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Evaluation of greenwaste mulch to control runoff quality from landfill sites during frequent storms

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1 Evaluation of greenwaste mulch to control runoff quality from landfill sites during frequent
2 storms

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6 Abstract

7 This paper describes a preliminary evaluation of two types of greenwaste (fresh and aged)
8 used as a mulch layer to control runoff from disturbed landfill areas. Fresh greenwaste refers
9 to woody and herbaceous garden waste that has been recently collected, chopped and
10 shredded. Aged greenwaste is greenwaste which has been stockpiled for 18 months. We used
11 rainfall simulator tests to investigate two aspects: (1) the performance of greenwaste mulch in
12 reducing runoff during designed storm events with a high frequency of occurrence and (2) the
13 release of pollutants via runoff as total suspended solids (TSS) and total organic carbon
14 (TOC) during rain. Rainfall of <5-year average recurrence interval (ARI) was generally
15 applied, consistent with stormwater compliance requirements for many Australian landfills.
16 TOC released from fresh greenwaste material was higher in concentration than from aged
17 greenwaste. However when used as a 10cm-deep mulch layer, fresh greenwaste was able to
18 completely prevent runoff, even when tested under rainfalls up to 50 year ARI duration. An
19 equivalent mulch layer of aged greenwaste was also effective in reducing runoff volume and
20 TSS concentration compared with the bare soil during a 3.5-year ARI rainfall, but mean TOC
21 concentration was higher. Based on these preliminary results, fresh greenwaste mulching of
22 bare soils is an attractive option to control runoff and erosion from areas subject to
23 intermittent landfill operations and worthy of further investigations.

24

25 **KEYWORDS** Stormwater; landfill; runoff, erosion, mulch; runoff quality; sediment control

26 1. Introduction

27 Municipal landfills used for the disposal of solid waste present considerable ecological and
28 human risks unless there is effective landfill cover that minimises erosive runoff and isolates
29 contaminants in the landfill from the nearby environment (Breshears et al., 2005). Physical
30 disturbance due to landfill activities can cause loss of vegetation and exposure of the surface
31 soil within the active parts of the site. Disturbed areas are also subject to compaction by
32 heavy machinery reducing infiltration which increases runoff. Low vegetative cover
33 combined with reduced infiltration may predispose landfill sites to excessive erosion during
34 storm events. As a consequence, effective erosion control of these disturbed areas is critical
35 in reducing turbid runoff generated from landfill sites.

36

37 For sustainable management of agricultural, urban and industrial landscapes, establishment of
38 full vegetative cover with grass is typically the most preferred method to reduce sediment
39 loss from sloping, disturbed soil surfaces (Adekalu et al., 2007; Gyasi-Agyei, 2004).

40 Revegetation is often used to rehabilitate inactive areas of landfill which are no longer part of
41 landfill operations for long-term erosion prevention (Athy et al., 2006). However, for areas
42 subject to intermittent landfill operations, a temporary control measure is often preferred over
43 full rehabilitation as these areas may need to be reactivated in the future.

44

45 Municipal landfill sites typically receive significant amounts of woody and herbaceous
46 garden waste (referred hereafter as 'greenwaste') that is suitable for recycling. Greenwaste
47 includes all material derived from the general maintenance of parks and gardens, tree pruning
48 and residential garden activities which is shredded and chipped to produce a mulch material.
49 This material could be used as a convenient and economic method for short term erosion
50 control on land fill sites as it is similar to woody waste which is known to be beneficial for

1 erosion control (Buchanan et al, 2002; Demars et al., 2004 and Benik et al., 2003), especially
2 for short term prevention of erosion from disturbed areas of construction sites (e.g. USEPA,
3 1993; QDMR, 2002). The performance of greenwaste could also be similar in the erosion
4 control of highway embankments using yard waste compost (Persyn et al., 2004). These
5 applications indicate that more specific information is required to test the suitability of
6 greenwaste mulch as a short-term erosion control to reduce offsite impacts associated with
7 sediment-laden runoff from disturbed landfill areas.

8

9 The performance of mulch to control runoff and erosion is often evaluated with simulated
10 rainfall. Using a simulated rainfall intensity of 95 mm h^{-1} , tests by Iowa Department of
11 Transportation indicated both runoff and erosion rate from areas treated with yard waste
12 compost to be 22% and 4% of bare soil, respectively (Persyn et al., 2004). In their study,
13 superior performance of yard waste compost over other compost treatments involving
14 biosolids and industrial wastes was due to the coarse nature of the material. This indicates
15 that surface roughness and detention or storage capacity of the mulch may be key properties
16 which could be important in reducing runoff and erosion.

17

18 Biophysical mechanisms of runoff and water erosion over land surface is reasonably well
19 known and modelled (e.g. Nearing et al., 1989; Misra and Rose, 1996; Van Dijk and
20 Bruijnzeel, 2004), but the interaction of mulch with both these processes are relatively
21 complex and not as well understood. Early work of Kramer and Meyer (1969) found that the
22 rough surface created by mulches lowers runoff velocity, provides greater water storage and
23 allows water to percolate into the soil. There are also indications that soil crusting occurs less
24 often when mulch is present on surface due to the dissipation of energy associated with the
25 raindrop impact and runoff (Risse and Faucette, 2003). Demars et al. (2000) reported an
26 increase in water infiltration and water holding capacity due to improvements in soil structure
27 when composted wood mulch was used to prevent erosion.

28

29 Although mulching directly affects runoff rates and erosion, the concentration of soluble and
30 sorbed chemicals in runoff are not necessarily affected in the same way. This is well
31 illustrated in the studies of Glanville et al. (2004) which showed significantly higher
32 concentration of soluble zinc, ammonium, nitrate and phosphorus in runoff from plots treated
33 with the yard waste compost than the untreated, bare soil plots. Marques (2007) sampled
34 stormwater runoff from different areas at one landfill site in southern Sweden and found the
35 highest concentration of total organic carbon, biochemical oxygen demand and nutrients were
36 associated with composting stockpiles.

37

38 These studies indicate that an improved understanding of the interaction between runoff,
39 erosion and water quality is required to evaluate greenwaste mulch performance as a
40 temporary measure to reduce erosion and offsite water quality impacts. A preliminary
41 evaluation using simulated rainfall tests on small landfill plots is described herein.

42

43 2. Materials and Methods

44 All runoff experiments were conducted at the main municipal landfill site of Toowoomba
45 city, a regional centre located in south east Queensland, Australia. The landfill is operated by
46 the Toowoomba City Council (TCC) and is designated as an 'Environmentally Relevant
47 Activity' (ERA) under the authority of the Queensland Environmental Protection Agency. All
48 ERAs need to comply with a number of licensing conditions including containment of
49 pollutants so that stormwater discharge from the landfill site does not exceed a critical
50 concentration of total suspended solids (TSS) and total organic carbon (TOC). Consistent

1 with these licence requirements, TSS and TOC were adopted as the water quality
2 determinants in our study. Furthermore, it is generally a licence requirement to monitor
3 runoff quality from the landfill site to check compliance during several representative storm
4 events over the course of a year, so runoff control in response to relatively minor, but
5 frequently occurring storms is of critical interest.

6
7 At this landfill site, TCC chips, shreds and stockpiles approximately 40,000 m³ yr⁻¹ of
8 greenwaste. Degradation of the greenwaste material increases temperature within the
9 stockpiles and reduces the viability of weed seeds. This onsite activity produced two types of
10 material for use in our tests: fresh greenwaste as a mulch that was chipped and shredded 3
11 weeks prior to tests, and aged greenwaste which had been stockpiled for a longer period of 18
12 months. Fresh greenwaste was lighter in colour and coarser than the aged greenwaste. Based
13 on visual observation, the aged greenwaste contained a relatively higher proportion of fine
14 particles as it was partially decomposed during storage.

15
16

17 2.1 Experimental Strategy

18 A rainfall simulator designed for soil erosion and infiltration research (Loch et al., 2001) was
19 used in all experiments. The rainfall simulator consisted of a tubular steel frame to support a
20 boom containing a series of nozzles. Alternating clockwise and counter clockwise rotation of
21 the boom allowed rain to be applied over test plots by a sweeping action. The rainfall rate
22 was controlled by stopping the boom at the end of sweep by a pre-set time. Details of rainfall
23 rate control as a function of pre-set time used to overcome direct rainfall measurement during
24 specific experiments is given in Loch et al. (2001). The nozzles of the simulator were
25 designed to provide a water droplet kinetic energy similar to natural rainfall, which for the
26 conducted tests was approx. 0.275 J m⁻² s⁻¹.

27

28 The simulator is designed to be easily transported by a 2-tonne trailer fitted with a 4 kVA
29 petrol generator used to supply power to operate the equipment, including a pump and control
30 systems. It is designed to be erected and operated by a fieldwork team of 2 to 3 persons and is
31 able to apply simulated rainfall to an overall test area 2.0 by 1.8m in size. A plastic canopy
32 was attached to the A-frame of the simulator to provide a windbreak and to reduce the
33 advection of applied rain from the target plot. The rainfall simulator has been widely used in
34 Queensland for studies of soil infiltration properties and nutrient mobilisation (Loch et al.,
35 2001).

36

37 Previous erosion studies with simulated rainfall have often used high intensity rainfall (e.g.
38 100-118 mm h⁻¹ used by Misra and Rose, 1996 and Teixeira and Misra, 2005) that coincides
39 with infrequent storm events. Past studies have also a tendency to measure total sediment loss
40 in preference to suspended solids in stormwater (TSS) and have tested the capacity of mulch
41 to reduce sediment loads rather than its potential to contaminate stormwater runoff. In our
42 experiments, we selected a base rainfall intensity of 40 mm h⁻¹ that has a high frequency of
43 occurrence and more representative of rainfall events likely to occur during stormwater
44 compliance monitoring at landfill sites. At this intensity, 30 minute duration of rainfall
45 application is equivalent to 1-year ARI (Average Recurrence Interval) storm magnitude
46 (Figure 1). The duration-ARI curve in Figure 1 is based on the design storm estimation
47 procedures as described for Australian Rainfall and Runoff (Pilgrim, 1987).

48

49 Simulated rainfall was applied for a period sufficient to provide at least a 30 minute duration
50 for runoff sampling. A few recent erosion studies (e.g. Grismer and Hogan, 2004; Gyasi-

1 Agyei, 2004) have used a similar approach of allowing a fixed duration of runoff. As runoff
2 commenced at different times depending on the mulch treatment, the duration of rainfall and
3 hence equivalent ARI also varied between tests. However, the rainfall applications of the
4 tests generally remained less than 5-year ARI, significantly less in magnitude than of the
5 order 100-year ARI simulated rainfalls used in various erosion experiments cited earlier.

6

7 2.2 Runoff plots and mulch treatments

8 A portion of a closed waste disposal cell at the Toowoomba landfill was cleared of vegetation
9 1 week before setting up the test plots. Onsite vegetation consisted of shallow-rooted grasses
10 which were scraped from the surface. The surface soil of the test plots is described as a self
11 mulching, black vertosol (Isbell, 1996). Macroporosity associated with surface roots was
12 considered to be minor, compared to that inherent within this soil type. The gravimetric
13 moisture content of the surface soil was 12%. The slope of all test plots (after surface
14 clearing) was 8.5°. The water used for the simulated rainfall study was obtained from a
15 groundwater bore and transported to the testing site. A grab sample of the bore water
16 indicated low TSS and TOC concentrations at less than 2 mg L⁻¹.

17

18 The simulator is designed to apply rainfall simultaneously onto two rectangular plots
19 positioned side by side. Each duplicate plot is 1 m wide and 1.6 m long defined by a steel
20 frame hammered into the soil surface to a depth of 75 mm. Although the size of each test plot
21 was small, border effects on runoff due to preferential flow and loss of sediment due to splash
22 was negligible. An open drainage pipe was fitted to the downslope end of each plot frame to
23 collect runoff by gravity to a central sample collection point.

24

25 Five plot treatments were used (Table 1). To facilitate the rainfall tests, five pairs of
26 duplicate plots (i.e $n = 2$) each of identical treatment were established at the landfill site.
27 Greenwaste treatments were not randomly allocated to test plots in order to minimise spatial
28 variation. Each pair was separated by a distance of approximately 2 m so they could be tested
29 individually using the moveable rainfall simulator. The plots were positioned along the
30 contour so test conditions at each plot site would not be affected by downslope runoff
31 generated from other sites. A total of five rainfall tests were conducted during January 2007;
32 one for each pair of duplicate plots. More testing to increase the number of treatment
33 replicates was restricted by site access and time constraints.

34

35 As greenwaste may be a source of contaminants, two treatments were designed to quantify
36 the TOC (and TSS) released directly from greenwaste during rainfall. These are referred to as
37 'greenwaste characterisation' tests which were conducted by placing fresh or aged
38 greenwaste over plastic sheets. Additional 'mulch performance' tests were conducted to
39 investigate the effectiveness of greenwaste in controlling runoff when placed as a mulch over
40 bare soil. Greenwaste was spread within the plot frames and lightly tamped to an even depth
41 of 0.1 m. The selected mulch depth was based on Queensland erosion and sediment control
42 guidelines (QDMR, 2002). Both fresh and aged greenwaste was tested. The placement
43 densities ranged from 16 kg.m⁻² for the fresh material to 50 kg.m⁻² for the denser, aged
44 greenwaste. A bare soil plot was used as a control to determine its contribution to runoff and
45 water quality.

46

47 2.3 Sampling and measurements

48 For each treatment, duplicate plots were exposed to simultaneously applied rainfall at a
49 constant rate of 40 mm h⁻¹. Runoff samples were collected using a methodology illustrated in
50 Figure 2 and were also taken simultaneously from both duplicate plots. After the start of

1 runoff, grab samples of runoff were collected at 5 min intervals for 30 min, after which
2 rainfall was stopped. Runoff was collected over a fixed time period of 1 min to obtain a flow-
3 weighted grab sample. This approach ensured samples were obtained to represent an event
4 mean concentration (EMC) of the runoff.

5
6 During the period between grab sampling, runoff was collected in a plastic measuring
7 cylinder to measure runoff volume for each test event. Time-averaged runoff rate was
8 estimated from runoff volume and sampling time (typically 5 min). Runoff volume estimated
9 from the discrete grab samples was also used as an instantaneous measure of runoff rate. A
10 runoff discharge hydrograph was generated for each test plot by combining the data from
11 both types of runoff collection.

12
13 The first and last discrete samples (referred to as [1] and [6] in Figure 2) from each test plot
14 were analysed in the laboratory to provide an indication of initial and steady-state runoff
15 conditions from each test event. The intermediate samples ([2] to [5]) were combined
16 together and analysed to provide a composite TSS and TOC determination for the middle
17 portion of the runoff hydrograph for each test plot.

18
19 TSS concentrations were determined by laboratory analysis using the APHA (2005) test
20 method 2540D. A Shimadzu analyser incorporating a combustion catalytic oxidation process
21 was used to determine TOC. The runoff samples were also analysed for dissolved organic
22 carbon (DOC) after filtering through 0.45µm glass filter paper. The DOC data was expressed
23 as a percentage of TOC.

24
25 The data on water quality (TSS and TOC) were subject to two-factor analysis of variance
26 (Zar, 1999) considering the type of mulch and time of sampling as two independent factors.
27 Most analysis involved comparison of two types of mulches (FGP and AGP or AGS and BS)
28 and three sampling times, all of which had two replicates. Statistical comparisons were also
29 reported using the t-test between the whole-of-event runoff characteristics (runoff volume,
30 event mean concentration, load etc.) involving only two types of mulches. However, when
31 two types of mulches were compared with a t-test, uncertainty with statistical analysis due to
32 the limited number of replicates means that each comparison is indicative only. As a result,
33 the results of the tests are discussed in terms of mean runoff characteristics, with comparisons
34 reported as being either significant ($P \leq 0.05$) or not significant (NS, $P > 0.05$).

35
36 Maximum values of selected runoff characteristics are also reported. These values correspond
37 to the single highest observation recorded from the duplicate plots during testing.

38 39 3. Results and Discussion

40 3.1 Greenwaste characterisation tests

41 Runoff and water quality measurements for fresh and aged greenwaste over plastic (FGP and
42 AGP) provided information on the ability of a layer of greenwaste to store and release water
43 and pollutants during storm events without affected by the underlying soil. Discharge
44 hydrographs for these tests are shown in Figure 3. Whole-of-event values of runoff and its
45 quality (TSS and TOC) are presented in Table 2 and temporal variation in TSS and TOC are
46 shown in Figures 4-5.

47
48 Runoff during the FGP and AGP tests (Figure 3) commenced fairly rapidly within a few
49 minutes after the start of rain as water infiltration into the soil was prevented by plastic. This
50 suggests that rain percolated quickly through the mulch layer to generate runoff and a steady

1 state runoff condition was evident for both types of greenwaste approximately 25 minutes
2 after rainfall simulation began. When rainfall ceased, runoff reduced gradually over a period
3 of several minutes.

4

5 Mean runoff characteristics, including initial loss (defined as the amount of rainfall that needs
6 to be applied before runoff is observed), runoff volume and maximum discharge for the fresh
7 and aged mulches were of similar magnitude (NS, $P > 0.05$, Table 2). Based on the volumetric
8 runoff coefficient (total runoff/total rainfall), both mulches have the capacity to retain
9 approximately 50% of the applied rainfall. Potential mechanisms for water retention by the
10 mulch layer are expected to be absorption and storage of water within the voids of the mulch
11 material and surface storage within small depressions on the plastic underlay.

12

13 Temporal variation in TSS and TOC data (mean \pm 1 standard error) for the FGP and AGP tests
14 are shown in Figures 4-5 as an 'initial' concentration (Sample 1) and an 'intermediate
15 concentration' for bulked runoff (Samples 2-5) to represent the middle part of the runoff
16 hydrograph and the 'final' and in some occasions 'steady-state' concentration (Sample 6).
17 Other TSS and TOC statistics are also shown in Table 2 to include the maximum
18 concentration, EMC and the mass load lost via runoff.

19

20 As shown on Figure 4, TSS concentration declined significantly over time ($P \leq 0.05$) for both
21 mulches indicating a 'first-flush' behaviour commonly observed in many erosion studies
22 without mulch. However, for these mulch treatments without soil these results suggest that
23 maximum pollutant concentrations are likely to occur during the early stages of runoff. As
24 stormwater compliance monitoring focuses on checking that landfill runoff quality is within
25 certain concentration targets, then management of this initial, relatively low-volume runoff
26 phase is an important consideration. The reduction of TSS concentration over the duration of
27 the applied rainfall suggests that the mobilisation of suspended particles in the runoff is
28 'supply-limited' and a dilution effect is present i.e. the runoff volume generated from the
29 mulch in response to rainfall becomes proportionally larger than the particle mass washed
30 out.

31

32 Maximum TSS concentration of runoff was found to be higher for the aged mulch than the
33 fresh mulch (Table 2). Overall, the mean TSS load and EMC in runoff from the fresh mulch
34 were 36% and 13% higher than the aged mulch, respectively (NS, $P > 0.05$, Table 2).

35

36 Mean EMC of TOC in runoff for the fresh mulch was approx. 1.5 times higher than the aged
37 mulch ($P \leq 0.05$, Table 2). As a stockpile of aged mulch is exposed to the weather, some loss
38 of TOC via leaching is expected prior to our testing. This leaching may have reduced the
39 mean TOC mass load in runoff (approx. one-third) from the aged mulch than the fresh mulch
40 (NS, $P > 0.05$, Table 2). Runoff produced from both types of mulches had a dark brown,
41 coffee colour and the TOC was predominately in a dissolved form (>94% DOC).

42

43 Temporal variation in TOC concentration was relatively constant for both mulches
44 throughout the event with no evidence of any first flush effect (Figure 5). This suggests that
45 TOC is not supply limited during the applied rainfall and a dilution effect that may be
46 introduced as runoff increases was not present. The difference in runoff response between
47 TSS and TOC could be attributed to the different kinetics that are involved i.e. TSS involves
48 the physical mobilisation of small particles whereas TOC, being mainly DOC, involves the
49 dissolution of organic carbon from the mulch material.

50

1 3.2 Mulch performance tests

2 Measurements for fresh and aged greenwaste over soil (FGS and AGS) provided an
3 opportunity to assess the performance of greenwaste mulch in controlling runoff and its
4 quality compared with a bare soil control (BS). Results are given in Table 3 and Figures 6-8.

5
6 In bare soil (BS) tests, runoff did not start until well after 30 minutes of rain (Figure 6) that
7 was equivalent to a total amount of 21 mm rain. Thus, applying rain at 40 mm h^{-1} (1-year
8 ARI rainfall) allowed most of the rain to infiltrate into the soil and increased the rainfall
9 duration for BS tests to 62 minutes, coinciding with a 3.5-year ARI rainfall. Runoff from the
10 bare soil was only 24% of the applied rainfall (Table 3) and it stopped quickly within a few
11 minutes of cessation of rainfall (Figure 6). The shape of the hydrograph for bare soil suggests
12 that runoff did not reach a steady state during the testing period although the magnitude of
13 maximum discharge from bare soil was similar to the mulch tests on plastic (Tables 2 and 3).
14 This suggests a reduction in infiltration towards the end of the tests for bare soil possibly due
15 to the formation of a surface seal and development of crust under the impact of rain (Geeves,
16 1997).

17
18 With fresh mulch over soil (FGS), the hydrological response was very different to other test
19 surfaces as there was no runoff even when rain was applied for 120 minutes coinciding with a
20 50-year ARI storm event. A few studies have reported complete infiltration of applied rain
21 with mulches. For example, Grismer and Hogan (2005) reported complete absence of runoff
22 from plots covered with a 0.3 m thick woodchip layer under a rainfall rate of 180 mm h^{-1} .

23
24 The coarse, open nature of the fresh mulch apparently controls percolation of water through
25 the mulch layer into soil at a rate that matches, or remains under the infiltration rate over time
26 to generate any runoff. The mulch is expected to physically protect the soil against the
27 impact of raindrop to prevent surface sealing and development of surface crust. Particle size
28 distribution of mulches suggests that fresh woody mulch is coarser than the composted mulch
29 that helps reduce runoff when the mulches are placed over soil (Persyn et al., 2004) by
30 possibly affecting the continuity of water flow through the mulch.

31
32 The hydrograph from the aged greenwaste over soil (AGS) showed an intermittent pattern
33 (Figure 6). Runoff commenced within <10 minutes from the start of rain in a pattern similar
34 to the behaviour of this mulch over plastic (AGP). During the first 20 minutes of runoff,
35 water may have moved downslope through and/or over the mulch layer with little infiltration
36 into soil. This first phase of runoff had an early peak and after 20 minutes, runoff became
37 negligible but re-established 35 minutes after the start of rainfall. The second phase of runoff
38 was relatively steady at a rate of 3 to 5 mm h^{-1} . The unusual pattern of runoff for AGS seen in
39 Figure 6 suggests that the hydraulics and storage properties of this material placed on soil are
40 complex.

41
42 Due to the sporadic nature of runoff from the aged mulch (AGS) tests, an additional sample
43 (referred to as Sample 0) was collected during the first 30 minutes of rainfall to represent the
44 early runoff phase. The total duration of rainfall for AGS tests (including the early runoff
45 phase) was 60 minutes that corresponded with a 3.5-year ARI storm similar to that used for
46 the bare soil tests. Based on the volumetric runoff coefficient (Table 3), mean runoff from
47 AGS plots was 13% of the applied 3.5-year ARI rainfall and its volume was approx. half of
48 that generated from the bare soil (NS, $P>0.05$, Table 3). Maximum runoff discharge from
49 AGS plot was also lower than the discharge from bare soil (Table 3).

50

1 The quality of runoff indicated a substantial reduction of 98% in mean TSS EMC from AGS
2 plots compared with the bare soil (BS) plots ($P \leq 0.05$, Table 3 and Figure 7). Thus, a 10-cm
3 layer of aged greenwaste is an effective method in reducing the turbidity of stormwater
4 generated from landfill surfaces.

5
6 The TSS EMC in runoff from AGS was of similar magnitude to that for the aged greenwaste
7 over plastic (AGP in Table 2), with the indication that the TSS in AGS tests may have
8 originated from the mulch itself, rather than from the soil. Total TSS load from the aged
9 greenwaste plot was <1% of that from the bare soil (NS, $P > 0.05$, Table 3).

10
11 TOC concentration in runoff from the bare soil (BS) during the 3.5-year ARI rainfall test was
12 in the range of 10-50 mg L⁻¹ (Figure 8) with an average EMC of 26 mg L⁻¹ (Table 3).
13 Approximately 40% of the total organic carbon was in a dissolved form, but it varied
14 considerably between runoff samples (11-86%). With a 10 cm layer of aged mulch on soil
15 (AGS), TOC concentration (both maximum and EMC) increased at least two fold over TOC
16 from the bare soil (NS, $P > 0.05$, Table 3). In addition, the temporal pattern of TOC in runoff
17 showed first flush effects for AGS but not for BS (Figure 8). Due to a reduction in runoff
18 volume from AGS, the mass load of TOC from the aged mulch was similar to BS (NS,
19 $P > 0.05$, Table 3). Runoff from the AGS plots had a higher mean dissolved organic carbon
20 (DOC) than from the bare soil (NS, $P > 0.05$, Table 3). The nature of greenwaste to export
21 carbon in dissolved form was consistent with that observed from the mulch characterisation
22 tests (AGP, Table 2).

23
24 The initial runoff phase for the AGS tests corresponded with a 1-year ARI rainfall duration.
25 Runoff generated during the first phase was 3 mm or 13% of the applied rain (Table 3).
26 During the same period, the 1-year ARI rainfall fully infiltrated into the bare soil (BS) plot.
27 This indicates that aged mulch on bare soil may contribute to TSS and TOC pollution during
28 minor storms when no runoff is occurring from bare soil.

29 30 4. Conclusions

31 A series of simulated rainfall tests were conducted at a landfill site in Toowoomba, Australia
32 to obtain a preliminary assessment of the TOC and TSS released from the greenwaste (aged
33 and fresh) material when it is exposed to rain and the performance of these waste materials as
34 a mulch to control turbid runoff. Storm events of high frequency of occurrence (generally <5
35 year ARI) were adopted in our tests to represent actual rain events likely to occur during
36 stormwater compliance monitoring at landfill sites. This contrasts with previous studies
37 which tend to focus on large, less frequent rainfall intensities of approx. 100 year ARI.

38
39 The mulch characterisation tests on plastic indicated that both fresh and aged greenwaste
40 have the capacity to retain approximately 50% of the 1-year ARI applied rainfall. This water
41 storage ability moderates the amount of water released during minor storms, either infiltrating
42 into the ground or appearing as surface runoff. TOC and TSS were mobilised from the
43 greenwaste material as the applied rainfall passes through it. Fresh greenwaste released a
44 higher EMC of TOC compared to aged greenwaste. TSS release exhibited a 'first flush'
45 behaviour of peak concentration at the commencement of runoff, whereas the temporal
46 variation in TOC concentration was small. TOC was predominately in a dissolved form
47 (>94% DOC).

48
49 Although fresh greenwaste had the highest potential to release TOC when subjected to rain,
50 as a 10 cm-deep mulch layer placed on bare soil, it prevented the occurrence of runoff even

1 under a 50-year ARI storm event. The ability of this material to limit runoff appears to be due
2 to its open, porous nature that not only allows water storage within the mulch layer but also
3 maintains infiltration into soil possibly by protecting soil from raindrop impact and
4 prevention of soil surface sealing.

5

6 Aged greenwaste was less effective than fresh greenwaste in restricting runoff; however, it
7 reduced the mean volume of runoff by >50% and TSS mass load and concentration to <1-2%
8 of these quantities in runoff from the bare soil during a 3.5-year ARI storm. The effectiveness
9 of aged greenwaste in reducing runoff turbidity was offset by an increase in mean TOC
10 EMC, predominantly in a dissolved form. Repeated testing of greenwaste over time and with
11 larger number of replicates is desirable to determine the full potential of aged greenwaste in
12 modifying runoff and its quality.

13

14 Overall, our preliminary research indicates that application of fresh greenwaste over the soil
15 surface is an attractive option to control runoff and erosion from areas subject to intermittent
16 landfill operations. Long-term benefit from mulch application can be sustained if the fresh
17 greenwaste is replaced before it 'ages'. Aged greenwaste has reduced capability in
18 controlling runoff during frequent storm events (~1-year ARI) as it tends to generate small
19 volumes of runoff when no runoff is produced from bare soil. Under these conditions, aged
20 greenwaste is a potential source for off-site export of organic carbon. It is suggested that
21 when fresh greenwaste naturally deteriorates into aged greenwaste over time, it may be
22 incorporated into soil with tillage before recovering the surface with fresh greenwaste.

23

24 As our experiments were based on relatively small plots with limited number of replicates to
25 overcome spatial variation, further studies are needed to examine how variation in the
26 thickness and placement density of the mulch layer contributes to water quality in runoff.
27 Long-term runoff plot studies are difficult to conduct on landfill sites as these are subject to
28 intermittent operations. Future studies in this area need to focus on a range of soil types,
29 slopes, rainfall intensity and duration, greenwaste age and thickness to extend the importance
30 and application of our results. Since there is a potential for mulches to add nutrients,
31 pesticides and other contaminants to runoff, the range of pollutants assessed for water quality
32 in these studies need to be broadened.

33

34 Acknowledgment

35 We are grateful to Toowoomba City Council for providing access to the Bedford Street
36 municipal landfill facility and financial support for this work.

37

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1

2 **Table 1.** Description of plot treatments used for simulated rainfall experiments.

Purpose of test	Plot treatment	Test run
Greenwaste characterisation	Fresh greenwaste over plastic	FGP
	Aged greenwaste over plastic	AGP
Mulch performance	Fresh greenwaste over soil	FGS
	Aged greenwaste over soil	AGS
	Bare soil (control)	BS

3

4

- 1 **Table 2** Runoff, total suspended solids (TSS) and total organic carbon (TOC) for ‘greenwaste
 2 characterisation’ tests during a 1-year ARI rainfall application. Mean values and standard
 3 errors of duplicate test plots are shown. Mean values shown **bold** indicate significant
 4 difference with a t-test ($n=2$, $P \leq 0.05$).

Parameters	Fresh greenwaste on plastic (FGP)	Aged greenwaste on plastic (AGP)
<i>Runoff Characteristics</i>		
Initial loss (mm)	3.3 ± 0	2.0 ± 0
Runoff volume (mm)	11.9 ± 1.5	10.3 ± 0.9
Runoff coefficient	0.50 ± 0.06	0.46 ± 0.04
Max. discharge (mm h ⁻¹)	27.2	25.3
<i>TSS Characteristics</i>		
Max. TSS (mg L ⁻¹)	272	320
TSS EMC (mg L ⁻¹)	133 ± 47	118 ± 6
TSS Load (g m ⁻²)	1.65 ± 0.75	1.21 ± 0.04
<i>TOC Characteristics</i>		
Max. TOC (mg L ⁻¹)	457	246
TOC EMC (mg L ⁻¹)	436 ± 0.9	177 ± 3.8
TOC Load (g m ⁻²)	5.2 ± 0.6	1.8 ± 0.1
%DOC	93.8 ± 0.4	98.0 ± 0.9

5

6

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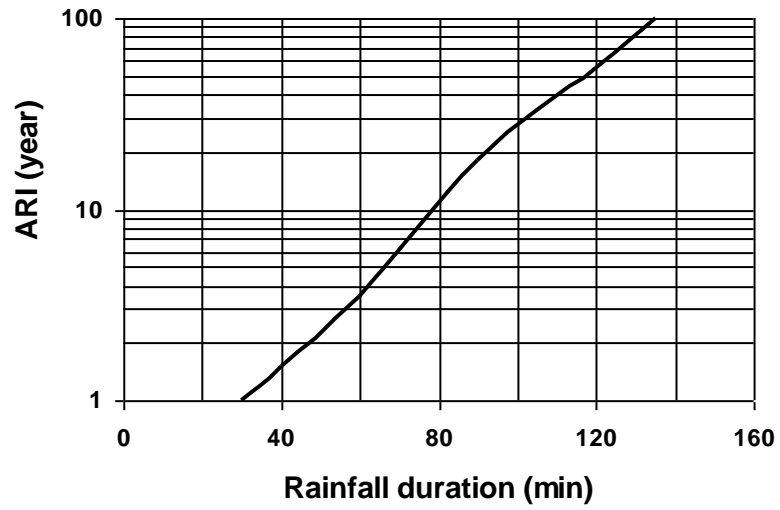
2 **Table 3** Runoff and its quality for ‘mulch performance’ tests during 1 and 3.5-year ARI3 rainfall applications¹. Mean values and standard errors of duplicate test plots are shown.4 Mean values shown **bold** indicate significant difference with a t-test ($n=2$, $P \leq 0.05$) between

5 BS and AGS for 3.5-year ARI rain.

Parameters	Bare Soil (BS) 3.5-year ARI rain	Aged greenwaste on soil (AGS) 3.5-year ARI rain	Aged greenwaste on soil (AGS) 1-year ARI rain
<i>Runoff Characteristics</i>			
Initial loss (mm)	21.3 ± 0	4.7 ± 1.3	4.7 ± 1.3
Runoff volume (mm)	9.9 ± 1.4	5.0 ± 0.5	3.1 ± 0.6
Runoff coefficient	0.24 ± 0.03	0.13 ± 0.01	0.13 ± 0.03
Max. discharge (mm h ⁻¹)	26.9	11.5	11.5
<i>TSS Characteristics</i>			
Max. TSS (mg L ⁻¹)	8300	246	164
TSS EMC (mg L ⁻¹)	7228 ± 91	132 ± 16	154 ± 29
TSS Load (g m ⁻²)	71 ± 11	0.63 ± 0.21	0.25 ± 0.05
<i>TOC Characteristics</i>			
Max. TOC (mg L ⁻¹)	48	103	103
TOC EMC (mg L ⁻¹)	26 ± 12	74 ± 4	95 ± 7
TOC Load (g m ⁻²)	0.27 ± 0.15	0.34 ± 0.03	0.16 ± 0.03
%DOC	38 ± 20	79 ± 10	83 ± 17

6 ¹ No runoff was generated from fresh greenwaste over soil (FGS) plots for all tests including
7 50-year ARI rainfall. No runoff was generated from bare soil plots (BS) for the 1-year ARI
8 rainfall.

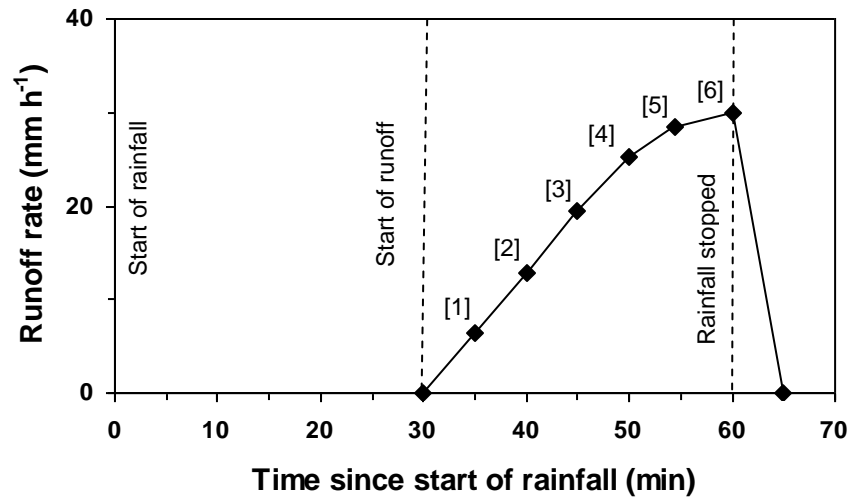
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2 **Figure 1.** The relationship between rainfall duration and its average recurrence interval (ARI)
3 for a constant rainfall intensity of 40 mm h^{-1} in Toowoomba.

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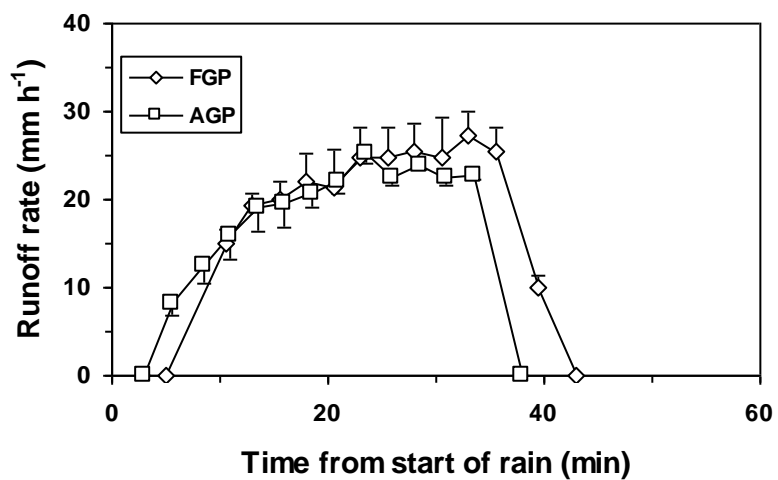


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2 **Figure 2.** A schematic diagram of runoff sampling procedure used by accumulating runoff
3 samples over time marked as [1] to [6].

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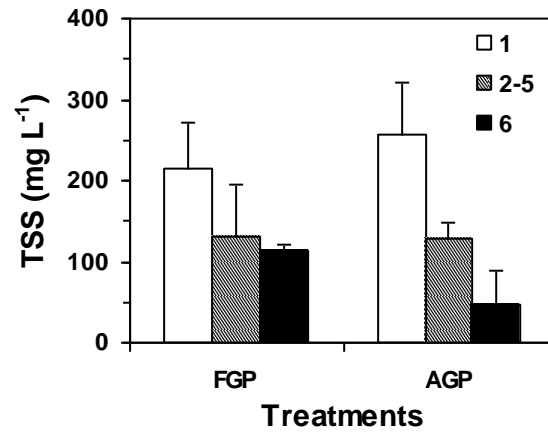
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3 **Figure 3.** Temporal variation in runoff rate during the greenwaste characterisation tests. FGP
4 and AGP respectively refer to a layer of fresh and aged greenwaste placed over plastic.

5 Vertical lines over mean values denote standard errors (SE), shown in one direction only for
6 clarity.

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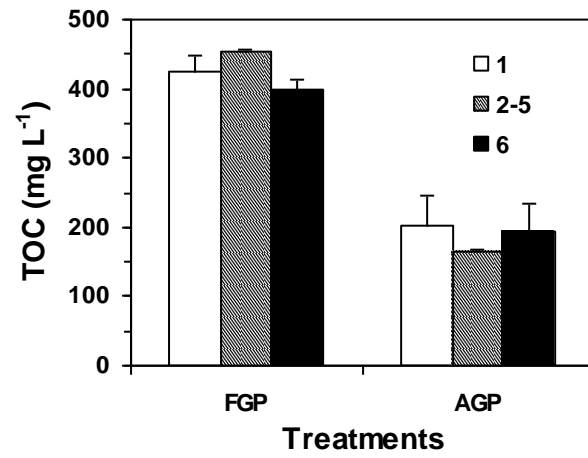
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4 **Figure 4.** Temporal variation in TSS during greenwaste characterisation tests. Treatment
5 descriptions are given in Figure 3. Initial sample is represented as 1, intermediate sample as
6 2-5 after combining runoff samples 2 to 5 and final sample 6 to represent steady state
7 concentration.

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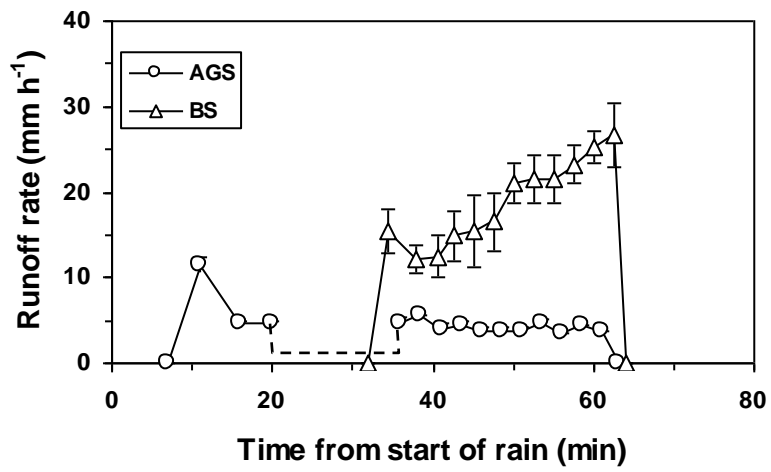
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3 **Figure 5.** Temporal variation in TOC during greenwaste characterisation tests. Treatments
4 and sample numbers as described in Figure 4.

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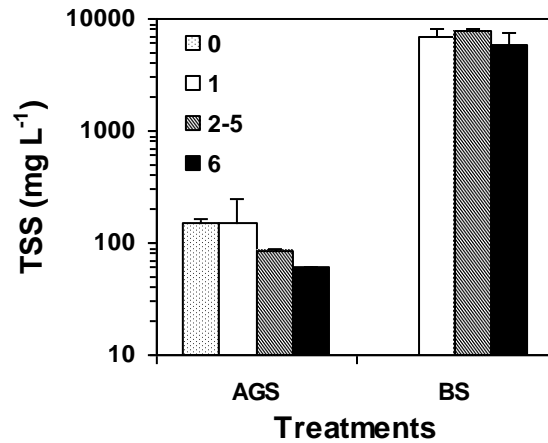
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4 **Figure 6.** Temporal variation in runoff rate during the mulch performance tests. AGS refers
5 to a layer of aged greenwaste placed over the soil surface and BS represents bare soil.

6 Vertical lines over mean values denote standard errors (SE). Dashed line shows period of
7 negligible runoff observed during AGS test.

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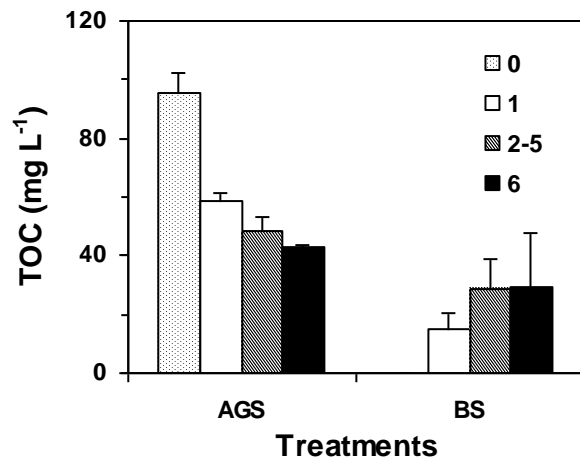
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2 **Figure 7.** Temporal variation in TSS during mulch performance tests. Treatment description
 3 as given for Figure 6. Initial sample for both treatments is represented as 1, intermediate
 4 sample as 2-5 after combining runoff samples 2 to 5 and final sample 6 to represent steady
 5 state concentration. Sample 0 for AGS treatment refers to concentration for early sporadic
 6 runoff phase.

7



1

2 **Figure 8.** Temporal variation in TOC during mulch performance tests. Treatments and
3 sample numbers as described in Figure 7.

4