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Seed contamination of sheep by barley grass (*Hordeum spp.*) in southern Australia: Livestock production and economic interactions

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Certain grass weeds produce seeds which penetrate wool and body tissue of grazing sheep, resulting in significant welfare and economic impacts. The efficacy of weed control strategies for mitigating impacts in lamb production systems has remained unknown. This research uses a bioeconomic modelling approach to simulate seed contamination and weed management impacts on productivity in lambs grazing infested lucerne pasture. Results indicate optimal

weed management strategies within livestock production systems and areas requiring further research.

Abstract.

Context. Barley grass (*Hordeum* spp. L.) is a pervasive annual grass weed of southern Australian crops and pastures, producing seeds that contaminate sheep carcasses and, causing weight loss and discounts at processing of impacted meat and wool. Previous modelling of barley grass control highlighted effective control strategies for reducing seed banks in lucerne over ten years. However, the impacts of weed management strategies on the productivity of lamb enterprises grazing pastures of varying infestation levels currently remain unknown. **Aims.** This study assessed the capacity of a ex-ante bioeconomic modelling approach to simulate the impacts of variable barley grass seed contamination and weed control strategies on the profitability and productivity of weaned lambs grazing a barley grass-infested lucerne pasture in southern Australia. **Methods.** A bioeconomic model was developed by incorporating a barley grass population model, a livestock growth model (incorporating impacts of seed contamination) within an economic framework to simulate impacts of weed control strategies applied to the barley grass population. Control strategies were activated in the model at various weed densities to investigate differences in lamb production and were simulated over a ten-year period to identify optimal weed control strategies. **Key results.** Simulating the absence of barley grass control demonstrated incursion of large losses ($793/ha) to the lamb production system over ten years. Economic returns tended to remain highest under integrated management scenarios at lower weed densities ($\leq$ 50 seedlings/m^2). Maximum profitability could be attained through strategies targeting weed fecundity, particularly at the lowest weed density (5 seedlings/m^2). **Conclusions.** Integrated management of barley grass produced the greatest economic benefit at low weed densities when control targeted seed production. The simulation of repeated mowing constrained the barley grass infestation and shows promise as a non-chemical practice for reducing seed contamination in sheep. Further field studies and development of associated model relationships will facilitate further substantiation of model outputs. **Implications.** Results highlight the potential for combined model frameworks to determine economic consequences of weed management in livestock grazing systems and to identify optimal strategies that maximise livestock health, welfare and production. **Keywords:** weed, simulation, herbicide, mowing, bioeconomic modelling, infestation, carcass

Introduction

Barley grass (*Hordeum* spp. L.) is a pervasive annual grass weed of Mediterranean origin, widely distributed across southern Australia's agricultural zone (Cocks et al., 1976; Llewellyn et al., 2016). Dense infestations of barley grass often inhabit degraded lucerne stands, due to reduced competition by lucerne plants and high soil nutrient conditions associated with legume production (Groves et al., 2003). Despite the valuable forage afforded by juvenile plants in grazed pastures, barley grass seed is considered a significant threat to animal welfare and a carcass contaminant of sheep grazing these pastures later in the growing season (Kelly et al., 2020). Penetration of body tissues by mature seeds can produce skin abscesses and significant discomfort, leading to reduced foraging behaviour (Dodd, 1919). Seed penetration of eyes, mouth and gums also limits feed intake and weight gain in grazing sheep (George, 1972; Hartley and Bimler, 1975).

Historically, herbicides have been used against barley grass populations and for managing barley grass seed contamination in sheep (Hartley and Atkinson, 1972, 1973; Hartley et al., 1974). Non-chemical tactics, such as grazing or mowing, are also effective in reducing barley grass seed production (El-Shatnawi et al., 1999; Hartley et al., 1978; Smith, 1968), while the combination of herbicides and mowing defoliations also show promise for control as an integrated weed management (IWM) strategy (Kelly et al., 2020). Economic considerations typically influence the decision of farmers to engage in innovative agricultural approaches such as IWM (Pannell and Schilizzi, 2006). Within an uncertain and dynamic decision-making environment, such interactions can be evaluated using bioeconomic modelling, where biological and economic components are combined within a model framework (Pannell et al., 2004; Kragt, 2012). Current models exist which simulate weed dynamics

(Pannell et al., 2004, Kelly et al., 2023) and daily livestock production (Freer et al., 1997; Moore et al., 1997), while other models have assessed the financial impact of weed seeds on carcass value at the processing level (Smith, 2014). Despite the existence of these models, no models exist that combine all these components to assess whether it is possible to simulate the impacts of weed seed contamination and associated weed control strategies on livestock production from infested pastures.

The current study explores the development of this concept, integrating a previously developed barley grass model (Kelly et al., 2023) with a novel bioeconomic model framework to investigate weed management outcomes in a trade lamb enterprise simulation in southern NSW. The model is designed to specifically simulate the biophysical and economic impacts of barley grass seed contamination in lambs grazing an infested lucerne pasture, demonstrating the potential to identify optimal weed control strategies to maximise economic outcomes. The objectives of this research were to: 1) develop an integrated bioeconomic model that could facilitate the simulation of production and health impacts of weed populations on livestock in a grazing system, and 2) determine the capacity of such a model to identify optimal weed management strategies for improved lamb enterprise productivity and profitability in a weed-infested pasture scenario at various weed densities under southern Australian conditions.

Model Description

Overview

The combined model (entitled the Barley Grass Seed Contamination Model, or BGSC) is comprised of three submodels (Fig. 1) using Microsoft Excel 2013 (ver. 15.0.5153.1000; Microsoft, Redmond, WA, USA) as the modelling platform: 1) the barley grass population submodel, adapted from, and described in detail by Kelly (2020) and Kelly *et al.* (2023), implemented over a 10-year planning horizon with stochastic climate interactions; 2) a simplified lamb enterprise submodel, which calculates annual livestock production , and 3) an economic submodel that calculates annual and aggregated economic returns over the simulation horizon. Daily pasture data was extracted from the simulation of a barley grass-infested lucerne paddock using the decision support tool, GrassGro™ (Moore et al., 1997), to parameterise the barley grass submodel. The data was used to simulate the impact of species competition and climate variability on daily pasture growth, weed seed production and botanical composition in different years (Kelly *et al.*, 2023). GrassGro™ derived pasture data sets were subsequently used by the livestock submodel to simulate daily weight gain using the biomass and feed quality values. Modelled inflorescence density within the barley grass submodel was connected to the livestock model using field study data to generate an empirical relationship between barley grass inflorescences and feed intake suppression. This was incorporated into the livestock submodel to influence the simulated daily weight gain of grazing sheep (refer to supplementary material), and the quality and value of livestock outputs (meat and skin) at different weed densities. The inclusion of simulated weed control impacts and costs within the barley grass submodel, associated GrassGro™ pasture simulation data and livestock product quality attributes and prices, were combined to facilitate an *ex- ante* economic assessment of the impact of seed contamination on lamb production within the economic submodel. This was expressed as the Net Present Value (NPV) over a 10-year planning horizon.

Insert Fig 1 here

Model assumptions

This study is the first attempt at modelling the process and impacts of seed contamination in sheep. Several assumptions therefore underpin the BGSC model. Those used within the barley grass population submodel are reported by Kelly *et al.* (2023). Those specific to the BGSC include:

- The BGSC model is currently a conceptual model, simulating alternative scenarios at a field scale – therefore outputs in relation to livestock production and economic value are not to be treated as absolute in the current study.
- The BGSC model is deterministic in relation to price risk, not representing annual variation in price, costs or herbicide efficacy.
- Sheep are considered to be second cross weaned lambs, grazing the pasture from weaning (1st September) to sale (31st December). Equations modelling livestock growth are based on Freer *et al.*, (1997). Wool and reproductive

performance parameters are not included due to sheep age and the focus on sheep meat production.

- For computational simplicity the more complex GrassGro™ functions related to animals selectively grazing from different digestibility pools were not included in this *ex-ante* modelling (Freer et al., 2012).
- The effect of seed contamination on sheep is expressed in the model through reduced liveweight gains due to feed intake suppression. This empirical approach is underpinned by research that has shown seed injury reduces grazing mobility, and subsequently feed intake and weight gain (Hartley, 1976; Hartley and Bimler, 1975). Seed impacts on production due to secondary health effects or seed position within animals are not explicitly included.

Pasture data

Pasture data was required on a daily time step to include the effects of climate variability within each simulated year on botanical composition and seed production (described by Kelly *et al.*, 2023). It was also required by the livestock submodel equations to generate parameters such as relative intake, rate of eating and relative time spent grazing (Freer *et al.,* 1997). Daily green dry matter digestibility, total available herbage mass, pasture growth rates, species composition, barley grass senescence dates and biomass loss rates were inputs to the livestock submodel with years randomly selected through a Monte Carlo simulation process. To facilitate the ability to vary stocking rates, total daily available herbage mass was calculated within the livestock submodel at a daily time step, and thus only required the initial biomass value from the GrassGro™ simulation of the pasture on day 1, which itself represented the 20-year mean state of pastures at that time of year. The calculation of herbage mass on subsequent days (B_t) was as follows:

$$B_{t+1} = B_t + PG_{t+1} - BL_{t+1} - (HI_{t+1} \text{ x } SR_{t+1}) \quad (1)$$

where $t + 1$ was the current day and t was the day prior. PG_{t+1} was pasture growth rate (kg DM/ha), BL_{t+1} was biomass loss rate, HI_{t+1} was herbage intake and SR_{t+1} was stocking rate on the current day.

Pasture data required by livestock submodel equations, as extracted from yearly GrassGro™ outputs, are defined in Table 1.

Insert table 1 here

Although grazing typically influences pasture (and subsequent livestock) growth, the pasture data sets generated in GrassGro™ (used as inputs within the livestock model) were simulated under ungrazed conditions, to facilitate consistency with the earlier development conditions of the barley grass model (Kelly et al., 2023). Although feedback interactions may exist between pasture growth and subsequent livestock growth, these were expected to be minimal given the stocking rates used and seasons being modelled, and that using ungrazed conditions facilitated the ability to focus on connecting the models and integrating the new empirical seed contamination relationship. Further, simulating a grazed pasture under different stocking rates would have required a significantly more complex dynamic systems modelling approach, preferably at a whole farm scale, which was beyond the scope of the current field-scale modelling and potentially is an important focus for future research.

Livestock submodels

Livestock submodels are comprised of equations and parameters used in simulating the growth of second-cross weaner sheep within the GrassGro™ animal model, as described by Freer et al. (1997), and were replicated for each year of the ten-year simulation horizon. However, for the purposes of this *ex-ante* analysis, simplifications were made to the functions described by Freer et al. (2012) to exclude the potential impacts of selective grazing for determining relative intake and the assumption that animals are thermoneutral. Within each year of the ten-year simulation, there was a random selection from all of the available GrassGro™ simulated years to embed climate risk and its impact on pasture variability. The livestock submodel operates on a daily time step to simulate livestock growth occurring between weaning (1^{st} September) to sale (31st December). Initial and final live weights, and levels of skin and carcass contamination obtained from the livestock submodel, were exported to the economic submodel to facilitate determination of carcass and skin values. The livestock model parameters which varied from the default values of the GrassGro™ animal model are described in Table 2.

Insert table 2 here

Derivation of Intake suppression: linking barley grass seed production to livestock growth

The relationship between annual barley grass inflorescence density and live weight loss in sheep during the simulated grazing period was a crucial and novel development linking the barley grass and livestock submodels within the BGSC model framework. In searching the available literature, findings from a 1969 field study conducted in Trangie NSW, Australia (referred to herein as "the Trangie study", Campbell et al., (1972)) were the only data found describing this relationship. GrassGro™ was used to replicate the conditions of the experiment, so that the impact of barley grass inflorescence density on livestock weight gain, and specifically the impact on feed intake suppression (I_S), could be simulated at the stocking rates supplied in the field study. The detailed description of the derivation of intake suppression is available in the supplementary material.

The empirical relationship between daily intake suppression (I_S), as generated by the Trangie study model simulations, and the associated inflorescence densities used to derive them, were modelled using non-linear regression and parameterised using Matlab Software (release R2019a) (Mathworks, 2019). A non-rectangular hyperbola (Johnson, 2008) was found to best fit the data (R^2 = 0.999, RMSE = 0.004519) and was fixed through zero, since zero inflorescences would be expected to correspond to zero intake suppression in practice. The function generated *the Intake Suppression Factor*,

(I_{SF}), in relation to barley grass inflorescence density, as generated by the barley grass submodel for the year type selected. The *Intake Suppression Factor* was given by:

$$I_{\mathrm{SF}} = \frac{1}{2b}\left(ax + 1 - \left((ax+1)^2 - 4abx\right)^{1/2}\right) \quad (2)$$

where *x* was barley grass inflorescence density/400cm^2, *a* and *b* are constants, where *a* = 0.0522 and *b* = 0.9773, and I_{SF} varies between 0 and 1.0 (Fig. 2).

Insert Fig 2 here

From Freer et al. (1997), the final herbage intake within the livestock model was given by:

$$I_{herb} = I_{max} \cdot I_{\mathrm{r}}$$

(3)

where I_{herb} was actual intake of herbage, I_{max} was maximum daily intake and I_{r} was relative intake of herbage (Freer et al., 1997). The intake suppression factor was used as an additional input within the livestock submodel to modify equation 3, thereby reducing herbage intake to influence weight gain as follows:

$$I_{herb} = I_{max} \cdot I_{\mathrm{r}} \; (1 - I_{\mathrm{SF}}) \quad (4)$$

The modification from equation 3 to 4 was triggered to coincide with the start date of barley grass seed desiccation simulated within the model, since this event typically coincides with intake suppression and weight loss in sheep grazing barley grass infested pastures (Hartley, 1976; Hartley and Bimler, 1975). Start dates for barley grass seed desiccation were obtained from the yearly GrassGro™ pasture outputs and varied between years depending on seasonal conditions.

The economic sub model

The economic submodel calculated the value of weight gain in livestock and all costs associated with barley grass control, as influenced by annual barley grass inflorescence density, and resultant seed contamination in sheep. Discounted annual net cash flows are summed to calculate net present value (*NPV*) over the ten-year simulation horizon. Net cash flow in each year was determined by subtracting total control costs, livestock costs and initial livestock purchase value from total livestock income for the set stocking rate. NPV was calculated as follows:

$$NPV = \sum_{t=0}^{T} \frac{\pi_t\ (C_t, F_t, L_t, SR_t)}{(1+i)^n}$$

(5)

where *T* was the simulation period (10 years), π_t was the measure of net cash flows in year *t* as a function of control costs (C_t); feeding costs (F_t), livestock costs (L_t) and stocking rate in DSE/ha (SR_t), *n* was the number of years in the simulation period and *i* was the discount rate (set at 5%, a figure considered typical for Australian livestock producers).

Net cash flow – livestock income

To determine livestock income, skin and carcass values can be estimated in relation to seed contamination. This considers the relationship between barley grass inflorescence density in the pasture, resulting fleece seed density and final skin mark density variables, which determines skin and carcass price discounts (Smith, 2014). Data encompassing each of these variables were provided by Atkinson and Hartley (1972) as the only available data for generating these relationships within published literature. A strong linear relationship existed between pasture inflorescence density and seed density within the fleece (R^2 = 0.991, RMSE = 0.650, $F_{1,2}$ = 226.9, Fig 3a), as such:

$$FSD = 2.3308\, I + 1.7586$$

(6)

where *FSD* was fleece seed density, and *I* was barley grass inflorescence density/ha. Secondly, the relationship between fleece seed density and skin mark density was required to determine the degree of total tissue damage. Hartley and Atkinson (1972) reported a declining trend in skin mark density as fleece seed density reached a maximum, potentially due in reality to seed loss from the fleece before processing, or as a result of a potential barrier generated in the fleece due to increasing levels of vegetable matter, thereby preventing further seeds reaching the skin (Warr & Thompson, 1976). Despite the lack of clarity around this relationship, the integrity of these field observations within the model was preserved by fitting a quadratic function to the data (R^2 = 0.998, RMSE = 0.088, $F_{1,2}$ = 310, Fig 3b):

$$PM = -0.0363\mathrm{x}^2 + 1.0508 FSD - 1.5452$$

(7)

where *PM* was the number of barley grass pelt marks per skin and *FSD* was the number of barley grass seeds per fleece. Within the model, these relationships provided the closest quantifiable estimation of the level of seed contamination expected in grazing sheep across the simulation horizon in relation to annual barley grass inflorescence density values, as generated by the barley grass submodel.

Insert figure 3a here

Insert figure 3b here

Carcass value

Hot standard carcass weight (hereafter referred to as carcass weight, *CWT* in kilograms) was determined in the model as follows:

$$CWT = LWT_{FINAL} \cdot DP \quad (8)$$

where LWT_{FINAL} was the final live weight (kg) output generated from livestock submodels, and DP was an average lamb dressing percentage of 45%. Long term average monthly nominal lamb prices (c/kg) for three carcass weight classes (*light lamb 12 – 18 kg, trade lamb 18 – 22 kg and heavy lamb ≥ 22 kg*) between the years of 2000 and 2017 were used were converted to real prices (c/kg CWT) using consumer price index data (ABARES, 2017) with 2018 as the base year.

The real average monthly carcass price (c/kg CWT) for each weight class in December (*RP_{DEC}*) was then used and averaged over the five-year period from 2013 to 2017. Final carcass value each year was determined as follows:

$$CV = CWT \cdot RP_{DEC} \quad (9)$$

where CV was carcass value ($/carcass), CWT was final carcass weight (kg) and RP_{DEC} was real average monthly carcass price (c/kg CWT).

To determine the level of seed-induced carcass price discount, the skin mark density, as determined from Equation 8, was used to generate values associated with low, medium or heavy contamination. Since there was no data available to predict the correlation between seed density in the fleece and carcass tissue, Equation 8 was considered as the closest representation. Contamination category boundaries were determined from an industry abattoir model developed for the assessment of carcass seed contamination during processing (Smith, 2014). Contamination categories consisted of: *Seed marks per carcass = 0 (zero), $\leq$ 12 seeds (low), 12 - 20 seeds (medium) and > 20 seeds (heavy)*. Price discount values allocated to each category were extracted from the abattoir model of Smith (2014) and surveys (Collins, 2013), being set at $0.10, $0.50 and $1.00 per kilogram of carcass weight for low, medium and heavy contamination, respectively. Discount values were subtracted from carcass price (c/kg CWT) in each year to produce the discounted final carcass price (c/kg CWT). When no seed marks were generated from Equation 7, the discount was set to zero.

Skin value

Seeds lodged within lamb skins (described as vegetable matter or VM) result in significant price discounts due to their impacts on pelt processing (Collins et al., 2013). Monthly nominal skin price data for VM-free and for Heavy VM 2-3 inch skins between 1990 and 2017 were used to determine average skin prices for three carcass weight classes (namely, $\leq$ 20 kg, 20.1 – 24 kg and > 24 kg) (MLA, 2016). Linear interpolation generated missing monthly skin price values. Nominal values were transformed to real price values (c/skin) using consumer price index data (ABARES, 2017) with a 2018 base year, and averaged over five years. The percentage change between VM free and Heavy VM skin prices across all years varied little between all carcass weight classes, averaging 33%. This was consistent with industry opinion, where 40 seed marks per skin was typically considered "heavy VM" and equivalent to a 30% price discount (G. Webster, personal communication, 23rd March 2019). Linear functions describing the relationship between percentage price discounts (values between zero and 33%), and seed mark densities per skin (values between 1 and 40) were determined for each carcass weight category. A single function thus describes the percentage skin price discount, D_S, in relation to skin seed mark density as follows:

$$D_S = aPM$$

(10)

where D_S was skin price discount (%), PM was skin seed mark density and a was a constant which varies with carcass weight class, namely a= 0.0063 (< 24 kg) and a= 0.0067 ($\geq$ 24 kg). D_S was constrained to values between 0 and 1 in the model (i.e. 0 to 100% discount) to remove derivation of negative values.

This relationship facilitated the calculation of the percentage skin price discount, based on carcass weight and skin seed mark density, as generated by Equation 8. The percentage price discount value was converted to a cents per kilogram value in the model by multiplying the percentage discount value by the VM free price as follows:

$$SP_D = SP_{VMF} \ (1 - D_S)$$

(11)

where SP_D was the discounted skin price (c/skin) due to skin seed density, SP_{VMF} was average VM free skin price (c/skin) and D_S was the percentage discount due to seed mark density (Equation 10).

Costs

Herbicide application costs were determined using local 2019 retail prices on a per hectare basis. Mowing and herbicide treatment costs included average labour and machinery costs per hour, based on those represented in industry gross margin budgets for dryland lucerne pasture establishment and grazing by prime lambs (DPI, 2012). Chemical, labour and machinery costs were summed to produce the total control cost per year.

Livestock cartage, selling costs, commission value on sheep sales and levy values were obtained from industry gross margin budgets for a terminal lamb enterprise, producing total annual livestock selling costs (NSW DPI, 2018). Since livestock are "purchased" as weaners in the model, a purchase cost was generated by using the five-year average nominal saleyard indicator price (cents per kilogram of hot standard carcass weight) for re-stocker lambs in NSW over the years 2013-2017 (MLA, 2016). Nominal prices were converted to real prices using consumer price index data (ABARES, 2019), with a 2018 base year. Purchase price was multiplied by the dressed hot standard carcass weight of the weaned lambs (using a 45% dressing percentage) to obtain the livestock purchase price.

Model constraints

Given the stochastic nature of pasture growth and quality, and the dynamic nature of barley grass density and seed desiccation, several constraints or decision rules needed to be integrated into the model to facilitate realistic outcomes. This included both livestock selling and supplementary feeding rules.

Live weight loss

Pasture simulations can produce extremely low pasture herbage mass and quality values in some years (<500 kg DM/ha with concurrent energy content of <8 MJ ME/kg DM) due to climate influences on pasture growth within a given year. Further, as the livestock submodel did not simulate selective grazing by animals, thus limiting the model's ability to simulate an intake with higher metabolizable energy and / or digestability (Freer et al., 1997), liveweight loss can be reported as unreasonably severe. To constrain daily weight loss in the model, a maximum weight loss threshold was introduced at 270 g/day, which was derived using the widely accepted decision support tool, GRAZFEED™ (Freer et al., 1997) for a 27 kg crossbred weaner sheep grazing no pasture. This represented a level of weight loss that corresponded to both rapidly increasing probabilities of animal mortality and conditions under which animals would usually be supplementary fed to avoid animal welfare issues.

Livestock destocking/selling

To constrain the model to simulate realistic welfare management practices in sheep production systems, animals were assumed to be sold if liveweight reached a critical minimum live weight of 20 kg, an effect that was observed to occur when low herbage mass and quality and the effects of seed contamination on intake were combined during some years. The 20kg value was selected as it is an established critical liveweight value for weaner sheep survival (Blackwood, 2006). Daily weight gains were triggered to zero until the end of the modelled grazing period if this weight was reached, simulating the effect of early "selling". The final live weight reached at that point thus became the selling live weight for that year within the economic submodel.

Supplementary feeding rule

A supplementary feeding rule was included in the model to trigger the feeding of a barley grain ration whenever herbage mass declined to levels below 500 kg DM/ha, simulating actions usually taken to prevent erosion and sustain pasture persistence (Robertson et al., 2020). The ration was generated in GRAZFEED™ and consisted of 780 g/day of barley (with no pasture intake) and resulted in 150g/day liveweight gain for a weaner sheep with an industry average weight of 27kg. The cost of feeding was based on a barley price of $179.80 per tonne, which reflected the average on-farm price over the years 2013-2017 in real terms (ABARES, 2019). These rules were included to reflect recommended practice for preventing mortality and poor performance in weaner sheep (Campbell et al, 2014).

Model validation

It is usual to consider the available literature and expert opinion in combination to develop functional form relationships in model construction, since availability of validation data for complex bioeconomic models can be limited due to the complexity and magnitude of information required and the lack and limitations of experimental studies (Beltran et al., 2012). As such, the outputs of the BGSC model have not yet been fully validated in this conceptual model as there are limitations arising from the lack of information available required to describe the connection between lambs grazing a barley grass infestation of pasture in relation to physical injury, particularly over a protracted period. These limitations are common to other bioeconomic models (Beltran et al., 2012; McCarl and Apland, 1986) and thus often require extensive review by experts (Beltran et al., 2012). However, process based models such as GrassGro™, are widely accepted, are used in many studies and found to be reliable for predicting livestock performance (Freer et al., 1997; Moore et al., 1997). Although live weight and carcass outputs from this study appear consistent with lamb performance observed from fields contaminated with barley grass levels similar to those considered in this study (Campbell et al., 1972; Little et al., 1992; Warr and Thompson, 1976), the outputs of the current model must still be considered as indicative, and not absolute, of the likely impacts of barley grass seed on lamb production from a lucerne pasture in southern NSW. Further field studies are required to facilitate adequate validation of these complex relationships.

Model sensitivity

A sensitivity analysis was performed to determine the demographic and economic parameters exerting the largest influence on NPV in the model. Methods used to determine the sensitivity index are described by Kelly et al., (2023). Physical and economic parameters of the model tested in the sensitivity analysis are shown in Table 3. The effects of changing parameter values within the model were relatively small, indicating low model sensitivity to parameter variability. The two parameters most sensitive to variation included the number of seeds per skin and the number of seed marks per skin.

Insert Table 3 here

Model Case study: Crossbred weaner lambs grazing barley grass infested lucerne in southern NSW.

A Monte Carlo simulation procedure was used to investigate the capacity of the combined model to simulate the effects of control strategies on lamb production, profitability, and risk within a barley grass-infested lucerne pasture in Wagga Wagga, NSW, Australia. Daily pasture databanks required by the livestock model were generated by GrassGro™ simulations of a barley grass-infested lucerne pasture between 1990 and 2017. The pasture parameters utilised in GrassGro™ simulations and detailed descriptions of all eight control strategies and trigger points for each control method within the BGSC model are described by Kelly et al., (2023).

The eight Barley Grass control strategies consisted of:

1. An uncontrolled population ("No control")
2. Early herbicide application, applied as an annual systemic herbicide at 2-3 leaf stage during autumn at 99% efficacy ("Early", E)
3. Late herbicide application, applied as a contact herbicide in late winter at 58% efficacy ("Late", L)
4. Repeated mowing at inflorescence emergence ("Mow", M)
5. Early + late herbicides ("Early_late", EL)
6. Early herbicide + repeated mow ("Early_Mow", EM)
7. Late herbicide + repeated mow ("Late_Mow", LM)
8. Early + late herbicides + repeated mow ("Early_Late_Mow", ELM)

Each simulation ran over a ten-year planning horizon as described by Kelly et al., (2023). Case study assumptions (in addition to those used by Kelly et al., (2023), included keeping the stocking rate constant at 10 weaner lambs per hectare. Further, all livestock and control costs used in the case study were based on typical Gross Margins for NSW to ensure alignment with the simulated location, listed in Table 4.

Insert table 4 here

Statistical analysis

All statistical analyses on the outputs of the simulated case study were performed using R software (ver. 3.5.1, R CoreTeam, 2016). Means and standard errors resulting from 1000 iterations of each experiment were calculated for NPV ($ ha^{-1}), annual control cost ($ ha^{-1}), skin price ($ head^{-1}), carcass price ($ kg CWT^{-1}), and live weight gain (kg ha^{-1}). Since NPVa represents profitability of each control strategy, the approach used to identify optimal strategies for maximising profitability included using a regression tree, fitting control strategy and weed threshold as factors and NPV as the dependent variable. Since regression trees facilitate a clear representation of complex and potentially non-linear interactions occurring between variables (Shalizi, 2006) and assist in identification of specific outcomes (Moisen, 2008), this method was considered a suitable method for investigating the complex interactions generated by this model. In the current study, the tree was first fitted completely by using a small complexity parameter (0.00001), a cross-validation value of 10 and a default minimum split value of 20, a value more appropriate for large datasets such as the one produced by the BGSC model. This tree was subsequently pruned using a complexity parameter of 0.00087478, since this produced the smallest tree within 1 standard error of the minimum cross validated error, as is consistent with the 1–SE rule used to identify optimal regression tree size (Breiman et al., 1984) (Fig. 4).

Insert Fig 4 here

Optimal management programs with regard to price risk were illustrated using the concept of a risk-efficient frontier (Cacho et al., 1999; Hardaker et al., 2015), generated by plotting the NPV means against their standard deviation resulting from the Monte Carlo simulation results, demonstrating the compromise between profit and risk (Behrendt et al., 2006). The frontier, represented by a dashed line, defines differing combinations of risk and profit under various control strategy and weed density scenarios where management is most efficient (Behrendt et al., 2006). Since standard deviation of NPV represents an estimation of the variability in profits resulting from a particular management combination, it was considered to be an adequate measure of risk, despite its simplicity (Hardaker et al., 2015). Risk-efficient management strategies were considered to be those situated along the frontier, corresponding to maximum economic returns at the lowest level of risk (Behrendt et al., 2006).

Results

Simulations demonstrated the capacity for modelled control strategies to produce marked differences in lamb enterprise profitability and productivity at all weed density thresholds.

Economic returns

The model generated a cost value associated with unmanaged seed contamination to a lamb enterprise grazing a barley grass infested lucerne pasture in southern Australia over the 10-year period (equivalent to a value of $793/ha, Fig. 5).

Insert figure 5 here

The model also identified the most optimal strategy overall for maximising profitability under the scenario conditions. This included an annual combination of late herbicide with repeat mowing ("Late_Mow") at the lowest weed density (represented by $525/ha at 5 seedlings/m^2, Fig. 5. and 6a). This strategy was also identified as the most risk-efficient strategy for managing grazed barley grass-infested lucerne pastures, demonstrated by its location (Fig.7). The model also successfully identified the superiority of combined strategies over individual tactics. Combined strategies, including mowing, were identified to be more profitable than those without, regardless of weed density.

Weed density was, however, a significant variable influencing the impact of all control strategies. Simulations produced greatest gains at the lowest weed densities, where the early herbicide ("early") and repeat mowing strategies ("Mow"), returned a value of $109/ha over ten years. Less profitable strategies were also identified by the model. For example, above densities of 50 seedlings/m^2, the repeat mowing strategy ("Mow") was not profitable in the simulation but generated the smallest financial losses of all individual strategies over ten years. This loss was smaller when mowing was combined with a late herbicide ("Late_Mow"), regardless of weed density (Fig. 5). Although the model simulated mowing as the most effective individual tactic for limiting losses over ten years in low density populations, this tactic still presented with a high degree of risk (Fig. 7).

The model was also able to simulate impacts from individual control strategies. The use of an isolated early herbicide was demonstrated to be analogous to the mowing application at a weed density of 5 seedlings/m^2 (Fig 5 and 6a), yet resulted in a loss at all other weed density thresholds ($147/ha). The single late herbicide application, however, was not seen to be profitable at any density and was the least profitable individual tactic at the lowest densities (Fig 5). Furthermore, simulations demonstrated both individual herbicide tactics tested to be associated with a high level of risk across all weed densities (Fig. 7).

Insert Fig 6a here

6a.

Insert Fig 6b here

6b.

Insert fig 7 here

Further utility of the model framework included the capacity to simulate cost differences between strategies. For example, despite their high efficacy, all combined strategies incurred the highest control expenditure when applied at densities of 5 and 50 seedlings/m^2 (Fig. 6b). Mowing consistently incurred the lowest control costs regardless of weed density, while individual strategies including an early herbicide were associated with maximum costs. Control expenditure generally declined with increasing weed density, regardless of the strategy.

Price and liveweight gain

The combined model simulated price and weight gain patterns in the livestock, following those obtained from the economic analyses. Highest carcass and skin prices were shown to be generated under the late_mow strategies at weed densities of 50 seedlings/m^2 and above. However, the model demonstrated all prices declining with increasing weed density (Fig. 8a and b). Differences in carcass and skin prices between strategies were also less marked as density increased (Fig. 8a and b).

Insert fig 8a here

8a.

Insert fig 8b here

8b.

The influence of control strategy on live weight gain was also able to be identified (Fig. 9), highlighting the greatest and least profitable weed control strategies (late_mow strategy at 54.2kg/ ha versus the uncontrolled scenario at 24.7 kg/ha).

Insert fig 9 here

Discussion

Although the BGSC model is narrow in its scope, the study results demonstrate the capacity of bioeconomic modelling for investigating key biophysical and economic impacts of weed populations on livestock over time with utility for identifying optimal weed control programs which influence productivity under scenario conditions.

Despite this study being the first attempt to quantifying costs associated with grass seed contamination in lamb production systems, the significant production and economic losses simulated by the unmanaged barley grass population (i.e. the no-control strategy) was reassuring and unsurprising, since the economic impacts of seed contamination in sheep are well established (Kelly et al., 2018). It must be noted that this result would be somewhat underestimated since the limited field data available for parameterisation does not allow it to consider additional impacts incurred from seed contamination in certain circumstances (such as higher mortalities in the youngest animals, flystrike incidence from seed penetration wounds, additional labour associated with managing affected sheep, etc). However, the loss identified provides a representation of the potential total cost of barley grass within a lamb production system, since it embodies the lost revenue from the lamb production system (i.e. liveweight and carcass weight loss and potential risk to maiden ewe fertility) due to an unmanaged barley grass population (Saville, 2002).

Consistent with results of previous modelling (Kelly et al., 2023), simulation results suggest the potential for considerable advantages associated with IWM programs for managing grass seed contamination in lamb production systems, while also emphasising the important influence of costs in determining overall profitability. Indeed, IWM principles are well-known to be highly effective for managing barley grass populations (Shergill et al., 2015), and it would therefore be reasonable to expect that the result of IWM imposed on weed populations would also include reduced impacts in sheep grazing infested pastures. Conversely, inconsistencies observed between the simulation results and those attained in in-field barley grass IWM studies (Kelly et al., 2020), provide further support to the importance of field data for generating accurate model relationships and realistic outputs.

Simulation results demonstrated the capacity of modelling to investigate hypothetical interactions between management and weed density and therefore could be useful in identifying weed thresholds where costs incurred in management may be advantageous. Other bioeconomic models simulating crop-weed infestations have demonstrated high weed control efficacy and long term profitability when combined strategies were applied in relation to weed density thresholds (Beltran et al., 2012). Such IWM strategies tend to be more profitable in practice as weed density declines, since fewer applications of each tactic are required as the weed challenge deteriorates, reducing control costs and production impacts in response to better weed control (King et al., 1986). This was a pattern observed in the current study and was well simulated in the model.

Model simulations suggest that strategies targeting plant fecundity (e.g. as simulated by late herbicide and mowing simulations), could lead to better weed population control, a concept supported by other modelling studies (González-Andújar and Fernández-Quintanilla, 1991, 2004). This is a logical idea in practice, since reducing seed set and inflorescence density directly reduces seed contact with sheep (Michalk et al., 1976). The results of the sensitivity analysis also strengthen these conclusions, since variation in the parameters for inflorescence density, seeds per fleece and seed marks per skin resulted in large differences in economic returns. The superior performance of a the strategies in this study targeting plant fecundity (e.g. late_mow) may, however, be less likely in reality due to the growing prevalence of herbicide resistance and subsequent plant survival associated with repeated chemical use in many southern Australian barley grass populations. Variable herbicide rates and additional herbicide costs associated with managing herbicide resistant populations will also influence profitability in practice, particularly when livestock value is lower (Orson, 1999).

Despite the previous success of individual herbicide applications in controlling barley grass populations in modelled populations (Kelly et al., 2023), control was not achieved in the current study in densities above 5 seedlings m^{-2}. This is consistent with an in-field situation, since residual plants can still induce a degree of contamination in the animals and incur control costs over time (Orson, 1999). Inadequate control can also lead to rapid population growth and high community-level seed production of the surviving population (Kelly et al., 2020). When combined with added herbicide costs, potential lamb production and profits can thus become limited, an effect likely to be more distinct in high density weed populations, since residual populations are larger (Gunsolus and Buhler, 1999).

It is possible that repeated mowing may be a useful non-herbicide strategy in limiting economic losses in sheep grazing low density populations, largely due to low numbers of surviving plants contributing seed to the seedbank (Fig. 5) and low implementation costs. In high density populations, mowing impacts can be analogous to those incurred by late herbicide applications (Kelly et al., 2023), yet are typically differentiated on the basis of cost. Despite this, sheep production losses incurred after mowing at higher densities are again expected to be significant due to the presence of the significant residual population. The possible level of economic risk associated with mowing notwithstanding (Fig. 7), this tactic may present a useful mechanical control alternative for limiting seed production. However, the spatial variation in weed maturity occurring will always present challenges for the implementation of timely defoliations. Subsequent action will likely be important to ensure effective and sustained weed management (Vitelli and Pitt, 2006).

Despite the limited data to develop model relationships associated with seed marks in lamb skin, significant skin and carcass price penalties were still observable in model simulations due to the impact of seeds (Fig. 8a and b). In practice, skin mark density can become limited by seeds dropping out of the fleece before reaching underlying tissues, a phenomena observed by previous authors (Atkinson and Hartley, 1972). A maximum seed load may also exist within the skin of sheep grazing high density barley grass populations (Atkinson and Hartley, 1972), preventing further seed penetration and capped price discounts. Such factors likely influence carcass and skin prices particularly as weed density increases (Atkinson and Hartley, 1972).

As evidenced by the early_late_mow strategy modelled previously by Kelly et al., (2023), combined programs targeting annual weed populations at different plant growth stages tend to be most effective for reducing overall plant survival and seed production. Reducing weed density should thus also influence financial returns from lambs grazing barley grass-infested pastures, where lower inflorescence numbers (Michalk et al., 1976) generate less seed contact with sheep (Campbell et al., 1972). However, it is important to assess the financial viability of weed control strategies within the context of the wider agricultural system.

Despite promising outputs from the model simulations, there are several limitations of this model that must first be strengthened before future results of the model may accurately quantify impacts under alternative conditions. The generation of data via field studies is required to examine variability in barley grass population dynamics under various climatic conditions, allowing more accurate analysis of impacts on sheep production (King et al., 1986). In particular, the major and complex dynamic interactions between inflorescence density, pasture biomass, digestibility and live weight loss requires significant field investigation to strengthen these key relationships within the model, since biomass availability, digestibility and inflorescence density were greatly associated with liveweight loss in the current study. Field studies by Campbell et al., (1972) and Little et al., (1992) also reported liveweight losses within the range reported by the BGSC model for sheep grazing unmanaged barley grass infested pastures, yet none of these studies considered the potential impact of reduced grazing behaviour on liveweight loss due to physical impediment caused by the inflorescences, a mechanism also considered to be influential in barley grass pastures (Warr and Thompson (1976). Other more complex considerations regarding live weight should also be included in future research, such as the weight variability in gut contents and organs occurring in response to reduced feed intake.

Greater refinement in modelling liveweight impacts within the BGSC model may also be attained by incorporating the GrassGro™ digestibility pool equations that were simplified in the current model, since diet digestibility is a key driver of liveweight in sheep (Little et al., 1992; Thomas et al., 2021). In addition, the development of methods for accurately assessing various levels of contamination within the skin and carcass (including other sheep breeds where the degree of seed penetration will vary) would assist in generating accurate determination of price discounts and subsequent carcass and skin value by breed. It should be noted that although this study focussed on crossbred lambs to investigate the economic impacts of seeds on carcass and skin value, results would be different in practice since the only available data used to generate the empirical model of intake suppression was from merino sheep, where seed penetration and impacts on intake may be different. The framework could largely be improved through the development of pasture and weed submodels at a whole system level to remove the requirement for third party decision support tools (i.e. GrassGro™) providing pasture databases. This would also enable the simulation of pasture parameters (namely, biomass, dry matter digestibility, daily growth rate) under various stocking rates to facilitate accurate live weight simulations.

The dynamic daily interactions between pasture quantity and quality, and stocking rate was not included in the current model framework due to the focus on relationships with barley grass inflorescence density and economic impact. These improvements could be integrated into any future modelling however, to improve the accuracy of modelling biophysical interactions between these variables. This would make the modelling framework more dynamic and adaptable to a broader scope of grazing systems and weed species, useful for defining their harmful impacts on livestock. Further validation of the model could also be implemented by running significantly more simulations in systems-based tools (e.g. Ausfarm™) and comparing results to those of the current model under various feed intake parameter adjustments, especially under extreme states.

Conclusions

This study demonstrates the potential of bioeconomic modelling methods for evaluating numerous weed management combinations in livestock grazing systems under stochastic conditions. Although preliminary, simulation results are supported by findings from previous in-field studies, suggesting that integrated weed management strategies may be effective and profitable for reducing seed contamination risks to sheep grazing barley grass infested lucerne pastures. Further field studies would be valuable for validating the complex relationships in this system. Such practices are likely to be most beneficial when applied in low density barley grass populations, reinforcing the benefits of proactive management for controlling this species.

In the selection of optimum barley grass management strategies in lamb systems, key consideration must therefore be given, as combinatorial factors, to weed density, application timing, herbicide rates, and input and output prices, since all are likely to exert an influence on economic returns.

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Data Availability

The data that support this study are available in the article and accompanying online supplementary material. This paper forms part of the PhD thesis of Jane Kelly (2020).

Conflicts of interest

The authors declare no conflicts of interest.

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Tables

Table 1. GrassGro™ pasture data variables used by livestock sub models from the simulation of an un-grazed barley grass infested lucerne paddock in Wagga Wagga, NSW.

GrassGro™ **pasture data variables**	**Variable Description**
Digestibility (green) (%)	Digestibility of sheep dietary intake per day [A]
Total available herbage: lucerne-winter active[B] + Annual grass-early (kg DM/Ha)	Starting herbage mass value on first day of simulation
Total growth rate: lucerne-winter active + Annual grass – early (kg DM/Ha.day)	Daily pasture growth rate
Total live loss rate (lucerne-winter active and Annual grass-early) (%/day)	Quantity of biomass lost per day through decay
Total Loss-biomass (lucerne-winter active and Annual grass–early) (kg DM/Ha)	Loss rates converted to biomass values
Percentage of lucerne-winter active (as a proportion of total herbage mass (%)	Proportion of lucerne in the pasture: when averaged across each year, this value became the percentage of lucerne competition within the barley grass submodel. Also used as the proportion of legume required by livestock submodel equations for each year.
Time of senescence (Time dependent on seasonal data for a given year)	Indicates initiation of seed desiccation (thereby signaling the start date of seed challenge (i.e. reducing feed intake) in the livestock model).

[A]Green dry matter digestibility was available as the most complete dataset for the simulation period and was thus determined to be a suitable measure of diet digestibility. Where data was unavailable on any given day within GRASSGRO, the previous day's value was used as the most recent average. [B]*Lucerne-winter active* and *Annual grass – early* are species terminology utilised in GrassGro™, with *Annual grass – early* representing barley grass in the simulations. Note: Kelly et al., (2023) list the parameters used in GrassGro™ simulations.

Table 2. Animal parameter values utilised within livestock sub models for the simulation of second cross lambs grazing a barley grass-infested lucerne paddock in Wagga Wagga, NSW from weaning on 1st September to sale on 31st December.

Parameter	**Source**
Standard Reference weight (cross bred ewe: 76kg)	(DPI, 2018)
Average birth weight (second cross lambs): 5kg	(Hocking Edwards et al., 2019)
Average weaning weight/starting weight (second cross lambs): 27kg	(Hocking Edwards et al., 2019)
Value for the effect of pasture height in calculating the relative rate of eating and relative time spent grazing lucerne in a mixed lucerne/barley grass sward: C_{R12}=1.0	(Freer et al., 2012)

Table 3. The sensitivity of NPV to variation in values of physical and economic parameters related to seed contamination of sheep within the bioeconomic model after a ten-year simulation (mean of 1000 iterations).

Parameters	Values			Sensitivity Index
	Maximum (+40%)	**Minimum (-40%)**	**Model value**	
Physical parameters				
Intake factor: *constant a*	0.073178	0.031362	0.05227	0.03
Intake factor: *constant b*	1.36822	0.58638	0.9773	0.02
Seeds/skin:				
constant a	3.26312	1.39848	2.3308	**0.35**[C]
constant b	2.46204	1.05516	1.7586	0.07
Seed marks/skin: *constant a*	0.05082	0.02178	0.0363	0.07
constant b	1.47112	0.63048	1.0508	**0.26**
constant c	2.16328	0.92712	1.5452	-0.06
Economic parameters				
Maximum carcase price seed discount (c/kg CWT[D])	140	60	100	0.08
Maximum skin price seed discount (%)	0.45	0.192	0.32	0.04

[C] Bolded, underlined index figures highlight parameters most sensitive to variation. [D]CWT = carcass weight. c/kg = cents /kilogram.

Table 4. Costs associated with control strategies, livestock purchase and sales within case study simulations.

Chemical Control	**Trade name**	**Application cost ($/Ha)**	**Reference**
Propaquizafop	Shogun®	$11.52	Local average retail price [E]
Paraquat	Gramoxone®	$6.86	Local average retail price
Adjuvant (alcohol alkoxylate)	Chemwet 1000®	$0.48	Local average retail price
Management Activity	**Value**	**Units**	**Reference**
Machinery maintenance	2.00	$/ha	(DPI, 2012)
Labour	20.00	$/hr	(DPI, 2012)
Time per hectare (spraying)	0.1	hr/ha	(DPI, 2012)
Time per hectare (mowing)	0.1	hr/ha	(DPI, 2012)
Livestock	**Value**	**Units**	**Reference**
Sheep Cartage/hd	2.00	$/hd	(DPI, 2018)
Sheep Selling costs	2.00	$/hd	(DPI, 2018)
Levies	2.90	$/hd	(DPI, 2018)
Feed: Barley grain	0.1798	c/kg	(ABARES, 2019)
Lamb purchase price	62.69	$/hd	(MLA, 2016)
Commission on sheep sales	4.95%		(DPI, 2018)

[E]Local retail price as of May 2019

Figure Captions

Fig. 1. A conceptual diagram of the BGSC model, showing relationships between GrassGro™ and the barley grass, livestock and economic sub models and their components.

Fig. 2. The relationship between barley grass inflorescence density/400cm^2 (*x axis*) and the degree of intake suppression in sheep (*y axis*, expressed as the *Intake Suppression Factor*) due to barley grass seed contamination. Data derived from Campbell et al. (1972) was fitted using a non-rectangular hyperbola (as shown by the blue line).

Fig. 3. The relationships between **a.** barley grass inflorescence density/ha (I) and the number of barley grass seeds per sheep fleece (FSD). Results are presented as a functional two-parameter linear model fitted to the number of barley grass inflorescences per hectare (x 10^5) and the number of seeds per fleece; and **b.** the number of pelt marks per sheep skin (PM) as a function of the number of barley grass seeds per sheep fleece (FSD)**.** Data is presented as a functional 3-parameter quadratic model fitted to the number of seeds per fleece and the number of pelt marks per skin (adapted from Atkinson & Hartley, 1972).

Fig. 4. Complexity parameter (cp) fitted against cross validated error for the final pruned regression tree, displaying diminishing returns in reducing error as the tree grows. The arrow highlights the optimal cp value of 0.00087478, which produces the smallest tree within 1 standard error of the minmial cross validated error (The 1-SE rule, Breiman et al., 1984).

Fig. 5. Regression tree of expected present value (mean NPV of 1000 iterations in $/ha), as estimated by the stochastic simulations of combined barley grass seedling density thresholds and control strategies within a grazed barley grass-infested lucerne pasture over ten years at Wagga Wagga, NSW. Weed threshold values of 5, 50, 250, 500 and 1000 represent barley grass seedling thresholds (seedlings/m^2). Strategy values 1 to 8 represent application of individual or combined control strategies (1=No control, 2= Early herbicide, 3=Late herbicide, 4=Mowing only, 5=Early herbicide +Late herbicide, 6=Early herbicide + Mowing,

7= Mowing +Late herbicide, 8 = Early herbicide + Late herbicide+ Mowing). Percentages represent the proportion of the total number of data points contributing to each node.

Fig. 6a. Mean present value (NPV), and **b.** control cost results per hectare of 1000 iterations (± 95% confidence interval) as obtained from stochastic simulations of eight control strategies applied to a grazed barley grass-infested lucerne pasture across at five barley grass density thresholds (seedlings/m^2) in Wagga Wagga, NSW. Early = early herbicide, late = late herbicide, mow = repeated mow at post-inflorescence stage of growth, ha = hectare.

Fig 7. Risk efficiency of different combinations of barley grass density thresholds (5, 50, 250, 500 and 1000 seedlings/m^2) and eight control strategies within a barley grass infested lucerne pasture grazed by lambs at Wagga Wagga, NSW. E = early herbicide, L = late herbicide, M = repeated mow at post inflorescence stage of growth. Conceptual risk-efficient frontier shown (**------**).

Fig. 8a. Mean carcass price (cents per kg CWT) and **b.** skin price (cents/skin), of 1000 iterations (± 95% confidence intervals) as obtained from stochastic simulations of eight control strategies applied to a grazed barley grass-infested lucerne paddock at various barley grass seedling thresholds in Wagga Wagga, NSW.

Fig. 9. Mean live weight gain results (total kg per ha gain between 1^{st} September and 1^{st} December each year) of 1000 iterations (± 95% confidence intervals) as obtained from stochastic simulations of eight control strategies applied across randomly selected years (between 1990 and 2017 inclusive) to a grazed barley grass-infested lucerne pasture at various barley grass seedling thresholds in Wagga Wagga, NSW.

Fig 10. Example of GrassGro™ data used in the BGSC model, depicting daily biomass values (Kg DM/ha) for each year type and control strategy simulated