An innovation systems approach to understanding the impacts of grass grub damage in irrigated Canterbury dairy pastures

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Abstract

An innovation systems approach involving agribusiness representatives, researchers and farmers identified that damage caused by grass grub (*Costelytra giveni*) was a key factor contributing to areas of reduced yield within high-producing pastures. Using a recognised yield mapping technique, areas of 'Low' and 'High' pasture height were identified in different paddocks over 3 years; 'Low' areas had significantly higher numbers of grass grub larvae than 'High' areas. Pasture production was measured for the 'Low' and 'High' pasture height areas, and the difference was calculated to be 6800 kg DM/ha for 2018/19. This difference persisted after grass grub larvae were no longer active. Farm systems modelling analysis estimated this 'yield gap' led to a $650/ha/year difference in profit. A survey of farmer perceptions of grass grub damage on 23 central Canterbury dairy farms estimated 19% of pastures were affected by grass grub, with 11% of the area in those paddocks being damaged. Econometric modelling showed differences in farmer perceptions of grass grub damage. Data from the survey and the pasture measurements were combined with the farm systems modelling results to estimate a $1,870,000/year regional-scale impact of the 'yield gap'. An integrated pest management approach is suggested to control grass grub damage.

Keywords: yield map, Farmax, econometric modelling, biopesticide

Introduction

All businesses need regular reviews of their performance and pastoral farming businesses are no exception. One approach is to use an "innovation systems" process to identify challenges and opportunities with pastoral farmers. A number of examples where similar approaches have been used are described by Botha et al. (2017).

The current study used a range of tools to identify farm systems' changes that could improve pasture production by 2 t DM/ha/year on an already high-producing irrigated Canterbury dairy farm (King et al. 2018). A multi-disciplinary team was assembled to apply these tools to find specific leverage points and, using this innovation systems approach, it was identified that grass grub (*Costelytra giveni* (formerly *C. zealandica* (White)) (Coleoptera: Scarabaeidae)) infestation was one of those leverage points.

Grass grub is a native New Zealand insect but has become one of the most common insect pests in improved pastures in New Zealand (Jackson et al. 2012). A focus of pastoral research for many years, grass grub has significant economic impacts (Ferguson et al. 2019) through direct damage and effects on pasture persistence (Zydenbos et al. 2011). Cultural, chemical and biological controls have been developed for managing the pest (e.g. Jackson et al. 1992; Johnson et al. 2001; Zydenbos et al. 2016; Wright et al. 2017) and decision-support tools have been described to manage infestations (Zydenbos et al. 2013). However, there still remains a key knowledge gap around how to detect the pest early enough to apply cost-effective controls.

This paper reports on the use of yield mapping to identify areas of grass grub infestation on one farm, along with modelling of the farm system to understand the financial impact of the pasture yield gap associated with these areas. In addition, a survey of 23 irrigated dairy farms was undertaken to assess the wider impact of grass grub, and the results were combined with outputs from econometric modelling to estimate the regional costs of the pest on this type of farming system and the opportunities for early detection and management.

Methods

An innovation systems approach at Rakaia Island Dairies

Rakaia Island Dairies (RID) operates four independent dairy units 45 km south-west of Lincoln, Canterbury, New Zealand. The current study focused on the Dairy 1 unit, which covers an area of 400 ha.

The research team assembled a set of resources that

ISSN 2463-2872 (Print) ISSN 2463-2880 (Online) https://doi.org/10.33584/jnzg.2019.81.412

included data sets held by RID (inputs, production, pasture renewal practices) as well as additional 'data layers' (soil maps, EM38 images (electromagnetic conductivity of soil; https://www.agrioptics.co.nz/), soil fertility maps, digital elevation maps, summer and autumn pasture yield maps) and interview data, such as the farm-development programme, pasture maintenance and renewal (addition of seed to existing pasture or full renewal), and frequency of observation of pests and pest damage.

The innovation systems process brought together researchers, land owners, farm managers and rural professionals from seed, fertiliser, agricultural contracting and irrigation companies. This group reviewed available data and identified key leverage points that could, if successfully managed, change systems performance. This co-innovation process led to an understanding that this property was at significant risk from grass grub damage.

Yield mapping to determine sampling areas

Pasture height data were obtained using a C-Dax pasture meter (C-Dax Ltd, Palmerston North, New Zealand) and used to generate yield maps from previously described methods (Dennis et al. 2014; Dennis et al. 2015). The equipment was driven at the recommended speed of 20 km/h taking measurements 5–7 m apart covering the complete area of the paddock. These data were interpolated using the QGIS multilevel b-spline interpolation tool (https://www.qgis.org) to produce a raster map of pasture heights. Using the r.reclass tool, the upper and lower 20% of the raster pixel values were classified as 'High' and 'Low' pasture height, respectively, the remaining 60% being classified as medium pasture height. Use of height classes deals with some inaccuracy (±2 m) due to the use of standard GPS.

Autumn yield maps were completed on the RID Dairy 1 Unit over 3 years (2016–2018) to identify: (a) poor performing areas with low pasture height; and (b) areas for grass grub sampling. Paddocks showing small-scale grass grub infestation the previous autumn/winter and/or paddocks that had been sown 2–3 years previously after a renewal phase that involved forage cropping were visually assessed in early autumn and a preliminary assessment of grass grub populations and disease status of the grubs was made. Four paddocks (#117 and #126 (2016), paddock #120 (2017) and paddock #119 (2018)) were chosen for further examination as they had patches of healthy grass grubs (e.g. 100–200 grubs/m^2 and little or no amber disease) and consistent irrigation, topography, etc. that would not 'interfere' with yield mapping.

Grass grub sampling

Sampling method depended on the number, size and stoniness of plots and differed between years. All samples were hand sorted in the field into individual cells of 24-well plastic trays and taken to the laboratory for assessment of amber disease as previously described (Zydenbos et al. 2016). The plots used in 2017 and 2018 were part of a currently unpublished study investigating the potential for biopesticide application to mitigate grass grub damage.

In 2016, 10 points were randomly selected for grass grub sampling from each of the 'Low' and 'High' pasture height areas in each of the two paddocks used (#117 and #126). Ten samples were taken in an area of approximately 2 × 2 m around each identified point using a spade to dig squares (15 cm × 15 cm to a depth of 15 cm) on 10 May 2016 in paddock 117 and on 10 June 2016 for paddock 126.

The sampling undertaken in 2017 was part of a larger study (data not shown). Two types of plot were sampled in paddock #120, with 10 replicates each of low-pasture height plots ('Low'; 6 × 12 m) and high-pasture height plots ('High'; 6 × 30 m). Between 20 and 25 soil cores (6.2 cm diameter) were taken per plot to a depth of 15 cm using a soil corer. Five spade squares were taken for each plot where the soil was particularly stony and precluded use of the corer. Samples were taken at establishment on 11 May 2017 and 6 weeks later on 20 June 2017.

Paddock #119 was sampled in 2018. Twelve sets of circular paired plots (5 m radius) were defined in each of 'Low' and 'High' pasture height. One of the 'High' plot sites was discarded due to localised water ponding, making it unsuitable. The plots were located by standard GPS. The centre of each plot was marked with a peg. Sampling was carried out by taking three spade squares for each of the paired 'Low' plots and six spade squares for each of the 'High' plots. For comparison of 'Low' vs 'High' plots, the paired 'Low' plot samples were pooled. Samples were taken at trial establishment on 17 April 2018 and 6 weeks later, on 29 May 2018.

Dry matter production

All pastures were perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*), grazed by dairy cows at the 2–3-leaf stage. No pasture-height measurements were made in the 2016/2017 season. For the 2017/2018 season, pasture height was measured in each grass-grub sampling plot 8 times before and after grazing from autumn 2017 to autumn 2018 using a C-Dax pasture meter driven through each plot three times (approximately 2 m apart). For the 2018/2019 season, a rising plate meter (AgHub F200 Rising Electronic Platemeter) was used to estimate pre- and post-grazing herbage mass measurements from average of 30 pasture height data points (clicks) on 10 occasions from autumn 2018 to autumn 2019, taken by walking 3 transects with 10 measurements on each transect. Pasture height measurements were converted to pasture mass using the recommended equations for Canterbury, i.e. kg DM/ha = (mm × 18.1) + 729 (C-Dax Ltd 2019) for the pasture meter data and (140 x “clicks”) + 355 (King et al. 2010) for the rising plate meter data. Two pre-graze herbage sample dates were missed in both 2017 and 2018 due to operational issues.

Plot shapes and sizes were different for each season, and the data from 2018 were used for modelling because the plot sizes were small enough to represent a single pasture height class, i.e. ‘Low’ or ‘High’.

System modelling

A “baseline” model of a “typical” irrigated Canterbury dairy farm was developed using Farmax Dairy Pro® version 7.2.1 (Bryant et al. 2010) using information from DairyNZ DairyBase, using Production System 4, 2017–18, Table 1. A “Potential growth” scenario was also developed to explore the effect of an added 1000 kg DM/ha to the farm system with increased cow numbers to utilise additional pasture production, without any increase in other inputs (fertiliser or supplements). This idealised farm was 255 ha with a stocking rate of 2.8 cows/ha and milk production of 1056 kg milk solids/ha (Table 1). The difference in DM yield between the ‘Low’ and ‘High’ areas was calculated using the 2018/19 yield data. In order to estimate annual yield, the pasture growth for the two missing periods was estimated from the paddock average for that period using the current growth rates from data for RID stored in the MINDA database (LIC’s web-based herd management system; https://www.lic.co.nz/products-and-services/minda/). These values were then scaled for the average annual difference between the ‘High’ and ‘Low’ yield plots.

Table 1 Parameters used for system modelling and the results of increasing annual dry matter production by 1000 kg DM/ha/year (potential growth).

Parameter[1]	Scenario	
	Baseline	Potential growth
Effective area (ha)	255	255
Stocking rate (cows/ha)	2.8	3.3
Potential pasture growth (kg DM/ha)	12800	14000
Cow numbers (1st July)	737	870
Peak cows milked	705	832
Milk solids (kg/ha)	1056	1246
Pasture eaten (kg DM/ha)	9	10.6
Profit ($/ha/year)[2]	976	1627

[1] expenses obtained from DairyNZ 2015/16 (https://www.dairynz.co.nz/business/dairybase/latest-dairybase-benchmarks)

[2] based on a milk price of $6.05/kg MS using 2018–2019 Fonterra milk schedule (https://www.fonterra.com/nz/en/investors/farmgate-milk-prices.html)

The economic assessment was based on the average difference in pasture production between the ‘Low’ and ‘High’ pasture height areas within a paddock. Also, profitability improvements did not take into account any benefits of increased pasture persistence and associated savings from delayed pasture renewal.

Farmer survey

A total of 23 farmers were asked five questions about grass grub by Ravensdown Agri Managers during annual farm-planning meetings:

1. How many hectares is your milking platform?
2. Do you have grass grub?
3. Number (%) of paddocks impacted?
4. Percentage of individual paddocks impacted (<10%, 10–20% or >20%)?
5. What is your estimation of $ loss/production loss?

These farms covered the area south of the Waimakariri River and north of the Rangitata River on the Canterbury Plains. Additional data about each farm was collated, either from existing records held by the Ravensdown Agri Managers or directly from each farmer. This information included: farm location, soil type, estimated annual pasture production (DM t/ha), annual milk production (MS/cow), which DairyNZ production system was in use and what pasture species were grown (if not ryegrass/white clover dominant). At the same time, farmers were supplied with an information sheet that included background information about grass grub (collated from AgPest™, www.agpest.co.nz) and a description of the Five Production Systems as defined by DairyNZ (Hedley et al. 2006). A Social Research Ethics Approval for this survey was granted through AgResearch’s People & Agriculture Research team.

The area of irrigated dairy land in Canterbury was estimated using data from Saunders and Saunders (2012). This value was combined with the farmer survey and Farmax model results to estimate the potential loss of yield between the “High” and “Low” pasture height areas on irrigated Canterbury dairy farms.

Econometric modelling

A Poisson regression model was used to analyse factors that may affect farmers’ perceptions of the scale of grass grub damage. Following Winkelmann and Zimmermann (1995), Y_i was the observed grass grub damages on farm for the i^{th} farmer, with Y_i assumed to be independent and Poisson-distributed:

$$E(Y_i \mid X_i) = \lambda_i = \exp(\beta' X_i), \quad i = 1, 2, \ldots N, \tag{1}$$

where λ_i is the ‘intensity-of-rate’ parameter when referring to the Poison distribution as $p[\lambda_i]$; X_i are the factors that may affect farmers’ perceptions, associated with the unknown parameters β to be estimated. Hence, the probability density function for the i^{th} farmer's perception of grass grub damage can be estimated by using Equation 2 (Paxton et al. 2011).

$$\Pr(Y_i = y) = f(Y_i) = \frac{e^{-\lambda_i}\lambda_i^{Y_i}}{Y_i!}, \quad Y_i = 0,1,2... \qquad (2)$$

The descriptions and descriptive statistics of each variable used in the model are shown in Table 2.

Statistical analysis

The 2016 grass grub numbers from areas of 'Low' and 'High' pasture height were compared using a Kruskal-Wallis one-way analysis of variance. The 2017 and 2018 dry matter production data were analysed with Analysis of Variance using nested, portioned model terms to understand the relationships between treatments, and grass grub data were analysed with a Generalised Linear Mixed Model. Genstat version 18 (VSN International, Hemel Hempstead, UK; https://www.vsni.co.uk/contact)

Results

Yield maps

Considerable variation in pasture height occurred across each of the paddocks (Figure 1) with circular patterns of pasture height visible that appeared to be influenced by the centre-pivot irrigation system. There were also numerous other areas of 'High' and 'Low' pasture height, which were targeted for investigation for grass grub larvae density. The points and plots sampled for each paddock are indicated on the maps.

Grass grub numbers

The number of healthy grass grub larvae in the 'High' pasture height areas was lower than in the 'Low' pasture height areas in all paddocks and sampling times (Table 3). These differences were statistically significant in 2016 and 2018.

Dry matter yield

Dry matter yield was calculated from the difference

Table 2 Descriptions of the variables included in regression models.

Variable	Description	Descriptive Statistics			
Outcome	**Dependent variable**	**Mean**	**SD**	**Min**	**Max**
Y	Scales, the intensity of observed grass grub damage measured by the percentage of infested paddocks and the intensity of infestation within individual paddocks	4.08	3.43	1	15
X (Factors)	**Independent variables**				
Farm size	Continuous, size of the milking platform (hectare)	216.1	30.1	100	500
Pasture loss	Continuous, estimated pasture production loss (DM t/ha)	0.91	1.1	0	2.5
Farm systems	Categorical variable				
	1 = System 2 (set as base)	0.08	0.05	0	1
	2 = System 3	0.13	0.1	0	1
	3 = System 4	0.71	0.62	0	1
	4 = System 5	0.08	0.1	0	1

Table 3 Number of healthy grass grub larvae/m^2 for areas of 'Low' and 'High' pasture height in each paddock and sampling date over the 3 years.

Date	Paddock no.	Low pasture height	High pasture height	P-value
2016 (May)	117	181 ± 3.7[1]	89 ± 5.3[1]	P<0.01
2016 (June)	126	24.8 ± 3.7[1]	4.5 ± 5.3[1]	P<0.05
2017 (April)	120	57.8 (26.1, 128.2)[2]	31.6 (14.3, 70.1)[2]	ns
2017 (June)	120	55.7 (20.2, 154)[2]	15.5 (5.6, 42.9)[2]	ns
2018 (April)	119	201 (72.1, 561)[2]	4.1 (1.5, 11.4)[2]	P<0.005
2018 (May)	119	108 (66.2, 177)[2]	10.9 (6.8, 18.3)[2]	P<0.001

[1] Standard error of the Mean (SEM)

[2] 95% Confidence Interval

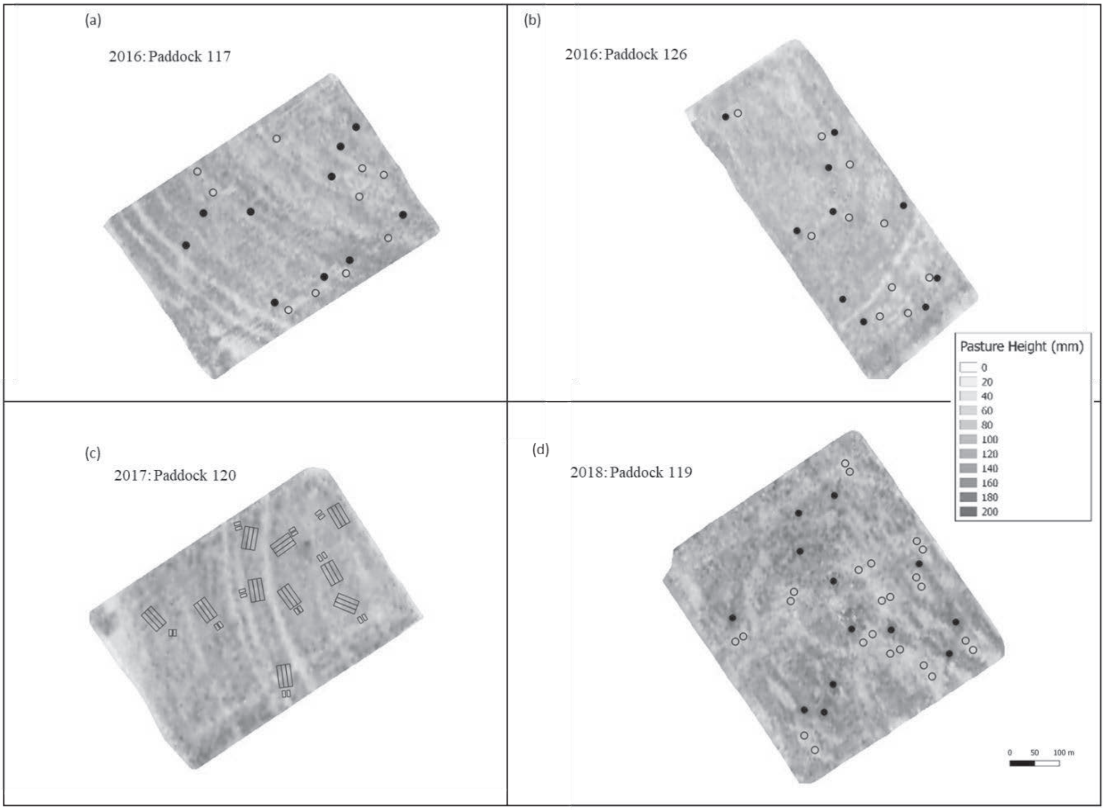

Figure 1 Maps of pasture height for four paddocks used for grass grub studies showing sampling sites of 'Low' (open circles) and 'High' height (solid circles) for: (a) 2016: paddock 117; (b) 2016: paddock 126; and (d) 2018: paddock 119; and plots of 'Low'(small rectangles) and 'High' (large rectangles) for (c) 2017: paddock 120.

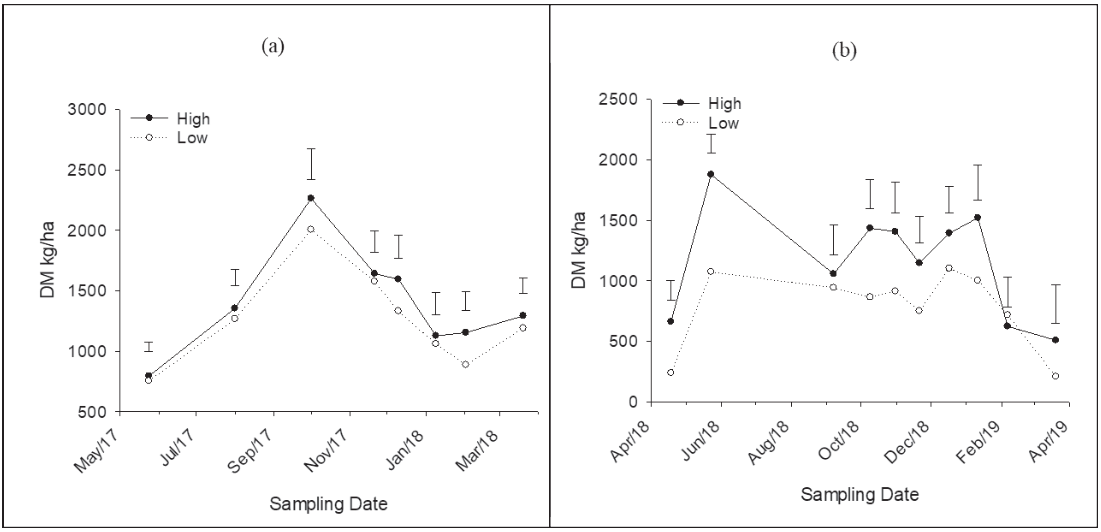

Figure 2 Estimated yield (kg DM/ha) for areas of 'Low' (open circles) and 'High' height (solid circles) for: (a) paddock 120 in 2017/2018 based on pasture height recorded using a C-Dax Pasture meter; and (b) paddock 119 in 2018/2019 based on pasture height recorded using a rising plate meter. Lines at each grazing point indicate 5% LSD.

between previous post-grazing residual and pre-grazing herbage mass and was consistently greater for the 'High' than 'Low' plots, at all sampling times in both the 2017/18 and 2018/19 seasons (Figure 2). The differences were statistically significant ($P<0.05$) for four of the eight samples collected in the 2017/18 season and for eight of the ten samples collected in the 2018/19 season.

Economic analysis

For the purposes of the Farmax analysis, total annual DM production in the 'High' pasture-height plots was estimated at 21,100 kg DM/ha and in the 'Low' pasture-height plots 14,200 kg DM/ha, giving a total difference in DM of about 6800 kg DM/ha over the 2018/2019 year. 'Low' plots covered 20% of the paddock area so it was assumed that the difference across the whole paddock would be at least 1000 kg DM/ha. The Farmax analysis examined the potential productivity increase if low-yielding areas of the farm were able to produce the same amount of dry matter as high-yielding areas. The production of an additional 1000 kg DM/ha would result in an increased stocking rate, greater production of milk solids per hectare and a higher profit (Table 1).

Survey data and econometric modelling

Farm size ranged from milking platforms of 100 ha to 500 ha, with milk solid (MS) production ranging from 1250–2380 kg MS/ha and 475–620 kg MS/cow for the 23 farms surveyed. Soils were predominantly Lismore silt loams, but also included farms on heavier soils, such as Templeton silt loam. Estimated annual pasture production ranged from 15,000–22,000 kg DM/ha. The farms covered DairyNZ production systems classification of 2 to 5, with the majority (n=14) being System 4 farms.

Farmer estimates of pasture losses from grass grub ranged from 0 to 10,000 kg DM/ha/year. Estimates of the percentage of paddocks on the farm affected by grass grub ranged from 0 to 80%, with most farmers (n=16) estimating that 20% or fewer paddocks were affected. The weighted average value for this variable was 18.7%. Estimates of damage within individual farms were <10% (n=16), 10–20% (n=5) and >20% (n=2), with the weighted average being calculated as 11.3%.

The estimated cost of the difference in yield between the 'Low' and 'High' height areas was $1,870,000 per annum based on an estimated 145,400 ha of irrigated dairy farms in Canterbury, and using the $650/ha increase in profit estimated by the Farmax analysis, along with the weighted average of 18.7% of paddocks affected by grass grub and the weighted average of 11.3% of the area within each paddock being damaged by grass grub. A simulation analysis on these data gave a modelled range of estimates ($27,000 to $3,850,000), with a mean of $1,940,000.

An econometric model was used to further analyse the survey data to look at potential bias in the results due to farmer perceptions of the damage. The data shown in Table 4 indicate that farmers on larger farms were more likely to observe grass grub damage. In addition, farmers who had given a higher estimation of pasture loss were more likely to perceive a higher scale of grass grub damage. The perception of grass grub damage may vary across different dairy systems, whereby System-4 dairy farmers seemed to observe higher levels of grass grub damage on their farms.

Innovation systems

The innovation systems approach was valuable in both identification of key leverage points in an already high performing system and the cohesive team approach to defining both questions and potential solutions. As intended, it did blur the boundaries between the scientists and the agricultural system stakeholders (Berthet et al. 2018) and facilitated knowledge flows between a diversity of 'actors'. The co-innovation approach was supported by many 'layers' of farm data and led to agreement in targeting potential solutions in a complex high performing farm system where there were multiple leverage points that could drive change in the systems' performance. Particularly useful were the joint discussions involving people with deep knowledge from diverse backgrounds, such as farm owners, farm managers, a long-time agriculture contractor, fertiliser and seed company representatives and researchers. Those with a historical perspective of the farm identified areas where grass grub infestations tended to be more frequent and/or more severe, and when this information was combined with expert knowledge, mitigation opportunities became apparent.

Discussion

The yield mapping technique was clearly able to detect areas of irrigated dairy pasture that had high or low populations of grass grub larvae in autumn. Thus, areas of the pasture with the highest 20% of pasture height

Table 4 Econometric modelling results of the Poisson regression model.

Variables	Coefficient estimates	Standard error	Significance
Constant	-5.45	1.94	P<0.01
Farm size	0.01	0.004	P<0.05
Pasture loss	0.27	0.09	P<0.01
Farm systems 3	-0.21	0.54	
Farm systems 4	0.19	0.05	P<0.05
Farm systems 5	0.02	0.61	

had consistently fewer grass grub larvae over 3 years, in different paddocks and at various sampling dates than areas of the pasture in the lowest 20% of pasture height. Differences in pasture DM production between the 'High-' and 'Low-height' areas persisted over a 12-month period following mapping.

Although grass grub infestation is associated with this 'yield gap', a direct 'cause and effect' could not be established, since grass grub larvae generally only feed until around mid-winter, at which time they will pupate (Fenemore 1966) and have no further direct effect on pasture plants. It is possible that specific characteristics of the low pasture height area, e.g. lighter soil favoured establishment of grass grub in those areas (Ferguson et al. 2019), and the pasture height was lower as a result of grass grub damage. Also, grass grub infestation may have had long-term impacts on those areas, e.g. a loss of productive pasture plants (Zydenbos et al. 2011), so that ongoing pasture growth (and therefore pasture height) was reduced. Further research is required to understand the reasons for the long-term effect of grass grub on yield.

The yield gap between 'High' and 'Low' areas was estimated at 6800 kg DM/ha for the 2018/2019 year. Lost profitability caused by this difference was estimated at $650/ha but did not include any costs of investment to improve the pasture production in the 'Low' areas. However, it does give an indication of the size of investment that could be made to obtain a cost-effective return on that investment. Spatial variation in pasture yield within a single paddock can be high (Dennis et al. 2015) so it was not possible to determine the proportion of the production differential due to grass grub infestation.

Much of the information about economic impacts of grass grub in pastoral systems has relied heavily on historical data from dryland systems, although economic losses have been estimated from grass grub populations of 50 larvae/m^2 on dairy pastures (Ferguson et al. 2019). Results of the current study agree with those of Ferguson et al. (2019), indicating grass grub control on irrigated Canterbury dairy farms has potential for significant economic benefits where improved pasture production can be achieved.

Results of the survey and the econometric analysis showed that farmers from larger farms and those with System 4 farms seemed to estimate higher levels of grass grub damage than other farmers, but further work is required to determine the causes of this apparent difference.

An integrated pest management (IPM) approach could be used to manage grass grub infestations. Options for IPM of grass grub include cultural controls, such as reducing cultivation frequency (Jackson et al. 2012), and proactive use of biological control in susceptible areas (Jackson et al. 1992; Townsend et al. 2004; Wright et al. 2017). Chemical control can be an effective way to reduce grass grub in the short term, but treated pastures may rapidly return to high grass grub populations (Zydenbos et al. 2016) and a biological approach is likely to be more effective in the longer term.

Although IPM was understood by the farmers, it took the innovation systems approach for them to realise the opportunity and value of adopting changes on-farm, which included new decision criteria for selection of paddocks for renewal.

Conclusions

Yield mapping can be used to detect grass grub infestations in 'at risk' pastures. In future this will enable targeted placement of high-cost treatments (e.g. biopesticides) and a paradigm shift in the economics of grass grub control on high performing farms in Canterbury.

ACKNOWLEDGEMENTS

The trial was undertaken as part of the "Future Farm Systems Rakaia Island project" with additional financial and logistic support from Biostart (http://biostart.co.nz/) through Jerome Demmer, AgResearch Pre-Seed funded project (Yield mapping to target pasture biopesticide applications), Next Generation Biopesticide MBIE programme (C10X1310), and Ravensdown. In-kind support was provided by Rakaia Island Dairies (Dave and Margaret Turner, Doug and Helen Turner and Rory Mackay), with special mention of Jared Porter, farm manager of Dairy1. From Ravensdown, Sonya Perkin has liaised with farmers, collected farm information and contributed to discussion along the way, while John Hodgkin coordinated the collection of the farm survey data. A team of AgResearch staff carried out grass grub sampling including Ray Moss, Tony Hilditch, Russell Croy and Erin Garnett. Willis Ritchie, AgResearch, carried out the Farmax analysis. AgResearch biometrician Peter Johnston carried out the analyses of data from 2018.

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