
Abstract
Black beetle attacks pasture grasses in the northern and coastal North Island and with a warming climate, the beetle has extended its range and damage has become more prevalent. On-farm investigations into prevention of damaging populations suggested that black beetle density was inversely related to soil pH. Two replicated black beetle trials, the first in 2013-2015 on two farms, and the second on four farms in 2015-2017 investigated the effects of late spring agricultural lime applications at the rate of 5 tonne/ha on summer black beetle populations. The results showed that lime can help suppress black beetle populations. Importantly, the effect of lime persisted into the second year in Trial 2, preventing larval populations reaching damaging levels of over 40/m². This adds to the already well-known benefits of lime in improving soil health and pasture quality, vigour and persistence.

Keywords: agricultural lime, soil pH

Introduction
Black beetle (Heteronychus arator (Fabricius) Coleoptera: Scarabaeidae) is a subtropical pest of pasture grasses, as well as ryegrasses (Loli um spp.) without a deterrent endophyte, are favourable hosts (King et al. 1981a; Black & Olson 1988; Bell & Prestidge 1992). In contrast, adult feeding, and in turn survival and oviposition are reduced by ryegrasses containing standard, AR37, NEA2 or Endo 5 endophytes (Ball et al. 1997; Popay & Balsam 2001; Bell et al. 2011). A major outbreak of black beetle occurred in Waikato and Bay of Plenty from 2007 to 2010, and many farmers experienced widespread failure of perennial pastures (Bell et al. 2011). While climate and black beetle were not the only factors, losses were reported of about $1300/ha/year during this period (Reynolds 2013). Since then, the widespread use of black beetle-active ryegrass endophytes, in particular AR37, has enabled pastures to persist even under drought conditions (Thom et al. 2014). However, with ongoing higher annual temperatures, pastures on peat or light soils still experience damage. Consequently there remains a high demand for additional practical tools to help combat this pest in established pastures. In the course of analysing data gathered from 12 paddocks across five Waikato farms during a black beetle/pasture persistence study, it was found that black beetle density was inversely related to soil pH (Gerard et al. 2013). This paper reports on field studies undertaken to investigate if the application of agricultural lime can help reduce black beetle populations.

Methods
Trial 1: 2013-2015
The trial was a randomised block design consisting of four paddocks on Waikato dairy farms, two on a farm with peat soils (Taupiri 1 and 2, 37°37’03.8”S 175°17’30.0”E) and two on a farm with ash soils (Waihou 1 and 2, 37°32’01.5”S 175°38’50.6”E). Each paddock (block) was divided into eight plots and AG lime supplied by McDonalds Lime (now Graymont) was applied at the rate of 5 tonne/ha to four randomly selected plots in each paddock on 4 November 2013, by the commercial operator, Wealleans, using a purpose built 4×4 ground-spraying vehicle. The timing of the lime application was during the black beetle ovi-position period. Black beetle populations were sampled by taking five 20×20 cm spade squares of turf to a depth of 15 cm and hand sorting in the field. This was done in December (a month after lime application) when the black beetle
population consists of adults that have survived the winter, eggs and early instar larvae. The sampling was repeated in late January 2014 when 3rd instar larvae are prevalent and causing pasture damage.

Soil pH was assessed by taking five 7.5 × 2.5 cm cores from each plot and pooling control and lime-treated samples from each paddock in April 2014. The samples were submitted to Hill Laboratories for analysis.

Lime was reapplied to the same plots as in 2013 in early November 2014 and the plots sampled for black beetle in December and January 2015.

**Trial 2: 2015-2017**

This trial was carried out on four Waikato farms (Table 1). At each site two paddocks (blocks A and B) were each split into four quarters (plots) and 5 tonnes/ha of Aglime was applied to two randomly selected plots/paddock using the same supplier and ground-spraying company as above. The first application was on 6 November 2015 at Taupiri and the final one on 18 November at Waikari. Rainfall was above normal (20-149%) and temperatures near normal for these districts during November but hotter and drier than average over summer and autumn (NIWA 2017). The larger plots were used to lessen the amount of drift onto control plots which was perceived to be an issue in the previous trial.

Ten 7.5 × 2.5 cm deep soil samples/paddock were taken in mid-March, the lime and control samples, pooled for each paddock, and the samples submitted to Hill Laboratories for analysis of soil nutrient levels, pH and soil organic matter. In October 2016, five 20 × 20 cm spade squares × 10 cm deep were taken from every plot, in the same way as in 2015. The soil had been sieved for laboratory experiments not be directly comparable as these later samples may not be comparable as the soil had been sieved for laboratory experiments not been collected from treated and untreated plots within the same paddocks.

**Results**

**Trial 1**

The November 2013 lime applications raised soil pH to an average of 6.0 across the treated plots, producing a significant contrast to the control plots averaging at pH 5.7 (P=0.01) in late April 2014.

Figure 1 summarises black beetle population data for December and mid-late January (when 3rd instar larvae are causing pasture damage) for the two summers following lime application in 2013. Populations in the December sampling appear lower than at the later sampling because oviposition is still occurring and even skilled researchers can miss some newly laid eggs and newly hatched larvae while hand searching in the field. In December 2013, a month after lime application, there was an overall 40% reduction in black beetle abundance in the limed plots compared to the control plots (P=0.022). The effects were most pronounced at Taupiri (P<0.001) but were not significant at Waikari where there was no response in one paddock and a 30% reduction in larvae in the other. The 31% difference between black beetle abundance in treated and untreated plots in late January 2014 was not significant (P=0.087).

A similar pattern was apparent in December 2014 at Taupiri with lime application having a positive effect in both paddocks (P=0.034). However, no other significant treatment effects were found that summer.

**Trial 2**

The November 2015 lime application in Trial 2 raised soil pH from an average of 5.7 in the control plots to 5.93 in the lime plots (SED=0.022, P=0.001) by March 2016 with all paddocks showing similar responses except for Ruakura B which did not change at all. Levels appeared lower and further apart by October 2016 (5.38 versus 5.81, SED=0.043, P<0.001) but these later samples may not be directly comparable as the soil had been sieved for laboratory experiments not reported in this paper. The other significant changes in soil chemistry following lime application were an increase in Ca (22.7 to 25.5, SED=0.82, P<0.011) but no change at all. Levels appeared lower and further apart by October 2016 (5.38 versus 5.81, SED=0.043, P<0.001) but these later samples may not be directly comparable as the soil had been sieved for laboratory experiments not reported in this paper. The other significant changes in soil chemistry following lime application were an increase in Ca (22.7 to 25.5, SED=0.82, P<0.011) and decrease in organic matter (30.0 to 27.5, SED=0.9, P=0.036). However, while the desired soil pH differences had been achieved below ground, there was visual evidence of lime particles on the control plot pasture during the black beetle oviposition period when adults were active above ground. Fence tags were placed to show plot boundaries and “No lime” signs put on the paddock gates to prevent accidental additional applications by contractors.

Black beetle populations (and other large soil invertebrates) were sampled as in Trial 1 in mid-December 2015 and late-February 2016 by taking ten 20 × 20 cm spade squares × 15 cm deep/paddock. Plots were sampled a year later, in mid-December 2016 and February 2017. The majority of the population in the February samples were third instar larvae, but also 2nd instar larvae, pupae and new adults were present.

**Statistical analyses**

Black beetle data from both trials were analysed by ANOVA, as were soil analytical data in Trial 2. In Trial 2, a paired sample t-test was performed on pH data from samples collected from treated and untreated plots within the same paddocks.

**Table 1**

<table>
<thead>
<tr>
<th>Locality</th>
<th>Coordinates</th>
<th>Type</th>
<th>Soil organic matter %</th>
<th>Paddock A</th>
<th>Paddock B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taupiri</td>
<td>34°7′30.8″S 175°17′22.7″E</td>
<td>Darry</td>
<td>49 ± 19.0</td>
<td>39 ± 20.4</td>
<td></td>
</tr>
<tr>
<td>Waihi</td>
<td>37°32′05.5″S 175°39′39.0″E</td>
<td>Darry</td>
<td>25 ± 14.0</td>
<td>22 ± 20.0</td>
<td></td>
</tr>
<tr>
<td>Gordonson</td>
<td>37°40′43.5″S 175°18′09.5″E</td>
<td>Darry</td>
<td>26 ± 13.0</td>
<td>21 ± 16.0</td>
<td></td>
</tr>
<tr>
<td>Ruakura</td>
<td>34°46.03.3″S 175°19′15.8″E</td>
<td>Dry stock</td>
<td>22 ± 11.0</td>
<td>21 ± 15.0</td>
<td></td>
</tr>
</tbody>
</table>

Lime application can help protect pastures against black beetle (P.J. Gerard and D.J. Wilson)

**Table 2**

Comparison of April 2015 soil pH and mean (± standard error, SE) black beetle population abundance on lime and control plots in two paddocks (1 and 2) at Taupiri and Waikari sites on four sampling dates.

<table>
<thead>
<tr>
<th>Site</th>
<th>Block</th>
<th>Treatment</th>
<th>pH</th>
<th>Dec 15</th>
<th>Jan 14</th>
<th>Dec 16</th>
<th>Jan 15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taupiri</td>
<td>Control</td>
<td>6.0 ± 0.1</td>
<td>33 ± 9</td>
<td>37 ± 10</td>
<td>47 ± 12</td>
<td>36 ± 6</td>
<td>51 ± 10</td>
</tr>
<tr>
<td></td>
<td>Lime</td>
<td>6.3 ± 0.2</td>
<td>39 ± 8</td>
<td>45 ± 11</td>
<td>56 ± 13</td>
<td>42 ± 6</td>
<td>60 ± 8</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>6.2 ± 0.3</td>
<td>37 ± 9</td>
<td>43 ± 11</td>
<td>54 ± 13</td>
<td>40 ± 6</td>
<td>58 ± 8</td>
</tr>
<tr>
<td></td>
<td>Lime</td>
<td>6.5 ± 0.4</td>
<td>42 ± 9</td>
<td>52 ± 12</td>
<td>63 ± 14</td>
<td>50 ± 6</td>
<td>70 ± 8</td>
</tr>
</tbody>
</table>

**Table 3**

Comparison of March 2016 soil pH and mean (± SE) black beetle population abundance on lime and control plots in two paddocks (A and B) at Taupiri, Gordonston and Ruakura sites on four sampling dates December 2015- February 2017.

<table>
<thead>
<tr>
<th>Site</th>
<th>Block</th>
<th>Treatment</th>
<th>pH</th>
<th>Dec 15</th>
<th>Feb 16</th>
<th>Dec 16</th>
<th>Feb 17</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taupiri</td>
<td>Control</td>
<td>5.9 ± 0.2</td>
<td>28 ± 6</td>
<td>35 ± 9</td>
<td>41 ± 12</td>
<td>28 ± 6</td>
<td>44 ± 10</td>
</tr>
<tr>
<td></td>
<td>Lime</td>
<td>6.3 ± 0.3</td>
<td>37 ± 10</td>
<td>47 ± 13</td>
<td>55 ± 15</td>
<td>42 ± 7</td>
<td>60 ± 9</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>6.0 ± 0.5</td>
<td>30 ± 9</td>
<td>39 ± 11</td>
<td>49 ± 13</td>
<td>36 ± 7</td>
<td>46 ± 9</td>
</tr>
<tr>
<td></td>
<td>Lime</td>
<td>6.3 ± 0.6</td>
<td>33 ± 10</td>
<td>43 ± 13</td>
<td>52 ± 15</td>
<td>39 ± 7</td>
<td>55 ± 9</td>
</tr>
</tbody>
</table>

**Table 4**

Comparison of the abundance of black beetle eggs and larvae in each instar in lime and control plots in 14-18 December 2015 and 5-7 December 2016. The bars denote least significant difference for 1st instar larvae in each year.
m^2 versus 13.2 m^2, respectively, \$\text{SED}=3.2\ P=0.013\)\]. There was no effect on egg abundance (35.5 m^2 versus 32.7 m^2, respectively).

As no black beetle were found in Ruakura paddock B, low numbers in paddock A (around 5 m^2) in December 2016, neither of these dry stock paddocks were sampled in February 2017. Over the six remaining dairy farm paddocks the lime treated plots had 32% fewer black beetle in the lime plots compared to the control plots (46.3 m^2 versus 67.5 m^2, \$\text{SED}=19.2, P=0.007\). Black beetle numbers on these farms were markedly high in February 2017, averaging 57 m^2 compared to 26 m^2 in the previous year (SED=21.9, P=0.001). Regression analysis showed February 2017 black beetle abundance was decreased with increasing soil pH (\$r^2=0.27, P=0.010\)

Application of lime did not appear to impact on the abundance of other soil macro-invertebrates. Earthworms were most abundant in December 2016, averaging 120 m^2 on the control plots and 113 m^2 on lime plots (SED=17.5, P=0.70), neither were there any differences in wireworm Conodorus eussel (Sharp) larval numbers (12.3 and 15.8 m^2, respectively (SED=2.8, P=0.22).

**Discussion**

The results from these two trials, combined with the previous finding that greater populations of black beetle are associated with lower soil pH (Gerard et al. 2013), show that the application of lime can help suppress black beetle. Importantly, the effect of the lime application persisted throughout the trial as indicated by the regression analysis, soil pH only explains around 30% of the variation in black beetle abundance, so it is important to combine this new information with other known management tools for black beetle, such as grasses containing black beetle-active fungal endophytes (Neotyphodium lolii et al. 1980) and the use of insecticide-treated seed when renovating pastures in black beetle-prone regions. As AR37 and wild-type endophytes have similar effects and that the effect persists at least into the second year, it can be assumed from pasture age that the endophyte fungus Acremonium lolii on adult black beetle (Heteronychus arator) feeding. pp. 201-204. In: Proceedings of the 45th New Zealand Plant Protection Conference.


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King, N.L.; Mercer, C.F.; Peekings, J.S. 1981a. Ecology of black beetle Heteronychus arator. Influence of plant species on larval consumption, utilization and


