Original Research Article

COMPARATIVE ROAD DUST SUPPRESSION CAPACITY OF MOLASSES STILLAGE AND WATER ON GRAVEL ROAD IN ZIMBABWE

.

ABSTRACT

Gravel road dust has significant health effect. The study was conducted to assess road dust suppression effect of molasses stillage in gravel at a Sugarcane Estate in Zimbabwe. Three, 2 km long gravel road sections (steep, sloping and gentle) had the following dust suppression treatments applied to 500m long segments: (i) molasses stillage, (ii) water and (iii) control. Data on dust deposition rates were subjected to Analysis Of Variance (ANOVA) to compare treatment means. Mean road dust deposition rates ranged from 998.46±50.04 to 6184.02±257 mg/m^2/30 days between January and June 2012. Road segments treated with molasses stillage had the lowest (P = .05) dust deposition rates compared to other treatments. Dust deposition rates were reduced by 77-83% and by 18-39% for molasses stillage and water treatments respectively. The sloping road segments had consistently the highest (P = .05) mean dust deposition rates. It was concluded that molasses stillage outperformed water as a road dust suppressant but variations were caused by type and volume of vehicular traffic together with meteorological factors at the Estate.

Keywords: molasses stillage, dust deposition rate, water, gravel road, suppression

1. INTRODUCTION

Gravel roads constitute about 90% of all road networks in the world and act as catalysts for the movement of people and agricultural produce [1, 2]. A gravel road consists of a mixture of gravel (40-80%), sand (20-60%) and fines (silt + clay: 8-15%) which are blended and compacted into a strong dense surface crust hard enough to resist breaking down under traffic [3]. Dust generation from vehicular traffic is a considerable problem on gravel roads. Estimates by the US EPA indicate that gravel roads contribute up to 40% of the total fugitive dust emitted into the atmosphere [4]. Fine particles in the road surface are pulverized by vehicular traffic as the moisture in the road decreases, creating more dust under dry conditions [5].Vehicle weight, speed, design and wind strength influence the amount of dust suspended by vehicles[6,7].

Dust is a solid particulate matter (PM) capable of temporary suspension in the air, with a diameter size range of 0.1 – 75.0 µm [8]. Compositionally, suspended dust consists mainly of oxides of aluminum, silicon, calcium, titanium, iron and other metal oxides [9]. Dust emissions from gravel roads are a nuisance to the environment, agriculture and the public health. Inhalable particulate matter (PM_{10}) is associated with respiratory and cardiovascular morbidity and mortality [10]. In addition, fallout dust particles (<5µm in diameter) reduce agricultural crop productivity [11,12].

In Zimbabwe, the policing for atmospheric pollution control legislation are done by the Environmental Management Agency (EMA) under the Ministry of Environment, Climate Change and Water. EMA's Department of Environmental Protection enforces the adherence to the Environmental Management Act Chapter 20:27 and its Environmental Management (Atmospheric Pollution Control) regulations Statutory Instrument (S.I.) 72 of 2007 which regulate the dust emissions and depositions [13]. The dust emission limits of 10mg/m^3 stipulated in the S.I. 72 of 2007 is used to check compliance to environmental laws for ambient air. The South African Standard (SANS) 1929:2010 and the German DIN air quality monthly dust deposition rate limits of 1300 mg/m^2/day for industrial and 650 mg/m^2/day for non industrial sites (which include unpaved roads) are also used to check compliance in Southern African countries [14].

The suppression of dust on gravel roads curtails PM loading in the atmosphere which contributes to air pollution. Application of proper dust suppressants to gravel roads is essential to ensure road safety, cleaner and healthier environment [4]. Water is key in gravel road dust suppression dynamics as it facilitates binding of individual soil particles [15]. Dust suppressants function either by attracting moisture from the surrounding air, which in turn holds the dust or by adhering particles together or retarding evaporation from the road surface [2,16]. Techniques of suppressing dust emissions range from spraying the roads with hygroscopic chemicals to using geo-textiles in road reconstruction [17]. The commonly used dust suppressants are lignin derivatives; chlorides of Ca, Mg and Na; road fabric; resinous adhesives and water [18].

Besides polluting the environment, the generation of dust means the loss of fine particles which are essential road surface binders. This loss of fines requires aggregate replacement and increases gravel road maintenance cost. Large volumes of stillage are generated from sugar processing and application on gravel roads is an option for managing waste from the sugar mills but limited research has been done on its effectiveness as a road dust suppressant in Zimbabwe. The aim of the study was therefore to evaluate the effect of molasses stillage on gravel roads in suppressing dust emissions using deposition rates as indices at the beginning of the harvesting season.

2. MATERIAL AND METHODS

Study site and work design

The study was carried out in a sugarcane Estate involved in growing and milling sugar cane which is situated about 650 km to the South east of Harare, Zimbabwe. The Estate falls in the Zimbabwean natural farming region 5 and receives a mean annual rainfall of 469 mm between November and March [19]. The Mean annual evaporation is 1751 mm and 50% of it occurs between December and March. The average monthly temperatures are 23℃ in June and 36℃ in October. The growing season is less tha n 90 days, making the region unsuitable for dry land cropping. General wind direction is East of South East (ESE) with an average speed of 1.3m/s [19].

The topography in the estate is generally flat (~1-2% gradient) and the estate is underlain by rocks associated with the Limpopo mobile metamorphic belt which are dominated by undifferentiated mafic and felsic gneisses and granulites intruded by quartz, dolerite and magnetite dykes [20]. A shear zone cuts across the estate and the rocks have an East of North East / West of South West strike.The dominant soils derived from the rocks are reddish in colour, unleached and base-rich [21].

The road network in the estate comprises gravel roads linking the agricultural production areas. Regular gravel road maintenance includes road surfacing, watering, blading and occasionally re-gravelling every 3 to 7 years. The reshaping of the driving surface and the road shoulder is done by graders whilst rollers compact the finished surface.

The experiment had three 2 km long road sites as the main sampling strata and dust suppressants applied constituted the following treatments: road segment where molasses stillage was applied (treatment 1), control segment (treatment 2) and road segment where water was applied (treatment 3). The road was divided into three sections (strata) according to the road topography (Table 1).

Table 1. Topographic characteristics of studied road sites

Road site	Average slope angle	Slope class
Site 1(RS1)	21 ± 4^0	moderately steep
Site 2 (RS2)	14 ± 7^0	sloping
Site 3 (RS3)	4 ± 3^0	Gentle

Road segments (500 m long) were randomly selected at each road site and allocated to the three treatments. A 200 m buffer band was left between the treatments in each road site to reduce dust carry over (Fig. 1). Molasses stillage and water were applied at a rate of 4 litres per square metre after every 14 days based on the recommendations from the Land Preparation Department of the Estate.

Dust deposition gauges were installed at each sampling site to collect dust fall [22]. Six dust deposition gauges (15 cm diameter, 30 cm height) were installed 2m above the ground in each treatment in a road segment (3 gauges on each side of the road) to determine the effectiveness of the dust suppressants (Fig.1). For the whole experiment, a total of 54 dust deposition gauges were installed. Dust deposition was monitored over six months through gravimetric weighing of the deposited dust after 30 days from 1st January to 30th June 2012. Samples were sent to the laboratory for gravimetric analysis. Dust deposition rates were calculated according to equation 1:

$$D = \frac{W}{A} \qquad (1)$$

Where: D is the deposition rate (mg/m^2/30 days); W is the weight of the deposited dust (mg) and A is the area of the deposition gauge (m^2).

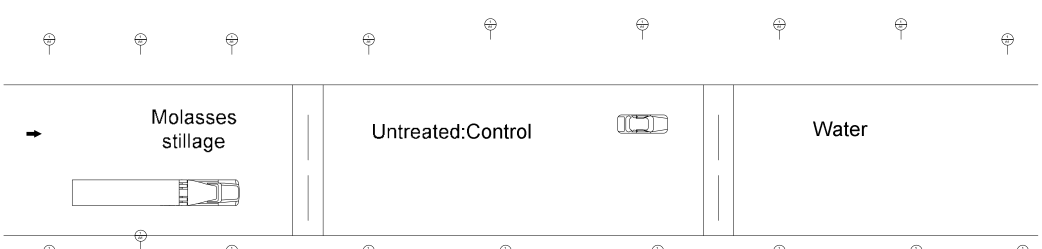

Fig. 1. Schematic diagram of the road segments showing the layout of dust gauges at the road sites (not to scale).

Data on dust deposition rates were tested for normality and subjected to Analysis Of Variance (ANOVA) in SPSS version 20.0 of 2011 to compare the treatment means. Fisher Least Significant Different (LSD) post-hoc tests were used to separate means of dust deposition rates.

3. RESULTS

Overall Dust deposition rates

Dust deposition rates ranged from 998.46±50.04 mg/m^2/30days on gentle slopes (RS3) to 6184.02±257 mg/m^2/30days on sloping terrain (RS2) (Table 2). RS2 (sloping terrain) had consistently the highest (*P* = .05) dust deposition rates when compared to the other sites (Table 2). However, at each road site the order of dust deposition rate was control>water>stillage over the six month period and all the treatment combinations were significantly different (*P* = .05) (Table 2). At RS1 (steep terrain), application of stillage to the road reduced the deposition rate of settlable dust by 3303 mg/ m^2/30days (or 77%) when compared with control which had a mean deposition rate of 4319.07±323.43 mg/ m^2/30days (Table 2). Dust deposition rate in the control treatment was more than four-fold bigger than that of stillage treatment at RS1. Water application marginally reduced dust accumulation rate by 18% when compared with the control. However, water treated road section had mean deposition rates 3.5 times higher (*P* = .05) than that of the stillage treated road section.

Dust deposition rates were highest at RS2 (on sloping terrain). Rates of settlable dust deposition of 5.7 times that of stillage applied segments were observed for the control. This represented an 82% reduction in dust deposition rate as a result of stillage application when compared with the control mean overall rate of 6184.02 ± 257 mg/m^2/30days (Table 2). Application of water overally reduced the dust deposition rate by 39% when compared with the control segment. At RS3, the dust deposition rates observed for the control (mean: 5984.09±322.61 mg/m^2/30days) were about six times that of stillage treatment. An 83% reduction in dust deposition rate was observed when stillage treatment is compared with control (Table 2). Water application also nominally reduced road dust deposition rate by about 39% when compared with the control. It was observed that the mean rate of dust deposition in the water segments were 3.7 times that of stillage treated segments.

Table 2. Overall mean dust deposition rates: 01 January 2012 to 30 June 2012

Road Site	Treatment	Mean dust deposition rate (mg/ m^2/30days)	Recalculated mean dust deposition rate (mg/ m^2/day)	(t/km^2/day)
RS1	Stillage	1016.23±61.75*	33.87±2.06	0.03
	Control	4319.07±323.43*	118.53±6.44	0.12
	Water	3556.10±244.68*	36.49±1.71	0.04
RS2	Stillage	1094.59±51.44*	143.97±10.78	0.14
	Control	6184.02±257*	206.13±8.57	0.21
	Water	3782.45±149.36*	126.06±4.98	0.13
RS3	Stillage	998.46±50.04*	33.28±1.67	0.33
	Control	5984.09±322.61*	199.47±10.75	0.20
	Water	3671.13±217.51*	122.37±7.25	0.12

****Means for the different treatments are significantly different at P = .05***

Temporal variation of dust deposition rates

The variation in dust deposition rates is illustrated on Figs 2, 3 and 4 for the six month period at each road site. At RS1 stillage treated segments had the lowest deposition rates whilst the control segments had the highest in any given month (Fig. 2). Dust deposition rates on stillage treated segments increased gradually between January 2012 and June 2012, but remained below 2000 mg/m^2/30days. On the contrary, mean dust deposition rates in the untreated road segments (control) exhibited high variability and deposition rates peaked in January 2012 (about 5800 mg/ m^2/30days); April (5200 mg/m^2/30days) and June 2012 (4100 mg/m^2/30days) whilst trough rates were observed in March 2012. The water-treated segments' dust deposition rates exhibited a pattern similar to that of the control segments, but were consistently lower throughout the six month period except in May 2012.

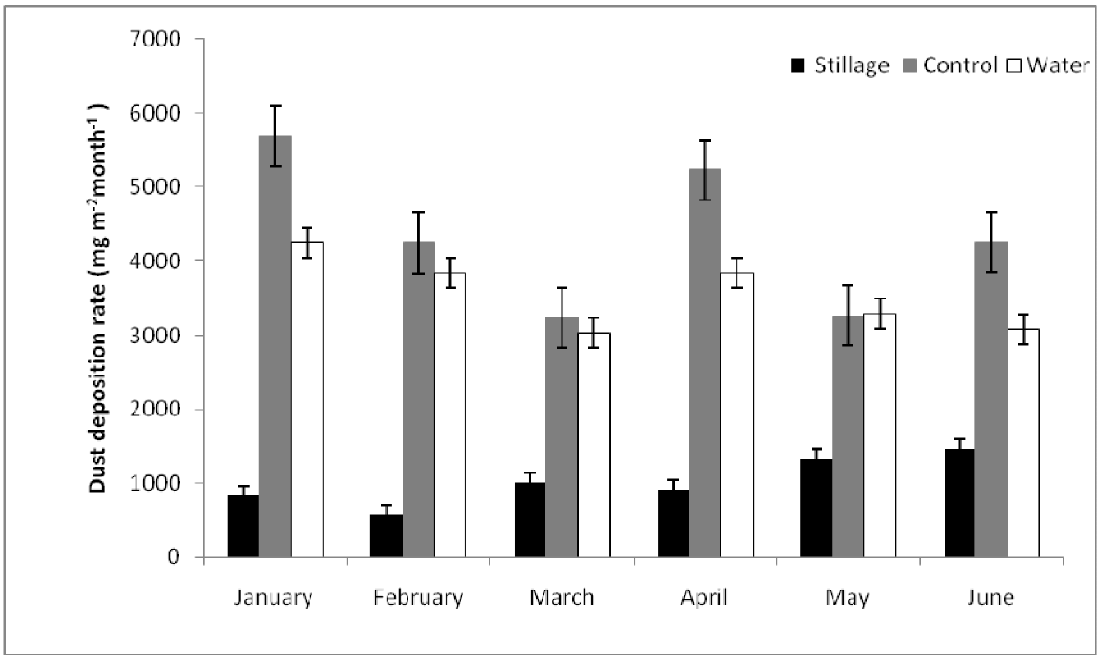

Fig. 2. Mean dust deposition rates for Steep sloping road site (RS1) for six months of 2012

Fig. 3 shows the mean dust deposition rates over a period of six months at RS2 (on sloping terrain, Table 1). There were no significant differences in dust deposition for the untreated road segments (control) over the six months (Fig. 3). Dust deposition rates gradually declined from 4000 mg/m^2/30days in January to about 3800 mg/ m^2/30days in May and June in water treated road segments at RS2. However, there were no significant differences between dust depositions over the months. Dust deposition rates in stillage treated segments were lower than water treated or control, but lowest in February and remained below 2000 mg/m^2/30days. However, the rates gradually increased to a peak in June 2012.

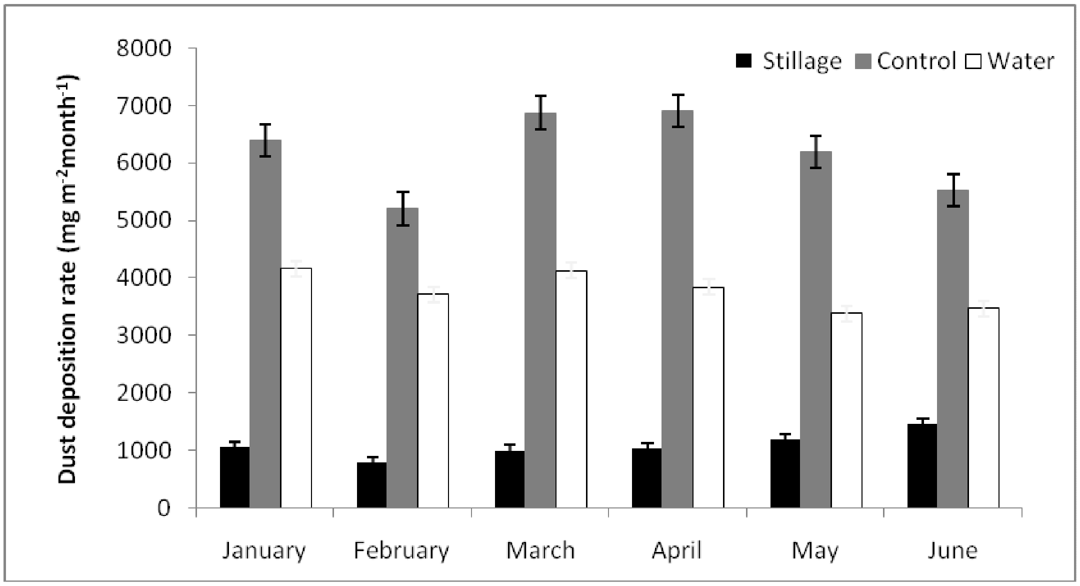

Fig. 3. Mean dust deposition rates for slopping road site (RS2) for six months

At RS3 road segment treated with stillage recorded lowest mean dust deposition rates when compared with other segments (Fig. 4). A similar trend for dust deposition rates for the stillage treated segments was observed over the period (<2000 mg/ m^2/30days; gradually rising to a maximum value in June). There were no significant differences in dust deposition in the untreated segments over the 6 months. The water treated road segments also showed no significant differences in dust deposition over the 6 months. The stillage showed the least dust deposition, and the lowest values were observed in February and the highest in June (Fig. 4).

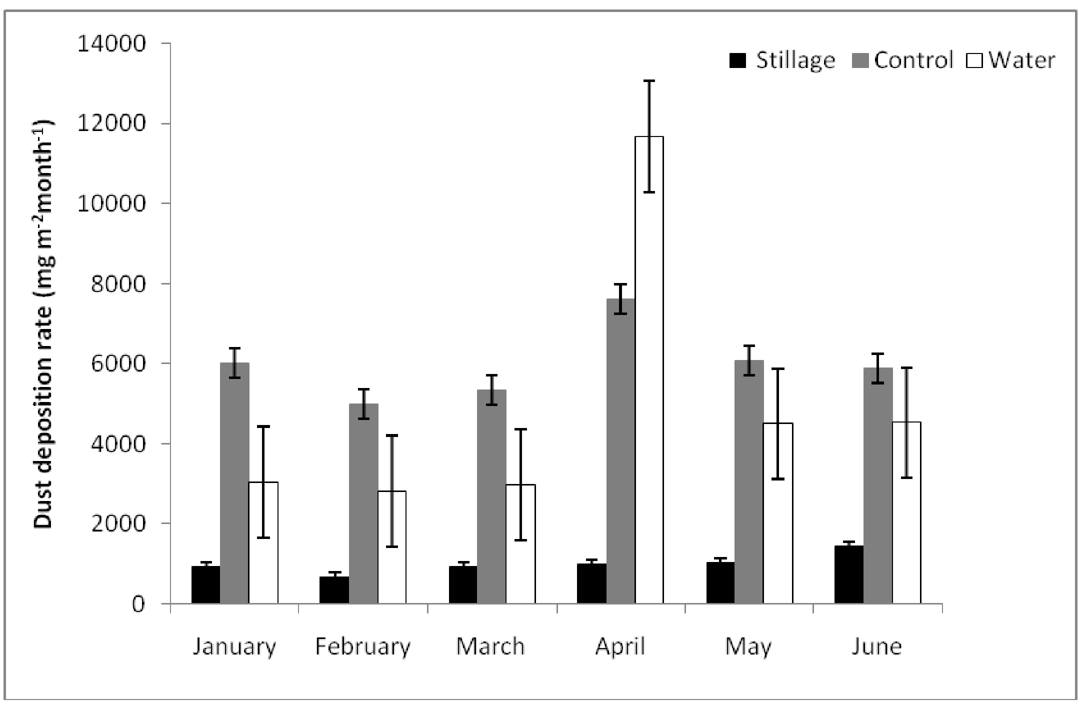

Fig. 4: Mean dust deposition rates for gentle slopping road site (RS3) from January to June 2012

Meteorological variables and vehicle counts: January 2012 to June 2012

Table 3 shows the rainfall and temperature data collected during the study period which was hypothesized to contribute to dust suppression dynamics. Rainfall was mostly received in January 2012 (48 mm) and February 2012 (5mm) (Table 3). Mean monthly temperatures ranged from 26.9°C to 34.4°C.

Table 3: Rainfall and Temperature data for the Estate: 01 January 2012 to 30 June 2012

	January 2012	February 2012	March 2012	April 2012	May 2012	June 2012
Total rainfall (mm)	48.0	5.0	0.0	0.0	0.0	0.0
Mean Monthly Temperature (°C)	32.7	31.3	34.4	32.1	27.4	26.9
Mean daily evaporation rate (mm/day)*	7.0	6.0	6.0	5.0	4.0	3.0

**Values calculated from more than 24 years of data (Lecler, 2003)*

Fig. 5 shows the monthly vehicle counts at the three road sites. The vehicles are the major sources of settlable road dust. Tractors and light vehicles plied the road sites from January through to June 2012 whilst haulage trucks trafficked the sites between April and June 2012 and dominated (33-54%) the traffic volumes. At RS1 vehicle count totals ranged between 393 (January 2012) and 877 (April 2012). Tractors dominated (54-64%) traffic volume on the roads before April 2012. Haulage trucks were dominant in last three months and in April they constituted 41% of total traffic; 43% in May and 40% in June (Fig. 5). Traffic at RS2 was also dominated (64%) by tractors in January where the total count was 872 and remained constant (600-800) thereafter. Haulage trucks also had the highest proportion of counts after March 2012 (Fig. 5) and accounted for 45% in April; 33% May and 54% June.

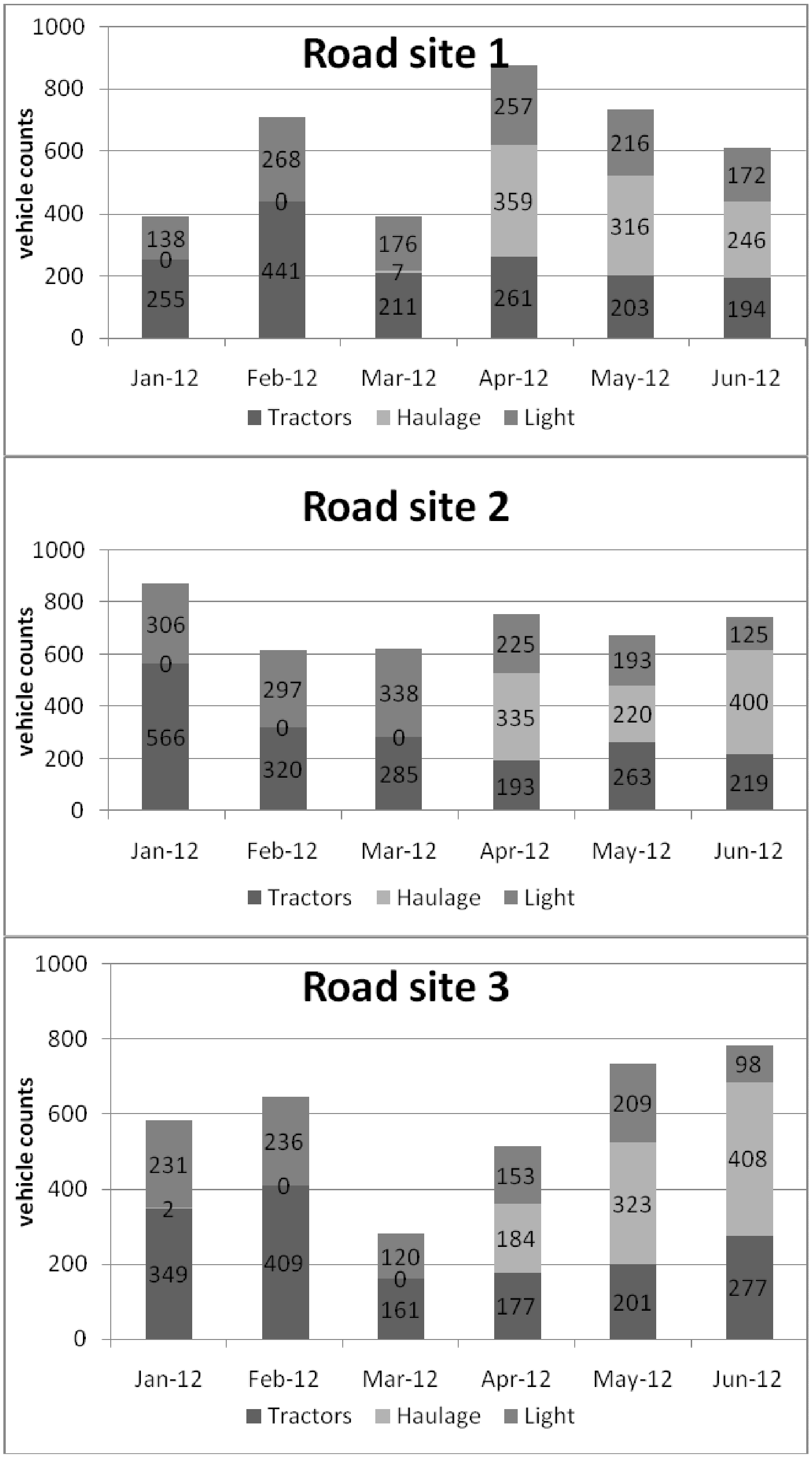

Fig. 5. Total vehicle counts at the study road sites: January 2012 to June 2012

Traffic volume was most variable at RS3 and a minimum total count of 281 was observed in March 2012 (Fig. 5). Haulage trucks contributed to 36% of vehicular traffic in April, 44% in May and 52% in June.

4. DISCUSSION

STILLAGE AS A ROAD DUST SUPPRESSANT

In this study, application of molasses stillage significantly reduced settlable road dust accumulation by between 77% (steep terrain; RS1) and 83% (gentle terrain; RS3). On steeper road terrain there was more traction (for ascending) and breaking (descending) required by vehicles. Both processes increased wearing of applied stillage coat which reduced its effectiveness and more dust deposition rates were consequently observed at steeper sites. The mineral composition of stillage makes it an effective soil binder and improves soil structure. Stillage is a lignin based dust suppressant which contains magnesium lignosulphonates, humic acid (2.36%) and fulvic acid (12.5%) that bind soil particles together due to a combination of chemical and physical interactions [23]. This agrees with the earlier findings that lignin based suppressants like stillage outperform other suppressants [24]. Lignin has been reported to be even more effective when incorporated into the road material but such an operation would raise maintenance costs in the short term [25].The lipids found in stillage increase the mass of the soil particles precluding their suspension. Stillage also contain sugars which are hygroscopic and attract moisture from the atmosphere when the air is humid enough. This was likely to be the case during the first three months of the study period which coincided with the tail part of the rainy season in the country when humidity is high. The hygroscopic nature of the stillage was therefore attributable to the reduced dust accumulation rates and its effect was more sustainable due to multiple advantages.

WATER AS A DUST SUPPRESSANT

Surface moisture content in unpaved roads plays a key role in dust control and water in the surface of unpaved roads causes particles to aggregate and the cohesion of the wetted particles even persists after the water has evaporated [17]. In this study, road segments treated with water had lower dust deposition rates than control segments at the three road sites. Water application reduced dust settling rates by at most 39% (gentle sites) and was less effective than molasses stillage (Figs 2, 3, and 4). According to Flocchii *et al. (*1994) cited in [6], raising of road surface moisture contents to more than 2% through addition of water led to a reduction (> 86%) in emission rates of PM compared to the control surface (with a mean moisture content of 0.56%). Research has shown that aggregate surface moisture content was the best predictor of dust control efficiency in unpaved roads [26]. Water adheres to individual soil particles, thus increasing their mass, adding surface tension forces and mitigating suspension [17]. Moisture content affects the ejection of particulates by vehicles, as well as the strength of the road bed and hence its ability to deform under vehicle loading [27]. The water treatment and the control represented contrasting extremes of soil water content of the gravel road surface.

RAINFALL AND TEMPERATURE EFFECT ON DUST DEPOSITION

Rainfall and temperature affected soil moisture dynamics in the surface layer of the roads in the Sugar Estate during the period studied. The dust deposition rates reflected a balance between the main hydrological processes of precipitation (rainfall) and evaporation. In January 2012 a total of 48 mm of rainfall were received, but the lowest rates of dust deposition were observed in February 2012 (the only other month that received rainfall with a paltry total of 5 mm). There was residual moisture carryover from January to February leading to low deposition rates in February (Table 3). The average monthly temperature of 30.8 ºC recorded from January 2012 to June 2012 influenced the evaporation of the moisture from the road surface. The lower dust deposition rates recorded in February were also attributed to lower mean monthly temperature of 31.3 ºC recorded compared to 32.7 ºC in January and the respective mean evaporation rates were 6mm/day and 7mm/day [28]. On the basis of mean temperature and mean daily evaporation figures, higher evaporation water losses were therefore experienced in January leading to drying of road surfaces resulting in higher dust deposition rates at all the three road sites despite receiving more rainfall. Similar observations were reported from studies on the effects of climatic factors on dust emissions [29,30,31].

VEHICLE TRAFFIC AND DUST DEPOSITION

The type and volume of vehicular traffic was in relation to agricultural activities taking place in any given month [28]. Sugarcane harvesting in the Zimbabwean lowveld begins in April and this is associated with larger volume of haulage traffic that emit the most dust from the unpaved roads. Before April, the agriculture activities were executed by tractor drawn implements, such as cultivators. Supervision light vehicles also frequented the roads before onset of harvesting from January to March 2012. Between January and March, the traffic was dominated by slower (tractors) and lighter traffic than the period when harvesting (April to June 2012) was in full swing when haulages were dominant and more dust was emitted and deposited at all road sites. This is in agreement with the findings of [6] who reported that dust emission factors showed a strong linear dependence on speed and vehicle weight. A study by Ediagbonya *et al* in Nigeria revealed that most particulate pollution emanates from various activities such as resuspension of dust from unpaved roads by traffic [32]. This is also in agreement with the findings of this study.

5. CONCLUSION

The study evaluated the effectiveness of molasses stillage application on gravel roads in suppressing dust emissions and its effect on the environment in a sugarcane estate. Molasses stillage was a better suppressant than water over the six month study period. In some months the dust deposition rates on roads treated with water compared well to the untreated sections because of the high temperatures which evaporated the moisture from the roads quickly. The control road segments had high levels of dust deposition through-out the monitoring period hence the rate of dust deposition on productive land is high. The application of stillage to roads is a potentially sustainable practical method for dust suppression for reduced emission of particulate matter into the atmosphere. Further studies to evaluate the life span of an effective stillage road coat need to be carried out as this study was only done over six months.

REFERENCES

1. Nchouji FD. The Effect of Road Transport Network on Agricultural Produce Marketing in Giwa Local Government of Kaduna State. *The Information Manager Journal* 2008; 8(2):6-11. http://dx.doi.org/10.4314/tim.v8i2.44818

2. Edvardsson K. Evaluation of Dust Suppressants for Gravel Roads: Methods Development and Efficiency Studies, Unpublished PhD Thesis, Department of Civil and Architectural Engineering, Royal Institute of Technology Stockholm. 2010:13-19.

3. Burningham, Stankevich. Why road maintenance is important and how to get it done. World Bank Washington D.C. 2005. Accessed on 09 February 2012.

Available: http:// www.worldbank.org

4. US EPA. Fugitive Dust Sources. U.S Environmental Protection Agency Research Triangle, NC. 2005 Accessed : 4 May 2012.
Available http://www.epa.gov

5. Addo JQ, Sanders TG, Melanie C. Road Dust Suppression: Effect on Maintenance Stability, Safety and the Environment Phases 1–3, Colorado State University, Fort Collins, Colorado. 2004.

6. Gillies JA, Etyemezian V, Kuhns H, Nikolic D, Gillette DA. Effects of Vehicle Characteristics on Unpaved Road Dust Emission. Journal of Atmospheric Environment. 2005; 39:2341-47. http://dx.doi.org/10.1016/j.atmosenv.2004.05.064

7. Sheridan J, Noske PJ, Whipp RK, Wijesinghe N. The effect of truck traffic and road water content on sediment delivery from unpaved forest roads. Journal of Hydrological Processes. 2006; 20(8):1683–99. http://dx.doi.org/10.1002/hyp.5966

8. ISO (International Standards Organisation) 4225. Air quality - General aspects. Geneva. 1994.

9. Chow JC, Watson JG, Fugitive emissions add to air pollution. Environ Protection. 1991; 3: 26-31.

10. World Health Organisation. Health risks of particulate matter from long-range transboundary air pollution. WHO Regional Office for Europe, Copenhagen. 2006.

11. Machian J, Navas A. Soil pH changes induced by contamination by magnesium oxides dust. Journal of Land Degradation and Development. 2000; 11: 37-50. http://dx.doi.org/10.1002

12. Frazer L. Down with road dust. Journal of Environment Health Perspectives. 2003; 111: 892- 95. http://dx.doi.org/10.1289/ehp.111-a892

13. EMA (Environmental Management Agency). Environmental Management Act Chapter 20:27 Statutory Instrument 72: Air pollution control Regulations. Government Printers, Harare. 2007.

14. SANS (South African National Standard) 1929. Ambient air quality – Limits for common pollutants. South African Bureau of Standards Edition 1.1. Pretoria. 2005.

15. Donnges C, Edmonds G, Johannessen B. Rural Road Maintenance - Sustaining the Benefits of Improved Access (SETP 19). International Labour Office, Bangkok. 2007.

16. Larkin Laboratory. Calcium Chloride and Magnesium Chloride for Dust Control. Midland, Michigan. 1986.

17. DCURC (Dust Control for unpaved roads Canada). Federation of Canadian Municipalities and National Research Council. 2005. Accessed: 8 January 2012.
Available: http//www.infraguide.ca.

18. Thenoux G, Vera S. Evaluation of hexahydrated magnesium chloride performance as chemical stabilizer of granular road surfaces. Journal of the Transportation Research Board. 2003; 1819: 44-51. http://dx.doi.org/10.3141/1819b-06

19. DMS (Department of Meteorological Services). Climate handbook of Zimbabwe Suppliment No.5. Harare: Government Printers. 1981:119-60.

20. Stagman JG. An Outline of the Geology of Rhodesia. Rhodesia Geological Survey Bulletin. 1978; 80: 126.

21. Nyamapfene KW. Soils of Zimbabwe. Nehanda Publishers, Harare. 1991.

22. ASTM Standard D1739. Standard Test Method for the Collection and Measurement of Dustfall (Settleable Particulate Matter). ASTM International, West Conshohocken. 2010. Accessed: 19 August 2013.
Available: http://www.astm.org/Standards/D1739.htm

23. Cortez L, Freire WJ, Rosillo-Calle F. Biodigestion of vinasse in Brazil. International Sugar Journal. 1998; 100(1196):403-13.

24. Addo JQ, Sanders TG. Effectiveness and Environmental Impact of Road Dust Suppressants. Department of Civil Engineering Colorado State University Fort Collins. 1993: 6-10.

25. MDNR (Missouri Department of Natural Resources). Air Pollution Control Program report No.6. 2006. Accessed : 27 April 2013
Available: www.dnr.mo.gov/env/apcp.

26. Johnson EN, Olson RC. Best Practices for Dust Control on Aggregate Roads. Final report. Minnesota Department of Transportation, Minnesota. 2009. Accessed: 27 April 2013. Available: http://www.lrrb.org/PDF/200904.pdf.

27. Rosbury KD, Zimmer RA. Cost-Effectiveness of Dust Controls Used on Unpaved Haul. PEDCo Environmental, Inc. 1983.

28. Lecler NL. Charts and calendars for irrigation scheduling of sugarcane in the Zimbabwe lowveld. Proceedings of South African Sugar Technology Association. 2003; 77: 364-68.

29. Grini AG, Myhre CS, Zender J, Sundet K, Isaksen I. Model simulations of dust sources and transport in the global troposphere: Effects of soil erodibility and wind speed variability. Journal of Geophysical Research. 2005; 110: 1-14.
http://dx.doi.org/10.1029/2004JD005037

30. Zender CS, Kwon EK. Regional contrasts in dust emission responses to climate. Journal of Geophysical Research. 2005; 110: 1-7.
http://dx.doi.org/10.1029/2004JD005501

31. Ediagbonya TF, Ukpebor EE, Okieimen FE, Okungbowa GE. Comparative study of TSP, Inhalable particles and Respirable particles in Urban and Rural areas in Niger Delta Region of Nigeria. Greener Journal of Physical Sciences. 2012; 2(3): 89-96.

32. Ediagbonya TF, Ukpebor EE, Okieimen FE. Heavy metal in inhalable and respirable particles in urban atmosphere. Environmental Skeptics and Critics. 2013; 2(3): 108-17.