Caring for Country Project CAG10-00453
Reconstructing vineyard soils with dung beetles
Final Report

Phase 1, 2010–11

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Background

The role of dung beetles in burying the dung of domestic stock and so improving soil health and pasture production is well recognised. Dung burial by deep-tunnelling dung beetles lodges dung in a system of underground tunnels at 40–60 cm, where it is consumed by beetle larvae, earthworms and microbes, creating humus and improving soil structure, fertility and subsoil carbon levels.

The concept of using dung beetles to bury dung in locations away from where the dung was deposited (e.g. moving waste dairy or feedlot dung into vineyards) is an important innovation with the potential to increase soil fertility and carbon levels, with corresponding increases in drought resistance and the sustainability of horticultural enterprises.

It is generally considered that the root zone in most Australian vineyards suffers poor aeration and permeability, high bulk density (compaction) and low nutrient and carbon levels. Further, many vineyard soils are acidic and deficient in essential minerals, especially at depth. The application of surface mulches to vineyard soils has proven beneficial but suffers the disadvantage that the organic decomposition occurs primarily at the soil–mulch interface and so encouraging root growth close to the surface where the roots are vulnerable to drought, especially during summer. Vine roots that follow dung beetle tunnels into the subsoil do not suffer this problem. This project begins to evaluate the capacity of deep-tunnelling dung beetles and imported dung to renovate vineyard soils and drought-proof vines.

The most economical way to apply dung to a vineyard is to run cattle there during winter. One crucial question to be answered by the project was whether there would be sufficient feed in vineyard inter-row grass swards to be turned into enough dung for measurable change to the vineyard soil. There was not, and so dung needed to be imported to the vineyard. Accumulated cattle manure in dairies and feedlots is a major disposal problem. Using dung beetles to bury such dung in vineyard soils could become an important aspect of vineyard soil renovation.

The Eden Valley dung beetle project

Eden Valley was a favourable environment for the dung beetle *Bubas bison*. The dung beetles tunnelled down through the topsoil (0–25 cm), lining their tunnels with dung, and excavating an extensive network of tunnels at 25–60 cm deep. At the lower ends of these tunnels they buried substantial amounts of dung, in which they laid eggs. The buried dung was eaten by beetle larvae, leaving tunnels filled with humus-like beetle faeces. The soil displaced through tunnelling was brought to the soil surface, where it became mixed with the unburied dung remains.

The project was conducted in Eden Valley, South Australia in the Boongarrie vineyard of Phil and Sarah Lehmann. The scientific work, data analysis and reporting was carried out by Dr Bernard Doube (soil ecologist) and Mr Mark Dale (viticultural scientist and hydrologist). A detailed 50-page report on the project including statistical analysis of all the chemical analyses and of some physical soil characteristics measured can be provided on request from Dung Beetle Solutions Australia.

Project objectives

- To assess whether cattle in a vineyard with introduced dung beetles generated sufficient dung to renovate vineyard soils.
- To assess the capacity of deep-tunnelling dung beetles to ameliorate the structure, fertility and carbon content of a vineyard soil using dung imported into the vineyard.

Project outcomes

- Cattle in the vineyard generated insufficient dung to enable renovation of the soil in a timely fashion.
- Deep-tunnelling dung beetles buried dung imported into the vineyard at 40–60 cm and substantially improved the structure, permeability, fertility and carbon content of the vineyard soil.

Cattle in vineyards

Cattle were grazed in the vineyard for about 6 weeks during winter of 2011 (Figure 1), during which time they ate most of the available pasture. They did not damage the vines. After 2 weeks, fresh naturally dropped dung pads (0–7 days old) were inoculated with *B. bison*: this dung was completely buried in 4 weeks. However, the amount of dung produced by cattle grazing the vineyard sward, including some hay as extra fodder, was not sufficient to enable renovation of the vineyard soil in an acceptable time frame. From this we concluded that it was necessary to introduce dung (from outside the vineyard), and dung beetles, in order to renovate vineyard soils in a timely fashion.

Evaluating beetle impacts on soil

Dung burial by the dung beetle *Bubas bison* and its impact on the structure and chemical composition of vineyard soil was tested using fresh cattle dung in 2011–2012. There were three treatments: dung+beetles, dung only and controls (no dung, no beetles). Soil cores of 20–30 kg dry weight were enclosed in beetle-proof bags and placed in a row in the ground adjacent to vines (Figure 1, Figure 2 and Figure 3).

Five kg of fresh cow dung and 5 pairs of *Bubas bison* were placed in the cylinders above the appropriate soil cores. The ground plan is shown in Figure 9.

Ten months later (1 May 2012) all bagged soil cores were extracted, divided into sections (surface litter and upper and basal soil sections). The basal section of the dung+beetles cores was further divided into two fractions, one comprising the tunnel surrounds and their contents (about 3 kg) and the other the surrounding bulk soil (about 12 kg). The bulk density, soil moisture levels and the chemical characteristics (organic carbon, total carbon, sulphur, nitrate, ammonia, phosphate, potassium, conductivity, pH) of a subsample of each fraction were assessed.

An identical set of treatments in the same number of PVC cylinders was installed in the same fashion in the same vine row but without the underlying bagged soil core. Excavation of the beetle tunnels 10 months later revealed the same vertical distribution of dung and tunnels in the unconfined and confined (bagged) soil cores, demonstrating that the bagged soil core system provided an acceptable model for dung burial and its effects on the soil profile.

Dung burial and surface litter

The dung beetles buried about half of the available dung, in the process of which substantial amounts of subsoil were brought to the soil surface where it became mixed with unburied dung remains. An average of 1.2 kg of soil was brought to the surface in the dung+beetles cores, which represented about 10 metres of underground tunnels.

Vine root growth

When the soil cores contained in the beetle-proof bags were extracted from the ground, the outsides of the dung+beetles bags were festooned with vine roots and there were substantial roots growing into the cores, especially into the basal sections that contained the buried dung (Figure 6, Figure 7 and Figure 8). The dung-only and control cores had no obvious root material on their outer surface or in the soil core (Figure 5).

Figure 1: Cows and calves towards the end of their six-week confinement in Boongarrie vineyard (photo: Sarah Lehmann)

Figure 2: July 2011: Establishing the trial in the Eden Valley vineyard

Figure 3: The soil profile inside the bags reflected the natural soil profile

Figure 4: Trial site on 1 May 2012 at the time of sampling

Figure 5: Soil at the base of the dung-only cores showing no obvious root development

Figure 6: Soil at the base of the dung+beetles cores showing vine roots and dung beetle faecal shells

Figure 7: Vine roots inside a dung+beetles soil core

Figure 8: Vine root entering dung+beetles soil core

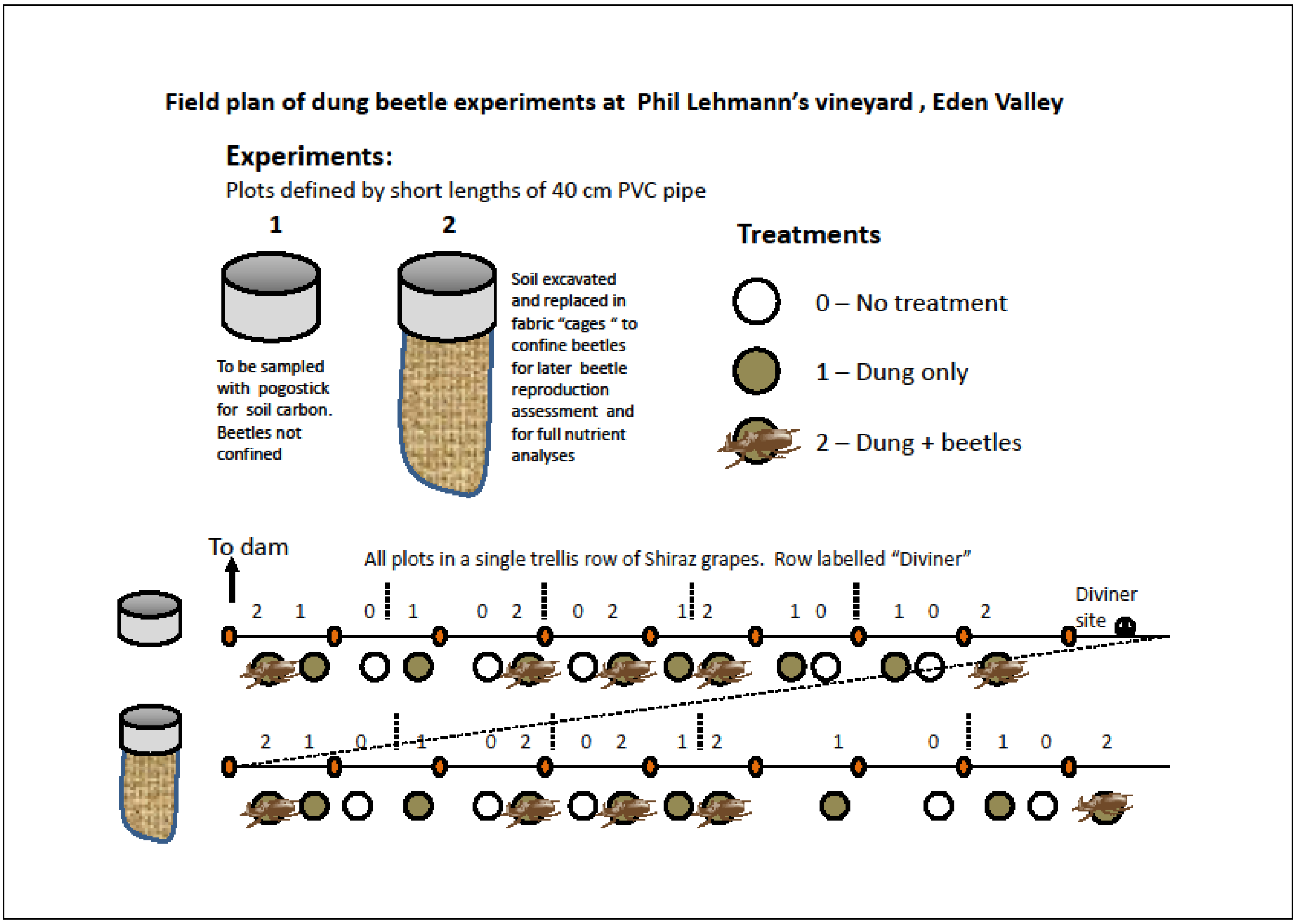

Figure 9: Field plan of dung beetle experiments, Eden Valley, 2011–12

Nutrient movement from dung into the soil profile

In the dung-only treatment some nutrient components remained in the dung and did not leach into the surface soil (organic carbon, sulphur and nitrate-N), whereas a small amount of others (ammonia-N, phosphate and potassium) leached into the surface soil but did not reach the subsoil.

Dung burial: soil structure and fertility

Subsoil bulk density

Dung beetle tunnels reduced the bulk density (compaction) of the basal section (25–50 cm) of the soil profile by about 20% (from about 1.28 to 1.08 g cc^{-1}). These data underestimate the impact of tunnelling on soil bulk density because of the unavoidable crushing of samples for assessment, collapsed the tunnels.

Soil water dynamics

The soil samples were taken on 1 May 2012 following substantial (57 mm) rainfall over the previous 2 months. An equivalent amount (57 mm) was recovered from dung+beetles soil cores, while only 12 mm was recovered from the noticeably drier control cores (Figure 10). We infer that the dung+beetles treatment resulted in much more effective rain infiltration. While most Eden Valley surface soils are sandy, they are also often non-wetting.

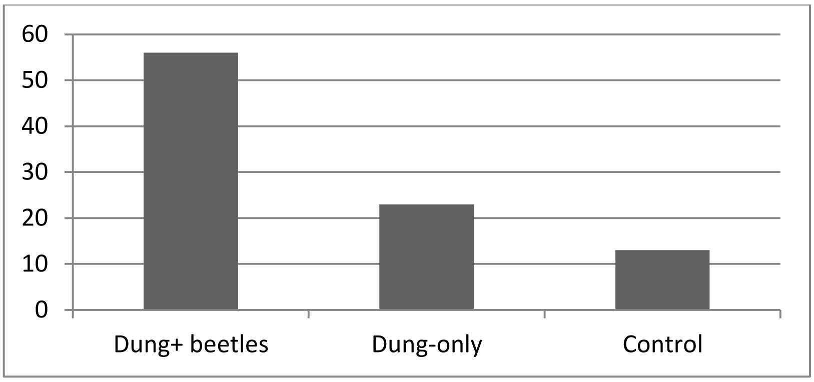

Figure 10: Moisture (mm) in vineyard soil profiles of three treatments on 1 May 2012 (March–April rainfall was 57 mm)

Soil carbon

The dung burial activity of *B. bison* redistributed surface organic carbon throughout the soil profile but it was concentrated mostly in the vicinity of the tunnels and their contents. The level of organic carbon in the basal soil section associated with the tunnels (1.3%) was about double that of the surrounding soil (0.7%), which was in turn greater than that in the basal sections of the soil cores in the other treatments (0.5%) (Table 1).

Table 1: Organic carbon levels (%) of the component parts of the soil cores

	Dung+beetles	Dung-only	Controls
Surface litter	2.6±0.7	4.1±0.3	1.3±0.2
Upper section	0.99±0.26	0.86±0.07	0.72±0.09
Basal section	0.69±0.07	0.46±0.25	0.58±0.07
Tunnels + contents	1.31±0.20		

A carbon-budget analysis of the experimental cores revealed that the presence of added dung (dung-only) increased the total organic carbon levels by 31% (48 g, Table 2) which is largely explained by the carbon in the litter (51 g). The addition of dung beetles increased the total organic carbon levels by 77% (118 g) over that in the control cores and this can be accounted for by the additional organic carbon in all soil fractions, but especially in the tunnels and their contents (38 g per core). It is important to note that the basal section figure of 1.3% organic carbon is an average taken from a substantial portion of the basal core. The percentage in the area where the dung was concentrated (i.e. inside the tunnels) would be much higher. This reservation applies also to the nutrients investigated below (Table 3, Table 4 and Table 5).

Table 2: Results of a carbon budget analysis of soil cores: organic carbon content (g) of the component parts of the soil cores

	Dung+beetles	Dung-only	Controls
Surface litter	43.6±18.6	50.6±6.3	3.0±1.1
Upper section	111.4±26.2	91.6±20.3	75.6±12.4
Basal section	78.2±34.0	58.4±25.0	74.2±15.3
Tunnels + contents	37.7±13.0		
Total per core	**270.8±21.6**	**200.6±25.3**	**152.9±19.9**

The presence of dung beetles increased the level of retained carbon over that in the dung-only cores by 35% and this can be accounted for largely by the additional organic carbon associated with the tunnels and their contents (Table 2).

Soil nutrients

The dung burial activity of *B. bison* redistributed sulphur (Table 3), nitrate-N (Table 4), phosphate (Table 5), ammonia-N and potassium from the surface to the base of the soil core, where it was most concentrated in the vicinity of the tunnels and their contents.

Table 3: Soil sulphur levels (mg kg^{-1}) of the component parts of the soil cores

	Dung+beetles	Dung-only	Controls
Surface litter	18.9±6.9	33.0±6.0	6.1±2.6
Upper soil section	5.1±0.6	5.0±1.6	3.8±0.9
Basal soil section	3.4±1.0	2.0±0.8	2.2±0.7
Tunnels + contents	8.2±3.3		

Table 4: Soil nitrate-N levels (mg kg^{-1}) of the component parts of the soil cores

	Dung+beetles	Dung-only	Controls
Surface litter	23.6±10.2	45.4±12.5	13.2±5.9
Upper soil section	7.6±3.0	7.0±4.4	4.6±2.1
Basal soil section	3.4±1.1	2.2±1.6	1.6±0.5
Tunnels + contents	6.4±2.6		

Table 5: Soil phosphate (mg kg^{-1}) of the component parts of the soil cores

	Dung+beetles	Dung-only	Controls
Surface litter	253±137	409±128	48±9
Upper soil section	37±6	33±11	20±3
Basal soil section	20±0.7	17±10	13±4
Tunnels + contents	48±9		

Conductivity and soil pH

The burial of dung substantially increased the conductivity of the dung beetle tunnel component of the basal section and increased its pH.

Eden Valley phase 2 trial: 2012–2013

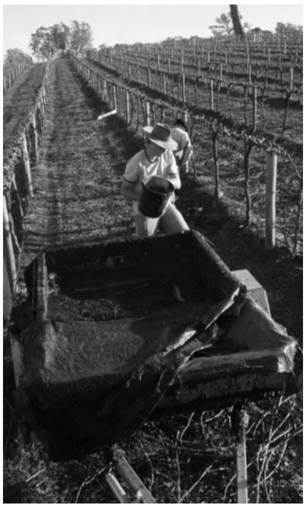

Figure 11: Adding dung and beetles l

Figure 12: Dung burial after 4 weeks

The work reported here has been extended to examine the effects of dung burial on vine vigour, grape yield and quality, soil condition and root growth.

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Recommendations

1. That medium-scale field trials be established in vineyards using feedlot or dairy manure to validate the soil renovation procedures on a larger scale and assess the impact upon soil carbon levels, grape production and quality.
2. That the mixing of beneficial soil ameliorants (e.g. lime, fertilisers, rock phosphate, biochar) with dung prior to its burial by dung beetles be investigated as a non-invasive mechanism for ameliorating degraded vineyard soils.
3. That the elevated levels of recalcitrant (long-lasting) carbon in dung be examined and the consequences for long-term carbon storage in soils be documented.
4. That the commercial use of dung+dung beetles be developed to improve fertility, physical soil structure and C-sequestration in vineyard soil.

Acknowledgements

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Bernard Doube & Mark Dale