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Short-term Changes in the Soil Physical and Chemical Properties due to Different Soil and Water Conservation Practices in a Sloping Land Oil Palm Estate

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ABSTRACT

The effectiveness of mulching materials, empty fruit bunches (EFB) and EFB mat (Ecomat) and the construction of soil trenches (silt pits) as soil water and nutrient conservation methods, have yet to be compared against one another in any single study. Moreover, as compared to the EFB studies, much less has been studied on the effectiveness of Ecomat and silt pit to improve soil properties and conserve water. Thus, this study was undertaken to compare the effects of the EFB, Ecomat, silt pit, and control (stacked pruned oil palm fronds) on several soil properties at soil depths of 0-150 and 150-300 mm, over a period of six months, at an oil palm estate with a hill slope of 6°. This study found that in just a period of six months, there were significant effects of the four treatments on the soil chemical and physical properties. Overall, the EFB was found to be the best treatment to improve the chemical properties of soil in both depths (CEC, Ca, Mg, K, P, C, and pH). However, both the EFB and Ecomat gave similar values for the soil available water content and aggregate stability. The mean daily total soil water content (up to 1 m depth) for the EFB, Ecomat, and control were found to be insignificantly different from one another, but silt pit had the statistically lowest total soil water content. The soil water distribution under the Ecomat mulches was rather uniform throughout the soil depths (up to 1 m), whereas in the EFB and silt pit treatments, the soil water tended to be concentrated at the upper soil layers until 0.6 m depth, with the concentration of water restricted to a shallower depth for silt pit as compared to the EFB. As for the control, water concentrated mostly below 0.5 m depth. This study is on-going, but the results have so far indicated that the EFB, followed by Ecomat, is the best soil and water conservation method, particularly to improving the chemical properties of soil. Ecomat, due to its lower nutrient content than EFB, generally did not improve the soil chemical properties by as much as the EFB. The poorer performance of the silt pit, as compared to the EFB and Ecomat (and to the control in some cases), was because the silt pit walls were observed to be easily collapsible, and in turn, silt pits became increasingly shallow and less effective to trap runoff over time.

Keywords: Empty fruit bunches, Ecomat, silt pit, oil palm, soil and water conservation, hill slopes, organic matter

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INTRODUCTION

New oil palm plantations today are often being limited to marginal lands which include those in hilly, steepland areas. These areas are frequently related to soil erosion and run off losses caused by excessive rain falls. In order to reduce soil and water losses by erosion, terraces are often built. Nonetheless, hill cutting activities to construct these terraces cause not only compacted soils but also reduce soil fertility because the fertile, top soils are physically removed from the area.

Nowadays, some oil plantations have forsaken the hill terracing practice and are planting oil palms on non-terraced hill slopes. Therefore, in order to reduce water and nutrient losses, several methods are used. One of them is the use of empty fruit bunches (EFB) as a natural mulching material. The beneficial effects of the EFB in improving soil properties and oil palm growth and yield have been well documented, among other by Chan and Goh (1978), Lim and Pillai (1979), Khoo and Chew (1979), Chan *et al*. (1980), Singh *et al*. (1981), Loong *et al*. (1987), Lim and Chan (1987), Zaharah and Lim (2000), as well as Lim and Zaharah (2002). In term of fertiliser use, one tonne of EFB is equivalent to 7 kg of urea, 2.8 kg of rock phosphate, 19.3 kg of muriate of potash, and 4.4 kg of kieserite (Singh *et al*., 1999).

Nevertheless, one well-known disadvantage of EFB is that it is bulky, making its transportation, storage, and distribution rather difficult and expensive. One recent method is to compress the EFB into a mat or carpet known as Ecomat. According to Yeo (2007), Ecomat is produced by shredding the EFB into its raw fibre and then combed out, after which EFB undergoes a high pressure hydraulic press to remove impurities, such as water, sludge, and oil traces. The EFB is then dried, using high temperature, to about 15% gravimetric water content, before it is trimmed to the required size and packed for shipping. Being less bulky, storage, transportation, and handling of Ecomat is therefore much easier and cheaper than the EFB. Moreover, Ecomat is more marketable and a better choice as a mulching material for landscaping purposes in urban areas because it is more aesthetically pleasing than the EFB. The use of Ecomat gained a wide public attention; for example, China imported Ecomat from Malaysia as a landscaping mulching material to be used during the Beijing Olympics in 2008.

In addition, the use of Ecomat has shown to be beneficial in improving soil properties and crop growth. MPOB (2003), as well as Khalid and Tarmizi (2004), reported that young oil palms planted on hill terraces with Ecomat mulching showed higher growth rates and higher uptake of N, P, and K nutrients than those without it. Several studies conducted in China have shown increased soil water content due to Ecomat mulching as compared to without it. Xin-Fu (2004), for example, reported higher water contents by 17.4% and 8.9% in the 0-200 mm and 200-400 mm soil depths, respectively. Similarly, Liu *et al*. (2005) reported a higher increase in soil water content by 44.3% in the 0-200 mm depth. Both these studies also reported that Ecomat helped to cool the soil during summer and to warm the soil during winter. In an unpublished study by the Beijing Forestry and Parks Department of International Cooperation, conducted from 2002 to 2006, Ecomat mulching was found to have increased soil water content by 35.5% after two years, N by 3.5% and 6.7% in the summer and winter periods, respectively, and K by between 20 to 128.6% as compared to bare soil alone.

Other than the EFB and Ecomat, another current method used to conserve soil water and nutrients on oil palm hill slopes is to construct silt pits, where long and wide trenches are dug into the soil somewhere between the planting rows and in perpendicular to the hill slope so that these trenches will collect runoff water and soil. The idea is that these silt pits will act as storage areas, and preserve the soil water and nutrients which will otherwise lose through run-off. These trenches will then help to redistribute the collected water and nutrients back into the plant roots after a rainfall event.

Unlike the studies on EFB, much less has been carried out on the effects of silt pit in improving soil properties. Among other, Murtilaksono *et al*. (2008) compared two soil conservation methods, namely silt pitting and bund terracing, against control (i.e. without any conservation methods) on increasing oil palm fresh fruit bunch (FFB) yield. They found that although silt pit had significantly given higher FFB yield (23.6 tons ha^{-1}) than the control (20.8 tons ha^{-1}), it was the plots with the bund terracing method that had produced the significantly highest FFB yield (25.2 tons ha^{-1}). In an earlier study by Soon and Hoong (2002), soil loss via runoff was found to have probably reduced significantly (by as much as five times lesser) by stacking the oil palm fronds along the hill contour rather than stacking them without any order. Furthermore, by combining the silt pitting method with the contour frond stacking method, it reduced soil loss further by 10.5%. Although silt pitting reduced soil loss significantly, the researchers found no significant effect at the 10% level of silt pitting on most of the oil palm vegetative growth properties (palm height, number of fronds, total number of leaflets, rachis length, leaf dry, weight, and petiole area), even after three years. Similarly, silt pitting was found to insignificantly affect the leaf nutrient contents (N, P, K, Ca, and Mg) at the 10% level during the same period. The treatments only had a significant effect on the FFB yield during the third year; however, the plots with the silt pitting method had unexpectedly lower FFB yield than those without any conservation methods (control).

Although much has been researched on the effects of EFB (but to a much lesser degree for Ecomat and silt pit) on the properties of soil, there is no single study, to the researchers' knowledge, that compares the effects of the three soil and water conservation methods on soil properties. Thus, it was the main objective of this paper to compare the effects of four soil and water conservation methods (namely, control, EFB, Ecomat, and silt pit) on several soil chemical and physical properties at a sloping land oil palm estate. This paper reports the results of the first six months of the field experiment.

MATERIALS AND METHODS

A field experiment was setup in an oil palm (*Elaeis guineensis*) site at Balau Estate (2.9325° N; 101.8822° E), located in Semenyih, Selangor. The study area has a slope of 6°, and under the USDA Taxonomy classification, the soil is classified as a Typic Paleudult (Rengam series), as the soil has a sandy clay texture (37% clay, 7% silt, and 56% sand). Meanwhile, the average bulk density for all the treatment plots at 0-150 mm soil depth was 1.62 Mg m^{-3}, while the organic carbon for 0-150 and 150-300 mm soil depth were found to be 1.14% and 1.05%, respectively. The oil palm trees in the study area at the time of the experiment were about eight years old, and the trees were planted with 8 m × 8 m spacing between them.

The field experimental design had four treatments and three blocks (replications), as shown in *Fig. 1*. The treatments were control (CON) (normal field practice where pruned fronds were heaped on the soil surface), empty fruit bunches (EFB), Ecomat (ECO), and silt pit (PIT). Each block was equally divided into four plots, whereby each plot was measured to 8 m x 8 m and with a gap of 8 m between two plots. The number of palms per plot was one, and each treatment was randomly assigned to a plot for each block. Each of the three blocks was located at different hill elevations, and the hill slope was the same for all the blocks, i.e. at 6°.

The application of the EFB and Ecomat treatments and the construction of the silt pits began in February 2006. In the middle of each EFB treatment plot, empty fruit bunches (rate of 1000 kg EFB $palm^{-1}$ $year^{-1}$) were heaped as a single layer on the ground. Likewise, in the middle of each Ecomat treatment plot, four Ecomat carpets (2 m × 2 m long and wide, and 0.02 m thick) were arranged in a single layer on the ground. The silt pits were constructed by digging a trench along the hill contour, measuring 1 m wide, 4 m long and 0.5 m deep. The silt pits were located in the middle of each silt pit treatment plot.

The field data collection was started in March 2006 and continued every month.

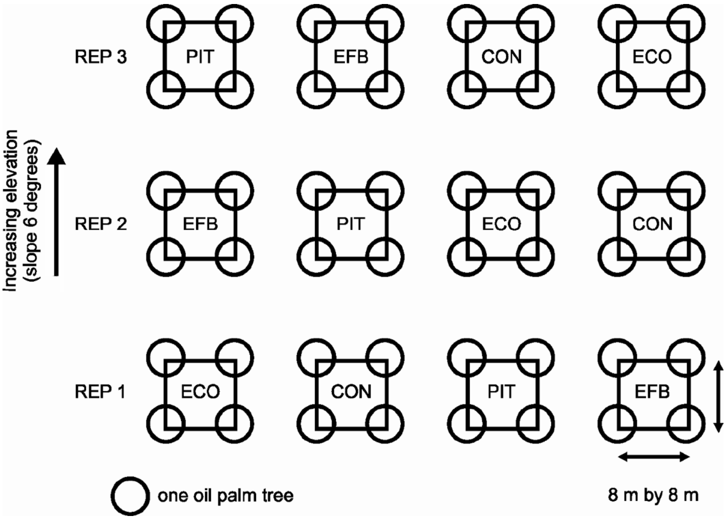

Fig. 1: Field experimental design

Thus, the data presented in this paper are for six months, ending in August 2006. A total of soil samples, from 0-150 and 150-300 mm soil depths, were randomly collected at several points in a plot. The air-dried soil samples were then analysed for their pH (1:2.5 soil to water ratio), cation exchange capacity (CEC) (using 1M ammonium acetate, pH7.0, (Lim, 1975), whereas the leachate was collected to determine the concentration of cations by atomic absorption spectrometry (Ca and Mg) and flame photometer (K), total N (Kjedahl method; Bremner and Mulvaney, 1982), available P (Bray and Krutz no. II, Molybdenum Blue method; Olsen and Sommer, 1982), organic C (combustion method; McKeague, 1976), bulk density (core ring method; Blake and Hartge, 1986), aggregate stability (wet-sieving method; Kemper and Rosenau, 1986), and aggregation (dry-sieving method; Kemper and Rosenau, 1986). Soil aggregate stability and aggregation were expressed as the mean weight diameter (MWD) in unit mm (Kemper and Rosenau, 1986). Meanwhile, soil water retention was measured using the pressure plate and membrane technique (Richards, 1947) to determine the available water content for plants (i.e. the difference between the water content at field capacity and permanent wilting point) and the slope of the soil moisture characteristic curve.

The above data were analysed using ANOVA (analysis of variance), according to the split-split block experimental design, with three replications and three main factors, namely the four treatments (treatment factor), the two soil depths (space factor), and the six monthly collection periods (time factor). The main plot, subplot, and sub-subplot were the time factor, treatment factor, and space factor, respectively. Meanwhile, the mean separation test was by the least significance difference (LSD) method at 5% level. The data analysis was done using the statistical software SPSS ver. 17 (SPSS Inc., Chicago).

The soil water content from every treatment plot was measured at the soil depths of 0.1, 0.2, 0.4, 0.6 and 1.0 m, using a soil water profile probe (PR1, Delta-T, Cambridge, England). The PR1 probe measures the soil water content based on the capacitance method. This probe consists of both a transmitter and a receiver, whereby the transmitter emits a low-powered signal of about 100 MHz that can be detected by the probe's receiver. The frequency of the signal, however, will change depending on the amount of water in the soil. In more specific, the more water a soil has, the more the frequency of this signal will be changed. By detecting this amount of change, the PR1 probe will then determine the corresponding soil water content.

In this study, soil water measurements were done between 6:00 to 7:00 hours each day, beginning from 1 March 2006 and ending on 14 May 2006. These measurement dates corresponded to the day of year (DOY) 60 to 137 (where Jan. 1 = 1, Jan. 2 = 2, Feb. 1 = 32, and so on). Nonetheless, soil water measurements ended earlier than expected due to the fault in the PR1 probe. As a result, this paper only reports the data for the soil moisture only for the first three months.

The soil water content between the treatments were first analysed by calculating their individual daily total soil water content up to 1 m soil depth. The one-way ANOVA and LSD were then used to detect the significant mean differences between the daily total soil water content of the four treatments. This was unlike the ANOVA done for analysing the other soil properties. Meanwhile, the soil water content was not analysed as a split-split block design mainly because of missing data due to the fault in installing the PR1 probe for the second replication of the control plot. This problem could only be rectified about a month into the field experiment. Finally, the daily rainfall data were collected using a portable weather station (Watchdog Model 700, Spectrum Technologies Inc., Illinois).

RESULTS AND DISCUSSION

Changes in the Soil Chemical Properties

The ANOVA revealed that the four soil conservation practices had a significant effect on all the measured soil chemical properties (Table 2). The interaction effect, Treatment (T) × Month (M) × Depth (D), was significant at least at the 5% level for almost all the soil chemical properties; CEC, exchangeable Ca, Mg and K, available P, organic C, and C:N. This indicates that the effect of the four conservation practices on the seven soil properties would vary according to time and soil depth. Only the total N and soil pH did not have any significant, T × M × D, interaction effect at the 5% level. As for N, the interaction effect T × M was significant at the 1% level, and the interaction effects T × D and T × M were significant for the pH at 1% and 5% levels, respectively.

The mean separation test using the LSD method at the 5% level showed that the EFB generally produced the highest values of CEC, Ca, Mg, K, P, C, and pH in both the soil depths and for all the months covered as compared to the other three treatments (Table 2). Meanwhile, the Ecomat treatment generally gave the second highest readings for these soil properties. The exceptions were observed for the P and C contents in the subsoil; both the EFB and Ecomat produced similar P and C contents in this lower soil depth for a given month.

The highest N contents in both the soil depths for all the months were derived from the EFB and Ecomat treatments. For a given soil depth and month, both the EFB and Ecomat gave similar N content. This was followed by the control and the silt pit treatment.

The soil C:N ratio for both the soil depths in all the treatments remained between 8 and 20 throughout the study. Any organic materials with a C:N ratio greater than 30 favours immobilisation, supplying C to the soil; however they may cause a reduction in plant-available N. In contrast, the organic materials with a C:N ratio below 20 will favour N mineralization and supply N to the soil. A C:N ratio of about 25 is often regarded as the point where immobilisation and mineralization are in balance. The LSD method showed that the silt pit treatment had given the highest C:N ratio for both the soil depths (mean C:N ratio for both depths were 15) as compared to the other treatments (Table 2). Similarly, LSD also showed that for a given soil depth, the C:N ratios in the control, EFB, and Ecomat plots were generally similar to one another (their means for both the soil depths were 10).

These results have so far supported the beneficial effects of the EFB mulching on the soil properties. The benefits of the EFB mulching have been known since 1934 (Abdullah *et al.*, 1987). Numerous studies have shown that a direct EFB application had increased vegetative growth, nutrition, and yield of oil palm (Chan and Goh, 1978; Lim and Pillai, 1979; Khoo and Chew, 1979; Singh *et al.*, 1981; Loong *et al.*, 1987; Lim and Chan, 1987; Lim and Zaharah, 2002), as well as increased the organic matter content, pH, and nutrient content of soil (Chan *et al.*, 1980; Zaharah and Lim, 2000; Lim and Zaharah, 2002).

It is well known that the main constraints to the EFB application are the high cost of transportation, storage, and distribution (due to the bulkiness and weight of EFB), as well as the potential of EFB to harbour pests and diseases (Turner and Gillbanks, 1974; Hartley, 1980). Converting EFB into a thinner and lighter material such as Ecomat is therefore attractive because this material is apparently easier and cheaper to transport, store, and distribute.

However, the results from this study have indicated that the EFB was generally better than the Ecomat in improving the chemical properties of soil. Although Ecomat is made solely from EFB fibres, the nutrient contents of Ecomat have been reported to be significantly lower than that of EFB (Table 1). Meanwhile, Wan Asma (2006) reported that the processing of EFB into Ecomat has caused Ecomat to lose most of the original benefits of the EFB. This loss of nutrients is most probably caused by the high pressure and heat required to convert and compress the EFB into a thinner and lighter material (Ecomat). In this study, nevertheless, the Ecomat treatment was generally found to be better than both the silt pit and control in improving the chemical properties of soil.

However, the silt pit treatment was not better than either the EFB or Ecomat in improving the soil chemical properties. Additionally, as compared to the control, the effects of the silt pit treatment on improving the chemical properties of soil were found to be better in some cases and worse in others. In more specific, the LSD showed that generally silt pit had given higher readings than the control for both soil depths for the CEC, K, and C. As for the soil properties N and pH, however, the control gave higher readings for both the soil depths compared to the silt pit. Both the silt pit and control generally gave similar readings for Ca (top soil) and Mg (subsoil).

As mentioned earlier, silt pit had the highest C:N ratio than the other three treatments. The mean C:N ratio for the silt pit for both the soil depths were 15 compared to only 10 for the other treatments. As stable organic matter had a C:N ratio between 10 and 12 (Pierzynski *et al.*, 2005), a higher mean C:N ratio for the silt pit plots suggested that their soil organic matters were relatively fresher and less stable than those in the other treatment plots. Norton *et al.* (2003) found that the steeper the gradient of a hill, the larger the soil's C:N ratio. The researchers attributed this particular observation to the fast removal of organic materials from the steep slope due to fast run-off, leaving relatively fresher and higher C:N organic materials in

TABLE 1
Chemical characteristics of the EFB, Ecomat, and pruned fronds

Properties (% dry matter)	EFB[1]	Ecomat[2]	Fronds[3]
Total C	61.20	33.85	50.43
Total N	0.86	0.55	0.79
Total P	0.16	0.39	0.08
Total K	2.21	2.59	2.26
Total Ca	0.48	0.22	0.48
Total Mg	0.37	0.21	0.10

[1] Rosenani and Wingkis (1999)
[2] Wan Asma (2006)
[3] The present study

TABLE 2
Soil properties in all the treatments, expressed as means of three replicates

Properties[1], units	Depth, mm (D)	Treatment [2] (T)	Month[3] (M)					
			1	2	3	4	5	6
CEC, cmol (+) kg^{-1}	0-150	CON	6.390 (0.006)	6.440 **a** (0.006)	6.973 **a** (0.007)	6.943 **a** (0.003)	7.013 (0.009)	7.033 (0.003)
T × M × D **		EFB	7.490 (0.006)	7.487 (0.003)	7.803 (0.003)	7.553 (0.003)	7.563 (0.003)	7.587 (0.003)
(F = 4.806, df = 15)		ECO	7.147 (0.009)	7.163 (0.012)	7.190 (0.001)	7.200 (0.009)	7.263 **a** (0.009)	7.270 (0.006)
		PIT	6.710 (0.390)	6.830 **a** (0.330)	6.947 **a** (0.432)	6.923 **a** (0.320)	6.983 a (0.293)	7.377 (0.604)
	150-300	CON	6.037 (0.003)	6.180 (0.006)	6.293 (0.007)	6.337 **a** (0.003)	6.433 **a** (0.009)	6.560 (0.012)
		EFB	7.303 (0.003)	7.313 (0.003)	7.320 (0.006)	7.353 (0.003)	7.353 (0.009)	7.367 (0.003)
		ECO	6.857 (0.019)	6.887 (0.006)	6.890 (0.006)	6.910 (0.006)	6.943 (0.012)	6.977 (0.009)
		PIT	6.423 (0.443)	6.427 (0.447)	6.443 (0.433)	6.457 **a** (0.447)	6.467 **a** (0.442)	6.480 (0.445)
K, cmol (+) kg^{-1}	0-150	CON	0.080 **a** (0.001)	0.090 (0.006)	0.100 (0.010)	0.333 (0.018)	0.477 (0.015)	0.670 **a** (0.006)
T × M × D **		EFB	0.090 **a** (0.001)	0.407 (0.003)	0.627 (0.003)	0.847 (0.003)	0.850 (0.003)	0.857 **b** (0.003)
(F = 5.541, df = 15)		ECO	0.080 **a** (0.001)	0.187 **a** (0.009)	0.377 (0.009)	0.463 (0.006)	0.680 (0.006)	0.840 **b** (0.071)
		PIT	0.077 **a** (0.007)	0.210 **a** (0.095)	0.320 (0.155)	0.530 (0.161)	0.613 (0.118)	0.667 **a** (0.097)

Table 2 (Continued)

	150-300	CON	0.070 **a** (0.001)	0.080 **a** (0.001)	0.097 (0.003)	0.320 (0.012)	0.413 (0.009)	0.560 **a** (0.006)
		EFB	0.077 **a** (0.003)	0.303 (0.003)	0.573 (0.003)	0.717 (0.003)	0.717 (0.003)	0.737 (0.003)
		ECO	0.070 **a** (0.001)	0.113 **a** (0.012)	0.267 **a** (0.012)	0.470 (0.010)	0.567 (0.009)	0.627 (0.003)
		PIT	0.080 **a** (0.001)	0.180 (0.065)	0.287 **a** (0.147)	0.430 (0.140)	0.483 (0.113)	0.580 **a** (0.075)
Ca, cmol (+) kg^{-1}	0-150	CON	0.100 **a** (0.001)	0.150 **a** (0.006)	0.290 (0.006)	0.427 (0.009)	0.587 **a** (0.003)	0.630 **a** (0.006)
T × M × D **		EFB	0.100 **a** (0.001)	0.237 (0.003)	0.483 (0.003)	0.507 (0.003)	0.640 (0.006)	0.710 (0.006)
(F = 7.571, df = 15)		ECO	0.100 **a** (0.001)	0.180 **b** (0.006)	0.287 (0.009)	0.463 (0.015)	0.580 **a** (0.015)	0.677 (0.003)
		PIT	0.113 **a** (0.007)	0.177 **ab** (0.032)	0.353 (0.069)	0.387 (0.057)	0.520 (0.060)	0.633 **a** (0.038)
	150-300	CON	0.090 **a** (0.001)	0.130 (0.006)	0.247 **a** (0.003)	0.387 (0.009)	0.413 **a** (0.009)	0.457 **a** (0.003)
		EFB	0.070 **a** (0.001)	0.147 (0.003)	0.390 (0.006)	0.353 (0.003)	0.427 **a** (0.009)	0.583 (0.003)
		ECO	0.080 **a** (0.001)	0.083 (0.003)	0.123 (0.003)	0.293 **a** (0.009)	0.460 (0.006)	0.497 (0.009)
		PIT	0.083 **a** (0.007)	0.120 (0.015)	0.273 **a** (0.054)	0.300 **a** (0.030)	0.373 (0.030)	0.450 **a** (0.065)

Table 2 (Continued)

Mg, cmol (+) kg^{-1}	0-150	CON	0.080 **a** (0.001)	0.100 **a** (0.001)	0.123 **a** (0.033)	0.127 (0.028)	0.223 **a** (0.007)	0.293 **a** (0.003)
T × M × D **		EFB	0.080 **a** (0.001)	0.180 (0.006)	0.253 (0.003)	0.290 (0.006)	0.320 **b** (0.003)	0.343 (0.003)
(F = 8.232, df = 15)		ECO	0.087 **a** (0.003)	0.100 **a** (0.001)	0.120 **a** (0.003)	0.253 (0.009)	0.303 **b** (0.009)	0.307 **a** (0.007)
		PIT	0.087 **a** (0.003)	0.130 (0.025)	0.173 (0.044)	0.207 (0.042)	0.223 **a** (0.048)	0.250 (0.045)
	150-300	CON	0.080 **a** (0.001)	0.090 **a** (0.001)	0.077 **a** (0.003)	0.137 **a** (0.003)	0.150 **a** (0.010)	0.153 **a** (0.003)
		EFB	0.070 **a** (0.001)	0.083 **a** (0.003)	0.157 (0.003)	0.200 (0.006)	0.213 (0.009)	0.253 (0.003)
		ECO	0.080 **a** (0.001)	0.083 **a** (0.003)	0.093 **ab** (0.003)	0.140 **a** (0.006)	0.157 **a** (0.003)	0.197 (0.003)
		PIT	0.077 **a** (0.003)	0.087 **a** (0.003)	0.103 **b** (0.023)	0.123 **a** (0.038)	0.123 (0.044)	0.157 **a** (0.047)
P, ug g^{-1}	0-150	CON	22.873 **a** (0.032)	23.667 **a** (0.337)	30.443 **a** (0.023)	32.907 **a** (0.032)	38.547 **a** (0.094)	40.013 **a** (0.009)
T × M × D **		EFB	21.860 **abd** (0.035)	22.373 **ab** (0.033)	38.987 (0.012)	39.553 (0.327)	41.433 **b** (0.052)	43.293 (0.052)
(F = 10.343, df = 15)		ECO	20.407 **bc** (0.033)	20.917 **b** (0.029)	23.963 (0.012)	36.393 (0.015)	39.427 **ab** (0.015)	41.347 **a** (0.029)
		PIT	21.543 **acd** (0.146)	23.057 **a** (0.358)	29.543 **a** (4.714)	32.927 **a** (3.467)	34.093 (3.623)	40.367 **a** (1.457)

Table 2 (Continued)

	150-300	CON	13.997 **a** (0.015)	14.313 (0.013)	15.923 (0.028)	26.383 **a** (0.026)	29.590 **a** (0.049)	33.850 **a** (0.035)
		EFB	19.563 **b** (0.019)	21.403 **a** (0.015)	22.963 **a** (0.052)	31.390 **b** (0.031)	35.633 (0.061)	36.723 **b** (0.012)
		ECO	19.007 **b** (0.023)	19.610 **a** (0.027)	22.617 **a** (0.027)	29.410 **b** (0.020)	30.667 **a** (0.047)	35.957 **b** (0.045)
		PIT	15.580 **a** (1.980)	17.603 **a** (1.889)	20.297 (1.337)	24.757 **a** (3.297)	30.877 **a** (2.377)	32.690 **a** (2.020)
N, ug g^{-1}	0-150	CON	0.097 (0.003)	0.103 (0.003)	0.120 (0.001)	0.107 (0.003)	0.130 (0.001)	0.133 (0.003)
T × M **		EFB	0.117 (0.003)	0.123 (0.003)	0.133 **a** (0.003)	0.130 (0.006)	0.157 **a** (0.003)	0.153 **a** (0.003)
($F = 3.982$, $df = 15$)		ECO	0.137 (0.003)	0.133 (0.003)	0.137 **a** (0.003)	0.147 (0.003)	0.153 **a** (0.003)	0.157 **a** (0.003)
		PIT	0.073 (0.023)	0.080 (0.025)	0.083 (0.028)	0.093 (0.019)	0.103 (0.028)	0.113 (0.023)
	150-300	CON	0.090 **a** (0.001)	0.090 **a** (0.001)	0.103 (0.003)	0.103 (0.003)	0.120 **a** (0.001)	0.120 (0.001)
		EFB	0.087 **a** (0.003)	0.097 **a** (0.003)	0.117 **a** (0.003)	0.113 (0.003)	0.127 (0.003)	0.137 **a** (0.003)
		ECO	0.103 (0.003)	0.110 (0.003)	0.123 **a** (0.003)	0.133 (0.003)	0.137 **a** (0.003)	0.140 **a** (0.001)
		PIT	0.067 (0.012)	0.063 (0.019)	0.077 (0.022)	0.083 (0.019)	0.097 (0.017)	0.107 (0.017)

Table 2 (Continued)

C, %	0-150	CON	1.160 **a** (0.010)	1.142 **a** (0.018)	1.177 **a** (0.013)	1.168 **a** (0.016)	1.145 (0.013)	1.154 (0.015)
T × M × D **		EFB	1.178 **a** (0.009)	1.196 **bc** (0.012)	1.351 (0.036)	1.441 (0.009)	1.572 (0.027)	1.725 (0.027)
(F = 11.386, df = 15)		ECO	1.109 **b** (0.009)	1.183 **ab** (0.005)	1.267 (0.054)	1.235 (0.041)	1.289 **a** (0.041)	1.420 (0.037)
		PIT	1.121 **ab** (0.017)	1.155 **ac** (0.018)	1.169 **a** (0.018)	1.183 **a** (0.020)	1.244 **a** (0.006)	1.296 (0.019)
	150-300	CON	1.026 **a** (0.006)	1.036 **a** (0.013)	1.039 (0.005)	1.028 (0.010)	1.062 (0.009)	1.068 (0.013)
		EFB	1.068 **a** (0.005)	1.058 **a** (0.003)	1.143 **a** (0.009)	1.151 **a** (0.023)	1.198 **ab** (0.020)	1.253 **a** (0.023)
		ECO	1.064 **a** (0.015)	1.040 **a** (0.009)	1.116 **a** (0.009)	1.176 **a** (0.026)	1.236 **a** (0.020)	1.261 **a** (0.016)
		PIT	1.042 **a** (0.004)	1.060 **a** (0.015)	1.102 **a** (0.022)	1.140 **a** (0.021)	1.180 **b** (0.028)	1.219 **a** (0.048)
C:N	0-150	CON	12.021 (0.356)	11.067 **a** (0.192)	9.811 **a** (0.108)	10.984 **a** (0.502)	8.810 **a** (0.103)	8.673 **a** (0.317)
T ´ M ´ D *		EFB	10.116 (0.335)	9.709 **ab** (0.174)	10.140 **a** (0.262)	11.128 **a** (0.523)	10.039 **a** (0.252)	11.258 **b** (0.252)
(F = 2.179, df = 15)		ECO	8.126 (0.247)	8.883 **b** (0.252)	9.283 **a** (0.180)	8.410 (0.177)	8.406 **a** (0.177)	9.076 **a** (0.389)
		PIT	18.108 (4.452)	17.053 (4.259)	17.140 (4.652)	13.670 (2.530)	13.712 (3.041)	12.345 **b** (2.214)

Table 2 (Continued)

	150-300	CON	11.396 **a** (0.063)	11.507 **a** (0.147)	10.072 **a** (0.274)	9.970 **a** (0.348)	8.850 **a** (0.072)	8.897 **a** (0.107)
		EFB	12.360 **a** (0.432)	10.968 **ab** (0.384)	9.815 **a** (0.274)	10.181 **a** (0.480)	9.467 **a** (0.222)	9.174 **a** (0.234)
		ECO	10.315 **a** (0.314)	9.455 **b** (0.217)	9.057 **a** (0.217)	8.825 **a** (0.192)	9.058 **a** (0.359)	9.010 **a** (0.115)
		PIT	16.572 (2.653)	19.312 (4.477)	16.388 (3.576)	14.837 (2.609)	12.806 (1.761)	11.922 (1.659)
pH	0-150	CON	4.847 **a** (0.084)	4.960 **a** (0.494)	4.833 **a** (0.090)	4.593 **a** (0.022)	4.850 **a** (0.146)	4.733 **a** (0.022)
T × D **		EFB	5.153 **a** (0.084)	5.330 **a** (0.257)	6.610 (0.197)	6.033 (0.496)	5.850 (0.195)	6.160 (0.195)
(F = 10.081, df = 3)		ECO	4.777 **a** (0.076)	4.557 **ab** (0.258)	4.957 **a** (0.226)	4.573 **a** (0.133)	4.650 **a** (0.133)	4.880 **a** (0.111)
T × M *		PIT	5.010 **a** (0.307)	4.390 **b** (0.125)	4.517 **a** (0.280)	4.080 **a** (0.106)	4.463 **a** (0.102)	4.547 **a** (0.063)
(F = 2.467, df = 15)	150-300	CON	4.950 **a** (0.178)	4.133 **a** (0.169)	4.643 **a** (0.113)	4.267 **a** (0.048)	4.787 **a** (0.081)	4.803 **a** (0.075)
		EFB	4.940 **a** (0.107)	4.800 (0.050)	5.037 **a** (0.529)	5.163 (0.432)	5.490 (0.215)	5.687 (0.209)
		ECO	4.570 **a** (0.040)	4.173 **a** (0.099)	4.513 **a** (0.099)	4.330 **a** (0.095)	4.457 **a** (0.063)	4.610 **a** (0.060)
		PIT	4.870 **a** (0.164)	4.277 **a** (0.054)	4.440 **a** (0.270)	4.393 **a** (0.438)	4.627 **a** (0.184)	4.570 **a** (0.140)

Table 2 (Continued)

Bulk density, Mg m^{-3}	0-150	CON	1.543 – (0.064)	1.596 – (0.067)	1.741 – (0.013)	1.630 – (0.024)	1.632 – (0.035)	1.616 – (0.008)
D *		EFB	1.581 – (0.051)	1.521 – (0.040)	1.554 – (0.007)	1.584 – (0.017)	1.555 – (0.002)	1.532 – (0.002)
(F = 61.813, df = 1)		ECO	1.652 – (0.023)	1.585 – (0.029)	1.592 – (0.048)	1.631 – (0.042)	1.592 – (0.042)	1.587 – (0.011)
		PIT	1.625 – (0.082)	1.607 – (0.073)	1.685 – (0.014)	1.603 – (0.045)	1.660 – (0.003)	1.623 – (0.077)
	150-300	CON	1.689 – (0.041)	1.653 – (0.067)	1.712 – (0.006)	1.671 – (0.059)	1.672 – (0.019)	1.621 – (0.027)
		EFB	1.626 – (0.027)	1.612 – (0.025)	1.633 – (0.084)	1.633 – (0.023)	1.625 – (0.014)	1.512 – (0.016)
		ECO	1.622 – (0.039)	1.598 – (0.089)	1.595 – (0.089)	1.637 – (0.047)	1.581 – (0.026)	1.588 – (0.028)
		PIT	1.635 – (0.061)	1.631 – (0.055)	1.704 – (0.053)	1.712 – (0.015)	1.656 – (0.039)	1.659 – (0.082)
Aggregation, mm	0-150	CON	3.036 **a** (0.074)	3.462 **a** (0.163)	2.891 **a** (0.266)	2.740 **a** (0.071)	2.646 **a** (0.073)	2.600 **a** (0.017)
T × M *		EFB	3.091 **a** (0.107)	3.447 **a** (0.231)	2.336 **b** (0.067)	2.272 (0.142)	2.640 **a** (0.017)	2.660 **a** (0.017)
(F = 2.596, df = 15)		ECO	2.859 **a** (0.239)	3.299 **a** (0.270)	2.678 **ab** (0.121)	2.822 **a** (0.080)	2.757 **a** (0.080)	2.830 **a** (0.017)
		PIT	2.750 **a** (0.099)	3.164 **a** (0.181)	2.588 **ab** (0.066)	2.702 **a** (0.149)	2.440 **a** (0.152)	2.510 **a** (0.017)

Table 2 (Continued)

	150-300	CON	3.316 **a** (0.073)	3.503 **ab** (0.157)	2.984 (0.219)	2.929 **a** (0.145)	3.032 **a** (0.056)	2.970 **a** (0.017)
		EFB	3.159 **a** (0.030)	3.765 **b** (0.235)	2.535 (0.047)	2.454 **b** (0.111)	2.685 **ab** (0.157)	2.700 **a** (0.017)
		ECO	3.139 **a** (0.148)	3.482 **ab** (0.220)	2.814 (0.220)	2.903 **a** (0.139)	2.869 **ab** (0.149)	2.760 **a** (0.017)
		PIT	2.979 **a** (0.127)	3.330 **a** (0.077)	2.862 (0.090)	2.732 **ab** (0.157)	2.645 **b** (0.110)	2.560 **a** (0.017)
Aggregate stability, mm	0-150	CON	1.210 **a** (0.017)	1.227 (0.015)	1.253 (0.015)	1.290 (0.017)	1.330 (0.017)	1.380 **a** (0.017)
T × M × D **		EFB	1.290 **b** (0.017)	1.280 **a** (0.017)	1.350 **ab** (0.017)	1.433 (0.020)	1.490 **a** (0.017)	1.560 **b** (0.017)
(F = 4.567, df = 15)		ECO	1.260 **ab** (0.017)	1.360 (0.017)	1.400 **a** (0.017)	1.380 **a** (0.017)	1.400 **b** (0.017)	1.430 **a** (0.017)
		PIT	1.240 **ab** (0.017)	1.300 **a** (0.017)	1.340 **b** (0.017)	1.370 **a** (0.017)	1.440 **ab** (0.017)	1.530 **b** (0.010)
	150-300	CON	1.220 **a** (0.017)	1.250 (0.017)	1.280 (0.017)	1.320 (0.017)	1.370 **a** (0.017)	1.430 **a** (0.017)
		EFB	1.360 (0.017)	1.380 **a** (0.017)	1.410 **ab** (0.017)	1.490 **a** (0.017)	1.530 (0.017)	1.680 (0.017)
		ECO	1.300 **b** (0.017)	1.380 **a** (0.020)	1.433 **a** (0.020)	1.260 (0.017)	1.467 (0.020)	1.450 **a** (0.017)
		PIT	1.270 **ab** (0.017)	1.340 **a** (0.017)	1.370 **b** (0.017)	1.440 **a** (0.017)	1.390 **a** (0.017)	1.420 **a** (0.017)

Table 2 (Continued)

Available water content, %	0-150	CON	11.213 **a** (1.891)	12.369 **a** (1.514)	15.193 **a** (0.109)	12.065 **a** (0.642)	12.425 **a** (0.130)	13.175 **a** (0.130)
T × M × D **		EFB	14.473 **b** (0.094)	15.204 **bc** (0.347)	16.918 **b** (0.035)	17.685 (1.301)	19.641 **b** (0.121)	20.391 **b** (0.121)
(F = 5.651, df = 15)		ECO	15.411 **b** (0.048)	16.062 **b** (0.073)	15.524 **ab** (0.463)	14.890 (0.138)	18.510 **b** (0.513)	19.260 **b** (0.513)
		PIT	12.689 **a** (0.493)	13.699 **ac** (0.385)	13.677 **a** (0.707)	12.874 **a** (0.338)	13.731 **a** (0.038)	14.481 **a** (0.038)
	150-300	CON	13.957 **a** (2.354)	13.258 **a** (1.623)	14.404 **a** (0.103)	13.608 **a** (0.724)	13.627 **a** (0.143)	12.637 **a** (0.125)
		EFB	12.734 **b** (0.083)	12.462 **bc** (0.284)	12.870 **b** (0.027)	12.870 **b** (0.947)	12.715 (0.078)	10.520 **b** (0.062)
		ECO	12.656 **b** (0.039)	12.190 **b** (0.055)	12.132 **b** (0.362)	12.948 **b** (0.120)	11.860 (0.329)	11.996 **b** (0.320)
		PIT	12.909 **a** (0.502)	12.831 **ac** (0.361)	14.249 **a** (0.737)	14.404 **a** (0.378)	13.317 **a** (0.037)	13.375 **a** (0.035)
Slope of soil water retention curve, % bar^{-1}	0-150	CON	3.227 – (0.434)	3.512 – (0.239)	2.805 – (0.113)	3.370 – (0.005)	2.930 – (0.002)	3.252 – (0.100)
		EFB	3.462 – (0.064)	3.552 – (0.083)	3.078 – (0.067)	3.180 – (0.050)	3.080 – (0.215)	2.990 – (0.178)
All factors are not significant		ECO	2.945 – (0.003)	3.075 – (0.013)	2.997 – (0.021)	3.245 – (0.206)	2.841 – (0.002)	3.181 – (0.162)
		PIT	3.059 – (0.028)	3.145 – (0.030)	3.021 – (0.074)	3.034 – (0.195)	2.832 – (0.047)	3.362 – (0.147)

Table 2 (Continued)

	150-300	CON	3.034 –	3.120 –	2.979 –	3.077 –	3.074 –	3.196 –
			(0.408)	(0.212)	(0.120)	(0.005)	(0.002)	(0.098)
		EFB	3.184 –	3.217 –	3.167 –	3.167 –	3.186 –	3.456 –
			(0.059)	(0.075)	(0.069)	(0.050)	(0.222)	(0.206)
		ECO	3.193 –	3.251 –	3.258 –	3.158 –	3.291 –	3.274 –
			(0.003)	(0.014)	(0.023)	(0.200)	(0.002)	(0.167)
		PIT	3.163 –	3.172 –	2.998 –	2.979 –	3.112 –	3.105 –
			(0.029)	(0.030)	(0.073)	(0.191)	(0.052)	(0.136)

[1] The significant interaction effects, if any, according to the ANOVA results; * $p < 0.05$, ** $p < 0.01$

[2] CON, EFB, ECO and PIT denote the control, empty fruit bunches, Ecomat, and silt pit treatment, respectively.

[3] Values in the brackets denote standard errors; for the same soil depth and month, the treatment means with the same letter are not significantly different from each other, based on the LSD method at the 5% level of significance, and for the bulk density and slope of the soil water retention curve, LSD was not performed because the ANOVA showed an insignificant effect involving the treatment factor (T) (a dash is shown instead).

the soil. The idea of constructing silt pits as a soil and water conservation method was to trap runoff water and nutrients which would later be redistributed after the rainfall event. In this study, however, the silt pit walls were found to be easily collapsible, particularly after a heavy rainfall period. Thus, over time, the silt pits became increasingly shallow, and this in turn would reduce their effectiveness to trap runoff water and sediments. Thus, the relative poor performance of the silt pits to improve the soil chemical properties (as well as the high C:N ratio in the sit pits) in this study was due to the increasingly ineffective silt pits over time to prevent the loss of soils and organic materials by erosion.

Changes in the Soil Physical Properties

The ANOVA revealed that the interaction effect T × M × D was significant at 1% level for only the aggregate stability property (Table 2). Meanwhile, the interaction effect T × M was significant at least at 5% level for the soil physical properties; aggregation and available water content (AWC). For the bulk density, only the depth (D) effect was significant at 5% level. This showed that bulk density was not significantly affected by any of the treatments (where as sole as interaction effect). In addition, the slope of water retention curve was not significantly affected by any of the factors (T, M, D, or their interactions with one another).

The mean separation test by the LSD method at 5% level showed that for a given month and soil depth, the EFB, Ecomat, and silt pit treatments generally had similar aggregate stability with one other, with the control treatment usually having the lowest aggregate stability.

There were, however, lesser significant differences between the effects of the four treatments on soil aggregation. Moreover, there was a trend of slow decline with time in the aggregation in all the treatments (nearly 2% mean reduction per month in aggregation). Soil aggregation is strongly affected by the cycles of wetting-and-drying of the soil (Wagner *et al.*, 2007). Throughout this study, the experimental site experienced a mean daily rainfall of about 9 mm, without any long continuous periods of dry weather. In the long periods of wet weather, soil aggregation might decline over time without any distinct wetting-and-drying cycles.

The LSD method revealed that the available water content (AWC) for the soils under the EFB and Ecomat mulches were generally similar to each other for a given soil depth and month. The soils under these mulches had higher AWC than those in both the silt and control plots. Both silt pit and control treatments gave a similar AWC to each other for the given soil depth and month.

The slope of the soil water retention curve measures the ability of a soil to keep the water it has during soil drying. The larger the slope, the steeper the gradient of the curve and the less capable the soil keeps its water. In other words, the larger the slope, the faster the soil dries. The ANOVA, however, revealed that there was no significant effect at 5% level by the four treatments on the drying rate of the soil.

Fig. 2 shows the soil water profile up to 1 m of soil depth in all the treatments. Meanwhile, the mean volumetric soil water content at saturation point, field capacity point and permanent wilting point were measured at 0.33, 0.13 and 0.01 m^3 m^{-3}, respectively. All the treatments showed that the soil water content below the 0.8 m soil depth was very wet and at times, it was over the saturation point. This was probably because of the rise of water from the ground water table (i.e. below the 1 m depth). In addition, the soil water content in all the treatments was consistently above the field capacity point, whereas all the treatments showed a general trend of increasing total amount of soil water content as the experiment progressed (*Fig. 3*). As stated earlier, this increasing trend was due to the heavy rainfall received throughout the study, as well as the absence of a long spell of dry weather. As expected, after any period of rainfall, there was an increase in soil water content throughout the soil depth (*Fig. 2*).

More importantly, *Fig. 2* shows that each of the four treatments had a distinct soil water profile. The distribution of water in the Ecomat

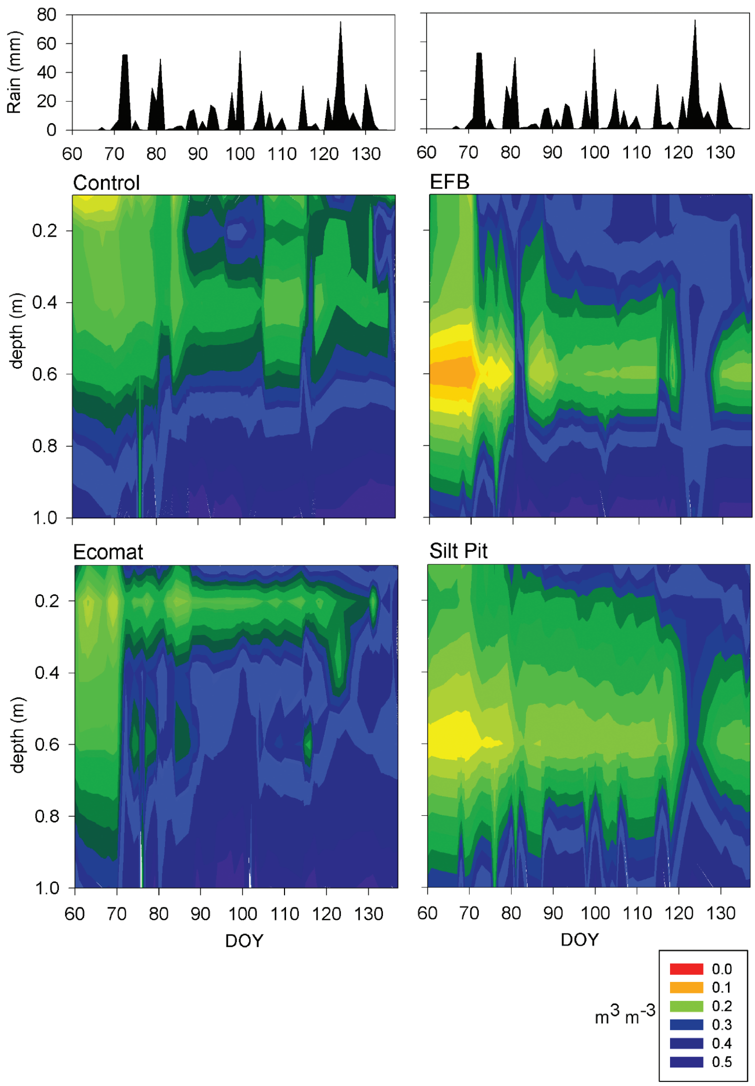

Fig. 2: Soil water profile in all the treatments, expressed as the average volumetric water content of three replicates

treatment was rather uniform throughout the soil profile, in particular, beginning from a depth below 0.3 m. In the EFB treatment, the soil water content tended to decrease with depth up to 0.6 m, after which the soil water content would increase. In more specific, the soil in the 0-0.5 m in the EFB treatment was generally the wettest, and the soil in the region of about 0.6 m was the driest. As compared to Ecomat, EFB concentrated water in the upper soil layers, whereas Ecomat tended to distribute the water more uniformly throughout the profile. Silt pit, like EFB, also concentrated water in the upper soil layers, but its water concentration was found to be restricted to a shallower depth compared to either EFB or Ecomat. In the control plots, the concentration of water occurred mostly in the lower soil layers, i.e. below 0.5 m. It was only during the wet weather periods (i.e. after DOY 90) that water would also be concentrated

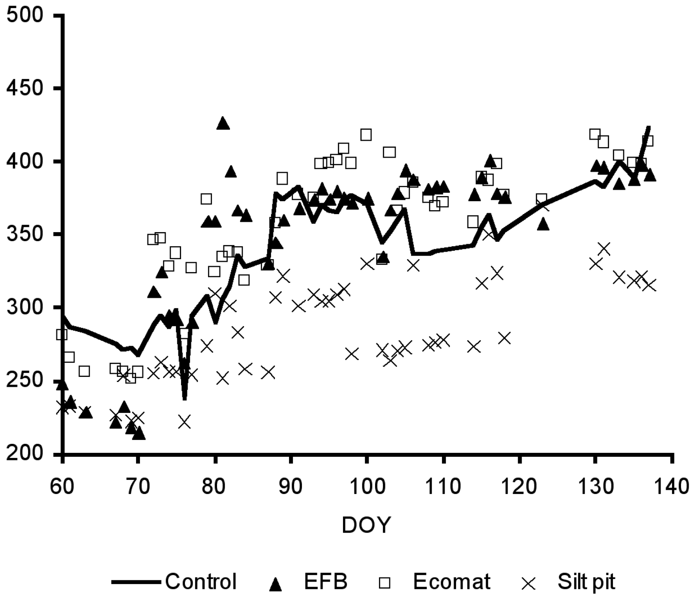

Fig. 3: Mean daily total soil water content (mm) up to 1.0 m soil depth in all the treatments. Solid line represents the control

in the upper soil layers as the soil increasingly received more rain.

The average daily total soil water contents up to 1 m of soil depth for the control, EFB, Ecomat, and silt pit treatment plots were calculated to be 338, 347, 356, and 285 mm, respectively. The ANOVA showed that there were significant differences at 5% level in the daily total soil water contents between the treatments. The mean separation test by the LSD method at 5% level, however, showed that there was no significant difference between the control, EFB, and Ecomat for the daily total soil water contents. Only silt pit had the significantly lowest mean daily soil water content compared to the other treatments. On average, the mean daily total soil water content in the silt pit plots were lower by nearly 18% compared to the control, EFB, and Ecomat plots.

The Ecomat mulches used in this study were only 20 mm in their thickness compared to the mean thickness of EFB, i.e. 130 mm. However, this study showed that the total soil water under the Ecomat mulches (though thinner than EFB) was statistically similar to that under the EFB mulches and the control plots which had pruned fronds as mulches. Surprisingly, silt pit, a conservation method supposedly to trap and redistribute runoff water, was shown to be the least effective method to conserve water, even when it was compared to control. The Department of Agriculture of Peninsular Malaysia recommends the use of silt pits for perennial crops on hill slopes between 6° to 25° (Eco-Factor Consulting, 2008). However, this study observed that even at 6° hill slope, the silt pit walls were easily collapsible, especially after heavy rainfalls. In some plots, the silt pits were observed to be half filled with soil in just one month and some completely filled two months later. Thus, over time and without rebuilding the walls, the silt pits became increasingly shallower and increasingly ineffective to trap runoff water. The observations carried out in this study suggest that silt pits require frequent maintenance so as to rebuild their walls and excavate the silt pits if they are to be effective as a soil and water conservation method, particularly for areas with high rainfalls and with even steeper hill gradients (> 6°).

CONCLUSIONS

Even in a short period of six months, there were significant effects of the four treatments (control EFB, Ecomat, and silt pit) on the chemical and physical properties of soil. Overall, the EFB was found to be the best treatment to improve the properties of soil, followed by the Ecomat treatment. In general, the silt pit and control treatments had similar effects on the properties of soil.

Although the intention of silt pit was to trap running water and return the water to the field, this study found that the plots with the silt pit treatment had the significantly lowest daily total soil water content as compared to the other three treatments (less by an average of almost 18%). Meanwhile, the mean daily water contents in the control, EFB, and Ecomat were not significantly different from one another at 5% level of significance.

This study in on-going and it will only end after three years of field experimentation. Nevertheless, the results have so far suggested that the EFB, followed by Ecomat, was the best soil and water conservation method, particularly to improve the chemical properties of soil. Silt pits are seen to be high-maintenance as their walls require frequent repairs and pit excavations if they are to be effective to trap runoff.

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