluation in other cropping locales should be potentially assessed using an expanded field trial protocol over several years. Data exist for several plant growth parameters recorded in the 2020 season when very good (6 t/ha) grain yields eventuated, as well as in earlier years when no grain yields were harvested due to drought conditions. These yield variations have been reported by Hendriks et al. [12] and may provide indications of the key parameters most worth recording in any new EV study.

5. Conclusions

A bioeconomic model was used to compare the gross margins between an EV wheat genotype and a single weed competitive commercial wheat cultivar, considering their grain yields and weed suppressiveness. Reductions in herbicide costs for EV wheat were estimated based on observed weed-suppressive characteristics of EV genotypes in replicated field experiments recorded over time. The observed advantages of EV adoption were then projected in the context of 7-year wheat–canola rotations. We accounted for wide variance in rainfall and crop performance in this model, in addition to uncorrelated variance in international commodity prices used for wheat and canola. The economic model showed that seasonal economic results are highly dynamic, and vary with growing seasons, with high yields and commodity prices in some years vs. low yields and low prices under extreme climatic conditions. The model generated annual background gross margins that varied from 300 AUD/ha to 1400 AUD/ha based on historical weather conditions, production costs and crop prices over the 30-year period from 1992 to 2021. The cost savings associated with the incorporation of EV wheat, while not significant, have a stronger influence on gross margins in climate-impacted years, when compared to those with high production potential. The adoption of a bioeconomic model including the impact of variable rainfall, genotype and yield, along with EV traits impacting weed suppression, can assist with prediction of the value and challenges associated with adoption of EV genotypes when incorporated into common crop rotations. At this time, EV genotypes have shown consistent weed-suppressive abilities while generating comparable commercial yields, and our model projects potentials for reduction in costs of weed control in a common canola–wheat rotation over a seven-year period.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agronomy15010103/s1, Figure S1: NSW wheat and canola yields, Wagga average rainfall values; Table S1: Wheat and canola gross incomes after all costs but chemicals; Table S2: Distributed budget calculator over 7-year samples; Table S3: Thirty years of wheat–canola GM results, with plotting data; and Table S4: Annual GMs to 7-year average per hectare GMs of canola and wheat.

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References

1. Gurusinghe, S.; Haque, K.S.; Weston, P.A.; Brown, W.B.; Weston, L.A. Impact of rotational sequence selection on weed seedbank composition in Australian broadacre crops. *Agronomy* **2022**, *12*, 375. [CrossRef]
2. Zhang, L.; Richards, R.; Condon, A.; Liu, D.; Rebetzke, G. Recurrent selection for wider seedling leaves increases early biomass and leaf area in wheat (*Triticum aestivum* L.). *J. Exp. Bot.* **2015**, *66*, 1215–1226. [CrossRef] [PubMed]
3. Hendriks, P.-W.; Gurusinghe, S.; Ryan, P.R.; Rebetzke, G.J.; Weston, L.A. Competitiveness of early vigour wheat (*Triticum aestivum* L.) genotypes is established at early growth stages. *Agronomy* **2022**, *12*, 377. [CrossRef]
4. Lee, K.; McDermott, S.; Fernandez, L. Using economics to inform and evaluate biological control programs: Opportunities, challenges, and recommendations for future research. *BioControl* **2024**, *69*, 237–252. [CrossRef]
5. Bland, L.M.; Li, C.; Kompas, T.; Chu, L.; Nguyen, H.-T.-M.; Hester, S.M. Resource allocation: Using economic principles to prioritise projects and allocate biosecurity budgets. In *Biosecurity*; Taylor & Francis: London, UK, 2024.
6. Hoffmann, M.; Llewellyn, R.S.; Davoren, C.; Whitbread, A. Assessing the potential for zone-specific management of cereals in low-rainfall south-eastern Australia: Combining on-farm results and simulation analysis. *J. Agron. Crop Sci.* **2017**, *203*, 14–28. [CrossRef]
7. Nordblom, T.; Penfold, C.; Whitelaw-Weckert, M.; Norton, M.; Howie, J.; Hutchings, T. Financial comparisons of under-vine management systems in four South Australian vineyard districts. *Aust. J. Agric. Resour. Econ* **2021**, *65*, 246–263. [CrossRef]
8. Mwendwa, J.M.; Brown, W.B.; Weidenhamer, J.D.; Weston, P.A.; Quinn, J.C.; Wu, H.; Weston, L.A. Evaluation of commercial wheat cultivars for canopy architecture, early vigour, weed suppression, and yield. *Agronomy* **2020**, *10*, 983. [CrossRef]
9. Mwendwa, J.M. Mechanisms of Weed Suppression in wheat (*Triticum aestivum* L.) and Canola (*Brassica napus* L.) in Southeastern Australia. Ph.D. Dissertation, Charles Sturt University, Wagga Wagga, Australia, 2019.
10. Mwendwa, J.M.; Brown, W.B.; Wu, H.; Weston, P.A.; Weidenhamer, J.D.; Quinn, J.C.; Weston, L.A. The weed suppressive ability of selected Australian grain crops; case studies from the Riverina region in New South Wales. *Crop Prot.* **2018**, *103*, 9–19. [CrossRef]
11. Hendriks, P.-W. The Role of Root Architecture and Associated Rhizosphere Interactions in Selection and Breeding for Weed-competitive Wheat Cultivars. Ph.D. Dissertation, Charles Sturt University, Wagga Wagga, Australia, 2023.
12. Hendriks, P.-W.; Gurusinghe, S.; Ingvordsen, C.H.; Rebetzke, G.J.; Ryan, P.R.; Weston, L.A. Breeding for shoot vigour modifies below-ground architecture and weed competitiveness in wheat (*Triticum aestivum* L.). In Proceedings of the 20th Australian Agronomy Conference, Toowoomba, Australia, 18–22 September 2022.
13. Rebetzke, G.J.; Ingvordsen, C.H.; Newman, P.; Weston, L.; French, B.; Gill, G. Delivering weed-competitive, wheat breeding lines to growers. In Proceedings of the GRDC Grains Research Update, Wagga Wagga, Australia, 13–14 February 2018; pp. 35–40.
14. GRDC. *Farm Gross Margin and Enterprise Planning Guide*; GRDC: Barton, Australia, 2022; p. 100.
15. French, R.J.; Schultz, J.E. Water use efficiency of wheat in a Mediterranean-type environment. I. The relation between yield, water use and climate. *Aust. J. Agric. Res.* **1984**, *35*, 743–764. [CrossRef]
16. Jeffrey, S.J.; Carter, J.O.; Moodie, K.B.; Beswick, A.R. Using spatial interpolation to construct a comprehensive archive of Australian climate data. *Environ. Model Softw.* **2001**, *16*, 309–330. [CrossRef]
17. Sadras, V.O.; McDonald, G.; Sadras, V.O.; McDonald, G. Water use efficiency of grain crops in Australia: Principles, benchmarks and management. *Change* **2012**, *11*, 24.
18. Nordblom, T.L.; Hutchings, T.R.; Godfrey, S.S.; Schefe, C.R. Precision variable rate nitrogen for dryland farming on waterlogging Riverine Plains of Southeast Australia. *Agric. Syst.* **2021**, *186*, 102962. [CrossRef]
19. ABARES. Agricultural outlook—Previous Reports. Available online: https://www.agriculture.gov.au/abares/research-topics/agricultural-outlook/previous-reports (accessed on 10 May 2024).

20. Cahill, M.; Kosicki, G. Exploring economic models using Excel. *South. Econ. J.* **2000**, *66*, 770–792.
21. Cornish, P.; Murray, G. Low rainfall rarely limits wheat yields in southern New South Wales. *Aust. J Exp. Agric.* **1989**, *29*, 77–83. [CrossRef]
22. Thompson, M.; Chauhan, B.S. Changing seasonality of *Lolium rigidum* (annual ryegrass) in southeastern Australia. *Front. Agron.* **2022**, *4*, 897361. [CrossRef]
23. Beckie, H.J.; Ashworth, M.B.; Flower, K.C. Herbicide resistance management: Recent developments and trends. *Plants* **2019**, *8*, 161. [CrossRef] [PubMed]
24. Gomez-Macpherson, H.; Richards, R. Effect of sowing time on yield and agronomic characteristics of wheat in south-eastern Australia. *Aust. J. Agric. Res.* **1995**, *46*, 1381–1399. [CrossRef]
25. Blackshaw, R.E.; O'Donovan, J.T.; Harker, K.N.; Clayton, G.W.; Stougaard, R.N. Reduced herbicide doses in field crops: A review. *Weed Biol. Manag.* **2006**, *6*, 10–17. [CrossRef]
26. Rebetzke, G.; Richards, R. Genetic improvement of early vigour in wheat. *Aust. J Agric. Res.* **1999**, *50*, 291–302. [CrossRef]