Final report

EPDS- Demonstrating the benefits of dung beetles for lamb enterprises

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Abstract

Healthy soils and pastures are critical for a productive prime lamb operation. There is limited research on the use of dung beetles in sheep production systems, however research in cattle systems suggests by burying and consuming dung, dung beetles improve nutrient cycling and soil structure, reduce pasture fouling and increase pasture growth (Doube 2008).

The South West Prime Lamb Group (SWPLG) undertook dung beetle trapping in conjunction with the Dung Beetle Environmental Engineers (DBEE) project to investigate existing populations of dung beetles and their seasonal abundance. Trapping was performed for twelve months across eight properties (four per year for two years). Twelve species were found, including eight introduced and four native species. A noticeable gap in the abundance of introduced dung beetles was observed from late autumn, through winter, into early spring.

The project also demonstrated the impact of deep tunnelling *Bubas bison* on soil fertility. Trials showed that dung beetles were mobilising nutrients and increasing soil fertility to depths of 10-30 and 30-60cm. Plant roots and earthworms were observed to be travelling down dung filled tunnels.

The project highlighted the benefits of dung beetles for prime lamb systems and opportunities to value add to these benefits by filling seasonal gaps in abundance.

Executive summary

Background

Research in cattle systems suggests by consuming and burying dung, dung beetles reduce pasture fouling, improve nutrient cycling and soil structure and increase pasture production.

Doube (2008) measured increases in nitrate, ammonia, phosphate, sulphur and soil carbon at 20-45 cm below dung pads through the action of dung beetles. Soil organic matter, soil pH and EC were also elevated. Large earthworm numbers were found under dung pads, soil hardness decreased and permeability to water increased where dung beetles buried dung. Doube (2008) also recorded increased pasture production of 25-27% lasting for at least two years in plots with dung and dung beetles.

Despite these findings, there is very little information about dung beetles in sheep systems. For this reason, the South West Prime Lamb (SWPLG) group embarked on a project to firstly find out what local dung beetle species were attracted to sheep dung, and secondly, to demonstrate the benefits of dung beetles. Ultimately, the group hoped to encourage further interest and understanding of dung beetles and the adoption of practices to grow dung beetle populations.

Objectives

The aim of this project was to demonstrate the benefits of dung beetles in a sustainable sheep farming system in southwest Victoria and to explore if these benefits can be utilised to add value to modern prime lamb operations.

More specifically, the project aimed to:

1. **Investigate what species of dung beetles are active on sheep dung in southwest Victoria and their seasonal patterns of abundance.**

This was achieved through monthly trapping across a total of eight properties, each for twelve months.

2. **Demonstrate the impact that dung beetles have on soil health and fertility, including through burial of dung infused with biochar.**

The impact on soil fertility of *Bubas bison* was demonstrated across four different soil types/ sites. However, the impact of biochar was not successfully demonstrated.

3. **Increase producers' knowledge of the role of dung beetles and improve skills and confidence in managing dung beetle populations.**

The group averaged an increase in knowledge from 3.7/10 to 7.3/10 and an increase in skills from 4.2/10 to 6.7/10. There was also adoption of monitoring and practices to encourage dung beetle populations.

Methodology

The SWPLG members undertook monthly trapping using sheep dung baits, to identify what dung beetles are active in sheep systems in southwest Victoria and when they are active. Four producers trapped beetles from June 2019- May 2020 and a further four producers trapped from December 2020- November 2021. Beetles were identified by the Dung Beetle Ecosystems Engineers (DBEE) project.

Additionally, dung burial trials were established over four sites. These sites involved Dung Only, Dung+Beetles and Control plots and measured changes to soil fertility using soil testing at 0-10cm,

10-30cm and 30-60cm to measure the impact of deep tunnelling *Bubas bison*. Biochar was incorporated into dung at one site by feeding pellets coated in biochar to sheep.

Results/key findings

Twelve species were trapped, using sheep dung, across the eight properties including introduced *Bubas bison, Euoniticellus fulvus, Euoniticellus pallipes, Onitis aygulus, Onthophagus binodis* and *Onthophagus taurus, as* well as native *Onthophagus australis, Onthophagus mniszechi, Onthophagus posticus* and *Onthophagus auritus*. Two dung dwellers (not true dung beetles) were also found; *Aphodius fimetarius*, *Aphodius lividus*.

O. taurus and *E. fulvus* were the prolific species and are active over the warmer months. A noticeable gap in introduced dung beetle abundance was observed from late autumn to early spring, however the native *O. mniszechi* was active year-round at Cashmore, Narrawong and Heywood.

Large increases in phosphorus and potassium were measured to depth through the action of deep tunnelling *Bubas bison.* The additional phosphorus measured at 10-30cm depth in the Dung+Beetle plots was equivalent to around 1 t/ha of single super valued at approximately $650/ha (not spread). The additional potassium at 10-30cm equated to between 150-430 kg/ha of applied potash valued at approximately $200- $470/ha (not spread).
High numbers of earthworms were observed under Dung+Beetle plots, including earthworms that had wrapped around the tunnels of dung. It is likely that this increased activity is from earthworms feeding on buried dung.

Project extension involved two public field days and a webinar as well as presentations, numerous media articles and two social media posts promoting the project results. A case study and project summary were also developed. Factsheets were produced for dung beetles trapped throughout the demonstration and have proved popular, with 565 webviews at the date of reporting. These activities led to a large, measured increase in the group's knowledge and skills, and adoption of dung beetle monitoring activities as well as members indicating they planned to purchase dung beetle colonies to build populations.

Benefits to industry

The project showed that dung beetles are active on sheep dung in southwest Victoria, particularly over the warmer months from late spring to early autumn. It identified that a gap in abundance exists in the cooler months from late autumn to early spring and there is an opportunity to fill this gap through the introduction of winter active species such as *Bubas bison*. The dung burial trials demonstrated the impacts of dung beetles on soil health and fertility. This information adds to the limited available information about dung beetles in sheep systems and can be used to further communicate their benefits.

Future research and recommendations

There is scope to increase the populations of winter active dung beetles such as *B. bison* in southwest Victoria, however more guidance on how to effectively do this would be beneficial given some group members had attempted releases and beetle rearing with mixed success. Furthermore, the project led to producers asking for more information about the impact of drenches on dung beetles and methods for managing drenched animals to minimise impacts on dung beetle populations.

PDS key data summary table

Project Aim: To demonstrate the benefits of dung beetles in a sustainable sheep farming system in South West Victoria, by identifying what dung beetles are active on sheep dung and demonstrating their impact on soil fertility.			
	Comments		**Unit**
There is no appropriate model to place a dollar return on dung burial and benefits of dung beetles (Doube 2008). Soil increases in phosphorus and potassium at the 10-30cm depth through dung beetle action was valued at approximately $200-$470/ha (potash equivalent) and $650/ha (single super equivalent), however no direct benefit was measured.			
Number of core participants engaged in project	Hosts/ key producers	9	
Number of observer participants engaged in project	Rest of SWPL group (many more attended field days etc)	31	
Core group no. ha	Approx.	8,100	
Observer group no. ha	Approx. (rest of SWPLG only)	21,000	
Core group no. sheep	Approx.	38,000	hd sheep
Observer group no. sheep	Approx. (rest of SWPLG only)	140,000	hd sheep
Core group no. cattle		400	hd cattle
Observer group no. cattle	Approx. (rest of SWPLG only)	2,500	hd cattle
% change in knowledge, skill & confidence – core & observers	Understanding benefits of dung beetles, how to encourage/ manage populations, species and seasonal abundance, skills in identifying beetles	Increase: Knowl. 100% Skills 60% Motivation to adopt 40%	Changes 3.7/10 to 5.3/10 4.2/10 to 6.7/10 6.1/10 to 8.6/10
% practice change adoption – core & observers	Monitoring DB Encouraging DB (through releases or changed drenching practices)	Adoption: Monitoring DB 62% Encouraging DB 50% (100% had adopted a new practice)	Changes Monitoring DB 38% to 100% Encouraging DB 38% to 88%

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1. Background

1.1 South West Prime Lamb Group

The South West Prime Lamb Group Inc (SWPLG) is a farmer discussion group that was formed in 1994 and joined the Bestwool/Bestlamb network in 2011. Since its inception, the group has maintained a membership of around 30 producers throughout southwest Victoria. All members produce prime lambs; with their production systems encompasing self-replacing crossbred systems, first-cross ewes and to a lesser extent flocks with a predominantly merino base.

The group collectively manages approximately 21,000 hectares and carries around 140,000 sheep and 2,500 cattle.

The SWPLG has a management committee of producers who meet several times a year to plan functions and provide input into projects.

1.2 Benefits of dung beetles

Between 1965-85, more than 50 dung beetle species were introduced to Australia by CSIRO to help control bush fly, of which 23 species are believed to have become established. There are also more than 500 species of native dung beetles in Australia, which evolved to process the coarse pellet-like droppings of marsupials but appear to be adapting to livestock dung (pers comm. J Feehan 2020).

Whilst there is a history of dung beetle releases throughout southwest Victoria, limited information exists about species establishment and abundance. The Dung Beetle Ecosystem Engineer (DBEE) project used historical data to suggest that five introduced species occur in the Glenelg Hopkins Catchment Management Authority region, home to the SWPLG.

Dung beetle research relating to sheep production systems is particularly limited. Yet mature sheep produce about 2.25 kg of wet dung each day. With the Australian sheep flock projected to reach 74.4 million head in 2022 (MLA sheep projections) over 61 million tonnes of dung will be dropped onto Australian pastures yearly.

Dung beetle research in cattle systems suggests by burying and consuming dung, dung beetles reduce pasture fouling, improve nutrient cycling and soil structure and increase pasture production.

Doube (2008) measured increases in nitrate, ammonia, phosphate, sulphur and soil carbon at 20-45 cm below dung pads through the action of dung beetles. Soil organic matter, soil pH and EC were also elevated. Large earthworm numbers were found under dung pads,soil hardness decreased and permeability to water increased where dung beetles buried dung.

There is also evidence that by removing fresh dung the beetles can lower internal parasite infections in livestock by burying parasite eggs in the dung so that they no longer hatch and infect the pastures (Coldham 2011).

Over the last decade biochar has been incorporated as an element of dung beetle research. Biochar is produced through thermal decomposition of biomass and has been seen as a strategy to improve soils and sequester carbon while also used as a supplement in animal feed (Joseph et al 2012).

Investigations looking at feeding biochar to cattle in Western Australia (Joseph et al 2015) and South Australia (Doube, B 2015) suggest that the biochar adsorbs nutrients from the cow's gut and from the dung. Dung beetles can transport this nutrient rich biochar into the soil profile which appears to be effective in improving soil properties including water holding capacity.

While there is little available information that quantifies the benefits of dung beetles and no appropriate model to place a dollar return on dung burial (Doube 2008), the SWPLG undertook a three-year project to demonstrate the soil health benefits of dung beetles for prime lamb enterprises. The SWPLG wanted to help bridge the knowledge gap relating to prime lamb systems by demonstrating research undertaken in cattle systems. They could also see a potential application for biochar, a by-product from local forestry that could benefit soils and pasture production.

Ultimately, the group hoped to encourage further interest and understanding of dung beetles and the adoption of practices to grow dung beetle populations.

2. Objectives

The aim of this project was to demonstrate the benefits of dung beetles in a sustainable sheep farming system in South West Victoria.

The specific project objectives were to:

1. **Investigate what species of dung beetles are active on sheep dung in southwest Victoria and their seasonal patterns of abundance.**

This was achieved through monthly trapping across a total of eight properties, each for twelve months.

2. **Demonstrate the impact that dung beetles have on soil health and fertility, including through the burial of dung infused with biochar.**

The impact on soil fertility of *Bubas bison* was demonstrated across four different soil types/ sites. The impact of biochar was not successfully demonstrated owing to complexities with dung becoming too dry for dung beetles when biochar was incorporated into a pellet ration (see results).

3. **Increase producers' knowledge of the role of dung beetles and improve skills and confidence in managing dung beetle populations.**

Producers indicated an average increase in knowledge from 3.7/10 to 7.3/10 and an average increase in skills from 4.2/10 to 6.7/10. There was also a large adoption of monitoring and encouraging dung beetle populations. This was achieved through extension activities and media. However, not all of the group members shared the same enthusiasm for dung beetles and field days were attended by a mix of SWPLG members and others, external to the group.

3. Demonstration Site Design

3.1 Methodology

3.1.1 Investigating species of dung beetles attracted to sheep dung and their seasonal patterns of abundance

This demonstration involved trapping dung beetles on four properties over 12 months in 2019-2020 and a further four properties for 12 months in 2020-2021 (Table 1) to identify existing dung beetle species and their seasonal distribution. The methodology was initially developed with dung beetle expert Dr. Bernard Doube and tested on two properties. Trapping methodology was aligned to the DBEE protocols to ensure consistency with other DBEE sites. This data is also utilised by the DBEE project.

Table 1: Sites involved in the dung beetle trapping

Site	Timing	No. Traps
Cashmore	Yr 1 (June 2019- May 2020)	4
Heywood 1	Yr 1 (June 2019- May 2020)	2
Heywood 2	Yr 1 (June 2019- May 2020)	2
Strathkellar	Yr 1 (June 2019- May 2020)	4
Hensley Park	Yr 2 (Dec 2020 - Nov 2021)	4
Hamilton	Yr 2 (Dec 2020 - Nov 2021)	4
Narrawong	Yr 2 (Dec 2020 - Nov 2021)	4
Woolsthorpe	Yr 2 (Dec 2020 - Nov 2021)	4

Site selection required traps to be placed in the open, more than 50 m from trees and with traps 0.5-1 km apart. Trap design (Fig. 1) involved the following:

Figure 1: Dung beetle trap

Mesh placed over the trap

- Pegging down the trap with four tent pegs
- Approximately 1 litre of pet-safe preservative added to each trap
- Fresh sheep dung bait (approx. 0.5 kg in mesh bag) attached with a cable tie

The traps were checked after 24 hours, and beetles were stored in a cool, dark location prior to sending to the DBEE project team for identification. Data and photos were also shared with the DBEE team using the 'My Dung Beetle Reporter' app. Unfortunately, the DBEE project did not provide feedback on native species.

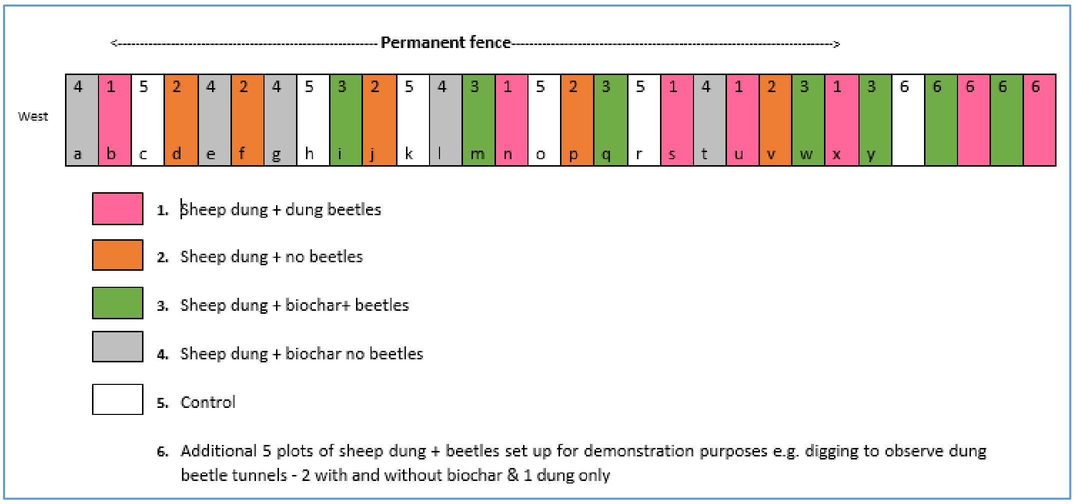
3.1.2 Demonstrating the impact that dung beetles have on soil health and fertility

2019 Dung burial trial with biochar

This trial aimed to demonstrate soil benefits from incorporating biochar-laden sheep dung into the soil profile using dung beetles (*Bubus bison*). It was based on research conducted in South Australia and Western Australia that used cattle dung.

This trial could not be undertaken at paddock scale due to the mobility of dung beetles, and was set up as five different treatments, each with six randomly allocated replicates (Fig. 2), which included a plot for digging investigations.

Figure 2: 2019 Dung burial trial design



Treatments included:

1. sheep Dung+Beetles
2. sheep dung + no beetles
3. sheep dung + biochar+ beetles
4. sheep dung + biochar no beetles
5. control

Incorporating biochar into sheep dung

Sixty composite ewe lambs (approximately 40kg) were used to produce the dung. Thirty lambs were fed a pellet ration with biochar (at 2% of their diet) and 30 were fed the pellets without biochar. Molasses was sprayed on the pellets to help mix in the biochar and was applied to both treatments. Sheep were inducted onto the pellet mix over seven days, fed adlib with water and hay (in the first week only). Dung was collected after the seven-day induction period. The biochar was produced at Portland from blue gum forest trash. Fig. 3 shows dung produced with and without biochar.

General setup

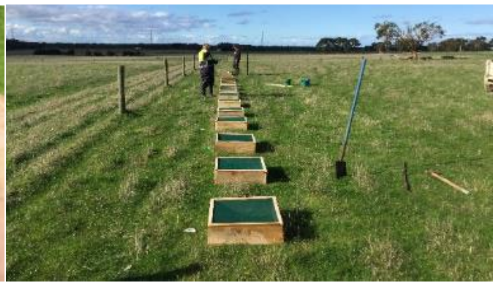
Sites were set up in June (when *B. bison* is active) as follows:

- 2 kg of dung was applied (with or without biochar to the replicates of all treatments except the control)
- 15 pairs of beetles were applied to each of the beetle plots (Fig. 4)
- 50cm x 50cm frames covered in shade cloth were applied to all plots to prevent dung beetles from escaping (Fig. 5)
- Plots were checked weekly and 0.5- 1 kg of dung was added as required, repeating until dung beetle activity ceased
- A total of 4.5 kg of dung was added to the plots with dung beetles (including the initial 2kg at set up) between June and mid-August
- Spare plots were excavated in November 2019 to observe activity
- Soil tests were taken one year later (June 2020) across the replicates at 0-10, 10-30 and 30-60cm

Figure 3: Sheep dung with biochar infused (left) and without biochar (right)

Figure 4: Male (left) and female Bubas bison

Figure 5: Trial set up including frames



2020 Dung burial trial

The project encountered some issues around the use of biochar in the 2019 trial. As a result, the SWPLG steering committee decided to trial a second dung burial demonstration in June 2020 on three different soil types (Fig. 6) using dung from sheep fed entirely on pasture and without biochar.

Figure 6: Soil information for the three 2020 trial sites

Paddock	**Site 1 (Heath Pdk)**	**Site 2 (Hill Pdk)**	**Site 3 (40 Acres)**
Soil type	Grey/brown Clay/loam	Dark grey, clay/loam with 5-10% gravel (0-30cm) heavy clay (30-60 cm)	Dark grey clay (0-10) Very heavy clay (10-30)

Four replicates were set up for each treatment, including a plot for excavation. The three treatments included:

1. sheep Dung+Beetles

2. sheep Dung Only (no beetles)
3. Control

General setup

Similar to 2019, sites were set up in June, as follows:

- 2kg of dung applied to the Dung Only and Dung+ Dung Beetle plots
- 15 pairs of beetles were applied to each plot with beetles
- 50cm x 50cm frames covered in shade cloth were applied to all plots to prevent dung beetles from escaping.
- Plots were checked weekly and 0.5- 1L of dung added as required, repeating until dung beetle activity ceased
- A total of 5 kg of dung was added to the plots with dung beetles (including the initial 2kg at set up) between June and mid-September. Sheep dung was analysed for nutrient content.
- Spare plots were excavated in November 2020 to observe activity
- Soil tests were taken one year later (June 2021) across the replicates at 0-10, 10-30 and 30-60cm

Pasture production

The group were interested in investigating whether dung beetle activity would lead to increased pasture dry matter production as previous research indicated (Doube, 2008). Fences protecting the 2020 dung burial trial had been removed in November to allow sheep to graze down the pasture. The three sites were re-fenced to exclude sheep in April 2021. Dry matter cuts (Fig. 7) were taken between June- November across the three replicates of the Dung Only, Dung+Beetles and Control treatments at each of the three sites.
Cuts were taken in June, August, September and November. The June cuts were not included in the results as plots had uneven pasture cover owing to sheep traffic when they were fenced from stock.

Figure 7: Pasture measurements

3.2 Economic analysis

An economic analysis was not undertaken regarding the benefits of dung beetles for several reasons.

- There is a deficiency of information that evaluates the economics of dung beetles and there is no appropriate model to place a dollar return on dung burial (Doube 2008).
- This demonstration measured no significant increase in pasture growth on dung beetle plots (despite other research measuring increased pasture growth).
- Dung beetles provide a range of ecosystem services that are difficult to value and can also differ between species that are active at different times of the year.

3.3 Extension and communication

Planned communication and extension activities included the following:

- Host/ core producer training in the specific set up of traps and how to find dung beetles
- 1 group field day or major engagement event per year
- 1 media article based on annual outcomes per year
- 2 social media posts/year (on AgVic Facebook and/or Twitter)
- 1 case study or fact sheet

3.4 Monitoring and evaluation

Monitoring and evaluation included:

- Surveys to benchmark KASA (knowledge, attitude, skills and aspirations) undertaken by the group prior to commencing the demonstration and at its completion.
- Evaluation of group activities using a typical feedback form.
- Annual steering group review of the demonstration to discuss how the project is performing, results and required changes.

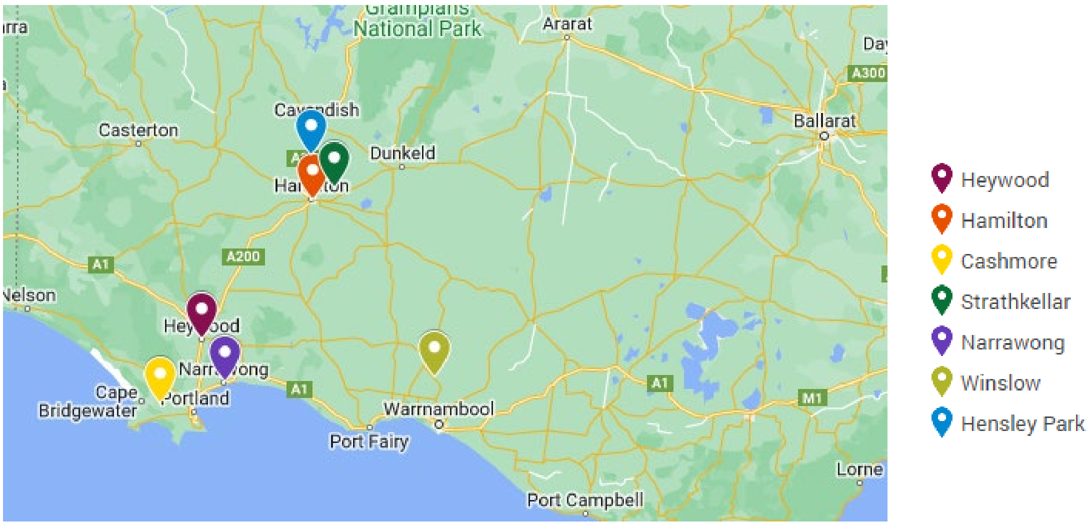
4 Results

4.1 Demonstration site results

4.1.1 Investigating species of dung beetles attracted to sheep dung and their seasonal patterns of abundance:

Across the eight monitoring sites (Fig. 9)the following introduced species were identified: *Bubas bison, Euoniticellus fulvus, Euoniticellus pallipes, Onitis aygulus, Onthophagus binodis* and *Onthophagus taurus as* well as the following native dung beetles; *Onthophagus australis, Onthophagus mniszechi, Onthophagus posticus* and *Onthophagus auritus.* Other dung inhabiting beetles such as *Aphodius fimetarius* and *Aphodius lividus* were also regularly observed.

Figure 9: Map of trap sites (Google Map data 2022)



Year 1 trapping (June 2019- May 2020)

Cashmore site (four traps)

The most prolific introduced dung beetle at this site was *O. taurus* with counts averaging over 2000 beetles across the traps in January and February (over 5000 in one trap in January).

These accounted for around 90% of introduced dung beetles found at this site in summer. *E. fulvus* was the next most common averaging around 200 (in January replicates ranged from 36 to 325). *O. binodis* was present in small numbers each month whilst *O. aygulus* was found in traps in January and February. Interestingly no *B. bison* was identified at this site, despite the farmer doing many field releases to establish colonies.

This site had very active *O. mniszechi*; an example of this can be seen in Fig. 9, taken the day after some old dung was thrown on the ground. These beetles were very active over winter when there were no records of introduced species being present.

Figure 9: Evidence of O. mniszechi activity about 15 hours after dung was thrown on the ground.

Heywood site (two neighbouring farms, each with two traps)

O. taurus was by far the most active introduced species at this site. Activity was first detected in September with numbers slowly climbing to a peak of well over 25,000 beetle across two traps in February. The pattern was similar for *E. fulvus* but in much lower numbers. *O. binodis* was present in small numbers in February. There was no evidence of introduced winter active beetles at this site.

Strathkellar site (four traps)

There was limited data collected/reported from this site. However from the information available it was evident that both *O. taurus* and *E. fulvus* were both active over summer/autumn but neither were in large numbers.

Year 2 trapping (Dec 2020 - Nov 2021)

Narrawong site (four traps)

All traps were within 500m of the coast. There was evidence of *O. taurus, E. fulvus* and *O. binodis* from September through to May. The numbers of all three species were reasonably consistent, peaking in February with around 3681 *O. taurus,* 695 *E. fulvus* and 887 *O. binodis* trapped. One *B. bison* was trapped in August, but this was the only evidence of any introduced winter active species present. The native species *O. mniszechi* was active all winter at this site.

Hamilton site (four traps)

O. taurus was active at this site from October through to May. Whilst the numbers peaked in January they were reasonably consistent over the other months. *E. fulvus* was found in lower numbers from October to March. *O. binodis* was present in low numbers in several traps in April. This was the only site that had consistent *B. bison* present. Whilst in very low numbers, *B. bison* was identified at this site from April through to August and in November.

Hensley Park site (four traps)

The main introduced species active at this site were *O. taurus* and *E. fulvus* with small numbers in September and consistent counts through to April-May. There was evidence of *E. pallipes* in March and a *B. bison* was trapped in June. There was no other winter activity of introduced species recorded at this site.

Winslow site (four traps)

Numbers of introduced dung beetle species were very low at this site however, there was evidence of *O. taurus* and *E. fulvus* from October to June and November to April, respectively. Unusually the numbers recorded for *O. taurus* peaked in November, whilst the low numbers of *E. fulvus* peaked in

January. No dung beetle activity was observed or recorded at this site from July through to September.

Across all sites

The most trapped beetle across all sites was *O. taurus*, followed by *E. fulvus and O. binodis* (Table 2). These beetles are largely active over the warmer months. *B. bison* was the only introduced winter active beetle found at three of the sites, however only one beetle was trapped at any time. It was also found around Hamilton and not further south around Cashmore, despite dung beetle releases at this site in the past. Whilst the DBEE project did not count native dung beetles, the native *O. mniszechi* was commonly found at Cashmore, Heywood and Narrawong and was active throughout the year.

These results indicate a general gap in an abundance of introduced beetles throughout winter and early spring.

Table 2: Summary and indicative numbers of dung beetles found across the sites

	Summer	Autumn	Winter	Spring	Natives beetles observed *
Cashmore	*O. taurus (2000+)* *E. fulvus (200+)* *O. binodis*	*O. taurus* *E. fulvus* *O. binodis*		*O. taurus* *E. fulvus*	*O. mniszechi* *O australis* *O. posticus* *O. auritus*
Heywood (2 farms)	*O. taurus (5000+)* *E. fulvus* *O. binodis*	*O. taurus* *E. fulvus*		*O. taurus* *E. fulvus*	*O. mniszechi* *O australis*
Strathkellar	*O. taurus* *E. fulvus*	*O. taurus* *E. fulvus*		*O. taurus* *E. fulvus*	*O australis*
Narrawong	*O. taurus (3000+)* *E. fulvus (600+)* *O. binodis (800+)*	*O. taurus* *E. fulvus* *O. binodis*	*B. bison (1)*	*O. taurus* *E. fulvus* *O. binodis*	*O. mniszechi* *O australis*
Hamilton	*O. taurus* *E. fulvus*	*O. taurus* *E. fulvus* *B. bison* *E. pallipes*	*B. bison (1)*	*O. taurus* *E. fulvus*	
Hensley Park	*O. taurus* *E. fulvus*	*O. taurus* *E. fulvus*	*B. bison (1)*	*O. taurus* *E. fulvus*	
Winslow	*O. taurus* *E. fulvus*	*O. taurus* *E. fulvus*		*O. taurus* *E. fulvus*	

Estimated beetles per trap: >1000 beetles, 100-1000 beetles, 10-99 beetles, <10 beetles
*Native beetles were not counted through the DBEE project

4.1.2 Demonstrating the impact that dung beetles have on soil health and fertility

2019 Dung burial trial with biochar

Dung removal across all plots was less than expected and noticeably lower in the plots with biochar. Plots were scored for dung removal and level of dung beetle activity (number of tunnels) revealing 55% removal in the plots without biochar compared to 15% in biochar plots and fewer tunnels in plots with biochar (Table 3). Fresh paddock dung was added in September to check activity levels, also showing less activity on biochar plots.

Table 3: Estimated dung beetle activity on biochar and non-biochar plots

	Estimated dung removal	Ave. number of tunnels per plot
Dung beetle plots without biochar	55%	3
Dung beetle plots with biochar	15%	<1

Given this lack of activity, samples of dung were analysed to investigate moisture content. Dung from sheep fed on pellets was much drier (66% moisture with biochar, 68% moisture without biochar) than dung from pasture fed sheep (87%) (Table 4). This is likely to have impacted dung beetle activity, given that dung beetles feed on the moisture in dung, and thrive on dung with a moisture content greater than 70% (B. Doube, personal communication 2019).

Table 4: Moisture content of dung from sheep fed pellets (with and without biochar) and pasture

Treatment	Moisture content (%)
Trial dung without biochar	68%
Trial dung with biochar	66%
Dung from pasture fed sheep	87%

Two spare dung beetle plots (one with and one without biochar) were excavated in November 2019 to investigate activity beneath the ground. This revealed a moderate level of beetle activity. Several dung tunnels up to 37cm long and around 2.5cm across were found beneath the beetle plots, with egg chambers at the base. These dung tunnels were filled largely with the fresh dung that had been added in September. Large numbers of earthworms were found under the plots and wrapped around the dung tunnels (Fig. 10 – Fig. 15).

Figure 10 Dung from the beetle tunnel, which ran to approximately 40cm

Figure 11 Dung from the beetle tunnel, which ran to approximately 40cm

Figure 12. Dung beetle egg buried at 37cm in dung tunnel

Figure 13. Part of the tunnel containing a dung beetle egg in a brood ball

Figure 14. Large numbers of earthworms found under the dung/ beetle plot

Figure 15. Earthworms wrapped around the dung tunnel

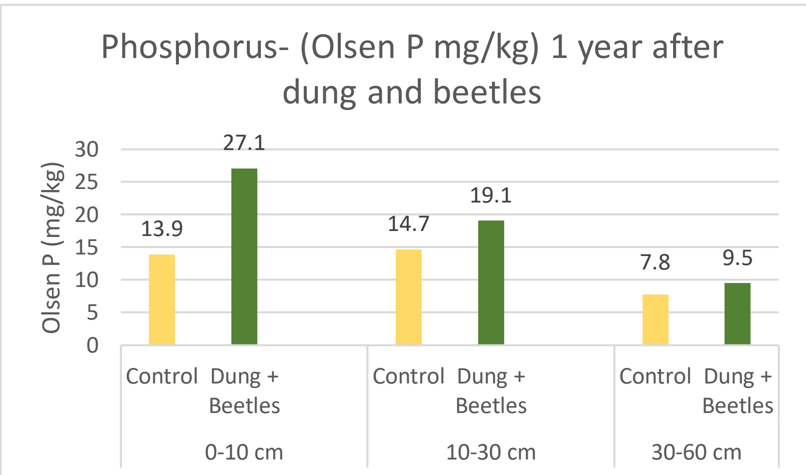
With little activity on the biochar sites, the soil testing regime was reduced; biochar sites were not tested, and carbon fractionation was not undertaken. Dung Only plots received less dung than Dung+Beetle plots over the trial period, so soil test results for these plots were not included in the results.

Results from soil testing on the Dung+Beetles and Control plots at 0-10, 10-30 and 30-60 cm depths showed obvious differences in phosphorus (P) and potassium (K) levels between treatments (Fig. 16 and 17). This was not observed for other soil nutrients (Appendix A).

Phosphorus levels were higher in the Dung+Beetle treatments than the Control plots at all depths- by approximately; 13 mg/kg in the top 0-10 cm, 4 mg/kg at 10-30 cm and 2 mg/kg at 30-60 cm (Fig. 17). The increases at 30-60 cm were small enough to be considered sampling variation.

On the light, sandy soils of this site, an increase in 13 mg/kg is extremely high, equivalent to around 104 kg P/ha or around 1 t/ha of single super in the top 10 cm. At a depth of 10-30 cm, the increased phosphorus was equivalent to 32 kg P/ha or 360 kg of single super.

Figure 16: Control and Dung+Beetle Olsen P June 2020- 1 year after treatment



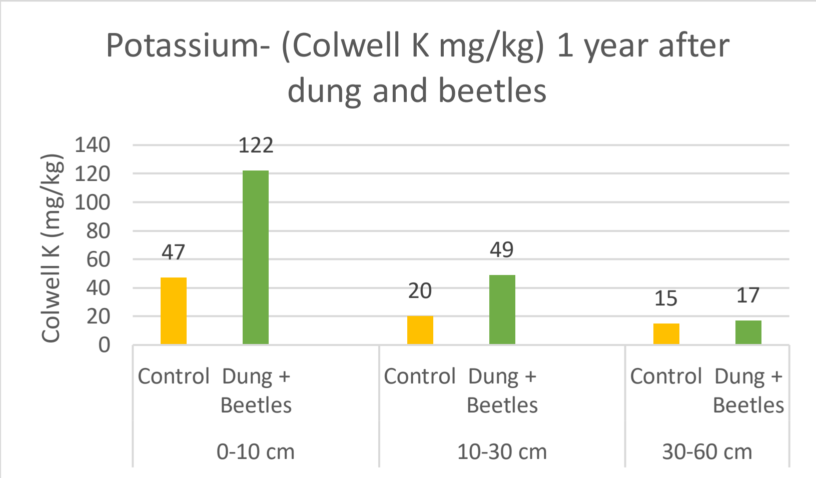
Phosphorus calculations:

(0-10 cm)
13mg/kg x 8 (capital P soil factor) = 104 kg P/ha
Single super is 8.8% P
$\frac{104 \text{ kg P/ha}}{8.8}$ x100 = 1.18 t/ha single super

(10-30 cm)
4 mg/kg x 8 (capital P soil factor) = 32 kg P/ha
$\frac{32 \text{ kg P/ha}}{8.8}$ x100 = 0.36 t/ha single super

These soils started with very low-level potassium in the top 10 cm (Colwell K= 47 mg/kg) (Fig. 17). u Potassium levels increased by around 75 mg/kg in the top 10 cm, 29 mg/kg at 10-30 cm and around 2 mg/kg at 30-60cm through the addition of dung and dung beetles (Fig. 16).

Figure 17: Control and Dung+Beetle Colwell K June 2020- 1 year after treatment



Potassium calculations:

(0-10cm)
1 mg/kg Colwell K increases with approx.1 kg K/ha applied K
75 mg/kg Colwell K equates to 75 kg/ha applied K
Potash is approx. 50% K
75 kg/ha K equates to 150 kg of applied potash

(10-30 cm)
29 mg/kg Colwell K equates to approx. 29 kg/ha applied K or 58 kg/ha of applied potash

This was a dramatic increase, particularly in the top 10 cm- equivalent to the addition of around 75 kg/ha K or 150 kg/ha of applied potash.

The increase down the profile in the 10-30 cm level was equivalent to the addition of 29 kg/ha K or 58 kg/ha of potash.

2020 dung burial trial

More dung beetle activity was observed in the 2020 trial that used fresh sheep dung than the 2019 trial that used dung from sheep fed pellets. Figure 18 shows the progression of dung burial between June and September 2020. As dung was buried on the Dung+Beetles plots, additional dung was added. In total, 5kg was added (an extra 3kg after the sites were set up). Dung was also added to the Dung Only plots to ensure the same starting point in terms of nutrients added.

Figure 18: Dung burial over time (June- September) at Site 1-3

A Dung Only and Dung+Beetle plot were excavated at each of the three sites in November 2020. Many dung-filled tunnels were found in the Dung+Beetles plots, particularly in Site 1 (grey/brown clay/loam) and Site 3 (dark grey clay). Fewer tunnels were observed in the gravellier Site 2 plots.

Excavations revealed large numbers of earthworms to depth, particularly in the Site 1 (Fig. 19). Brood balls containing dung beetle larvae were found at the base of dung tunnels (Fig. 20). Excavation at Site 1 also clearly showed that plant roots had travelled down the soil profile through dung tunnels (Fig. 21).

Figure 19: Earthworms under the Dung+Beetle plot, Site 1

Figure 20: Dung beetle egg and larvae and an earthworm found under dung beetle plots

Figure 21: Dung beetle tunnels at Site 3

Figure 22: Earthworms and grass roots following the dung tunnels through the soil profile

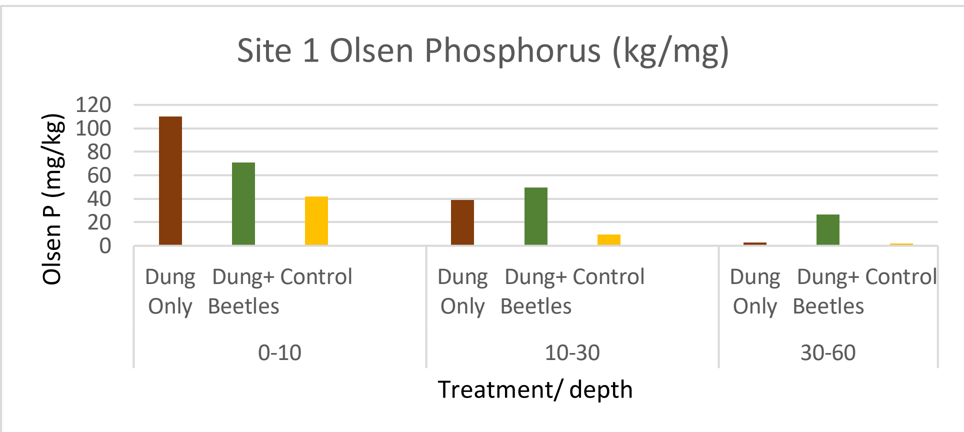
Soil testing across the treatment plots at 0-10, 10-30 and 30-60 cm showed differences in phosphorus (P) and potassium (K) levels between treatments (Fig. x and y), a similar result to the 2019 trial. This was not observed consistently for other soil nutrients (Appendix A).

Phosphorus

All three sites showed a large phosphorus increase in the Dung Only plots at 0-10 cm and to a lesser extent in the Dung+Beetles plots compared to the Control (Fig. 23-25). Site 1 and Site 2 also had a large phosphorus increase at 10-30 cm in the Dung+Beetles treatment and to a lesser extent, the Dung Only treatment.

This result is indicative of dung beetles mobilising the applied dung through the soil profile. The dung beetle action moved more phosphorus than the leaching effect on the Dung Only plots. The difference in phosphorus at 10-30 cm between the Dung Only and Dung+Beetles plots was equivalent to around 1 t/ha of single super at Sites 1 and 2. The value of the single super equivalent was approximately $650/ha (not spread). Site 3 was extremely difficult to soil sample due to the wet clay. A 30-60 cm sample was not obtained, and it is possible that the reduced sampling at 10-30 cm was insufficient to pick up variation within the plots.

Figure 23: Site 1: Dung Only, Dung+Beetle and Control Olsen P June 2021- 1 year after treatment

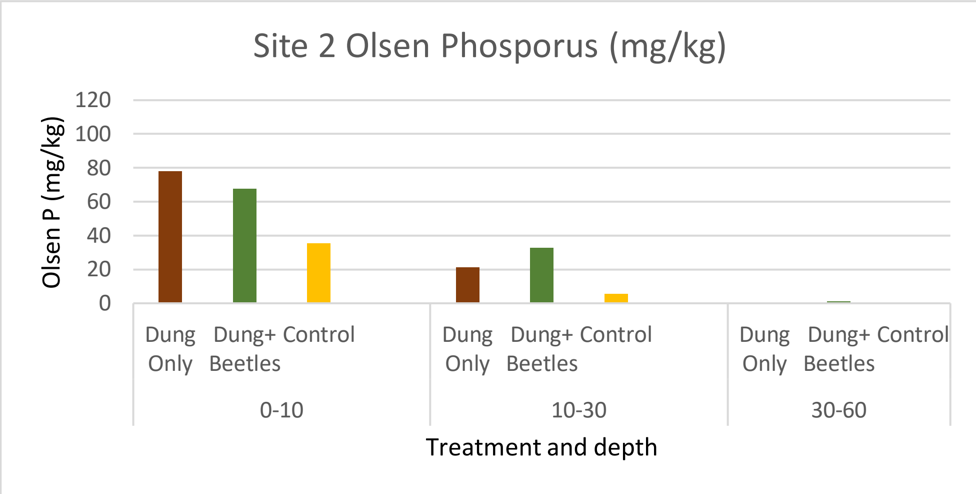


Phosphorus calculations:
<u>10-30 cm Difference between Dung Only and Dung+Beetles=11 mg</u>

11 mg/kg x 8 (capital P soil factor) = 88 kg P/ha
<u>88 kg P/ha</u> x100 = 1.00 t/ha single super
8.8

1t = approx. $650/ha (not spread)

Figure 24: Site 2: Dung Only, Dung+Beetle and Control Olsen P June 2021- 1 year after treatment



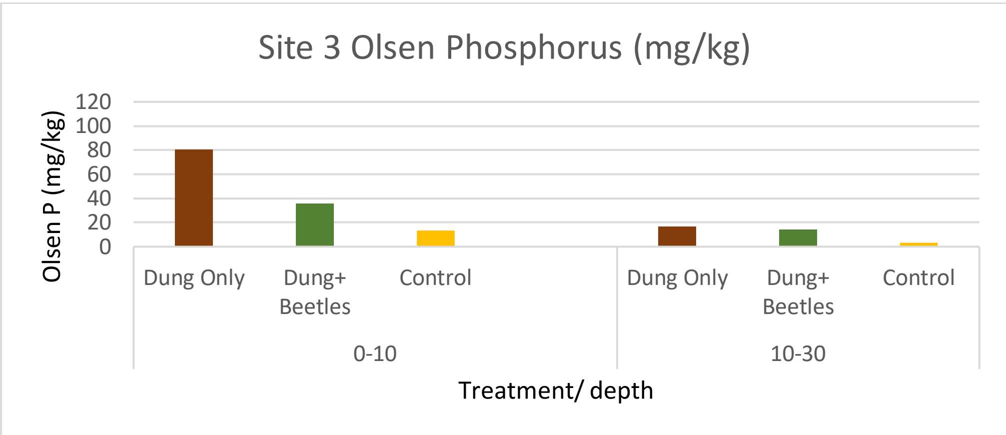
Phosphorus calculations:

10-30 cm Difference between Dung Only and Dung+Beetles =12mg

12mg/kg x 8 (capital P soil factor) = 104 kg P/ha
Single super is 8.8% P
96 kg P/ha x100 = 1.09 t/ha single super
8.8

1.09t = approx. $709/ha (not spread)

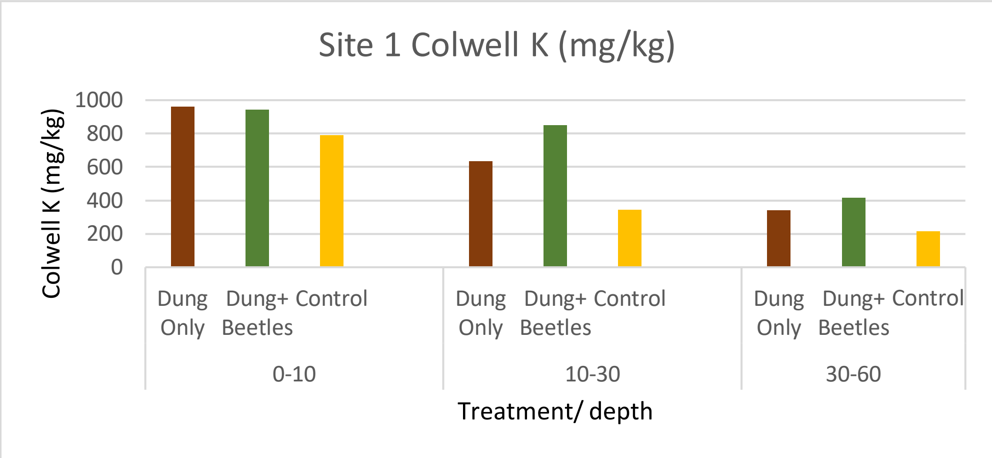
Figure 25: Site 3: Dung Only, Dung+Beetle and Control Olsen P June 2021- 1 year after treatment



Potassium

A similar trend was observed with potassium across the three sites (Fig 26-28). Potassium levels were highest in the top 10 cm in Dung Only plots. However more potassium had been mobilised in the Dung+Beetles plots, resulting in higher levels in the 10-30 cm and 30-60 cm depths than the Dung Only and Control treatments. The difference in potassium at 10-30cm between the Dung Only and Dung+Beetles plots equated to between 150 and 430 kg/ha of applied potash. The value of potash equivalent was approximately $200- $470/ha (not spread).

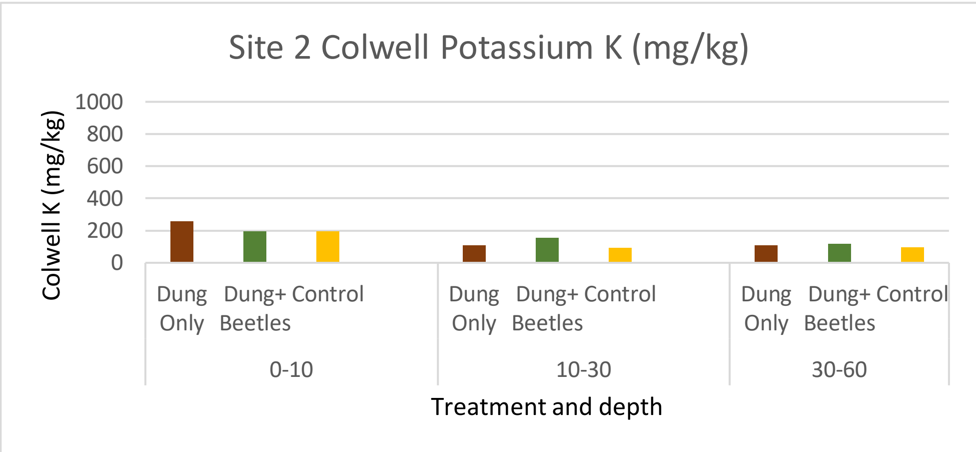
Figure 26: Site 1: Dung Only, Dung+Beetle and Control Colwell K June 2021- 1 year after treatment



Potassium calculations:
10-30 cm Difference between Dung Only and Dung+Beetles
1 mg/kg Colwell K increases with approx. 1 kg K/ha applied K on this soil type.
215 mg/kg Colwell K equates to 215 kg/ha applied K
Potash is approx. 50% K
215 kg/ha K equates to 430 kg of applied potash

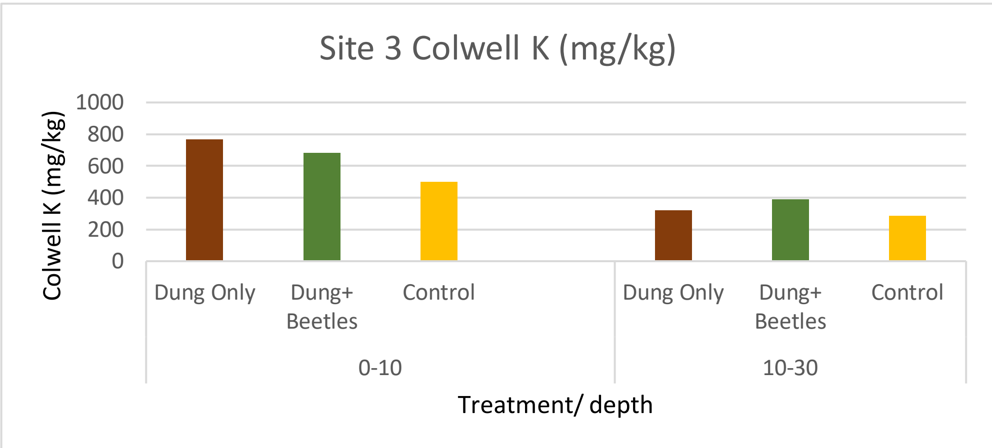
430 kg x $1,100/t (not spread)= approx.$473/ha equivalent

Figure 27: Site 2: Dung Only, Dung+Beetle and Control Colwell K June 2021- 1 year after treatment



Potassium calculations:
10-30 cm Difference between Dung Only and Dung+Beetles
1 mg/kg Colwell K increases with approx. **2** kg K/ha applied K for this soil type.
45 mg/kg Colwell K equates to 90 kg/ha applied K
Potash is approx. 50% K
90 kg/ha K equates to 180 kg of applied potash
180 kg x $1,100/t (not spread)= approx. $198/ha equivalent

Figure 28: Site 3: Dung Only, Dung+Beetle and Control Colwell K June 2021- 1 year after treatment



Potassium calculations:
10-30 cm Difference between Dung Only and Dung+Beetles

1 mg/kg Colwell K increases with approx. **2** kg K/ha applied K for this soil.
68 mg/kg Colwell K equates to 136 kg/ha applied K
Potash is approx. 50% K
136 kg/ha K equates to 272 kg of applied potash
272 kg x $1,100/t (not spread)= approx. $300/ha equivalent

Comparison to similar research

Increases in soil phosphorus and potassium to depth were observed in Dung+Beetles treatments at each trial site, however no other consistent changes to soil nutrient levels were measured. In similar trials, experimental design used by Doube (2008) involved large soil cores (22cm diameter, 50cm deep) placed in mesh bags and into the ground with dung and dung beetles applied and contained within the core. Soil testing involved dissecting the bag and sampling the whole core (at 0-10, 10-20 and >20 cm). Measured increases in nitrate, ammonia, phosphate, sulphur and soil carbon at 20-45 cm below dung pads with increases in soil organic matter, soil pH and EC wereobserved. Doube's result suggest that additional changes in soil nutrients may be occurring however the high level of background soil variation together with the soil sampling technique used in the demonstration meant they were not measured. It is also likely that the already high background organic carbon level would require huge input for a shift to show in soil test results.

Pasture production

There was no significant difference in pasture production between the treatments (Appendix B and C), however, the highest pasture dry matter was grown in the Dung+Beetles plots in Site 1 and Site 3 (Table 5). Site 1 had a freer draining clay/loam and the most observed dung beetle activity, while the least activity was observed at Site 2. Soil fertility and moisture were not limiting pasture growth at these sites. Doube (2008) measured an increased pasture production of 20% in Dung+Beetle plots and a lasting impact for more than two years. It is possible (but not discussed) that these soils were low in fertility and the impact of the dung and beetles led to greater pasture response, and/or that pasture on the dung+beetle plots was able to access more moisture as their roots travelled down dung tunnels.

Table 5: Pasture production (June- November 2021) comparison

	Pasture productions June-Nov (t/ha)		
	Site 1	**Site 2**	**Site 3**
Dung Only	8.54	6.42	6.16
Dung+Beetles	8.60	6.17	6.22
Control	7.29	5.55	6.14

4.2 Economic analysis

Dung beetles are known to provide a range of soil, pasture, and environmental benefits, however there is no available model that places a dollar value on these benefits. Doube (2008) measured increased pasture production of 25-27% from dung beetles, although it is difficult to apply this to a paddock situation given the variable distribution of dung and dung beetles. It is also likely that the scale of increased pasture production depends on initial soil fertility levels. Pasture production did not increase significantly in this demonstration.

Although the value of dung beetles could not be estimated, the cost of investing in dung beetles is extremely low. Colonies (1000 beetles) of *Bubas bison* cost $755, and whilst it can take several colonies and several years to develop a population, the benefits would appear to outweigh the cost.

4.3 Extension and communication

Two field days and a webinar were held over the three years to extend demonstration results, in addition to media, social media and group presentations. The webinar replaced a field day in the first year, which was cancelled due to COVID-19 restrictions. Field days had reasonable attendances. These events were open to the public and attracted the SWPLG steering committee members and a

largely Landcare audience external to the SWPLG. Dung beetles did not attract many SWPLG members to events beyond the steering committee, however at regional, state and national, level there is increasing interest in dung beetles. The DBEE project has played a large role in this, and the SWPLG demonstration has also contributed. Factsheets were produced about dung beetles trapped in the demonstration and have proved popular, with 565 webviews at the date of reporting.
The project team have also been invited to join a dung beetle information sharing group for southwest Victoria coordinated by the Corangamite CMA.
COVID-19 is likely to have had an impact on SWPLG member attendances, with reduced numbers attending all producer group events throughout Victoria. A change of SWPLG coordinator provided some additional disruption to meetings throughout the project period.
Extension and communication activities are summarised in Table 6.

Table 6: Extension activities, attendance and evaluation

Extension event	Activity	Number of participants	Av satisfaction (/10)
AgVic website	Project summary document developed for AgVic website		
Oct 2019 – Aust/ New Zealand Biochar conference visit	Project presentation, site visit and discussion with delegates	90	
Feb 2020- Field day display	Dung beetle project display at the Sungold Field days, Allensford	75	
Apr 2020- training	Group paddock walk and dung beetle ID and trapping training with host producers	7	
May 2020 – webinar	Project webinar including guest speaker (in lieu of cancelled field day)	15	
May 2020- media	Beef and Sheep Newsflash		
Oct 2020	'How to find dung beetles' video developed and shared with group		
Dec 2020 – Media	Newsflash profile		
Mar 2021- field day	SWPLG field day with guest speaker and paddock walk	12	
Oct 2021- Presentation	Cashmore-Oakley ram sale	72	
Nov 2021 Media	Newsflash article		
Nov 2021 Factsheet development- also uploaded to webpage	Development of 11 factsheets for dung beetles found throughout the demonstration *Aphodius fimetarius* – Introduced *Bubas bison* – Introduced *Euoniticellus fulvus* – Introduced *Euoniticellus pallipes* – Introduced *Geotrupes spiniger* – Introduced *Onitis aygulus* – Introduced *Onthophagus australis* – Native *Onthophagus binodis* – Introduced *Onthophagus mniszechi* – Native *Onthophagus posticus* – Native *Onthophagus taurus* – Introduced	**Page views (18/8/22)** 139 61 24 27 63 39 28 28 69 32 55	
Dec 2021 Media	SALRC Newsflash		

Extension event	Activity	Number of participants	Av satisfaction (/10)
Social Media	AgVic Facebook and Twitter post		
Mar 2022 **Field day**	Final presentation and interpretation of results	24	8.5
Aug 2022	Project display at SheepVention Hamilton		
Aug 2022	SALRC Newsflash (Case study)		
Aug 2022	Sheep & Beef Newsflash article (Case study)	>3500 subscribers	
Aug 2022	Project Factsheet		

Figure 29: Group training in dung beetle monitoring

Figure 30: 2021 field day

4.4 Monitoring and evaluation

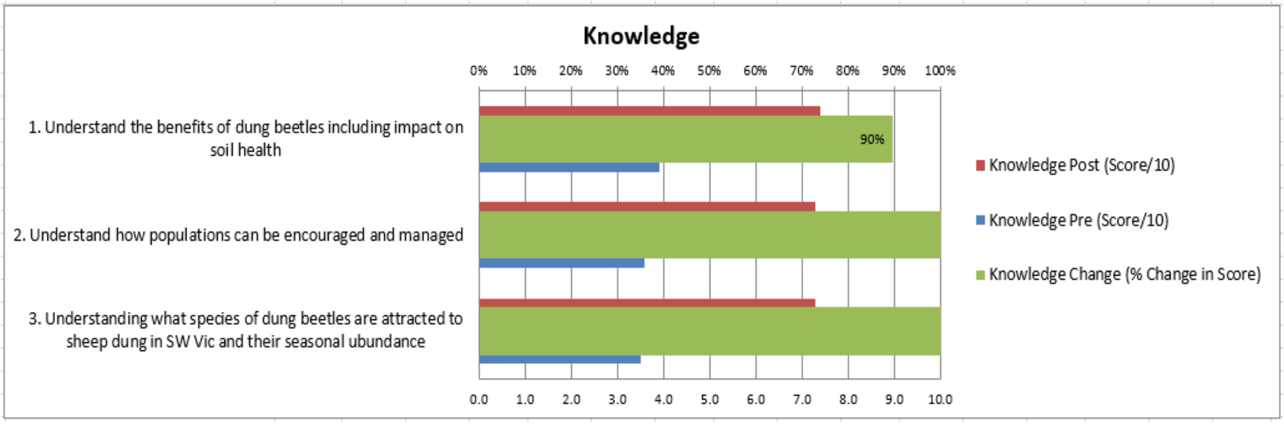
KASAA

A pre and post evaluation survey was completed with SWPLG members. The evaluation measured changes in knowledge, attitude, skills, aspiration and adoption (KASAA). The pre demonstration survey was undertaken by 16 producers and eight completed the survey post demonstration. The survey involved producers rating their knowledge, attitude and skills from 1-10 and indicating practices they had adopted.

Knowledge

Producers indicated their knowledge of dung beetles had grown substantially over the three years (Fig 31). This included understanding the benefits of dung beetles, management to encourage dung beetles and knowledge of local species and their seasonality. Pre-demonstration knowledge was low averaging 3.7/10 and increased to 7.3/10 post-demonstration.

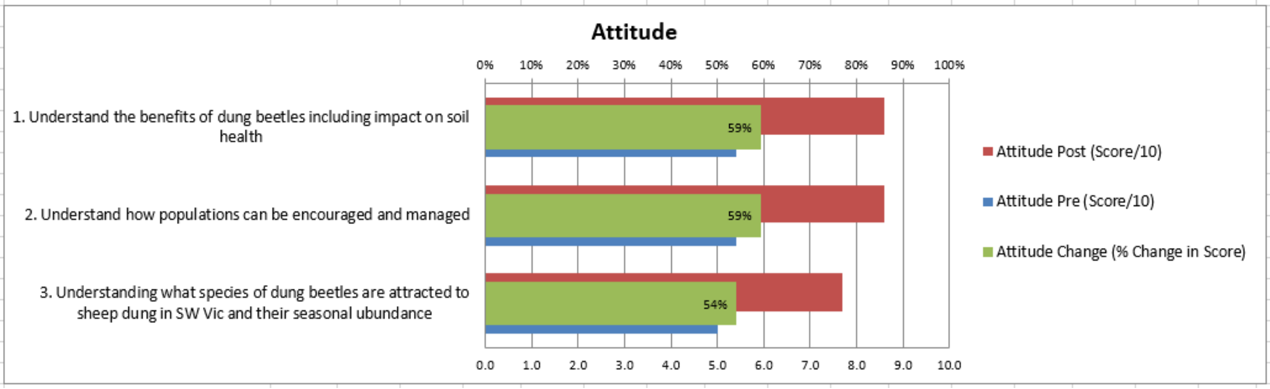
Figure 31: Knowledge pre, post and change



Attitude

Attitude towards dung beetles had increased over time, averaging 5.3/10 pre-demonstration and 8.3/10 post demonstration (Fig. 32).

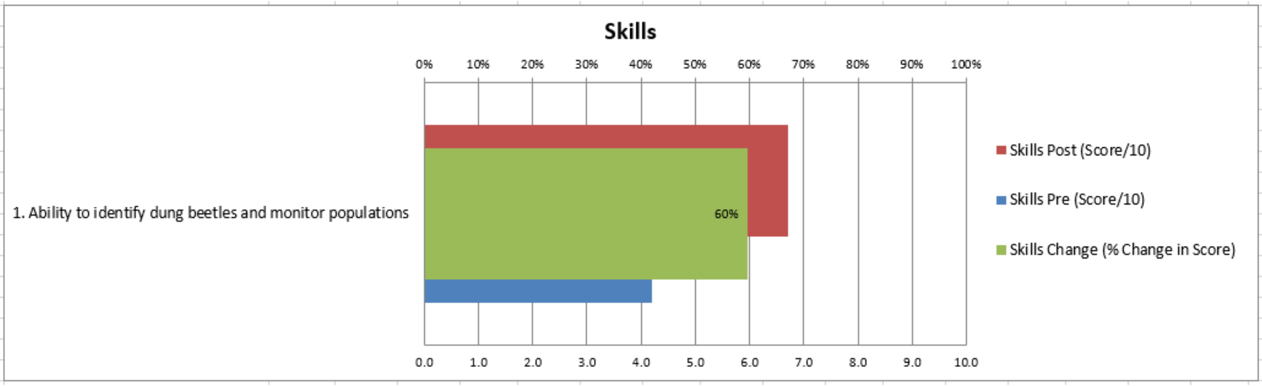
Figure 32: Attitude pre, post and change



Skills

Skills in identifying and monitoring dung beetles increased by 60% from 4.2/10 to 6.7/10 (Fig 33).

Figure 33: Skills pre, post and change



Adoption

The proportion of producers monitoring for dung beetles increased from 37% pre-demonstration to 100% at the end of the demonstration. Some producers were extensively monitoring populations

(Fig. 34) while others were occasionally checking under dung pats or observing activity within paddocks.
There was also a large increase in producers encouraging dung beetle populations (Fig. 35). This included purchasing and releasing beetle colonies and attempting to manage drenching practices to minimise impacts on dung beetle populations.

Figure 34: Adoption of dung beetle monitoring

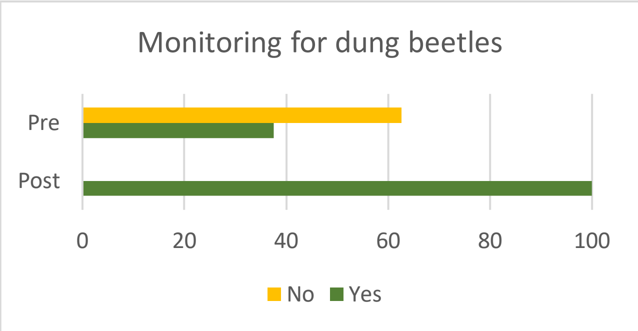
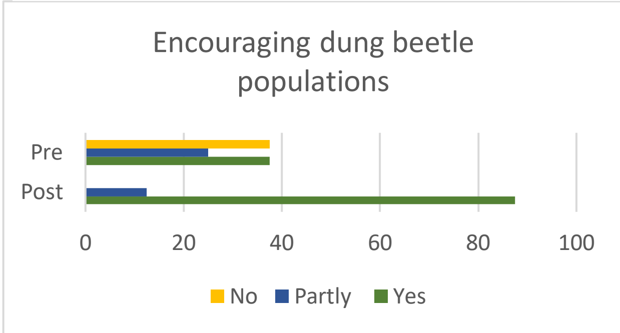


Figure 35: Adoption of strategies to encourage dung beetles



Additional comments:

1. ***Have you made changes during the project?***
   - I have started looking for dung beetles under dung pats to check what's about
   - 3x I'm looking for dung beetles
   - We have tried to establish populations
   - I'm more attentive to dung beetle activity
   - 2x Monitoring dung beetles
2. ***Are you planning any future changes after your involvement in the demo?***
   - I'm still working on the timing of drenching stock to minimise the impact on dung beetle populations
   - More monitoring of beetle populations
   - I would like to know more about when drenching is unlikely to affect dung beetle populations
   - I'm considering changes
   - Yes
   - I will purchase some beetles to build bigger populations
   - We will purchase dung beetles
3. ***What benefits are you seeing or do you hope to see?***
   - Soil carbon and soil fertility benefits seem very worthwhile
   - Better soil health, fewer parasites
   - Less pasture contamination from manure. Improved soil structure & water infiltration
   - Increased soil fertility to depth and improved soil structure
   - More dung beetle species
   - Soil health benefits
   - Ecosystem benefits
4. ***Is there anything stopping you from making changes?***
   - Need more knowledge on timing of beetle populations
   - Lack of confidence establishing populations and not killing them with drench. Difficulty accessing enough of the right beetles to establish a population.

- 2x No
- 2x Money/ cost of purchasing

5 Conclusion

This demonstration investigated the wild populations of dung beetles in southwest Victoria and their seasonal abundance. An effective dung beetle population would ideally have species active throughout the year. The project also demonstrated the impact of deep tunnelling *Bubas bison* on soil fertility and attempted to measure the impact on pasture production to encourage further interest in and understanding of dung beetles. The demonstration has contributed to knowledge of dung beetle activity in sheep systems.

The project identified that:

- Southwest Victoria has a seasonal gap in dung beetle abundance from late autumn through to early spring. A few winter-active *B. bison* were found around Hamilton, however none were found further south around Cashmore despite previous dung beetle releases.
- Sheep dung is a valuable source of nutrients and led to dramatic increases in soil phosphorus and potassium when incorporated into the soil profile.
- The deep tunnelling *Bubas bison* mobilised nutrients in the dung (particularly P and K), taking a large quantity down into the 10-30 cm zone and into the 30-60 cm zone. The additional phosphorus at 10-30cm depth in the Dung+Beetle plots was equivalent to around 1 t/ha of single super valued at approximately $650/ha (not spread). The additional potassium at 10-30cm equated to between 150 and 430 kg/ha of applied potash valued at approximately $200-$470/ha (not spread).
- High numbers of earthworms were observed under Dung+Beetle plots, including earthworms that had wrapped around the tunnels of dung. It is likely that this increased activity is from earthworms feeding on buried dung.
- We would expect that the tunnelling activity from dung beetles and the increased nutrient levels at depth would drive plant roots further down the soil profile, allowing them to access moisture from deeper down. This could potentially increase the growing season.
- Dung beetles provide multiple benefits for a relatively low cost.

Knowledge gaps and opportunities

- There is certainly scope to release dung beetle colonies to boost populations, particularly winter-active species. Mass releases have been undertaken in other regions such as the Fleurieu Peninsula in South Australia and northeast Victoria resulting in *B. bison* becoming endemic.

  Further research into the suitability of *B. bison* (and other winter active species) for the far southwest would be beneficial, given past releases at the Cashmore site do not appear to have been successful.

  The native *O. mniszechi* was found to be actively burying sheep dung throughout the year to around 20cm, particularly on light soils. There may be further potential for this species in sheep systems.

  SWPLG ran a concurrent dung beetle breeding project with DBEE, for the newly introduced French and Moroccan *O. vacca*, a winter/early spring active species. It is hoped that this species will also contribute to filling the winter gap.

Better guidelines around releasing and breeding dung beetles on-farm would be beneficial for interested groups such as SWPLG.

- SWPLG are interested in the impact of drenches on dung beetles and methods of managing drenched animals to minimise impacts on dung beetle populations. SWPLG also plan to explore whether drench tolerance is developing within dung beetle populations.
- This demonstration was undertaken in the high rainfall region of southwest Victoria. It would be interesting to understand what species are active and to what degree on sheep enterprises in drier environments.
- Dung beetles and the benefits they offer can be difficult to observe. Further uptake of dung beetles by producers could achieved by:
    - Further promotion of the benefits of dung beetles
    - Developing a cost: benefits for dung beetles
    - Promoting methods to establish populations (including local lists of suitable species, costs, clear guidelines for establishing populations)
    - Local case studies and mentors

  (The DBEE project will address some of these points.)

6 Benefits to industry

The project showed that dung beetles play an important role in nutrient cycling on sheep enterprises. It also identified that a gap in dung beetle abundance exists in the cooler months from late autumn to early spring that could potentially be filled through the introduction of winter active species such as *B. bison* or *O. vacca,* if conditions proved appropriate. This information adds to the limited available information about the role of dung beetles in sheep systems and can be used to further communicate their benefits.

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8 Acknowledgements

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9 Appendix

9.1 Appendix A: Soil test results

2019 Dung burial trial: soil tests June 2020

Depth	Name	Texture	Ammonium Nitrogen	Nitrate Nitrogen	Phosphorus Olsen	Phosphorus Colwell	Potassium Colwell	Sulfur	Organic Carbon	Conductivity	pH Level (CaCl2)	pH Level (H2O)	DTPA Copper	DTPA Iron	DTPA Manganese	DTPA Zinc	Exc. Aluminium	Exc. Calcium	Exc. Magnesium	Exc. Potassium	Exc. Sodium	Boron Hot CaCl2
			mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	%	dS/m			mg/kg	mg/kg	mg/kg	mg/kg	meq/100g	meq/100g	meq/100g	meq/100g	meq/100g	mg/kg
0-10	Dung + Beetles	1.5	5	10	**27.1**	**67**	**122**	3.7	2.03	0.074	**5.5**	**6.7**	0.51	106.50	0.74	4.01	0.030	3.70	0.69	0.24	0.14	0.46
0-10	Dung	1.5	4	7	17.3	34	65	4.8	1.97	0.055	5.0	6.1	0.48	208.00	0.79	4.25	0.080	3.66	0.63	0.13	0.17	0.47
0-10	Control	1.5	5	6	13.9	26	47	3.9	1.91	0.048	4.8	6.2	0.59	189.40	0.67	2.82	0.150	2.93	0.55	0.08	0.14	0.39
10-30	Dung + Beetles	1.5	2	**5**	**19.1**	34	**49**	3.1	1.01	0.045	4.8	6.0	0.46	157.70	0.49	1.60	0.150	1.99	0.33	0.10	0.13	0.31
10-30	Dung	1.5	2	2	13.0	22	25	3.3	1.13	0.031	4.6	5.8	0.55	190.40	0.40	1.44	0.340	1.84	0.27	0.04	0.14	0.31
10-30	Control	1.5	2	2	14.7	25	20	2.9	1.04	0.031	4.8	5.9	0.40	185.20	0.38	1.21	0.230	2.09	0.30	0.03	0.12	0.31
30-60	Dung + Beetles	1.5	2	3	**9.5**	15	17	4.7	0.42	0.064	5.0	5.9	0.45	87.10	0.23	0.68	0.160	1.26	0.17	0.03	0.17	0.19
30-60	Dung	1.5	2	2	7.8	13	15	3.3	0.37	0.052	5.0	6.0	0.38	105.40	0.34	0.24	0.170	1.40	0.22	0.03	0.15	0.25
30-60	Control	1.0	1	3	7.8	13	< 15	3.3	0.55	0.041	5.1	5.9	0.24	136.60	0.43	0.59	0.210	1.57	0.23	0.02	0.12	0.28

2020 Dung burial trial: Soil tests June 2021

Heath Site 1	Depth	Colour	Gravel	Texture	Ammonium Nitrogen	Nitrate Nitrogen	Phosphorus Colwell	Potassium Colwell	Sulfur	Organic Carbon	Conductivity	pH Level (CaCl2)	pH Level (H2O)	DTPA Copper	DTPA Iron	DTPA Manganese	DTPA Zinc	Exc. Aluminium	Exc. Calcium	Exc. Magnesium	Exc. Potassium	Exc. Sodium	Boron Hot CaCl2	P Olsen
			%		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	%	dS/m			mg/kg	mg/kg	mg/kg	mg/kg	meq/100g	meq/100g	meq/100g	meq/100g	meq/100g	mg/kg	mg/kg
Dung Only	0-10	GR BR	5	2.5	6	145	437	**959**	19.2	3.92	0.394	5.3	6.1	0.77	327.40	4.68	8.01	0.040	9.11	3.21	2.13	0.52	1.08	**110.0**
Dung Beetles	0-10	GR BR	5	2.5	5	75	255	**943**	20.9	3.18	0.304	5.0	5.9	1.05	411.80	7.82	9.35	0.060	7.50	2.30	2.25	0.42	1.00	**70.7**
Control	0-10	GR BR	5	2.5	7	115	115	**788**	34.4	3.36	0.371	4.7	5.5	0.80	409.50	9.90	12.24	0.200	8.07	2.10	1.91	0.36	1.23	**41.8**
Dung Only	10-30	GR BR	5	2.5	4	55	119	**634**	17.1	2.43	0.225	4.8	5.8	0.64	426.90	5.80	2.86	0.150	7.45	2.02	1.41	0.51	0.85	**38.9**
Dung Beetles	10-30	GR	5	2.5	2	80	150	**849**	23.9	**2.59**	0.292	4.7	5.6	0.61	415.40	7.42	2.50	0.150	7.22	1.98	1.80	0.47	0.95	**49.6**
Control	10-30	GR	5	2.5	2	50	32	**344**	10.2	2.42	0.154	4.6	5.5	0.59	382.20	4.88	2.63	0.220	7.67	1.74	0.75	0.19	0.92	**9.5**
Dung Only	30-60	GR YW	5	2.5	< 1	55	11	**339**	8.9	1.19	0.199	4.9	5.8	0.26	121.90	2.85	0.81	0.080	8.21	1.60	0.72	0.42	0.92	**2.8**
Dung Beetles	30-60	GR YW	5	2.5	< 1	68	61	**415**	14.6	1.26	0.255	5.2	6.0	0.25	126.50	2.60	0.81	0.070	8.86	1.92	0.82	0.46	0.90	**26.8**
Control	30-60	GR YW	5	2.5	2	73	7	**213**	5.0	1.05	0.193	5.2	6.0	0.40	90.40	2.16	1.12	0.050	8.51	1.58	0.46	0.26	0.74	**2.0**

Hill Site 2	Depth	Colour	Gravel	Texture	Ammonium Nitrogen	Nitrate Nitrogen	Phosphorus Colwell	Potassium Colwell	Sulfur	Organic Carbon	Conductivity	pH Level (CaCl2)	pH Level (H2O)	DTPA Copper	DTPA Iron	DTPA Manganese	DTPA Zinc	Exc. Aluminium	Exc. Calcium	Exc. Magnesium	Exc. Potassium	Exc. Sodium	Boron Hot CaCl2	Phosphorus Olsen
			%		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	%	dS/m			mg/kg	mg/kg	mg/kg	mg/kg	meq/100g	meq/100g	meq/100g	meq/100g	meq/100g	mg/kg	mg/kg
Dung	0-10	DK GR	5	2.5	6	29	261	**257**	62.2	3.84	0.265	4.9	5.8	1.39	283.00	9.95	2.22	0.140	6.97	1.99	0.60	0.31	0.62	**77.9**

Only																								
Dung Beetles	0-10	DK GR	5	2.5	6	24	206	**196**	10.5	3.65	0.128	4.9	5.8	1.53	307.70	7.42	1.70	0.130	5.88	1.46	0.39	0.23	0.58	**67.6**
Control	0-10	DK GR	5	2.5	31	12	88	**195**	30.7	6.38	0.161	4.7	5.7	1.58	383.00	12.08	2.66	0.510	5.56	0.97	0.53	0.28	0.54	**35.3**
Dung Only	10-30	GR	5-10	2.5	5	8	65	**109**	27.3	1.33	0.088	5.1	6.2	0.46	174.70	5.46	1.23	0.100	3.07	0.96	0.25	0.32	0.42	**21.2**
Dung Beetles	10-30	DK GR	5-10	2.5	2	13	89	**155**	23.0	**2.12**	0.102	5.1	6.2	0.56	212.50	5.18	2.19	0.110	3.82	1.22	0.32	0.33	0.57	**32.8**
Control	10-30	GR	5	2.5	1	20	18	**93**	18.6	1.26	0.084	5.0	6.0	0.60	169.20	4.71	1.57	0.160	2.74	0.80	0.19	0.25	0.39	**5.6**
Dung Only	30-60	GR YW	5	3.5	2	12	5	**109**	53.2	0.54	0.185	5.6	6.5	0.05	22.30	0.30	0.46	0.160	2.39	3.10	0.25	1.03	0.86	**0.4**
Dung Beetles	30-60	GR YW	5	3.5	< 1	13	8	**116**	50.5	0.48	0.168	5.4	6.4	0.18	24.50	0.57	0.54	0.130	2.17	2.52	0.23	0.88	0.71	**1.0**
Control	30-60	GR YW	5	3.5	9	17	5	**96**	41.6	0.53	0.190	5.8	6.6	0.06	24.30	0.40	1.42	0.190	2.76	3.18	0.20	0.99	0.87	**0.2**

Site 3	**Depth**	**Colour**	**Gravel**	**Texture**	**Ammonium Nitrogen**	**Nitrate Nitrogen**	**Phosphorus Colwell**	**Potassium Colwell**	**Sulfur**	**Organic Carbon**	**Conductivity**	**pH Level ($CaCl_2$)**	**pH Level (H_2O)**	**DTPA Copper**	**DTPA Iron**	**DTPA Manganese**	**DTPA Zinc**	**Exc. Aluminium**	**Exc. Calcium**	**Exc. Magnesium**	**Exc. Potassium**	**Exc. Sodium**	**Boron Hot $CaCl_2$**	**Phosphorus Olsen**
			%		**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**%**	**dS/m**			**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**meq/100g**	**meq/100g**	**meq/100g**	**meq/100g**	**meq/100g**	**mg/kg**	**mg/kg**
Dung Only	0-10	DK GR	0	3.0	8	34	337	**767**	34.5	5.13	0.295	5.4	6.3	1.13	334.30	16.09	4.69	0.030	18.88	6.19	1.94	1.00	1.47	**80.3**
Dung Beetles	0-10	DK GR	5	3.0	6	57	127	**682**	17.2	6.14	0.220	5.2	6.1	0.96	332.20	11.87	1.47	0.040	16.17	4.99	1.61	0.81	1.67	**35.9**
Control	0-10	DK GR	5	3.0	14	76	60	**500**	20.1	5.29	0.264	5.0	5.8	0.94	351.80	12.82	25.30	0.110	16.08	4.28	1.08	0.65	1.71	**13.4**

Dung Only	10-30	DK GR	0	3.5	2	45	63	**320**	22.6	2.95	0.183	5.3	6.2	0.42	115.50	3.34	5.26	0.140	14.72	5.44	0.69	0.80	1.47	**16.9**
Dung Beetles	10-30	DK GR	0	3.5	3	42	54	**388**	24.9	**3.07**	0.177	5.3	6.3	0.36	140.70	5.14	3.29	0.130	14.00	5.49	0.83	0.90	1.68	**14.1**
Control	10-30	DK GR	0	3.5	2	16	16	**286**	21.3	2.76	0.110	5.2	6.1	0.34	111.80	3.15	3.10	0.130	12.18	5.08	0.62	0.65	1.59	**3.2**

9.2 Appendix B: Pasture production: Comparison of Dung Only, Dung+Beetles, Control at each of the three sites

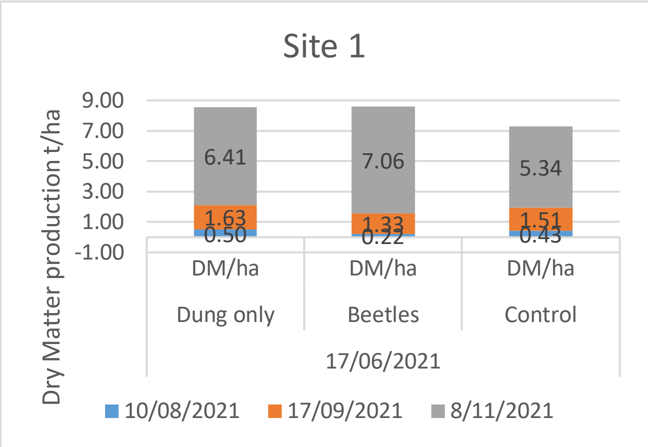

Figure x Dry matter production Site 1 (Aug-Nov 2021)

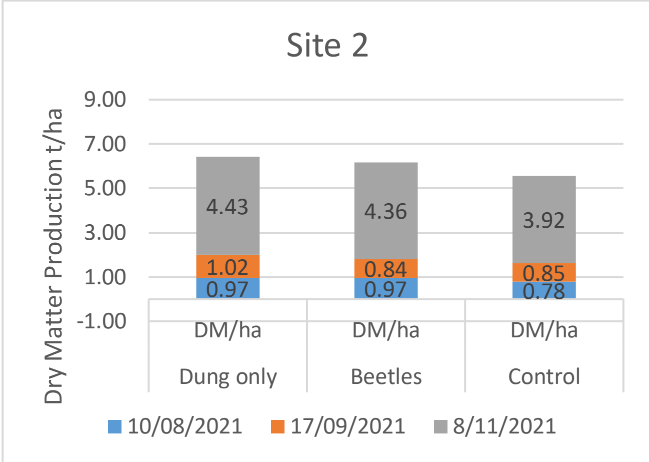

Figure 2Dry matter production Site 2 (Aug-Nov 2021)

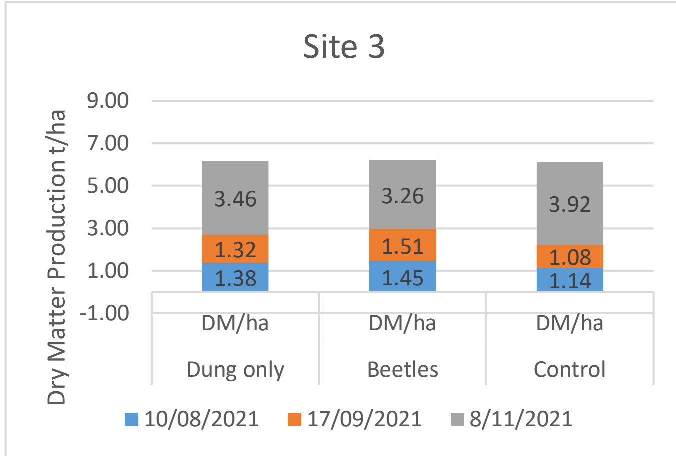

Figure 3Dry matter production Site 1 (Aug-Nov 2021)

9.3 Appendix C: Pasture production statistics: Comparison of Dung Only, Dung+Beetles, Control

* Analysis of variance by ANOVA, REML or regression

Information summary

Design is orthogonal. Analyse by ANOVA.

Analysis of variance

Variate: DM

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Paddock stratum	2	24.845	12.422	8.21	
Rep stratum	2	0.520	0.260	0.17	
Paddock.Rep stratum	4	6.055	1.514	1.22	
Paddock.Rep.*Units* stratum					
Treatment	2	2.857	1.428	1.15	0.340
Residual	16	19.801	1.238		
Total	26	54.078			

Tables of means

Variate: DM

Grand mean 6.79

Treatment	Beetles	Control	Dung only
	7.00	6.33	7.04

Standard errors of differences of means

Table	Treatment
rep.	9
d.f.	16
s.e.d.	0.524

Least significant differences of means (5% level)

Table	Treatment
rep.	9
d.f.	16

l.s.d. 1.112

Analysis of variance by ANOVA, REML or regression

Information summary

Design is orthogonal. Analyse by ANOVA.

Analysis of variance

Variate: DM

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Paddock stratum	2	8.2816	4.1408	30.59	
Paddock.*Units* stratum					
Treatment	2	0.9523	0.4762	3.52	0.131
Residual	4	0.5415	0.1354		
Total	8	9.7754			

Tables of means

Variate: DM

Grand mean 6.79

Treatment	Beetles	Control	Dung only
	7.00	6.33	7.04

Standard errors of differences of means

Table	Treatment
rep.	3
d.f.	4
s.e.d.	0.300

Least significant differences of means (5% level)

Table	Treatment
rep.	3
d.f.	4
l.s.d.	0.834