Dung beetles, biochar and improved water quality and pasture growth: interim report

Prepared for
Adelaide Hills Council
With a Primary Production Innovation Grant

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December 2015

Contents

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Summary

A field trial was established in July 2015 at Heathfield, SA, to assess the effects of added biochar, dung, and dung burial by the dung beetle *Bubas bison* on pasture growth, water infiltration into soil and contamination of run-off water with dung nutrients. Biochar-inoculated dung was obtained by feeding cattle biochar (1% dry weight) as part of their diet. The experiment comprised eighteen one-square-metre plots. A split-plot Latin square design was used: nine plots were inoculated with biochar (in dung or as a biochar powder at the rate of 2 tonnes per hectare (ha)) and nine plots had no biochar (Figure 1). Six plots had dung+beetles (nine 2-kilogram (kg) pads per plot and about 15 pairs of dung beetles per pad), six had dung-only (nine 2-kg pads per plot) and six were control plots (no dung, no beetles). Beetle-excluding cages were placed over all plots. Pasture production was assessed in October and December 2015. A rainfall simulator was built and standardised and 120 mm of even rain was applied across all plots in December 2015. The rainfall was applied to each plot for 30 minutes and all overland run-off water was collected at one minute intervals until run-off stopped (about 5 minutes after rainfall ceased). The plots were surrounded by a channel which collected the run of-off water and directed it into a pit in the ground at the lower end of each plot. From the data collected we conclude that:

- Biochar in the diet of the cattle appeared to increased their growth rates and improve dung quality (as indicated by dung odour).
- The presence of dung and dung burial substantially increased the pasture growth rate.
- Added biochar appeared to produce a modest increase in pasture production.
- Biochar appeared to increase the permeability of soil to applied water.
- Tunnelling by the beetles (up to 15 tunnels per pad, each to about 50 centimetres (cm) deep) generated a network of tunnels under the dung pads which, following rain, were presumed to fill with water. As a consequence water moved from the plots laterally through the soil profile and overland run-off was delayed until the tunnels were full of water.
- Dung burial substantially increased the permeability of the soil to water. In three dung+beetles plots there was no overland run-off. In another three, water was observed to flow into the collection pits through the soil profile (and not across the soil surface into the collection channels) and only in the latter stages of the rainfall event did water flow down the surface collecting channels.
- The analysis of the nitrate, phosphate and dissolved organic carbon (DOC) levels in the run-off water will be reported in the final report for phase 1, once the data are available.

Background

Cattle dung is a major pollutant in the Adelaide Hills, contributing nitrate, phosphorus and organic residues to run-off water which then pollutes waterways and reservoirs:

Blue-green algal blooms resulting from high phosphate levels can poison water, killing stock that drink it. Year-round removal of this dung would seriously improve the quality of water produced from the Adelaide Hills Catchment. Dung beetles provide a unique opportunity to achieve this goal and this project addresses that issue.

Biochar is a fine charcoal product that is considered to improve soil health, pasture production and animal growth (when eaten). Biochar contains a large number of 'active sites' that can bind with water pollutants, effectively removing them from circulation. Biochar is readily eaten by cattle as part of their diet, producing biochar-inoculated dung which is readily buried by the winter-active dung beetle *B. bison*.

Stock numbers are naturally limited by the supply of paddock-grown fodder. Factors that increase pasture production (such as dung burial and biochar) will increase carrying capacity, with a corresponding increase in the profitability and sustainability of the Adelaide Hills cattle industry.

Summer dung beetles are widely dispersed throughout the Adelaide Hills and bury most of the summer dung produced. The winter dung beetle *Bubas bison*, when abundant, buries most of the cattle dung produced between May and October, but is patchily distributed. Spring-active dung beetles are currently being reared in CSIRO Canberra for field release in South Australia through DBSA.

Dung burial by the autumn-active dung beetle *Geotrupes spiniger* has been shown to dramatically reduce pollution levels in run-off water at Flaxley, SA (a Dairy SA trial carried out by DBSA). Winter cattle dung is likely to be even more polluting than is autumn dung because the fresh dung can be washed directly into the waterways by winter rain. Strong water-quality benefits are expected from dung burial during winter but no data are available. This project addresses that deficiency.

Project details

This project investigated the role of winter burial of dung with and without incorporated biochar on pasture production and the level of water pollutants present in run-off water following dung burial by *B. bison*. In addition, the effect of dietary biochar on the growth rates of young cattle was examined.

The project was established on the Adelaide Hills property of Bob and Jean Evans at Heathfield, where the soil is well suited to the winter dung beetle *B. bison*.

The experimental design

The experiment comprised a split plot Latin square design in which there were three replicates of three treatments (controls (no dung, no beetles), dung only and dung+beetles) in which each of the nine test sites comprised two adjacent paired plots (that is, the same treatment), one with and one without added biochar (Figure 1). Overall, 18 plots (each of one square metre) were established in nine columns of three plots each. Each column and each row contained one replicate of each treatment with or without biochar (the split plot). Adjacent plots were separated by one metre to allow access to the plots for pasture growth evaluation and irrigation for assessing water run-off and infiltration. The pasture was a mixture of kikuyu, perennial ryegrass and some annuals. The plots were established in a fenced-off area (to exclude cattle) with a moderate slope such that the irrigation water that ran off the plots would run downhill into a collection system (see later section on the design of the rainfall simulator).

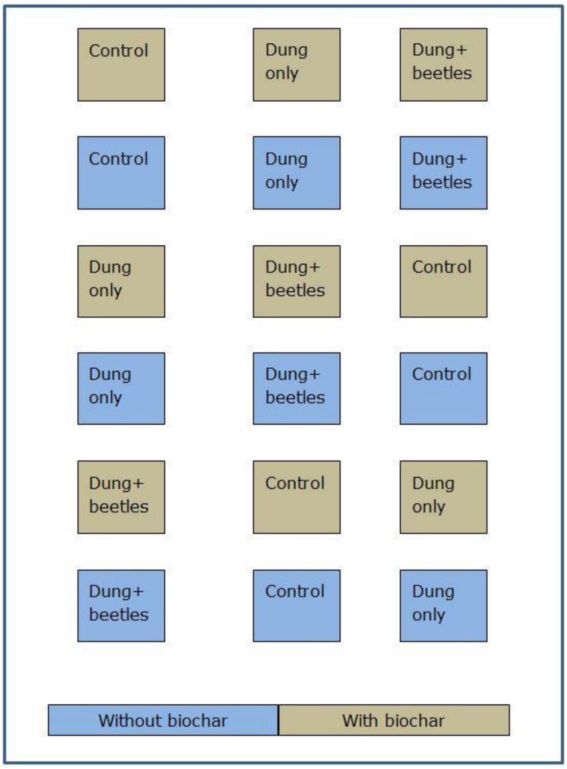

Figure 1: Design of experimental plots for the Heathfield biochar experiment

Plot layout at Heathfield SA

Experimental paddock at Heathfield

Dung production

Dung was produced in controlled conditions on the Evans property by two groups of weaner cattle, one fed added dietary biochar (approximately 1% by dry weight in the diet) and one not fed biochar. Bob and Jean Evans fed two groups of young cattle chaff, grain and straw. The biochar was mixed with the grain and chaff in a chaff bag before being presented in a trough to the cattle. For the first three weeks one group received feed with biochar while the other group received feed without biochar. After three weeks, the groups were reversed so that the group that had received biochar did no longer and the group that had not received biochar did. This continued for a further 35 days. The cattle readily ate the biochar-amended diet. Dung was collected twice daily and stored in covered containers until sufficient for the experiment had been accumulated.

The biochar used was supplied by Clean Carbon Pty Ltd (Greg Butler) and was made from coconut husks.

Biochar and cattle growth

In the process of producing the dung for the experiment, the effect of biochar in the diet (approximately 1% by dry weight) of the young cattle was assessed. This was an additional, unfunded component of the project. The results from the 50-day trial are presented in Appendix 1. Our preliminary conclusions are that the addition of biochar to the diet of the cattle appeared to increase their growth rates substantially and that the enhanced growth rate appeared to persist for at least some weeks after the biochar was withdrawn from their diet. In addition, the inclusion of biochar in the diet altered the smell of the dung from an acrid unpleasant odour to an acceptable odour reminiscent of that from pasture-fed cattle. This is presumed to reflect a change in the microbial composition of the gut flora in the cattle and may be associated with the reduced methane production from biochar-treated cattle that has been reported in the literature.

Establishing the plots

The section of pasture on which the plots were to be established was fenced and mowed just before the plots were established. The dung and beetles were added to the plots on 17 July 2015. Each of the plots with dung was supplied with nine 2-kg dung pads (3x3) (Figure 2) and between 200 and 300 *B. bison* (average 150 pairs per plot) were introduced to each of the plots designated as dung+beetles. All beetles were sourced from the field in South Australia. All plots were covered with beetle-proof mesh supported by a steel frame manufactured by Bob Evans. The edges of each mesh cover were secured in the ground using a series of tent pegs and then the flaps of the covers were covered with sand, which effectively sealed the chamber, preventing beetle escape and maintaining the dung-only plots as beetle-free areas. Over the following few weeks most of the dung in the dung+beetles plots was buried by the beetles.

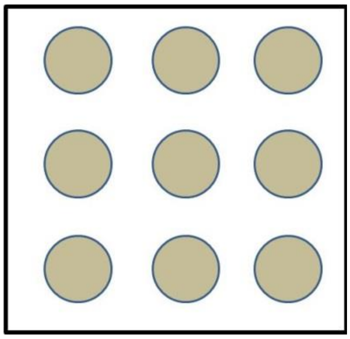

Figure 2: Each dung only and dung+beetles plot had nine 2-kg dung pads placed in a 3X3 design

Steel support frame to support the beetle-proof mesh placed over the dung pads (manufacturer: Mr Bob Evans)

Nine dung pads confined in a beetle-proof cage

Sampling pasture growth

On 2 October 2015 the mesh covers were removed from the plots, at which time the pasture had filled the cages in the dung only and dung+beetles plots. These plots were inspected by Mr Mike Fleur (AHC) and the pasture growth was sampled on the same day. Pasture growth under the mesh covers (1.2 x 1.2 m) was cut using a 'whipper-snipper' with a sharp metal blade, after which the moist grass was collected, bagged and weighed. Subsamples of the pasture were taken to assess the moisture levels in the pasture samples. This allowed calculation of the dry weight of pasture produced.

Pasture before pasture cuts on 2 October 2015

Preparing for the second pasture cut on 22 December 2015

The second pasture sample was taken on 22 December 2015 after the plots had been trimmed back to a 1 x 1 m square. The same sampling method was used.

Sampling water infiltration

A rainfall simulator that delivered an even supply of rain droplets over the one-square metre plots was constructed, tested and used. A 50-litre reservoir with a 12-volt pump supplied water to a series of jets set in rigid elevated piping attached to a steel frame that surrounded a one-square metre area beneath the frame. The rate of water application could be altered using variable valves and the pressure of the water delivered was monitored using a pressure gauge. The rate of delivery was assessed by placing the simulator over a 1-square metre galvanised collection tray and assessing the amount of water delivered at different pressures for different periods of time. At 20 psi the system delivered 2.7 litres per minute (equivalent to 6.8 mm rainfall over the one square metre) and at 30 psi it delivered 4.2 litres per minute (equivalent to 10.3 mm rainfall over the one square metre).

Calibrating the rainfall simulator

One-square metre field plot with run-off collection tray

The rainfall simulator ready to go

Steel frames designed to confine the water to the plots and to channel it into a collection vessel at the end of a collection tray were designed and constructed, and tested in the field on a trial plot. The edges of the frames fitted over the edges of the 1-square metre plot and the junction between the frame and the soil was filled with loam in order to seal it against water leakage. However, the seal was not perfect and the front edge of the frame partially inhibited overland flow of the water into the collection tray so this method was considered to be unsatisfactory. A second method to collect the run-off water was adopted. In this, a trench was dug around the edge of each plot and a collection pit (15 cm deep) was dug into the soil at the lowest point at the front of each plot. Before the artificial rain began, the trench and pit were watered such that run-off water would flow into the pit and not be lost into the trench and pit soil.

In order to determine the amount of applied water that was required in order to induce overland (surface) run-off we set the rainfall simulator over the initial trial plot, turned on the rain, set the pressure at 30 psi and recorded the time taken for a moderate amount (some litres) of water to run off the plot. The soil proved quite permeable to water and so it was decided to use a rainfall application period of 30 minutes at 30 psi for all test plots (126 mm). The rainfall was applied and all overland-run-off water was collected by bailing out the collection pit and recording the run off volume at one minute intervals: this continued until run-off stopped (about 5 minutes after rainfall ceased). The entire run-off from each plot was bulked and held in buckets, from which water samples (one each for nitrate, phosphate and dissolved organic carbon) were taken at the end of each test session for each plot. This generated 45 samples. Dam water was used for irrigation of the plots and a sample of this was also taken to determine background levels of nitrate, phosphate and dissolved organic carbon. The phosphate samples were kept as cool as possible and refrigerated overnight. All samples were delivered within 24 hours of collection to the Australian Water Quality Centre for chemical analysis.

Results

Biochar and weight gain in cattle

Appendix 1 presents these data.

Pasture growth

There was a substantial impact of the presence of dung on pasture growth in the first 5 months of the project.

In the first 10 weeks the dry matter pasture yield in the dung-only plots was 4-fold greater than that in the control plots. Similarly there was a substantial increase (over 2-fold) in the dung+beetles plots. Inspection of the plots in August and September showed clearly that dung burial by the beetles had inhibited the pasture growth in the area immediately beneath the dung pads in the +beetle plots. This has not been observed in previous trials. Subsequently the pasture grew back over the affected area such that by December 22, when the second pasture sampling occurred, the pasture had fully covered the in the dung+beetle plots but there remained some smothering of pasture in the dung-only plots where some old surface dung remained. On this latter sampling occasion the pasture production was greater in the dung+beetles plots than in the dung-only plots, reversing the previous trend, and both were substantially greater than the control plots (Table 1). The dry matter data will be reported in the final report.

Table 1: Effects of dung, dung beetles and biochar on pasture production for the period 17 July to 2 October and 22 December 2015

	Pasture wet weight (kg per plot)		Pasture (% dry matter)	10-week pasture production (tonnes DM per ha)
	October	December		
Plus biochar	1.88	0.29		3.3
No biochar	1.45	0.35		2.7
Dung+beetles	1.53	0.43	21	2.9
Dung-only	2.61	0.35	21	4.9
Controls	0.86	0.18	30	1.2

Water infiltration

The overall pattern of surface run-off is presented for the pooled biochar (n=9) and non-biochar (n=9) plots (Figure 3, Figure 4). These data indicate that there was virtually no surface run-off for the first 10 minutes during which time all of the rainfall (about 40 mL) soaked into the soil. This was followed by a period of about 20 minutes, during which, on average, the rate of run-off (millilitres per minute) increased as the soil became more saturated and a higher proportion of the applied water ran off the plots. At 30 minutes the rainfall ceased and over the next 4–8 minutes the run-off declined to a negligible amount.

There is a suggestion from these data (Figure 4) that plots with added biochar were more permeable to water than were the non-biochar plots. However, the data contain considerable variability and these observations need to be repeated in order to establish whether this effect is real.

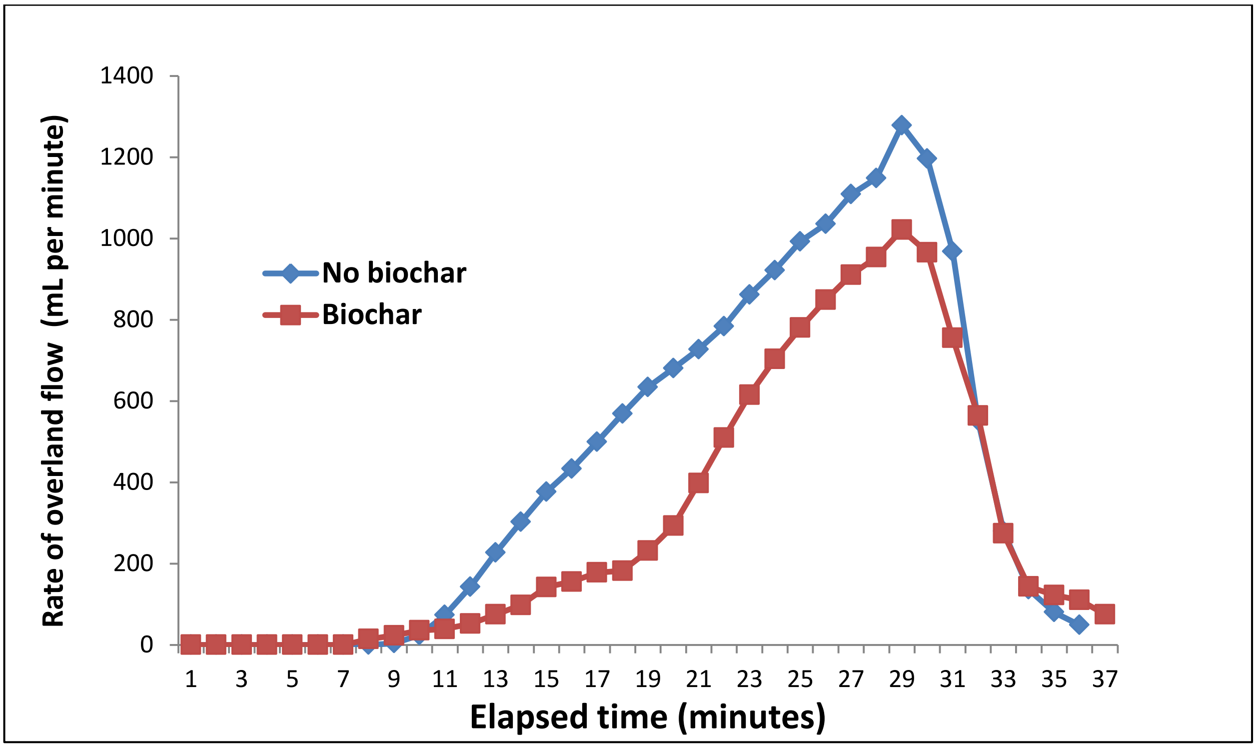

Figure 3: **The overall pattern of overland run-off for the pooled biochar (n=9) and non-biochar (n=9) plots**

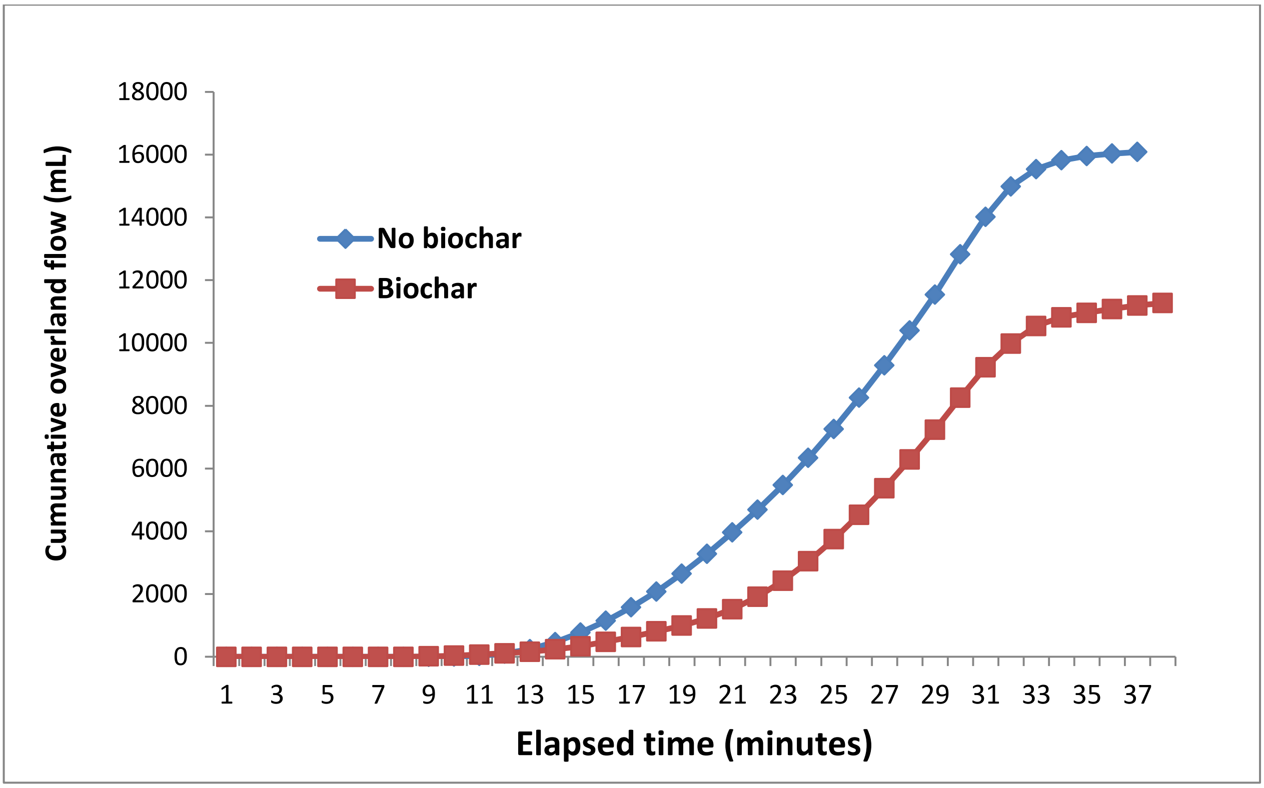

Figure 4: **The cumulative pattern of overland run-off for the pooled biochar (n=9) and non-biochar (n=9) plots**

Effect of dung, beetles and biochar

There were nine 2-kg dung pads in each of the dung+beetles plots and on average there were about 15 pairs of beetles per dung pad. Tunnelling by the beetles (each breeding tunnel to about 50 cm) will have generated a network of tunnels beneath the dung pads which, following rain, we presume, will fill with water. As a consequence water applied as simulated rainfall moved from the plots laterally through the soil profile and I assume that overland run-off was delayed until the tunnels were full of water.

Dung burial substantially increased the permeability of the soil to water. In three of the dung+beetles plots there was no overland run-off and no movement of water through the soil profile into the collecting pit downhill and adjacent to the plots. In the other three plots, after about 15 minutes water began to seep out from the soil profile into the collection pits but there was no overland run-off. The through-soil seepage continued and increased to a plateau of 400 to 500 mL per minute and this rate persisted for about 5 minutes, after which a small amount of overland water flow was evident in the channels leading to the collection pit. The overland water flow in the dung+beetles plots was taken as the difference between the through-soil seepage and the observed total collection for each sample.

The average amount of overland run-off from the plots appeared to be affected by dung burial in that the average amount of run-off in the dung+beetles plots was about one fifth of that in the control plots (Figure 5, Figure 6).

The data suggest that in all three comparisons (dung+beetles, dung-only and controls (no dung, no beetles)) the overland run-off in the plus-biochar plots was less than that observed in the no-biochar plots (compare Figure 5 and Figure 6). These data indicate that there appears to be little difference between the infiltration rates observed in the dung-only and control plots in the non-biochar treatments whereas, in contrast, in the biochar plots the infiltration rates appear to be greater in the dung-only plots than in the control plots. This suggests that the presence of biochar in dung increased the permeability of the soil onto which these inoculated dung pads had been placed. However, again, these data contain considerable variability and the observations need to be repeated in order to establish whether the effect is real.

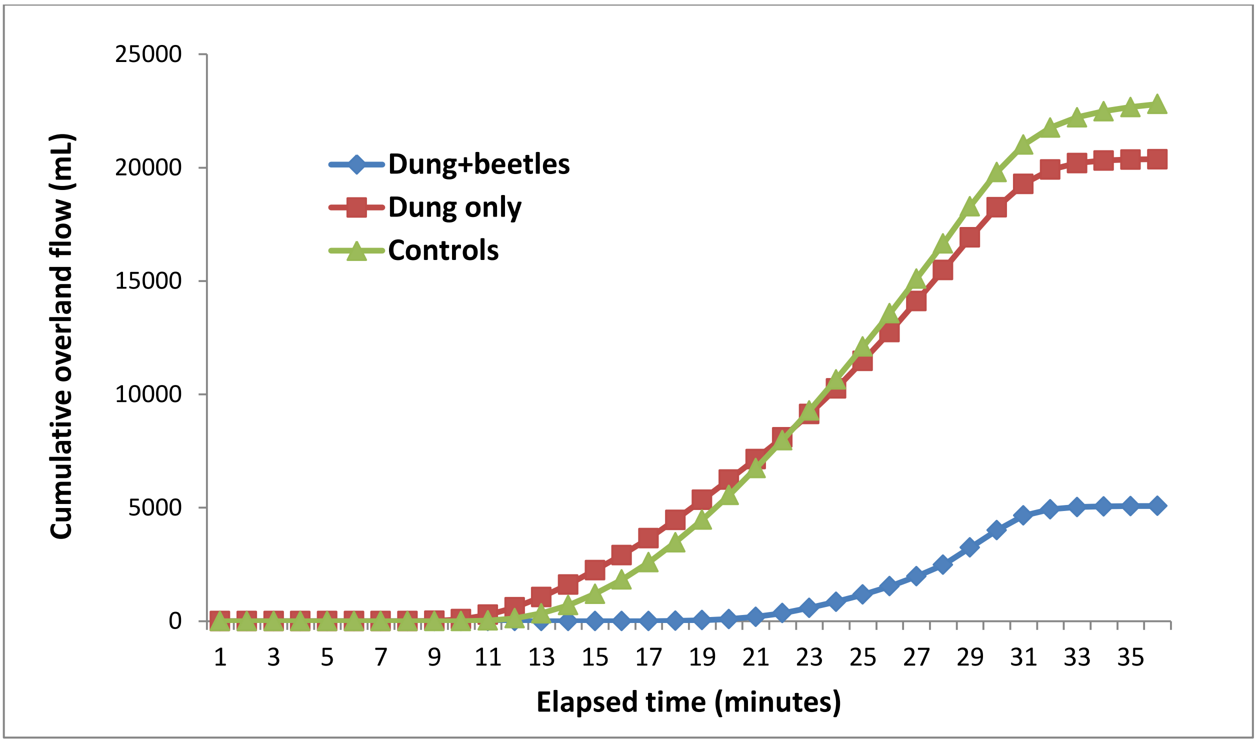

Figure 5: The cumulative pattern of overland run-off for no-biochar (n=9) plots

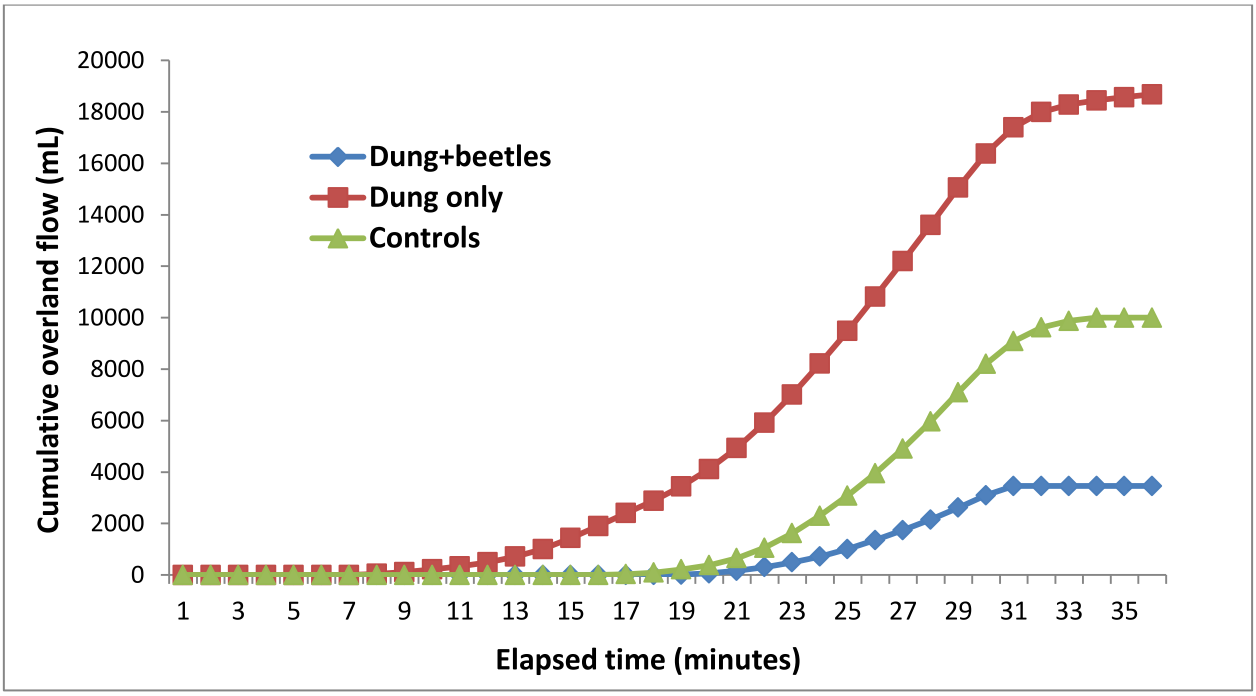

Figure 6: The cumulative pattern of overland run-off for plus-biochar (n=9) plots

Discussion

Benefits to the primary production sector and the community

The long-term outcome of this study should benefit primary producers (of cattle, horses, sheep and goats) throughout the Adelaide Hills region by promoting the case for widespread regional establishment of dung beetles for all seasons of the year. Currently the summer beetles are widespread and the winter beetles patchily distributed. Spring beetles should be available in a few years' time.

This achievement will substantially improve the sustainability of the Adelaide Hills farming system and benefit catchment water quality and should also achieve biological control of the bush fly in spring. The specific benefits for the farming community include increased soil fertility, increased pasture production, improved water and nutrient retention on property and storage at depth in the soil, reduced loss of nutrients, and reduced chemical inputs for pasture promotion and pest control (pasture pests and gut worms).

Achieving widespread beetle distribution of dung beetles in all seasons can be used to showcase the clean-green and sustainable image of Adelaide Hills primary produce. This should benefit the entire rural community.

Grazing intensity and run-off

Clearly the Evans property is well managed and there is no over-grazing. This results in a well structure soil with ample vegetative cover which impedes run-off. As a consequence the study site soil has a relatively high permeability to rainfall, as illustrated in Figure 3 and Figure 4. In this instance, with very dry soils (no significant rain since the experiment began), the first 40 mm of rainfall entered the soil and there was no overland-run off in that time and commonly overland run-off began after 10–15 minutes of heavy simulated rainfall.

In other situations in the Adelaide Hills, especially horse properties, overgrazing is common, resulting in bare soil with minimal vegetative cover, which is often quite compacted. The same experiment conducted in that situation would have a different result, with run-off occurring within minutes of the simulated rainfall commencing and most of the applied water running off into the collection pit.

It is therefore logical that the impact of strategies that increase the permeability of soil will have a far greater relative impact in overgrazed than in well-managed situations. Despite this, the effect of dung burial on the Evans property was quite clear, and this represents a minimum impact of dung burial.

Dung beetle tunnels and run-off water

The fact that tunnelling by dung beetles under dung pads substantially increased the permeability of the soil is no surprise, but the degree to which that occurs in Adelaide Hills soils has not been previously examined and, as discussed above, the impact will vary with soil condition and management.

The impact of dung burial by beetles is important for both the primary producer and the environment. The fact that, where dung had been buried, the applied water entered the soil and often did not flow overland means that, where dung beetles are abundant, any incident rainfall will be stored for a time on the property and also that the nutrients that would be lost in run-off water will be retained on the property.

The observation on the Evans property that there was no overland run-off in three of the dung+beetles plots, and that in the other three dung+beetles plots the added water moved through the soil profile into the collection pits long before a small amount of overland flow began, supports the idea that the applied rainfall first filled the dung beetle tunnels and moved laterally through the soil profile: only when the tunnels filled with water did overland flow commence, and this continued only as long as the applied rainfall persisted. The volume of the tunnels can be roughly calculated because we know that there were 15 pairs of beetles per pad and 9 pads per plot which converts into about 170 tunnels 1 cm wide and 50 cm deep: these can hold a lot of water before they fill and overflow to generate overland flow.

The lateral movement of water through the soil profile will have significant environmental effects because it will buffer and slow the movement of water from heavy rain into the waterways. This will reduce paddock and creek erosion and deliver the water to the waterways over an extended period of time, rather than as a pulse. This means that for well-managed and degraded properties alike, the improved permeability of the soil that dung burial induces will buffer environmental flows and retain moisture and nutrients in the landscape.

Biochar and run-off water

The data in Figure 3 and Figure 4 suggest that the presence of biochar increased the permeability of the soil to water. If true this finding is of considerable interest, but the explanation is not clear. The biochar may have had a direct effect on soil structure, increasing its permeability to water, or the increased pasture production in the +biochar plots may have altered soil conditions such that its permeability to water was improved, and hence overland run-off was reduced.

There was no consistent change in the pasture production in response to the addition of biochar to the system although there was an apparent initial benefit of +22% in the first 10 weeks of the experiment.

Recommendation

Further monitoring is necessary to confirm the observed trends and to assess whether the effects of biochar and dung burial persist and become clearer beyond the initial 5 months of this study. We recommend repeat evaluations of the 18 plots in autumn and spring 2016.

Acknowledgements

Bob and Jean Evans are thanked for their substantial contribution to the project including grant managing, supplying the cattle, collecting biochar, feeding biochar daily to the cattle, collecting dung daily from the cattle, organising weighing of the cattle, providing the experimental site and welding the frames for the cages (Bob). Tom Woods is thanked for his assistance in building the frames for the rainfall simulator, upgrading and standardising the rainfall simulator, and for technical support in conducting the experiment. Zane McDonnell is thanked for unknowingly supplying the sand to secure the cages. Rod Stater is thanked for weighing the cattle on three occasions. Greg Butler is thanked for supplying the biochar used in the experiment and advice on biochar quality and rates of application. Loene Doube is thanked for providing technical assistance with the field work, data entry and analysis, and with editing the report and grant application. Mike Fleur of the AHC is thanked for his support of the program. AWQC analysed the water samples.

This work was supported by a Primary Production Innovation Grant 2014 awarded by the Adelaide Hills Council.

Appendix 1: Production of biochar inoculated dung and corresponding weight gains in cattle

Procedures

A group of 16 approximately even-aged weaners were divided into two groups such that the mean weights of the eight animals in each group were similar to each other (151.8 and 151.1 kg respectively, Table 2) at the beginning of the experiment. Both groups were fed a similar food ration throughout the test period of 50 days, except that group 2 was given approximately 1% (by dry weight) biochar in their daily grain-plus-chaff ration from 29 June to 20 July 2015 (21 days, period 1) and group 1 (but not group 2) was give the same ration with 1% biochar for the second period 20 June to 18 August 2015 (39 days, period 2). The cattle were given 20 kg of grain and chaff (ratio 1.9:1) each day and allowed free access to straw during the day.

The cattle were weighed at the beginning of the experiment (29 June), after 21 days (20 July) and again after a total of 50 days (18 August 2015).

The mean weights of the two groups of cattle on the three assessment occasions are given in Table 2. The rate of weight gain was expressed as grams weight gained per day per kg of beast at the beginning of each test period.

Results

The data have not yet been analysed statistically. However, the following trends are initially indicated:

- Over the first three weeks of the trial, the rate of weight gain of the plus-biochar cattle was 23% greater than that in the control group (15.4 and 12.6 g/day/kg) respectively
- During the second test period (39 days) the rates of weight gain in group 2 remained higher (+32%) than in group 1.
- Overall (50 days) the initial plus-biochar group grew 29% faster than the other group and this trend was statistically significant ($P = 0.014$, $t_{16} = 2.41$).
- Once the biochar had been administered, the smell of the dung changed from an unpleasant sour acrid odour to a sweet-smelling dung.

Table 2: Weight change in the two groups of cattle during the 50-day experimental period

	Initial mean weight (kg)	Mean weight gain (kg)			$$ value at $3 kg LW
		Period 1	Period 2	Periods 1+2	
Group 1	151.8	12.6	13.3	27.7	620
Group 2	151.1	15.4	17.8	33.2	796
		Weight gain g/day /kg beast			
Group 1		3.9	2.1	3.4	
Group 2		4.9	2.7	4.4	

Discussion

The initial administration of biochar appeared to increase the health and weight gain in the cattle. This may reflect a change in the gut flora of the cattle following administration of the biochar, resulting in a more favourable and effective gut flora. Once the biochar had been provided, the dung odour improved dramatically. The improved dung odour persisted for at least 39 days following the cessation of administration of biochar in the diet of the cattle. It may be that a period of 'priming' the gut with biochar has a long-term effect on the gut flora so that improved rate of weight gain can persist beyond the period of administration of biochar.

This experiment needs to be repeated and expanded to involve a herd of cattle that is divided into a series (possibly 5) of groups of equivalent initial weight but run as one herd. Over the duration of the experiment, each group would be removed to a separate paddock, where they would be fed a biochar supplement for a time (possibly 2 weeks) then returned to the main herd. The weight of each individual would be recorded at the beginning of the experiment and every 2 weeks thereafter for 10 weeks and then after another 10 weeks. If biochar increased the rate of weight gain and if that change were a permanent effect, we would predict that, after each group was introduced to the biochar supplement, their rate of weight gain would increase and would exceed that of their biochar-free peers for the duration of the experiment (20 weeks). This experiment could be conducted with a herd of 40 weaners.