

RIM 2004

Reference Manual

A decision tool for integrated management of herbicide-resistant annual ryegrass

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Introduction

This chapter gives a brief introduction to RIM, this manual and its intended users.

RIM is a decision support system that is designed to provide information and insight to users to help them in making long-term decisions about management of ryegrass, the most important weed of crops in southern Australia. As the model is not an optimisation model, the optimal strategies are determined for different scenarios through a series of runs. RIM allows the user to simulate many different combinations of weed control treatments and observe their predicted impacts on ryegrass populations, crop yields and economic outcomes. The user evaluates the strategies and decides on the optimal management regime to implement.

Underlying RIM is a dynamic simulation model. The model is deterministic and integrates economic, biological and agronomic components. For economic aspects, the time step is annual. For biological processes, particularly weed population dynamics, seven periods of the year are defined. The model is implemented in a spreadsheet program, Microsoft Excel®, using formulae and Visual Basic macros.

The model includes approximately 500 parameters (biological, agronomic and economic) which are adjustable by users. Specification of values for each of these parameters was a major task in the development of RIM. Sources of data and information were numerous and diverse. Economic parameters were obtained from an existing whole-farm economic model (Morrison *et al.*, 1986; Kingwell and Pannell, 1987; Pannell, 1996), and updated from Budget Guides published for farmers. Parameters for control effectiveness of weed control options were estimated based on long-term field experiments designed to evaluate their effects (Bill Roy, pers. comm.) and from other field trials conducted by the Western Australian Department of Agriculture (WADA). Parameters for weed competition functions were calibrated in cooperation with weed scientists from WADA to provide relationships consistent with field trial evidence.

RIM represents a single field. The user can specify whether or not the ryegrass population in the field is resistant to each herbicide group, or how many applications of herbicides from each group are available before resistance will develop. This implies a sudden loss of herbicide efficacy, which approximates the reality of herbicide resistance development by annual ryegrass in southern Australia (Tardif *et al.* 1993). A wide variety of non-herbicide weed treatment options is

included, so that as herbicides are lost, the best substitute treatments can be identified.

The enterprise options available for users to select are wheat, barley, canola, lupins, volunteer pasture, subterranean clover pasture, and cadiz phase pasture. The user may select these in any agriculturally feasible sequence. There are inter-year impacts of one enterprise on another, depending on the sequence selected. For example, a cereal crop grown after a legume crop or pasture benefits from a higher yield and a reduced requirement for nitrogen fertilizer (Pannell, 1995a, 1998).

The main outputs that can be obtained from RIM are "average" annual profit (\$/ha/yr) for years 1-10 or years 1-20 and net return or gross margin for each year, ryegrass seeds/m² in the soil in April and ryegrass setting seed (per m²) in November. In addition, other biological and economic results are provided in the **Biological results** and **Economic results** sheets (see Chapters 3 and 4).

This manual

Information presented in this manual extends upon the detail found in the RIM 99 User's Manual. It is expected that readers of this manual are familiar with the RIM 99 computer model and User's Manual but wish to gain a deeper understanding of the equations that drive the model. A web page providing the latest information and relevant reference papers about RIM is available at: <http://www.general.uwa.edu.au/u/dpannell/rim.htm>.

We present the overall assumptions of the model in Chapter 2, the biological equations in Chapter 3, and the economic equations in Chapter 4. Details of a hidden sheet called the **Calcs** sheet are outlined in Chapter 5 to enable the user to fully understand how RIM is driven. Chapter 6 outlines the scope of Rim and provides contact details for people able to provide extra information or assistance. The key variables used in the equations are listed in the Appendix.

Principal Assumptions

This chapter outlines the principal assumptions behind the RIM model.

Introduction

Results derived from a model such as RIM are contingent upon the assumptions driving them and should be interpreted accordingly. The principal assumptions are detailed in this chapter with minor assumptions described in relevant sections of Chapters 3, 4 and 5.

Outline of assumptions

Time Frame

The User can generate annual results from RIM for either a 10 or 20 year time period. Weed populations are measured at six different times during the year with seed populations being monitored at seven specified times.

Region and climatic variation

RIM is not limited to a region. Default values pertain to the Merredin region, but the model can be adapted to any region with a similar farming system. RIM does not represent year to year variation in weather, potential weed-free yield or herbicide performance. Yields in the model vary from year to year due only to the sequence of crops and pastures selected, and the level of weed competition. Climatic conditions do not rule out any of the treatment options.

Herbicide applications and weed control

It is possible to specify a maximum number of applications for each group of herbicides before weeds are assumed to be mainly resistant (in either the **Start here** sheet or the **Select strategy** sheet). If ryegrass is fully resistant to a herbicide group, the limit for that group should be set to zero.

Weeds other than ryegrass are assumed to be adequately controlled through the use of herbicides. RIM contains assumptions regarding the control effectiveness (kill percentage) of the different weed control options. These values are presented in the **Control %** sheet. They were selected by reviewing trial results conducted in

Western Australia and elsewhere and have been checked against farmer experience. It is possible to alter these values if the user wishes to assume a different level of weed control.

Control treatments included in the model have different implementation times and will affect weeds at different stages of their life cycle. Weeds germinate at different times following the break of season and continue to germinate well into the growing season. Time of germination also affects the competitiveness of weeds. Late-germinating weeds are less competitive and so produce fewer seeds per plant.

Enterprise options

In this version of RIM there are seven enterprise options: wheat, barley, canola, lupins, regenerating pasture (assumed to be subterranean clover), phase pasture (assumed to be cadiz serradella) and volunteer pasture. Almost any sequence of these enterprises can be specified in the **Select strategy** sheet. The exception is that production of lupins or canola for two or more consecutive years is not permitted due to the very high yield losses that would occur from disease. For some purposes, cadiz and sub-clover pastures are treated as being equivalent for factors such as weed treatment effectiveness and weed treatment costs.

The sequence of crops and pastures may affect yields for the following reasons.

- A non-legume crop (wheat, barley or canola) grown after a legume (lupins, clover or cadiz) is expected to achieve a higher yield than if grown after a non-legume crop or volunteer pasture.
- It is expected that canola or lupins grown after a break of only one year (i.e., after a single year of wheat, barley or canola) will realise a lower than average yield due to the increased risk of disease occurring. The applicable yield penalty is specified in the **Crops & weeds** sheet.
- The set of available weed control options differs depending on the selected crops and pastures. This selection in turn has a bearing on the number of ryegrass seeds in the soil in autumn and the number of ryegrass plants setting seed in spring, resulting in varying levels of weed competition on crops and hence varying crop yields.

In RIM, it is assumed that the variety of canola is triazine-tolerant (TT canola). However, the user may assume a non-TT canola by imposing an appropriate chemical regime and making any necessary adjustments to yield.

Similarly, the parameters specified in the model for barley pertain to Unicorn barley. Even so, there is sufficient flexibility in RIM for the user to alter the parameters to represent a different variety. Weed control treatments and yields must be carefully changed to reflect the alternative barley variety selected.

The model has been designed to represent a farming system based on soil types suited to lupins. The price, yield, rotational impacts and competitiveness of lupins can be adjusted to approximate another legume crop if desired (e.g. field peas, chick peas, faba beans). The treatment options available to another legume using

this proxy approach is the same as that available for lupins. It is not possible to represent both lupins and another legume crop in a single model run in this version of RIM.

It is assumed in RIM that subterranean clover is self-regenerating with a cost for establishment included only if the interval between clover phases in the rotation is three years or greater. Cadiz pasture exists in the model as a representative of a new class of phase pasture species that is re-sown regularly (in the first year of any pasture phase) rather than regenerating naturally after a crop phase.

Tillage and machinery

It is assumed that a minimum tillage crop establishment system (one pass operation) is used. An autumn tickle is included as a control option and may be selected by the user.

Machinery costs are calculated on a per hectare basis and include purchase and repayment costs. The costs are only included if a strategy that requires the machinery is selected. The cost is then distributed across all 10 (or 20) years of the analysis. If special machinery is required for a treatment (e.g. seed catching), it is assumed that it is purchased new and repaid over a specified period – by default, 8 years. If the User wishes to include the purchase of second hand machinery, the purchase cost can be adjusted in the **Prices & rates** sheet.

Biological Equations

This chapter presents the biological equations entailed in the RIM model.

The biological equations in RIM are predominately used to determine the number of ryegrass plants per square meter, the quantity of ryegrass seeds per square meter and crop yields.

The key factors that drive the pattern of ryegrass population change over time include, initial ryegrass seed density in the soil, the timing of ryegrass seed germination relative to the crop, natural mortality of weeds and seeds, seed production per plant, impacts of weed and crop densities on seed production per plant and the timing and effectiveness of treatments to reduce weeds or seeds.

For the purpose of this model, the year is broken into seven periods: First rains of the growing season which allow crop sowing, seeding to 10 days later, 11 to 20 days after seeding, up to time of post-emergence herbicide application (if selected), post-emergence spraying to mid spring, mid spring to harvest, and harvest to opening rains of the next season.

Crop-related variables used in the equations include, standard weed-free yields for crops after a break of at least three years without a legume, yield boosts for cereals after legumes, canola or a pasture, yield effects on crops of green manuring and swathing, yield effects from disease in short rotations, seeding rates, savings in nitrogen fertiliser following lupins and pasture, impacts of delayed seeding on yield, parameters of the competition functions, phytotoxic effects of herbicides and some physical control measures on each crop.

RIM does not include detailed simulation of the population dynamics for each possible pasture species, so the biological impacts of a pasture phase on ryegrass populations are represented in a relatively simple way. For each type of pasture, the impact on ryegrass seed density under standard and high intensity grazing conditions is specified by the user. The standard reduction in weed seeds is greater in a second or third consecutive year of pasture because the non-ryegrass components of the pasture stand are denser and more competitive at these stages.

Weed control options

There are a total of 35 different weed control options included in the RIM model (Table 1). They can be broken into four separate groups: selective herbicides (11),

non-selective herbicides (5), non-herbicide treatments (16) and user-defined treatments (3).

Table 1. The weed control options included in the RIM model where N pertains to non-selective herbicide, S to selective herbicide, and B to “biological” treatment (non chemical).

Treatment	Type
1 Knockdown option 1 - glyphosate (Group M)	N
2 Knockdown option 2 - Spray.Seed (Group L)	N
3 2 knocks: glyphosate+Spray.Seed (Gr M&L)	N
4 Trifluralin (Group D)	S
5 Simazine® pre-emergence (Group C)	S
6 Atrazine pre-emergence (Group C)	S
7 Glean® pre-emergence (Group B)	S
8 Use high crop seeding rate	B
9 Seed at first chance (default)	B
10 Tickle, wait 10 days, seed	B
11 Tickle, wait 20 days, seed	B
12 Simazine post-emergence (Group C)	S
13 Atrazine post-emergence (Group C)	S
14 Glean® post-emergence (Group B)	S
15 Hoegrass® (Group A)	S
16 Fusilade® (Group A)	S
17 Select® (Group A)	S
18 Other Dim for lupins or canola (Group A)	S
19 Other selective herbicide	S
20 Grazing (selected automatically if pasture)	B
21 High intensity grazing winter/spring	B
22 Glyphosate top pasture (Group M)	N
23 Gramoxone® top lupins/pasture (Group L)	N
24 Green manure	B
25 Cut for hay, then glyphosate (Group M)	B
26 Cut for silage, then glyphosate (Group M)	B
27 Swathe	B
28 Mow pasture, then glyphosate (Group M)	B
29 User defined option A (Spring)	B
30 Seed catch - burn dumps	B
31 Seed catch - total burn	B
32 Windrow - burn windrow	B
33 Windrow - total burn	B
34 Burn crop stubble or pasture residues	B
35 User defined option B (at or after harvest)	B

Crops & weeds sheet

Unless otherwise stated, specified data in this sheet has been collected by talking to experts in industry or derived from the MIDAS model. Specific

references are recorded in the **Crops & weeds** sheet and can be found by scrolling to the right of the sheet.

Crop variables

The standard density (plants/m²) for each of wheat (PD_w), barley (PD_b), canola (PD_c) and lupins (PD_l) is based on the same formula. Using wheat as an example the PD_w (plants/m²) is determined using seeding rate (SR_w) (kg/ha), average kernel weight (KW_w) (mg) and expected plant establishment (E_w) (%).

$$PD_w = \frac{SR_w \times 10^2}{KW_w} \times E_w$$

According to J. Holmes (pers. comm.) the standard plant density for wheat is between 100 and 200 plants/m². Barley is expected to be slightly higher than wheat. P. Carmody (pers. comm.) estimates the density for canola to be between 83 and 117 plants/m² while J. Holmes (pers. comm.) expects lupins to be between 40 and 66 plants/m². Jarvis *et al.* (1991) expect 75 per cent of wheat seeds to establish successfully and the same could be expected for barley. P. Carmody (pers. comm.) estimates 50 per cent of canola seeds will become established while Nelson and Delane (1990) believe 85 per cent of lupin seeds will establish.

The last 8 variables in the "crop variables" table in the **Crops & weeds** sheet are based on figures derived from those working in the relevant fields and should only be changed with expert advice.

Phytotoxicity

The values for yield loss due to toxic effects of herbicides on crops have been supplied by David Bowran from the Department of Agriculture, Western Australia. The percentage estimates presented in the table in the **Crops & weeds** sheet can be altered if necessary.

Biological results sheet

Ryegrass plants per square meter

Germinated ryegrass seedlings at the time of the "break of season" (i.e., the first chance to seed) (G_{R0}) (plants/m²) are calculated by multiplying the number of viable ryegrass seeds per square meter just before the break of the season (R_{VS}) by the ryegrass germination prior to the first chance to seed (G_{PS}) (%).

$$G_{R0} = R_{VS} \times G_{PS}$$

The number of ryegrass plants per square meter that are present 10 days after the season break (G_{R10}) is calculated using the following formula.

$$G_{R10} = G_R \times WS_S + (R_{FS} \times G_{10})$$

where WS_S signifies the proportion of weeds surviving beyond day 0 (plants/m²) (which depends on the treatments selected in the **Select strategy** sheet), R_{FS} refers to the number of ryegrass seeds/m² that remained viable in the soil beyond the first chance to seed and G_{10} is the percentage of those viable seeds that germinate 1-10 days after the break (as specified in the **Crops & weeds** sheet).

The number of germinated ryegrass plants/m² alive at 20 days after the season break (G_{R20}) is found in much the same way as for those surviving 10 days after the break.

$$G_{R20} = G_{R10} \times WS_{S10} + (R_{10} \times G_{20})$$

where WS_{S10} is the proportion of plants/m² surviving beyond day 10 (found in the **Calcs** sheet), R_{10} refers to the number of ryegrass seeds/m² that remained viable in the soil beyond 10 days after the break and G_{20} represents the percentage viable seeds that germinate 11-20 days after the season break.

The user can specify that seeding occurs on day 0, 10 or 20. RIM simulates weed and seed numbers at each of these points in time, regardless of when seeding is specified to occur.

In the model, ryegrass seeds/m² at the time for post-emergent spraying (G_{RPS}) is found by:

$$G_{RPS} = G_{R20} \times WS_{S20} \times WS_{PE} + (R_{20} \times G_{CS})$$

WS_{S20} is the proportion of plants/m² surviving beyond day 20, WS_{PE} represents the proportion of plants/m² surviving pre-emergence treatments, R_{20} is ryegrass seed/m² 20 days after the break and G_{CS} is the additional percentage germination before in-crop spraying (that is, percentage germination of seeds remaining in the seed bank beyond day 20, not the percentage of the original seed bank) (**Crops & weeds** sheet).

Note that WS_{PE} captures the combined effect of pre-emergence treatments over all the time periods up to the time for post-emergence spraying. In reality, pre-emergence treatments would kill weeds in earlier time periods, but in RIM they are not removed from the population until this point in the simulation. This simplification has no impact on the results of the model, apart from it displaying higher than realistic weed densities in the first three time periods. It has no effect on yields or seed production.

The ryegrass plants/m² in early spring (G_{RES}) (i.e. the density of weeds surviving all treatments) is found using the following equation.

$$G_{RES} = G_{RPS} \times WS_{ET} + (R_{SPS} \times G_{AS})$$

where WS_{ET} is derived in the **Calcs** sheet and represents the plants/m² surviving post-emergent treatments. R_{SPS} is the ryegrass seeds/m² present at the time for post-emergent spraying and G_{AS} is the germination percentage of seeds remaining in the seed bank at that time (**Crops & weeds** sheet).

The number of ryegrass plants/m² when weeds are setting seed in September (G_{RSS}) is transferred to the **Select strategy** sheet as "ryegrass setting seed, Nov. (per m²)". It is calculated from G_{RES} as calculated above, ryegrass plants/m² surviving spring treatments (WS_{ST}) and weed proportion surviving grazing (W_{AG}) as derived in the **Calcs** sheet.

$$G_{RSS} = G_{RES} \times WS_{ST} \times W_{AG}$$

Ryegrass seeds per square meter

The figure derived for ryegrass seeds/m² just before the break of the season (R_{SBB}) for year one is transferred to the **Select strategy** sheet as "ryegrass seeds in soil, April (per m²)" and is taken from the **Crops and weeds** sheet (viable ryegrass seed in April, seeds/m²) for year 1. The ryegrass seeds/m² in the soil in April for each of the remaining years is equivalent to the previous year's ryegrass seeds/m² in the soil after summer (R_{SAS}) (as described below).

The ryegrass seeds/m² at the first chance to seed (R_{SFC}) take into account R_{SBB} as above and the germination percentage prior to first chance to seed (G_{PS}).

$$R_{SFC} = R_{SBB} \times (1 - G_{PS})$$

The ryegrass seeds/m² in the soil at 10 days after the break (R_{S10}) also considers the germination percentage but at 1-10 days after the break (G_{10}).

$$R_{S10} = R_{SFC} \times (1 - G_{10})$$

The germination percentage 11-20 days after the break (G_{20}) is included in the formula along with R_{S10} to calculate ryegrass seeds/m² remaining at 20 days after the season break (R_{S20}).

$$R_{S20} = R_{S10} \times (1 - G_{20})$$

The ryegrass seeds/m² at the time for post-emergence spraying (R_{PES}) is calculated using R_{S20} and the additional germination percentage after day 20 and before in-crop spraying (G_{BCS}).

$$R_{PES} = R_{S20} \times (1 - G_{BCS})$$

The effect of competition by the crop on ryegrass seed set (R_{SET}) (seeds/m²) is described by the following equation which has been adapted by Diggle from Maxwell, Roush and Radosevich (1990). Provision is made in the model to only include the parameters in this equation that are relevant to the specific strategies that are selected for a scenario.

$$R_{SET} = R_{MS} \times \left(\frac{1}{a + W_H + (c \times D)} + \frac{1}{a + W_H + f} \right) \times \frac{W_H}{G_{RES}} \times s$$

where R_{MS} is the maximum ryegrass seed production (seeds/m²/year), a is the ryegrass background competition factor (used to calculate base level of intra-species competition affecting ryegrass seed production), W_H is the healthy equivalent ryegrass plants/m² in spring, c is the competition factor of crop on ryegrass, D represents density of crop (plants/m²) and either refers to high density seeding or standard density depending on what is selected in the model, f is the competition effect of pasture on ryegrass (equal to the competition factor of wheat multiplied by an assumed wheat-equivalent pasture density), G_{RES} is the ryegrass plants/m² in early spring (as calculated previously) and s is the sub-lethal effect of selective herbicides resulting in lower seed production of surviving weeds.

Ryegrass seeds/m² present at spring time (R_{SS}) depend on the germination after in-crop sprays (R_{PES}) the additional germination percentage before in-crop sprays (G_{ACS}) and the natural mortality of dormant seeds during the season (M_S) (%) at the time for post-emergence spraying.

$$R_{SS} = R_{PES} \times (1 - G_{ACS}) \times (1 - M_S)$$

Spring-seed produced, R_{SP} (seeds/m²) is calculated by multiplying the number of seeds produced per plant, R_{SET} (derived above), by the ryegrass plants/m² setting seed in September (G_{RSS}) (see above).

$$R_{SP} = R_{SET} \times G_{RSS}$$

The ryegrass seeds/m² present just before harvest (R_{SBH}) is based on the parameters, spring-seed present (R_{SP}) and ryegrass seeds present at spring time (R_{SS}) as explained above.

$$R_{SBH} = R_{SP} + R_{SS}$$

The ryegrass seeds present after summer (R_{SAS}) (seeds/m²) can be calculated by:

$$R_{SAS} = [R_{SS} + (R_{SP} \times P_{SH})] \times (1 - M_{SS})$$

where, P_{SH} refers to the proportion of seeds surviving harvest as calculated in the **Calcs** sheet, and M_{SS} is the percent natural mortality of seeds over summer as in the **Crops & weeds** sheet.

Crop phytotoxicity

Phytotoxic damage occurs when a herbicide has adverse direct effects on a crop. This number feeds into the expected weed-free yield equations. The proportion of crop not phytotoxically damaged by a specific herbicide (P_{CND}) is

derived from the "phytoxicity" table in the **Crops & weeds** sheet and transferred to this table in the **Biological results** sheet.

Yields

In calculating the results displayed in the **Economics results** and **Biological results** sheets, we assume that the yields and the various impacts on yields (e.g. rotation, weed competition) remain constant over the whole 20 year time frame. This also applies to the gross margin results displayed near the top of the **Select strategy** sheet. This makes those results easy to relate to current circumstances. However, in reality, agricultural yields in Australia have shown clear upward trends in recent decades, and this seems likely to continue. For this reason we assumed that yields increase over time. The rate of increase is hard to predict, but over the long term is a very significant factor. In the standard RIM model the annual rate of yield increases is set to 1.0 percent for crops and 0.5 percent for sheep products. The latter value relates to production per hectare, not per sheep.

The **Biological results** sheet includes a number of possible adjustments to the standard weed-free yield.

- a percentage yield penalty for late sowing (depending on the seeding strategies selected in the **Select strategy** sheet and the relevant yield penalty as entered in the **Crops & weeds** sheet).
- a percentage yield penalty for not swathing barley/canola (taken directly from the **Crops & weeds** sheet).
- a percentage yield boost if green manuring is included in the previous year (from the **Crops & weeds** sheet).
- a yield boost when a cereal crop is grown after pasture or lupins. The expected weed-free crop yield (e.g. wheat, Y_{WFW}) (t/ha) is dependant on the crop position in the rotation i.e., the number of years it is grown after pasture or lupins. In Table 9 in the **Calcs** sheet, all of the yields for each possible rotation scenario are calculated. Depending on selections made in the **Select strategy** sheet, the appropriate yield is used in calculations in the **Biological results** sheet together with adjustments for yield penalties or boosts, to determine final weed-free crop yield. For wheat (YF_{WFW}) (t/ha), the equation is,

$$YF_{WFW} = Y_{WFW} \times (1 - YP_{LS}) \times (1 + YB_{GM}) \times D_P$$

where YP_{LS} refers to the percentage yield penalty for late sowing, YB_{GM} denotes the percentage yield boost from previous green manuring and D_P is the total proportion of crop not affected by phytotoxic damage.

Following the same reasoning as above, the final expected weed free yield for barley (YF_{WFB}) (t/ha) can be calculated. The only change is that for barley there may be a yield penalty for not swathing (YP_{NS}) (%).

$$YF_{WFB} = Y_{WFB} \times (1 - YP_{LS}) \times (1 - YP_{NS}) \times (1 + YB_{GM}) \times D_P$$

As there may also be a yield penalty for not swathing canola the equation to calculate final expected weed free yield for canola (YF_{WTC}) (t/ha) has the same structure as for barley.

$$YF_{WFC} = Y_{WFC} \times (1 - YP_{LS}) \times (1 - YP_{NS}) \times (1 + YB_{GM}) \times D_P$$

In the case of lupins, a yield penalty occurs when the break between lupin crops is only one year (YP_L) (%). There is also a yield penalty if lupins are sown into a burnt crop stubble (YP_B) (%).

$$YF_{WFL} = Y_{WFL} \times (1 - YP_{LS}) \times (1 - YP_L) \times (1 - YP_B) \times (1 + YB_{GM}) \times D_P$$

Depending on whether "use high seeding rate" is selected in the **Select strategy** sheet, either the relevant crop plant density corresponding to "standard density" or "high density" options in the **Crops & weeds** sheet is transferred into the **Biological results** sheet. The procedure is the same for finding the plant density (plants/m²) for wheat (PD_W), barley (PD_B), canola (PD_C) and lupins (PD_L). These parameters are used in the following equation.

The yield of a crop depends on the relative competitive abilities of that crop and of ryegrass, and the densities of each. The "proportion of weed-free yield with weeds" for each of the crops gives the proportion of the weed-free yield that is achieved after competition from weeds is accounted for. In the case of wheat, the proportion of weed-free yield with weeds (actual crop density) (PY_W) (plants/m²) is found using the following equation.

$$PY_W = \frac{1+a}{P_{OW}} \times \frac{PD_W}{a + PD_W + (f_{RCW} \times G_{RES})} \times M + (1-M)$$

where a is the background competition factor, P_{OW} is the standard wheat density (not actual density, a standard level for comparison) (plants/m²), f_{RCW} is the ryegrass competition factor in wheat and G_{RES} is the ryegrass plants/m² in early spring (as previously discussed). M is the maximum proportion of wheat yield lost at high weed densities.

The default value of M for all crops is 0.60, selected on the basis of statistical analyses of field trials. There are a wide range of values in the literature. Pannell (1990) analysed data from 14 field trials in Western Australia, New South Wales and Victoria, amounting to 339 data points. He estimated M to be 0.5436. Using the same data but a simplified statistical model Pannell (1995) then estimated M as 0.7525. Using data from a single field trial in Western Australia, Pannell and Gill (1994) estimated M to be as low as 0.29 using a relatively sophisticated statistical model, but 0.64 using a simple model. From this information, it appears that 0.6 is a reasonable "best-bet" value to use. The same equation is applicable for all crops but with the relevant parameters to each crop selected from either the **Biological results** or **Crops & weeds** sheets. For wheat in competition with annual ryegrass, the default values are as

follows: $P_{0W} = 100$, $M = 0.60$, $a = 5$, and $f_{RCW} = 0.33$. This competition function is similar to the widely used hyperbola of Cousens (1985) but is more flexible in that it allows representation of different crop densities.

Yield after weeds, haying, etc. for each of the crops can be calculated by multiplying the expected weed-free crop yield by the proportion of weed-free yield with weeds. Using wheat as an example, the yield after weeds, haying etc. (Y_W) (t/ha) is found by multiplying the aforementioned parameters YF_{WFW} and PY_W .

$$Y_W = YF_{WFW} \times PY_W$$

Note: the model adjusts yield to zero if the crop has been used for hay, silage or green manure.

If a crop is converted into hay or silage the following equation is used to estimate yield of hay (Y_{HW}) (t/ha) (using wheat as an example).

$$Y_{HW} = YF_{WFW} \times HI_W$$

where HI_W is the harvest index (for wheat). The harvest index figures were supplied by Wal Anderson, Agriculture Western Australia and are recorded in the **Crops & weeds** sheet. The equation for the other crops is the same as for wheat but with the relevant parameters substituted.

The yield of hay or silage made from ryegrass (Y_{HR}) (t/ha) is calculated using the following equation

$$Y_{HR} = \frac{R_{SS}}{R_{SKG}} \times \frac{1}{HI_R} \times 10$$

Where R_{SS} refers to the ryegrass seeds/m² present at springtime (as defined above), R_{SKG} is the number of ryegrass seeds per kilogram (**Crops & weeds** sheet). Note: the equation is multiplied by 10 to convert the answer from kg/m² to t/ha.

Pasture hay or silage can be produced from regenerated subterranean clover, cadiz serradella phase or volunteer pastures. Depending on the strategies selected, the appropriate hay yield is transferred from the Hay/Silage production table in the **Pasture** sheet to the **Biological results** sheet.

Economic Equations

This chapter outlines the economic equations used in the RIM model.

RIM highlights the importance of taking a long-term view on the economics of weed management by illustrating the potential for some long-term benefits from short-term economic sacrifices. Whether a preventative strategy provides long term economic benefits depends on several factors, including the cost of the strategy, its impact on weeds, prices of outputs and the initial weed seed density.

Taking a long-term view of economics is difficult due to such complexities as interest rates, tax and price and/or yield trends. Validly comparing costs and benefits that occur in different years and assessing the overall economics of a strategy for which the gross margin changes from year to year is a challenge. Economists and financial analysts use a standard “discounting” approach to assess long-term investments so that all costs and benefits are expressed in the equivalent of their present day value (Robison and Barry, 1996). The Net Present Value (NPV) for each strategy of interest can be determined by discounting and adding the costs and benefits of all strategies. The preferred strategy has the highest NPV.

It is common practice to equate the discount rate to the bank interest rate. In so doing the process is equivalent to identifying the strategy which would result in the highest bank balance at the end of the period given the assumption that all income is deposited in the bank account and accumulates interest, and all costs are withdrawn from the bank account so reducing interest earned. The “final bank balance” approach is the method used in RIM because realistic complexities that are often ignored in long-term financial analyses can be more easily incorporated.

Prices and rates sheet

The parameters in this sheet are either based directly on data obtained from various sources or derived from calculations based on this data. Derived data relies on the equations as described in the proceeding sections of this chapter.

Cost of fuel

The cost of fuel (assumed to be diesel) (C_D) (\$/L) is used in the model to calculate the cost of direct drill cultivation (C_{DD}), shallow cultivation (C_{DCU}), seed catching (C_{DSC}), cycloning (C_{DC}) and harvesting (C_{DH}). Oil and grease costs

are assumed to be negligible so are not included as individual costs. The cost of fuel depends on the quantity of fuel used for each operation (Q_D) (L/ha) as well as the price of diesel (P_D) (\$/L). The generic equation used to determine the cost of fuel (\$/ha) is:

$$C_D = Q_D \times P_D$$

Seed catching and cycloning operating costs

Seed catching and cycloning operating costs are calculated in the model. The operating costs for seed catching (C_{OSC}) (\$/ha) are found by multiplying the quantity of fuel required (Q_{DSC}) (L/ha) by the price of fuel (P_D) (\$/L) and adding in the repairs and maintenance of the machinery (RM_{SC}) (\$/ha).

$$C_{OSC} = Q_{DSC} \times P_D + RM_{SC}$$

By substituting the relevant figures for cycloning, the same equation can be used to determine operating costs for this activity (C_{OC}).

Repayment costs of machinery

The cost of using windrowing, seed catching and cycloning machinery is interpreted in the model as a yearly repayment for purchasing that machinery. The annual payment (PMT) (\$/ha) is calculated using a constant interest rate (r) (%), the purchase price of the machinery (P_M) (\$), a time period representing the expected life of the machine (t) (years) and the total area over which the machinery is used (A) (ha).

$$PMT = \left\{ r \times P_M \times \left[\frac{(1+r)^t}{(1+r)^t - 1} \right] \right\} \times \frac{1}{A}$$

Note, the model will calculate this cost for each of the machinery types for the life of the machine even if it is used only once in that time period.

Machinery and input costs for crops

The machinery and input costs for a crop include machinery maintenance costs (\$/ha) and the total cost of crop inputs (\$/ha). The machinery and input costs for wheat (C_{MIW}) (\$/ha) are calculated using the following equation.

$$C_{MIW} = RM_{DD} + RM_H + C_{DD} + C_{DH} + C_{IW} + C_{WCW} + C_{FW} + C_{SW} + C_{INW}$$

RM_{DD} refers to repairs and maintenance costs to machinery used for direct drill cultivation (\$/ha) and RM_H pertains to the same but for harvesting (\$/ha). The cost of diesel for direct drill cultivation (C_{DD}) (\$/ha), and for harvesting (C_{DH}) (\$/ha) are also included in this equation. The remaining parameters are described below.

For wheat the cost of insecticide (C_{IW}) (\$/ha) is derived from the following equation;

$$C_{IW} = C_{IOW} + C_A$$

where C_{IOW} is the cost of insecticide only (\$/ha) and C_A is the cost of application (\$/ha).

The cost of weed control (C_{WCW}) in a wheat crop (\$/ha) can be estimated by adding the cost of herbicide for broadleaf control (C_{WCO}) (\$/ha) and the cost of application (C_A) (\$/ha).

$$C_{WCW} = C_{WCO} + C_A$$

The cost of fertiliser (C_{FW}) (\$/ha) for a wheat crop is described by:

$$C_{FW} = [P_{PF} \times R_{PFW}] + [P_{UF} \times (R_{UFW} - NS_L - NS_P)]$$

where P_{PF} is the price of phosphate fertiliser (\$/t), R_{PFW} is the rate (t/ha) at which the phosphate fertiliser is applied, P_{UF} is the price of nitrogen fertiliser (\$/t), R_{UFW} is the rate at which nitrogen fertiliser is applied (t/ha), NS_L is the savings (t/ha) in nitrogen fertiliser in years following lupins and NS_P is the savings (t/ha) in nitrogen fertiliser after growing pasture.

In the model, the cost of seed is estimated but it could be derived using the following formula. In the case of wheat, the cost of seed (C_{SW}) (\$/ha) can be determined using the equation below where $(P_W - C_{RF} - C_T)$ is the opportunity cost of holding back the seed from sale.

$$C_{SW} = (P_W - C_{RF} - C_T) \times \frac{SR_W}{1000}$$

where P_W is the sale price of wheat (\$/t), C_{RF} is the cost of rail freight (\$/t), C_T is the transport cost (farm to receival point) (\$/t) and SR_W is the seeding rate for wheat (kg/ha).

In RIM, the cost of insurance, is calculated for each crop with the equation to determine insurance for a wheat crop, C_{INW} (\$/ha) presented below.

$$C_{INW} = WFY_{NLW} \times \left(\frac{I_{NRW}}{100} \right) \times (P_W - C_{RF} - C_T)$$

where WFY_{NLW} is the weed-free yield after a break with no legume (t/ha), I_{NRW} is the rate of insurance (hail and fire) for wheat (%), P_W is the price of wheat (\$/t), C_{RF} is the rail freight cost (\$/t) and C_T is the transport cost from farm to receival point (\$/t).

The equations for calculating the machinery and input costs for barley, canola and lupins are similar to those for wheat with the only difference being the

substitution of the relevant parameters for each crop. Note that the cost of lupin seed includes inoculation cost (C_{IC}) (\$/ha).

Cultivation can be used by farmers to stimulate weed germination and subsequently uproot and kill plants. Until recently, it was the predominant method of weed control. Currently in Western Australia, tillage referred to as "early tickle" or "a shallow cultivation" is used by many farmers. This has the effect of burying weed seeds to a depth of one to two centimetres, which enhances weed germination (Roberts, 1997). Seedlings that then germinate can be eliminated by the following cultivation. The effectiveness of cultivation is largely dependent on rainfall (Gill, Holmes and Kelly, 1994) to ensure adequate weed germination and hence weed control.

When seeding is delayed the extra cultivation cost (C_{CU}) (\$/ha), termed "extra cost of tickle" (shallow cultivation) in the model is calculated by:

$$C_{CU} = RM_{CU} + C_{DCU}$$

where, for shallow cultivation, RM_{CU} is the cost of repairs and maintenance of machinery (\$/ha), C_{DCU} is the cost of diesel (\$/ha).

Extra cost of high seeding rate

In the model there is an option for increasing the seeding rate. Using wheat as an example, the extra cost incurred from selecting this option (C_{HSRW}) (\$/ha) is calculated by:

$$C_{HSRW} = \left[(SR_{HW} - SR_W) \times \frac{1}{SR_W} \right] \times C_{SW}$$

where SR_{HW} is the high seeding rate (kg/ha), SR_W is the standard seeding rate (kg/ha) and C_{SW} is the cost of wheat seed (\$/ha).

Total input costs for volunteer, sub-clover and cadiz serradella pastures

In calculating the total input costs for pastures (C_{MIP}) (\$/ha), the equations are similar to those used for wheat except for the inclusion of a basic fixed operating cost for pasture (C_O) (\$/ha), termed "other cost" in the model. The remaining parameters are explained below.

$$C_{MIP} = C_O + C_{SPC} + C_{IC} + C_{IP} + C_{FP}$$

The cost of sowing pasture is only applicable for the year the pasture is sown. Volunteer pasture is never sown. Cadiz pasture is sown if it was not grown in the previous year. Clover pasture is sown if it was not grown in any of the previous three years. In the case of clover, the cost of sowing (C_{SPC}) (\$/ha) is calculated using the following equation:

$$C_{SPC} = SR_p \times P_C + RM_{DD} + C_{DD}$$

where SR_p is the pasture seeding rate (kg/ha), P_C is the price of clover seed (\$/kg), RM_{DD} is the cost of repairs and maintenance for direct drill (\$/ha) and C_{DD} is the cost of direct drill cultivation (\$/ha).

The cost of clover inoculum (C_{IC}) (\$/ha) can be calculated by multiplying the clover inoculation price (P_{IN}) (\$/kg of seed) by the seeding rate (SR_p) (kg/ha).

$$C_{IC} = P_{IN} \times SR_p$$

The cost of insecticide application to pasture (C_{IP}) (\$/ha) includes the cost of insecticide only (C_{IOP}) (\$/ha) and the cost of application (C_A) (\$/ha).

$$C_{IP} = C_{IOP} + C_A$$

The fertiliser cost for pasture (C_{FP}) (\$/ha) is simply the rate of application (R_{PFP}) (t/ha) multiplied by the price of fertiliser (P_{PF}) (\$/t).

$$C_{FP} = R_{PFP} \times P_{PF}$$

If sowing is delayed, the cost of "tickle" or shallow cultivation for pasture (C_{CUP}) (\$/ha) is simply added to C_{MIP} above.

$$C_{CUP} = RM_{CU} + C_{DCU}$$

where RM_{CU} is the cost of repairs and maintenance for shallow cultivation (\$/ha) and C_{DCU} is cost of diesel (\$/ha).

Control costs sheet

Herbicide costs

The generic equation for the cost of herbicide (\$/ha), C_H , is:

$$C_H = R_{HA} \times P_H + C_A$$

where R_{HA} is the rate at which the herbicide is applied (L/ha or kg/ha), P_H is the price of the herbicide (\$/unit) and C_A is the application cost. This equation is applied to all of the herbicide practices included in the model, these being:

- Glyphosate at sowing (knockdown option 1) C_{GL}
- Spray Seed[®] at sowing (knockdown option 1) C_{SP}
- Glyphosate + Spray Seed[®] (2 knocks) C_{GSP}
- Trifluralin C_{TR}
- Simazine C_{SM}
- Artizine pre-emergence C_{APE}
- Glean[®] (pre-emergence) C_{GPE}

- Simazine (post-emergence) C_{SAE}
- Artizine post-emergence C_{ATE}
- Glean[®] (post-emergence) C_{GAE}
- Hoegrass[®] C_{HG}
- Fusilade[®] C_{FS}
- Select C_S
- Other Dim for lupins or canola C_{DLC}
- Other selective herbicide C_{OH}
- Glyphosate crop top C_{GLT}
- Gramoxone[®] crop top C_{GRT}

Other costs

The cost of "use high crop seeding rate" is shown as the "extra cost of high seed rate" (C_{HSRW} in the case of wheat) that is presented in the table, "Crop inputs rates and per hectare costs" in the **Prices & rates** sheet.

A nominal cost is shown in the **Control costs** sheet for "Seed at first chance". Since sowing must occur anyway, the cost that would be attributable to weed control is very low or zero.

The cost of the option, "tickle, wait 10 days, seed" (C_{TW}) (\$/ha) is worked out by adding the extra cost of shallow cultivation (C_{CUW} in the case of wheat) (\$/ha) and the environmental cost of cultivation (C_{ECU}) (\$/ha), both of which are presented in the **Prices & rates** sheet.

Green manuring involves using shallow cultivation to plough the standing crop into the soil. This is done before the weeds set seed and so although it involves a loss in revenue, it is an effective method of weed control. The cost of green manuring (C_{GRW} , with wheat used as an example crop) (\$/ha), is specified simply as the cost of ploughing the standing crop (C_{DCU}) (\$/ha).

$$C_{GRW} = C_{DCU}$$

However, green manuring has an additional cost, shown only indirectly in RIM, which is the loss of crop yield that results. This cost is not included in the **Control costs** sheet but it is included as a reduction in receipts in the **Economics results** sheet.

Cutting a weedy crop for hay can greatly reduce ryegrass seed set. For good results hay should be cut before the weed has a chance to set seed (Gill, Holmes and Kelly, 1994). The cost of producing hay from a wheat crop, for example (C_{CHW}) (\$/ha), is calculated using a similar equation to that for green manuring based on the added costs (\$/ha) of hay baling (C_{HB}) and glyphosate crop topping (C_{GLT}) to clean up any surviving weeds.

$$C_{CHW} = C_{HB} + C_{GLT}$$

Converting a crop into silage reduces weed seed set to a greater degree than cutting it for hay because the crop/pasture is cut earlier and therefore the weeds have less opportunity to set seed. The cost of producing silage from, for example, a wheat crop (C_{CSW}) (\$/ha) is calculated in the same way as for hay, except that it is based on the cost of cutting silage (C_{Si}) (\$/ha).

$$C_{CSW} = C_{Si} + C_{GLT}$$

The cost of swathing (C_{Sw}) (\$/ha) is based on the cost of fuel and repairs and maintenance to the tractor and swather. For simplicity the cost in the model is based on a contract price.

Mowing is used as a weed control option in pasture only and involves cutting all the plants above a certain height before they set seed and then crop topping with glyphosate. In so doing, the taller ryegrass plants are selected over the improved pasture species and the smaller plants are removed by the herbicide. The cost of mowing pasture (C_M) (\$/ha) is calculated using a contracted mowing rate as specified in the **Prices & rates** sheet (C_{MD}) (\$/ha) and the additional cost of a follow-up application of crop topping with glyphosate (C_{GLT}).

$$C_M = C_{MD} + C_{GLT}$$

The cost of the "user defined option A" (C_{UA}) (\$/ha) is specified by the user.

Due to the negative effect that burning has on the soil, most farmers have removed the burning option from their program apart from selective targeted use. However, herbicide resistance has forced some farmers to rethink this option as part of an overall plan for managing resistance. The results of burning are dependent on paddock use and the quality and distribution of fuel available for the fire. When stubble is grazed, the effectiveness of a burn is decreased because the animals' hooves bury the seed into the soil shielding it from the heat (Davidson, 1992). Grazing the stubble also means there is less fuel available for an effective burn. Trials run by the Department of Agriculture suggest up to 80% of the viable seed can be destroyed by fire (Gill, Holmes and Kelly, 1994). In this model, the cost of burning crop residues (C_B) (\$/ha) is set at a level that is meant to represent the labour cost of supervising the fire to ensure that it does not spread out of control.

The number of ryegrass seeds reaching the soil can be reduced when the crop is harvested. Towing a cart behind a harvester to catch chaff that is released from the back of the machine stops some ryegrass seeds returning to the soil. Once the cart is full, the contents can either be dumped in a heap and burnt, or removed from the paddock (Stewart, 1993).

Seed catching costs (C_{SC}) (\$/ha) combined with burning the dumps can be calculated by:

$$C_{SC} = C_{OSC} + PMT_{SC} + C_{FR}$$

where C_{OSC} is the seed catching operating costs (\$/ha), PMT_{SC} is the seed catcher repayment (\$/ha) and C_{FR} is the cost of supervising the fire when burning dumps/windrows (\$/ha).

When there is a total burn (rather than just burning windrows or dumps), degradation to the environment, such as that caused by erosion, may result and incur a cost. RIM allows the user to specify this environmental cost of burning, C_{EB} (\$/ha). If the whole paddock is burnt and not only the dumps, seed catching costs (C_{SCB}) (\$/ha) are calculated by substituting C_{EB} for C_{FR} .

The only cost associated with windrowing and burning the windrow (C_{WB}) (\$/ha) is the cost of managing the fire risk from burning (C_{FR}) (\$/ha). As with seed catching if the whole paddock is burnt, the cost of windrowing (total burn) (C_{WTB}) (\$/ha) is C_{EB} instead of C_{FR} .

The cost of "user defined option B" (C_{UB}) is specified by the user.

Economic results sheet

Receipts

Crop gross receipts (R) (\$/ha) are the returns before production costs have been deducted for all crops grown and are calculated by summing receipts derived from wheat (R_W), barley (R_B), lupins (R_L), and/or canola (R_C) (all parameters have the unit, \$/ha).

$$R = R_W + R_B + R_L + R_C$$

Receipts for each crop (\$/ha) are calculated in a similar way. Using wheat as an example, receipts are found by multiplying the relevant yield (Y_W) (t/ha) by the net price, which is the sale price (P_W) (\$/t) minus the cost of transport from farm to receival point, (C_T) (\$/t) and the cost of rail freight, (C_{RF}) (\$/t).

$$R_W = Y_W \times (P_W - C_T - C_{RF})$$

Hay gross receipts (R_H) (\$/ha) include the return from wheat hay, barley hay, canola hay, lupin hay and summer pasture hay.

$$R_H = P_{HAY} (Y_{HW} + Y_{HB} + Y_{HC} + Y_{HL} + Y_{HP})$$

where P_{HAY} is the price of hay (assuming all hay sells for the same price) (\$/t), Y_{HW} is wheat hay yield (t/ha), Y_{HB} is barley hay yield (t/ha), Y_{HC} is canola hay yield (t/ha), Y_{HL} is lupin hay yield (t/ha) and Y_{HP} is pasture hay yield (t/ha).

The equation for silage gross receipts (R_S) (\$/ha) uses the same yield parameters as for hay but with the price of hay replaced by that of silage (P_S) (\$/t).

$$R_S = P_S (Y_{HW} + Y_{HB} + Y_{HC} + Y_{HL} + Y_{HP})$$

Pasture/livestock gross receipts (R_p) (\$/ha) is found by multiplying the stocking rate (S_{RATE}) (DSE/ha) by the gross margin for sheep (GM_s) (\$/DSE),

$$R_p = S_{RATE} \times GM_s$$

Grazing is differentiated into sustainable grazing, high intensity grazing and grazing in conjunction with cutting hay. The gross margin for sheep is used in the equation to reduce the complexity that could be associated with modeling a sheep enterprise. While this gross margin includes a deduction for the production costs of sheep it excludes costs specific to pastures, which are accounted for separately.

The total receipts (TR) (\$/ha) is an aggregate of each of the enterprise receipts as described above.

$$TR = R + R_H + R_S + R_p$$

Expenses

In RIM the total non-weed-control cost (TC_{NW}) (\$/ha) is the sum of production costs for wheat, barely, lupins and canola crops. Non-weed-control costs consist of figures for total machinery and input costs taken from the **Prices & rates** sheet.

The total pasture production cost depends on the pasture enterprise used (volunteer, cadiz phase, or regenerated subterranean clover pasture) and takes the relevant total input cost figures directly from the **Prices & rates** sheet.

Total weed control cost (TC_w) (\$/ha) comprises of non-selective and selective herbicide costs (as identified under herbicide costs above) as well as non-herbicide weed control costs and environmental costs. If a particular herbicide treatment is not selected in the **Select strategy** sheet, the cost for that treatment is zero. Depending on the herbicide strategies selected in the **Select strategy** sheet, the model allocates the appropriate herbicide costs from the **Control costs** sheet to the **Economic results** sheet.

$$TC_w = C_{GL} + C_{SP} + C_{GSP} + C_{TR} + C_{SM} + C_{APE} + C_{GPE} + C_{SAE} + C_{ATE} + C_{GAE} + C_{HG} + C_{FS} + C_S + C_{DLC} + C_{OH} + C_{GLT} + C_{GRT} + C_{HSR} + C_{TW} + C_{GR} + C_{CH} + C_{CS} + C_{SW} + C_M + C_{UA} + C_{SC} + C_{SCB} + C_{WB} + C_{WTB} + C_{SWP} + C_B + C_{UB}$$

All of the parameters are defined in the Appendix, and all are explained above in the section describing the **Control costs** sheet, except for C_{SWP} , the seedcatch/windrow machinery purchase (\$/ha). The repayment costs are defined in the description in the **Prices & rates** sheet, "1) Repayment costs of machinery", and are included in the **Economics results** sheet if the age of the machine is still within the loan repayment period.

The total variable input cost (TVC) (\$/ha) is found by summing the total non-weed control costs and the total weed control costs.

$$TVC = TC_{NW} + TC_W$$

Net returns

To calculate the net returns (NR) (\$/ha) the total variable costs are subtracted from the total receipts. The net return for each year is transferred into the **Select strategy** sheet as the "gross margin".

$$NR = TR - TVC$$

Results that allow for inflation, interest and tax

The inflation rate on sale prices in agriculture has historically been lower than the inflation rate on input purchase prices. This is commonly referred to in Australia as the "cost-price squeeze" and in North America is recognised as the cause of the "farm problem". It is the reason why farmers have had to improve their productivity levels in order to remain in business. In RIM it is assumed that this trend will continue for the time being so the inflation rate set on crop and sheep product prices is lower than the assumed inflation rate on input costs.

Consistent with the approach used in relation to increasing production trends, most of the results in RIM do not allow for inflation. The ones that do are (a) the "Average" annual profit values near the top of the **Select strategy** sheet, (b) a table of receipts, costs, interest and tax labelled "Results that allow for inflation, interest and tax" near the bottom of the **Economic results** sheet, and (c) just below that table, results for "Final balance", "Equivalent opening balance" and "Equivalent annual profit". The equivalent annual profit is the same as the "Average" annual profit in (a). In finance jargon, it is an annuity. The description below relates to (b) and (c).

In the table referred to above in (b), crop gross receipts (R) (\$/ha) are adjusted for an increase in potential crop yield (I_{CY}) and inflation for crop sale prices (I_{CP}) while pasture gross receipts (R_p) are adjusted for an increase in sheep/pasture productivity (I_{SP}) and inflation for sheep product prices (I_{SPP}). The model bases figures for these parameters on the "rates of price and yield increase" table in the **Rates & prices** sheet. Therefore total adjusted gross receipts (TR_A) can be calculated by:

$$TR_A = (R + R_H + R_S) \times I_{CY} \times I_{CP} + (R_p \times I_{SP} \times I_{SPP})$$

Total variable costs are adjusted (TVC_A) (\$/ha) by allowing for inflation for input costs (I_{IC}).

$$TVC_A = TVC \times I_{IC}$$

Interest received (I) (\$/ha) in Year 1 is zero. From Year 2 onwards for any one year, it is based on the product of the long-term interest rate (r) as in the "rates

of price & yield increase" table in the **Prices & rates** sheet, and the running total balance at the end of the previous year.

Tax is paid on interest earned. In RIM, the tax system is represented simply, because there is so much variability between farmers in their tax arrangements. RIM allows the user to specify a single marginal tax rate, which should be the rate of tax he or she would pay on any additional income earned above current income.

Tax costs (T) (\$/ha) are based on the marginal tax rate (MTR) (%) as specified in the "rates of price & yield increase" table in the **Prices & rates** sheet. For any one year, i ,

$$T_i = MTR \times (TR_i - TVC_i + I_i)$$

In year 1, the running total (RT_1) (\$/ha) is the addition of the adjusted gross receipts (TR_{A1}) and interest (I_1), minus the adjusted costs (TVC_{A1}) and tax (T_1) for that year. In all other years the running total for the previous year (RT_{i-1}) is added to the equation.

$$RT_1 = TR_{A1} - TVC_{A1} + I_1 - T_1$$

$$RT_i = TR_{Ai} - TVC_{Ai} + I_i - T_i + RT_{i-1}$$

The final balance after 10 years (FB_{10}) (\$/ha) is the running total in year 10. This is used to calculate the equivalent opening balance (EOB_{10}) (\$/ha). If a bank account began in year 1 and earned interest at a rate r (minus tax, MTR) over 10 years, the EOB_{10} would be the opening balance that would give the FB_{10} .

$$EOB_{10} = FB_{10} \times \left(\frac{1}{1 + r \times (1 - MTR)} \right)^{10}$$

The equivalent opening balance is the same as the "net present value" concept as used by economists.

If it was possible to earn a constant profit per hectare per year over 10 years, the equivalent annual profit (EAP_{10}) (\$/ha) is an annual amount that would result in the FB_{10} , after allowing for interest and tax.

$$EAP_{10} = \left\{ r \times (1 - MTR) \times EOB_{10} \times \left(\frac{(1 + r)^{10}}{(1 + r)^{10} - 1} \right) \right\} \times \left(\frac{1}{1 - MTR} \right)$$

We use the PMT function in Excel, which uses the parameters EOB , N (number of years) and r . When no allowance is made for tax and interest, the formula is used as follows,

$$EAP = PMT(r, N, EOB)$$

However, in Rim, where we do make allowances for tax and interest, the formula used is

$$EAP = PMT(r \times (1 - MTR), N, EOB) \times \left(\frac{1}{1 - MTR} \right)$$

This is equivalent to the complex looking equation given above.

The value of EAP_{10} is transferred into the **Select strategy** sheet as the "average annual profit (\$/ha/yr) years 1-10".

The final balance after 20 years (FB_{20}) (\$/ha), the equivalent opening balance for 20 years (EOB_{20}) (\$/ha) and the equivalent annual profit (EAP_{20}) (\$/ha) are calculated as for the 10 year time period.

The Calcs Sheet

*This chapter provides a descriptive explanation of the workings within the **Calcs** sheet hidden in RIM.*

The **Calcs** sheet is hidden in the RIM model as its major role is to convert parameters from some sheets into appropriate forms for use in other sheets. It also deals with selected strategies ensuring that only relevant calculations for those strategies are completed and form part of the results. The information in this sheet is presented in tables and will be described accordingly.

The first table is used to determine if each weed control option, order and use of crops in rotation, seeding time and other producer practices selected by the user are logical and acceptable. Information from this table is transferred into the **Select strategy** sheet to generate either "OK" or "Error" messages.

Each enterprise is allocated a number for use throughout the **Calcs** sheet. Enterprises consist of wheat, barley, canola, lupins, volunteer pasture, regenerated subterranean clover pasture and cadiz serradella phase pasture. Table 2 indicates which weed control treatments have been selected by the user by displaying the enterprise number for that year in each selected treatment row. Treatments that are not selected are blank.

Table 3 shows the proportion of weeds surviving each selected control practice and is dependant upon enterprise information from Table 2 and the percentage reduction in current ryegrass or seed numbers for each treatment as displayed in the **Control %** sheet. The details in this table are use in Table 5 as described below.

Costs of each selected control practice are shown in Table 4 based on enterprise information from Table 2 above and the cost of the relevant ryegrass control treatments from the **Control costs** sheet. This information is fed directly into the "Expenses" section in the **Economic results** sheet.

Table 5 details the proportion of weeds surviving all treatments (tillage, herbicide and/or harvesting) and is based on data from Tables 2 and 3 above. The results are transferred into the **Biological results** sheet to calculate the ryegrass plants/m² in each of the time periods represented. The proportion of seeds surviving harvest as calculated in this table is also used in calculating ryegrass seeds per m² after summer (**Biological results** sheet).

The proportion of weeds remaining after grazing is calculated in Table 6 and is contingent upon whether the enterprise was devoted to normal or high intensity grazing as selected in the **Select strategy** sheet. Depending then on the type of pasture, the proportion of weeds killed is selected from data in Table 9 as described below. This data is derived directly from either the "ryegrass mortality" table or the "ryegrass mortality - high intensity grazing" table in the **Pastures** sheet.

Estimates for healthy equivalent weeds per m² for ryegrass germinating at different times are presented in Table 7. They are calculated using the figures derived in the **Biological results** sheet ("ryegrass plants per m²"), relevant figures from Table 5 as outlined above and from ryegrass variables and competitive indices for ryegrass found in the **Crops & weeds** sheet.

Table 8 records the enterprises selected and codes then for use in other tables depending on how the enterprise is used in the rotation. There are 98 different enterprise codes combining enterprises and rotations. Information is used in other tables in the **Calcs** sheet and elsewhere in sheets where data input into specific cells depends on the enterprise and/or rotation.

Table 9 records the weed free crop yield, crop sale price, weeds killed in pasture, stocking rate, stocking rate at high density, stocking rate if hay is cut and nitrogen saving from legumes for each of the 98 enterprise codes in Table 8. This information is used in the **Biological results** sheet in calculating weed-free yield and in other tables in the **Calcs** sheet.

The crop sale prices (\$/t) for wheat, barley and canola for each of the relevant years that each crop is produced are presented in Table 10. The table relies on data presented in Table 9 (as described above) that has been derived from grain sale prices shown in the **Prices & rates** sheet. This information is transferred into equations for grain gross receipts in the **Economic results** sheet.

The yield figures calculated for wheat, barley, canola and lupin hay in the **Biological results** sheet are allocated to the relevant years of production in Table 11. The production of pasture hays presented in the **Pasture** sheet is similarly allocated. This information is used in equations to calculate hay and silage gross receipts in the **Economic results** sheet.

Production costs in terms of tillage, harvest and pest control are displayed in Table 12. The production cost for lupins is transferred from the "Crop input rates and per hectare costs" table in the **Prices & rates** sheet into this table if lupins are grown in the year in question. Likewise for wheat, barley and canola, the equivalent cost is transferred from Table 14 to this table but with savings in nitrogen fertiliser deducted from the cost. Production costs for pasture are transferred from the total inputs calculation (**Prices & rates** sheet) and placed in the table according to pasture grown and number of years of consecutive growth for each year that it is grown. Data from Table 12 is used in the **Economic results** sheet to calculate non-weed control costs for grain and pasture.

Table 13 details the cost of re-sowing regenerating clover pasture if it is required. If this cost is applicable it is included in the production costs for regenerating clover pasture in Table 12 as explained above.

Table 15 displays the returns for pasture for each year in which pasture is selected as an enterprise. It takes into account the strategies for grazing, the stocking rate (as calculated in Table 9 above) and the sheep gross margin (as calculated in the **Prices & rates** sheet). The total pasture returns from this table are transferred directly into the "pasture/livestock gross receipts" line in the **Economic results** sheet.

Machinery costs are collated in Table 16. If seed catching or windrowing are selected in the **Select strategy** sheet it is assumed that machinery will be required and will incur repayment costs as calculated in the **Prices & rates** sheet. This translates to the cost of machinery (\$/ha) for each year that repayments are required. The cost for each year is transferred directly into the "seed/catch windrow machinery purchase" row of the **Economic results** sheet.

Table 17 presents the inflation figures for each year based on the "rates of price and yield increase" in the **Prices & rates** sheet. These figures are used to inflate the annual "gross receipts" and "costs" in the "results that allow for inflation, interest and tax" in the **Economic results** sheet.

Yield penalty for late sowing in Table 18 simply shows the penalty for late sowing depending on the crop and number of days (10 or 20) that sowing was delayed. These figures are used to calculate the "yield penalty for late sowing" in the **Biological results** sheet.

Competition functions showing yields at standard and high crop densities for varying levels of weed density are calculated in Table 19 using data from the **Crops & weeds** sheet and a series of weed density levels from 0 to 1,000. These figures are used to generate the **Charts** that show the effect of weed density on wheat, barley, lupin and canola yields at standard and high crop densities.

Adding a New Treatment

Should you wish to add a new treatment option, the procedure is outlined in this chapter.

The procedure to add a new treatment option in RIM is not difficult but does require care to ensure that all sheets in the workbook have been altered accordingly. The following instructions describe the order that the steps should be followed to ensure that the formulae correspond to the correct labels and errors do not appear.

When making such substantial changes as the following, always keep a copy of the unedited version and work on a renamed copy.

Instructions in italics are specific to RIM version 99 and would be somewhat different in RIM 2002.

1. Insert a row into the **Select strategy** sheet at the appropriate position. It is important to make a note of where you place this row because when you insert rows into other sheets as instructed later, they must all correspond. Insert all required labels and formatting in accordance with the rest of the sheet. You may find it easier to simply copy another row into that row to ensure that the formatting (colours, borders, protection) are correct. Update the treatment number in column A and renumber the treatments below it to ensure that all numbers in this column are now in numerical order.
2. Insert a new row into the appropriate position in the **Control costs** sheet. Do not forget to update the numbers in column A. You will need to enter new formulae in this row but before you can do so you may need to add new information in the **Prices and rates** sheet to represent the costs. Please note that volunteer pasture and legume pasture in the **Control costs** sheet are in opposite columns in the **Prices and rates** sheet. So if you are copying formulae by copying and pasting then you must check that your formulae are correct.
3. Insert a new row into the appropriate position in the **Control %** sheet. Put in values for "weeds killed or seeds removed/prevented (%)". Update the numbers in the first column.
4. Insert a new row into the **Compatibility** sheet so that it corresponds to the other new rows that you have entered. Enter either 1 for "yes" or 0 for "no" to

indicate what treatments that can be used on what enterprises. Update the formatting and the numbers in column A.

5. Maintaining consistency with the previous rows inserted elsewhere in the workbook, insert a new row into Table 1 of the **Calcs** sheet. Copy formulae into this row from the row above. *Be careful when copying the formula into years 11 and above because these formula refer to cells in the **Select strategy** sheet and there is a blank column in that sheet after year 10.* To ensure that the formulae that check compatibility work, you must have updated the treatment numbers in column A.
6. You may need to update the error checking that is done below Table 1 (depending on the nature of your added treatment).
7. Insert a new row into the appropriate position in Table 2 of the **Calcs** sheet. Select the row above or below and copy it into your new row. Check to make sure that the copying allows for the space after column 10 in the **Select strategy** sheet. Update the treatment numbers in column A.
8. Insert a new row into the correct space in Table 3 of the **Calcs** sheet. Do not forget to update the numbers in column A, including the ones below the row that you have just inserted. Again, select and copy the row above or below into your newly inserted row. Then scroll across to the right of Table 3 to the "HLOOKUP table for control percentages" and copy the formulae from the cells in the row above or below your inserted row and paste them in your new row.
9. Insert a new row into the corresponding row in Table 4 of the **Calcs** sheet. Copy the formulae into the new row from the row above or below. Remember to update the treatment number in column A.
10. Insert a new row into the "Expenses" section of the **Economic results** sheet. The formulae that you copy into this row will reference cells from the **Calcs** sheet. As the top of this section contains non-weed control costs that are not included in reference tables in the **Calcs** sheet, it is easy to copy cells incorrectly. Therefore you should check that the formulae that appear in the new row correspond to the correct cells in the **Calcs** sheet.
11. Update Table 5, "Proportion of weeds surviving beyond different time periods" in the **Calcs** sheet. Include the survival percentage for the new treatment in each of the appropriate rows for the time period when it would be used. Remember to copy across the entire row. *Don't forget that if a cell refers to a reference in the **Select strategy** sheet, then you need to allow for the column gap between years 10 and 11.*
12. Update all macros as needed. You may firstly have to unprotect the macros by going into the Microsoft® visual basic editor and entering the password. The CopyYear macro, activated by selecting the grey "Copy year" button in the **Select strategy** sheet, copies all of the treatments you have selected for a year.

In the CopyYear macro, update the following lines to reflect the appropriate ranges to copy:

```
Set r2 = Range(Cells(9, YearToCopy), Cells(16, YearToCopy))
```

```
Set r3 = Range(Cells(18, YearToCopy), Cells(27, YearToCopy))
```

```
Set r4 = Range(Cells(29, YearToCopy), Cells(43, YearToCopy))
```

It is the numbers in the "Cells" function that you need to update. So if you inserted a row into Row 12 then the changes that you would make would be: 16 to 17, 18 to 19, 27 to 28, 29 to 30 and 43 to 44.

You then need to make the same changes to the macro "Paste year" in these rows:

```
For Rw = 9 to 16
```

```
For Rw = 18 to 27
```

```
For Rw = 29 to 43
```

In the same way, update the macros for the grey "Blank all" button by changing the "ClearSheet" macro to correct the following ranges:

```
Range("C9:W16").Select
```

```
Range("C18:W27").Select
```

```
Range("C29:W43").Select
```

Do NOT go to the **Select strategy** sheet and select to *restore a saved strategy* or *save a strategy for later* until you have adjusted the macro for that purpose. If you do, you may end up overwriting important equations. Instead you must first go in and change the macros. In the macro sheet, find the macro RestoreStrategy and edit it. Change the ranges to correspond with the appropriate ranges in the **Select strategy** sheet. Scroll down to RestoreStrategy1 and change the ranges so that they correspond to the appropriate ranges for Strategy 1 in the **Strategies** sheet. Change the remaining RestoreStrategyN macros. Using the "search and replace" command for text can speed this procedure up, but you need to be very careful not to replace something you shouldn't, especially in another part of the macro module. Follow the same procedure for the SaveStrategy macros. Remember to start with the long version first.

Before you return to the **Select strategy** sheet, to test your edited macros you MUST go to the **Strategies** sheet (usually hidden in RIM) and select "Edit", "Clear", "All".

Only then should you return to the **Select strategy** sheet. So that you do not lose formulae and formatting, firstly go to *Save a strategy for later* and click on each button for the "save" strategies 1 to 5. By completing this procedure you avoid the risk that you will restore a set of data that doesn't line up with the place it's supposed to go into.

To ensure the "Print this page (years 1-10)" button in the **Select strategy** sheet prints the correct range, adjust the print range in the macro "Print10". That is, change "Range("A1:L67").Select" to the correct range. Likewise change the range "Range("A1:W67").Select" for the "Print20" macro.

13. *If the additional treatment is a herbicide you will need to change the TestHerbUsage macro so that it's label turns grey when the specified number of herbicide "shots" are used up. You may also need to adjust some of the named ranges referred to by that macro. (Note that in RIM version 2002, you would instead adjust the conditional formatting in the **Select strategy** sheet. There is no conditional formatting in RIM 99).*
14. In the **Crops and weeds** sheet you will need to check if your new herbicide is represented in the "Phytotoxicity" section and if not you will have to insert a new row with the appropriate levels. This being the case you would then have to go to the **Biological results** sheet and insert an appropriate row and formulae to correspond with your new herbicide.
15. If the additional treatment is a herbicide you will need to link it into the "checking herbicide shots" on the **Select strategy** sheet. Scroll right, across to column Y ("Time used") and then go down to the blank cell that corresponds to the new herbicide. Copy the cell above down into this cell. Check that this formula adds up the number of shots used for that herbicide.

Scroll back to the left of the sheet and go down to the table "Number of uses of herbicide groups before weeds are mainly resistant". In the grey column ("Used") only change the formula in the cell that is relevant to the new herbicide, e.g., if the new herbicide was in Group A, you would go to the corresponding cell in the "Used" column and include the "Y" reference for the herbicide in the formula.

To ensure that you have completed all of the changes required, you may like to run RIM with a strategy that includes the new treatment and check that the output is logical.

Procedure to Create a Version for Public Release

The password on all aspects of RIM99h is “syt”.

(a) Things to check in the development version before converting it into a release version

1. Check that all auditing arrows are removed.
2. Check that all cells with blue text are not locked but that all others are.

(b) To save

1. Read the completed development version into Excel.
2. Save As the latest version of the model into a new file.
3. Run the ProtectAll macro (the workbook has to be unprotected for this).
4. Check that the visual basic code is password protected. To do this, run the visual basic editor (Alt-F11) and select Tools|Project properties (the last item in the menu)|Protection, tick the little box and enter the password into the two bottom boxes.
5. Work through each visible sheet, unprotect it, and then protect it with the password. Leave Select strategy protected but without a password for now.
6. Protect the workbook with password.
7. Select Title sheet, cell A1.
8. Save the file.

Chapter

8

The Procedure to Convert Standard RIM to Workshop RIM

1. “Blank all” in **Select strategy** and save it as the strategy to all 12 strategies.
2. Hide the columns for years 11 to 20.
3. Delete the button: “View years 11-20”
4. Add these tables to Start here

	Wheat	Barley	Canola	Peas	Vol. Pasture	Legume pasture
Kill rates						
Trifluralin (Group D)	90%	90%	90%	90%		
Crop/pasture top Gramoxone®				75%	80%	80%
Seed catch - burn dumps	60%	60%	60%	60%		
Burn crop stubble/pasture residue	20%	20%	20%	20%	20%	20%
Standard seeding rate (kg/ha)	50	60	5	100		
High seeding rate (kg/ha)	80	100	7	130		
Yield penalty - sowing delayed 10 days	10%	5%	12%	0%		
Yield penalty - sowing delayed 20 days	20%	10%	30%	5%		

5. Grey out those variables in the later sheets, protect them and include notes that they are “From Start here sheet”.

Scope of RIM and Contact Details

This Chapter explains the capacity of RIM and gives contact details if you need further information about RIM or herbicide resistance.

The following is a series of explanations describing RIM's capacity to solve problems associated with the management of herbicide-resistant annual ryegrass. Understanding the scope of RIM is important for interpreting the results derived from the model.

RIM will not automatically calculate which strategy is “best”. Users evaluate strategies using experimentation and “trial and error”.

RIM does not represent year-to-year variation in weather, potential yield or herbicide performance. Yields in the model do vary from year to year due to the sequence of crops and pastures selected, and the level of weed competition. Climatic conditions do not rule out any of the treatment options. Users can self-impose constraints on the use of different treatments.

Some strategies may involve changes in machinery or livestock management that have impacts at the whole-farm level. However, as RIM represents only a single field the model does not automatically allow for such changes. Similarly, RIM makes particular assumptions about the way that investments in machinery are financed. Therefore it may be appropriate to consider the whole-farm cash flow implications of strategies outside of RIM before making adoption decisions based on output from this model.

Despite considerable effort being expended on data collection, it is inevitable in such a comprehensive model that there will be areas where the available information is not strong. Sensitivity analysis as described by Pannell (1997) is an important approach for evaluating the significance of data deficiencies. A related issue is the variation in biological and economic parameters that occur between farms. The values included in the standard version of RIM are representative of a typical farm in a region of Western Australia, but need adjusting for other farm types and for other regions. Users can readily alter the parameter values to suit their particular situation.

Contact details for information pertaining to RIM

To purchase RIM, for information about RIM and for technical information related to herbicide resistance and weed management, contact The Western Australian Herbicide Resistance Initiative (WAHRI)

WAHRI
Faculty of Natural and Agricultural Sciences
The University of Western Australia
35 Stirling Hwy
Crawley WA 6009
Phone (08) 9380 7870
Email: wahri@agric.uwa.edu.au
Web site: <http://wahri.agric.uwa.edu.au>

For technical information related to herbicide resistance and weed management, advice on using RIM effectively and advice on running RIM workshops, contact Vanessa Stewart.

Vanessa Stewart
Dryland Research Institute
Agriculture Western Australia
Merredin WA 6415
Phone (08) 9081 3111
Email vstewart@agric.wa.gov.au

To suggest improvements, changes, or to report bugs in the RIM software, or for advice particularly related to the software, contact David Pannell.

David Pannell
C/- Agriculture Western Australia
Albany WA 6330
Phone (08) 9892 8495
Fax (08) 9844 8659
Email David.Pannell@uwa.edu.au

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Appendix: Key to Variables used in Equations

Variable	Data Name	Units
a	Ryegrass background competition factor	constant
A	Total area on which machinery is used	ha
c	Competition factor on ryegrass	constant
C_A	Cost of herbicide or insecticide application	\$/ha
C_{APE}	Cost of Atrazine pre-emergence	\$/ha
C_{ATE}	Cost of Atrazine post-emergence	\$/ha
C_B	Cost of burning crop stubble or pasture residues	\$/ha
C_{CHW}	Cost of cutting hay (wheat)	\$/ha
C_{CSW}	Cost of cutting silage (wheat)	\$/ha
C_{CU}	Extra cost of shallow cultivation	\$/ha
C_{CUP}	Shallow cultivation cost - pasture	\$/ha
C_{CUW}	Shallow cultivation cost - wheat	\$/ha
C_D	Cost of diesel fuel	\$/ha
C_{DD}	Cost of diesel (direct drill)	\$/ha
C_{DH}	Cost of diesel (harvest)	\$/ha
C_{DC}	Cost of diesel (cycloning)	\$/ha
C_{DCU}	Cost of diesel (shallow cultivation)	\$/ha
C_{DLC}	Cost of other Dim for lupins or canola	\$/ha
C_{DSC}	Cost of diesel (seed catching)	\$/ha
C_{EB}	Environmental cost of burning	\$/ha
C_{ECU}	Environmental cost of cultivation	\$/ha
C_{FW}	Cost of fertiliser (superphosphate & urea) (wheat)	\$/ha
C_{FP}	Cost of fertiliser (pasture)	\$/ha
C_{FR}	Cost of fire risk from burning dumps or windrows	\$/ha
C_{FS}	Cost of Fusilade [®]	\$/ha
C_{GAE}	Cost of Glean [®] (post-emergence)	\$/ha
C_{GL}	Cost of Glyphosate at sowing (knockdown option 1)	\$/ha
C_{GLT}	Cost of Glyphosate crop top	\$/ha
C_{GPE}	Cost of Glean [®] (pre-emergence)	\$/ha
C_{GRW}	Cost of green manuring (wheat)	\$/ha

Variable	Data Name	Units
C_{GRT}	Cost of Gramoxone® crop top	\$/ha
C_{GSP}	Cost of Glyphosate + Spray Seed® (2 knocks)	\$/ha
C_H	Cost of herbicide	\$/ha
C_{HB}	Cost of hay baling	\$/ha
C_{HG}	Cost of Hoegrass®	\$/ha
C_{HSRW}	Extra cost of high seeding rate (wheat)	\$/ha
C_{IC}	Total cost of inoculation of legume pasture or lupins	\$/ha
C_{INW}	Cost of insurance (wheat)	\$/ha
C_{IOP}	Cost of insecticide only (pasture)	\$/ha
C_{IOW}	Cost of insecticide only (wheat)	\$/ha
C_{IP}	Cost of insecticide including application (pasture)	\$/ha
C_{IW}	Cost of insecticide including application (wheat)	\$/ha
C_M	Cost of mowing (total)	\$/ha
C_{MD}	Cost of contract mowing	\$/ha
C_{MP}	Machinery & input costs - pasture	\$/ha
C_{MIW}	Machinery & input costs - wheat	\$/ha
C_O	Fixed operating cost for pastures	\$/ha
C_{OH}	Other selective herbicide	\$/ha
C_{OSC}	Operating costs for seed catching	\$/ha
C_{OC}	Operating costs for cycloning	\$/ha
C_{RF}	Cost of rail freight	\$/t
C_{SW}	Cost of seed (including dressing/cleaning etc) (wheat)	\$/ha
C_S	Cost of Select	\$/ha
C_{SAE}	Cost of Simazine (post-emergence)	\$/ha
C_{SC}	Cost of seed catching	\$/ha
C_{SCB}	Cost of seed catching - total burn	\$/ha
C_{Si}	Cost of cutting silage	\$/ha
C_{SP}	Cost of Spray Seed® at sowing (knockdown option 1)	\$/ha
C_{SPC}	Cost of sowing pasture (clover)	\$/ha
C_{SM}	Cost of Simazine	\$/ha
C_{Sw}	Cost of swathing	\$/ha
C_{SWP}	Cost of seed catch/windrow machinery purchase	\$/ha
C_T	Cost of transport (farm to receival point)	\$/t
C_{TR}	Cost of Trifluralin	\$/ha

Variable	Data Name	Units
C_{TW}	Cost of tickle, wait 10 days, seed	\$/ha
C_{UA}	Cost of User Defined Option A	\$/ha
C_{UB}	Cost of User Defined Option B	\$/ha
C_{WB}	Cost of windrowing (burn windrow)	\$/ha
C_{WCO}	Cost of herbicide only for broadleaf weed control	\$/ha
C_{WCW}	Cost of broadleaf weed control (wheat)	\$/ha
C_{WTB}	Cost of windrowing (total burn)	\$/ha
D	Density of seeding	plants/m ²
D_P	Crop not phytotoxically damaged	proportion
EAP_{10}	Equivalent annual profit (10 years)	\$/ha
EAP_{20}	Equivalent annual profit (20 years)	\$/ha
EOB_{10}	Equivalent opening balance for 10 years	\$/ha
EOB_{20}	Equivalent opening balance for 20 years	\$/ha
E_W	Expected plant establishment (wheat)	%
f	Competition factor of pasture on ryegrass	constant
f_{RCW}	Ryegrass competition factor in wheat	constant
FB_{10}	Final balance after 10 years	\$/ha
FB_{20}	Final balance after 20 years	\$/ha
G_{10}	Ryegrass germination 1-10 days after break	%
G_{20}	Ryegrass germination 11-20 days after break	%
G_{ACS}	Additional germination before in-crop spaying	%
G_{AS}	Germination after in-crop spraying	%
G_{BCS}	Additional germination before in-crop sprays	%
G_{CS}	Additional germination before in-crop spraying	%
GM_S	Gross margin for sheep	\$/DSE
G_{PS}	Ryegrass germination prior to the first chance to seed	%
G_{R0}	Germinated ryegrass seedlings at the "break of season"	plants/m ²
G_{R10}	Germinated ryegrass plants 10 days after season break	plants/m ²
G_{R20}	Germinated ryegrass plants 20 days after season break	plants/m ²
G_{RES}	Ryegrass plants in early spring	plants/m ²
G_{RPS}	Ryegrass seeds at time for post-emergent spraying	seeds/m ²
G_{RSS}	Ryegrass plants setting seed in September	plants/m ²
HI_W	Wheat harvest index	constant
I	Interest received	\$/ha

Variable	Data Name	Units
I_{CP}	Inflation for crop sale prices	proportion
I_{GY}	Potential crop yield increase	proportion
I_{IC}	Inflation for input costs	proportion
I_{NRW}	Rate of insurance (hail and fire) (wheat)	%
I_{SP}	Increase in sheep/pasture productivity	proportion
I_{SPP}	Inflation for sheep product prices	proportion
KW_W	Average kernel weight - wheat	mg
M	Maximum yield lost at high weed densities	proportion
MTR	Marginal tax rate	%
M_S	Natural mortality of dormant seeds during the season	%
M_{SS}	Natural mortality of seeds over summer	%
NR	Net returns	\$/ha
NS_L	Savings in nitrogen fertiliser from growing lupins	t/ha
NS_P	Savings in nitrogen fertiliser from growing pastures	t/ha
P_C	Clover seed price	\$/kg
P_{CND}	Crop not phytotoxically damaged by a specific herbicide	proportion
P_D	Price of fuel (diesel)	\$/L
PD_B	Plant density - barley	plants/m ²
PD_C	Plant density - canola	plants/m ²
PD_L	Plant density - lupins	plants/m ²
PD_W	Plant density - wheat	plants/m ²
P_H	Price of herbicide	\$/unit
P_{HAY}	Price of hay	\$/t
P_{IN}	Price of clover inoculation	\$/kg of seed
P_M	Purchase price of machinery	\$
PMT	Yearly repayment on machinery	\$/ha
PMT_{SC}	Yearly repayment on seed catcher	\$/ha
P_{OW}	Standard wheat density	plants/m ²
P_{PF}	Price of superphosphate fertiliser	\$/t
P_S	Price of silage	\$/t
P_{SH}	Proportion of seeds surviving harvest	\$/t
P_{UF}	Price of nitrogen (urea) fertiliser	\$/t
P_W	Price of wheat (standard - not after a legume)	\$/t
PY_W	Actual crop density (wheat)	plants/m ²

Variable	Data Name	Units
Q_D	Quantity of diesel fuel used	L/ha
Q_{DCU}	Quantity of diesel used : shallow cultivation	L/ha
r	Long term interest rate	%
R	Crop receipts	\$/ha
R_{10}	Ryegrass seeds 10 days after the break	seeds/m ²
R_{20}	Ryegrass seeds 20 days after the break	seeds/m ²
R_B	Barley receipts	\$/ha
R_C	Canola receipts	\$/ha
R_{FS}	Ryegrass seeds at first chance to seed	seeds/m ²
R_H	Hay receipts	\$/ha
R_{HA}	Rate of herbicide applied	L or kg /ha
R_L	Lupin receipts	\$/ha
R_{MS}	Maximum ryegrass seed production	seeds/m ² /yr
RM_{CU}	Machinery R&M : shallow cultivation	\$/ha
RM_{DD}	Machinery R&M : direct drill	\$/ha
RM_H	Machinery R&M : harvest	\$/ha
RM_{SC}	Machinery R&M : seed catch	\$/ha
R_P	Pasture/livestock receipts	\$/ha
R_{PES}	Ryegrass seeds at time for post-emergence spraying	seeds/m ²
R_{PP}	Rate of superphosphate fertiliser (pasture)	t/ha
R_{PFW}	Rate of superphosphate fertiliser (wheat)	t/ha
R_S	Silage receipts	\$/ha
R_{S10}	Ryegrass seeds 10 days after the break	seeds/m ²
R_{S20}	Ryegrass seeds 20 days after the break	seeds/m ²
R_{SAS}	Ryegrass seeds present in the soil after summer	seeds/m ²
R_{SBB}	Ryegrass seeds just before break of season	seeds/m ²
R_{SBH}	Ryegrass seeds present just before harvest	seeds/m ²
R_{SET}	Effect of competition by crop on ryegrass seed set	seeds/m ²
R_{SFC}	Ryegrass seeds at the first chance to seed	seeds/m ²
R_{SKG}	Number of ryegrass seeds	seeds/kg
R_{SP}	Ryegrass seed produced in spring	seeds/m ²
R_{SPS}	Ryegrass seeds present at time for post-emergent spraying	seeds/m ²
R_{SS}	Ryegrass seeds at spring time	seeds/m ²
R_T	Running total receipts	\$/ha

Variable	Data Name	Units
R_{UFW}	Rate of nitrogen (urea) fertiliser (wheat)	t/ha
R_{VS}	Viable ryegrass seeds just before season break	seeds/m ²
R_W	Wheat receipts	\$/ha
s	Sublethal effect of selective herbicides on seed production of surviving weeds	constant
SR_{HW}	High seeding rate of wheat	kg/ha
SR_P	Pasture seeding rate	kg/ha
SR_W	Wheat seeding rate (standard)	kg/ha
S_{RATE}	Stocking rate	DSE/ha
t	Expected life of machinery	years
T	Tax costs	\$/ha
TC_{NW}	Total non-weed control costs	\$/ha
TC_W	Total weed control costs	\$/ha
TR	Total receipts	\$/ha
TR_A	Adjusted total receipts	\$/ha
TVC	Total variable input costs	\$/ha
TVC_A	Adjusted total variable input costs	\$/ha
W_{AG}	Weeds remaining after grazing	proportion
WFY_{NLW}	Weed-free yield (after a long break with no legume) (wheat)	t/ha
W_H	Healthy equivalent weeds in spring	plants/m ²
WS_{ET}	Weeds surviving post-emergent treatments	plants/m ²
WS_{PE}	Weeds surviving pre-emergence treatments	plants/m ²
WS_S	Weeds surviving seeding at day 0	plants/m ²
WS_{S10}	Weeds surviving seeding at day 10	plants/m ²
WS_{S20}	Weeds surviving seeding at day 20	plants/m ²
WS_{ST}	Weeds surviving spring treatments	plants/m ²
YB_{GM}	Yield boost from previous green manuring	%
YF_{WFB}	Final weed-free barley yield	t/ha
YF_{WTC}	Final weed-free canola yield	t/ha
YF_{WTL}	Final weed-free lupin yield	t/ha
YF_{WFW}	Final weed-free wheat yield	t/ha
Y_{HB}	Barley hay/silage yield	t/ha
Y_{HC}	Canola hay/silage yield	t/ha
Y_{HL}	Lupin hay/silage yield	t/ha

Variable	Data Name	Units
Y_{HP}	Pasture hay/silage yield	t/ha
Y_{HR}	Ryegrass hay/silage yield	t/ha
Y_{HW}	Wheat hay/silage yield	t/ha
Y_{PB}	Yield penalty if lupins are sown into burnt crop stubble	%
Y_{PL}	Yield penalty when break is only one year	%
Y_{PLS}	Yield penalty for late sowing	%
Y_{PNS}	Yield penalty for not swathing	%
Y_W	Wheat yield after weeds, haying etc	t/ha
Y_{WFB}	Weed-free barley yield	t/ha
Y_{WFC}	Weed-free canola yield	t/ha
Y_{WTL}	Weed-free lupin yield	t/ha
Y_{WFW}	Weed-free wheat yield	t/ha