Fate of Soil Pesticides: Microbial Activity of Different Tea Soils in Sri Lanka

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ABSTRACT

Use of pesticides is an integral component in modern agriculture to ensure high agricultural productivity by controlling insect, mite and nematode pests, diseases and weeds. Pesticides cause soil and water pollution, affect non–target organisms in the soils and animal and human health indirectly. Fate of soil pesticides on microbial activity which is important in crop productivity has been poorly studied. Therefore, an experiment was conducted to evaluate the fate of soil pesticides recommended by the Tea Research Institute of Sri Lanka in different tea soils as a measure of soil microbial activity. Tea soils representing the different Agro Ecological Regions, elevations and organic matter status were studied (Deniyaya, Kottawa, Hantana, Passara, Ratnapura and Talawakelle). Rehabilitated soils with Guatemala and Mana and undisturbed forest soils were also used. The soil fumigants (Dazomet and Metham Sodium) insecticides (Carbofuran) nematicides (Cadusafos and Phenamiphos) and herbicides (2, 4-D, Diuron, Glufosinate Ammonium, Glyphosate and Paraquat) at recommended rates were tested. The CO_2 evolution rate was determined using Anderson method (1982) as a measure of change in soil microbial activity due to application of different soil pesticides. In general, soil pesticides negatively affected the microbial activity. The lowest and highest microbial activity were shown in Talawakelle and Hantana respectively. Among the soil pesticides tested, Metham Sodium and Glufosinate Ammonium respectively caused the greatest (60.1%) and the lowest (8.2%) reduction in soil microbial activity of all the soils exposed. Compost treatment resulted in mean improvement of microbial activity in all tea soils by 9.5% and in Mana, Guatemala and Forest soils by 11.7% respectively.

KEY WORDS: Microbial activity, Soil pesticides, Tea soils

INTRODUCTION

The overall fertility of soils can be described as physical, chemical and biological properties of soils. Soil organisms play a greater role more than physical and chemical properties (Kühnelt, 1961). The soil microbial biomass is the living component of the soil organic matter pool, which is responsible for organic matter decomposition and nutrient turnover. The soil micro-organisms such as bacteria, fungi, algae and nematodes are maintaining soil nutrient status through their role in decaying of plant and other organic matters. Hence it becomes an important indicator of a measure of soil fertility and its health. However, management practices greatly meditate the soil microbial communities (Wolters, 2000). Therefore maintenance of soil organic matter is important for the long term productivity of any agro ecosystem (Goyal *et al*., 1999).

Tea (*Camellia sinensis* (L.) O.Kuntze) is a crop of wide adaptability and grows in a range of climate and soils (Watson, 1986). According to the soil map published by Soil Science Society of Sri Lanka, there are 13 major soil series in upland where tea is grown (Dissanayake *et al.*, 1999). Some important properties of tea soils of different Agro Ecological Regions of Sri Lanka are shown in Annex 1. Tea is popular among Sri Lankan plantation crops, which is contributed 2% to the Gross Domestic Production (GDP) and 317 million kilograms of tea produced in 2005 (Anon., 2005). The tea plant is subjected to attacks by various types of insects, nematodes diseases and also competition by weeds. According to its economic importance, unless these are kept in check it could lead to great economic losses. One of the many measures adopted to prevent this loss is the usage of pesticides (Thirugnanasuntheran, 1988).

Pesticides form an integral component of tea cultivation to ensure high yield, that are of five kinds i.e. insecticides, nematicides, fungicides, herbicides and fumigants. Besides, usage of soil pesticides is known to cause problems in water as well as soil pollution, damage the non-target organisms and affect human health. Degree of the problem in soils is determined by the fate of pesticides which depends on several factors such as properties of pesticides, properties of soils, condition of the sites and management practices etc. Soil properties affecting the movement of pesticides include soil texture, soil permeability, and organic matter content (Anon,1992). Some important properties of soil pesticides are shown in Table 1. Organic matter is opportunity to be degraded by soil microorganisms.

The organic carbon adsorption coefficient (K_{oc}) describes the relative affinity or attraction of the pesticide to soil materials (Anon,1997). The mechanisms affecting the degradation of pesticides include adsorption, leaching, volatilization and abiotic and biotic conversions to other compounds,

Table 1- Some important properties of soil pesticides

Treatment	Half life (Days)	Adsorption (ml/g)	Movement rate	Water solubility (mg/l)
Dazomet	7	10	Moderate	3,000
Metham Sodium	7	6	Moderate	963,000
Carbofuran	50	22	Very high	351
Cadusafos	Not available			
Phenamiphos	50	100	High	400
2,4-D	10	20	Moderate	890
Diuron	90	480	Moderate	42
G. Ammonium	7	100	Low	1,370,000
Glyphosate	47	24,000	Extremely low	900,000
Paraquat	100	1,000,000	Extremely low	620,000

(Source-http://ace.orst.edu/info/npic/ppdmove.html)

ultimately leading to mineralization. In addition, pesticides can be lost to the environment *via* wind and water erosion plus plant and animal uptake (Büyüksönmez *et al.*, 1999). Persistence of pesticides is governed by the chemical structure and environmental conditions (Alexander, 1976). The persistence of a pesticide in soil on the other hand depends partly on the effectiveness of the transferring processes such as evaporation, leaching, erosion and uptake by harvested plants (Misra and Mani, 1994). Therefore, it is important to understand the fate of a pesticide once it is applied, as this allows applicators to select the most effective and environmentally safe product (Anon, 1994). The method used to determine the fate of Carbofuran in soils by Watawala *et al.*, (2005) is the most effective approach to determine the fate of soil pesticides. However it is very expensive and time consuming. According to Misra and Mani (1994) and Abeykoon (2002), most of the fungicides, nematicides and insecticides applied in the soil suppress microbial activity in soils. Therefore, microbial activity could be considered as one of the most reliable indicator that determines the effect of the soil pesticides on different soils.

MATERIALS AND METHODS

A. Sample Collection

Soils were collected from 20 randomly selected places in each location (*i.e.* Deniyaya, Kottawa, Hantana, Passara, Rathnapura and Talawakelle) for the study. Soil from rehabilitated land with Mana (*Cymbopogon confertiflorus*) and Guatemala (*Tripsacum laxum*) and undisturbed forest soils were also collected. The thoroughly mixed composite samples of respective locations comprising of about 10 kg were used for the laboratory bio assay. Important properties of tea soils of different Agro Ecological Regions of Sri Lanka are shown in Annex 1 and the description of the sample locations are shown in Table 2.

Soil pesticides recommended by the Tea Research Institute of Sri Lanka were tested in different tea soils. Selected soil pesticides and their application rates are shown in Table 3. The pesticides in Table 3 were compared with compost and untreated control.

Table 2 - Description of sample locations:

Soil	Location	Field	Sample code
Tea	Deniyaya	TRI station	DNY
	Kottawa	TRI station	KTW
	Hantana	Looleconder a	HNT
	Passara	TRI station	PSR
	Ratnapura	St. Joachim	RTN
	Talawakelle	St. Coombs	TLW
Forest	Talawakelle	Great Western	FRT
Rehabilitated	St .Coombs	Mana	MA
	St .Coombs	Guatemala	GTM

B. Determination of soil microbial activity

This study was carried out at the Nematology laboratory, Tea Research Institute of Talawakelle. The soil collected was stored under cool and humid conditions at the laboratory until used. All soils were sieved and exactly 10g of soils were placed into each of the reagent bottle and the respective soil pesticides were applied at recommended rates. Then 3.5 ml of distilled water was added to bottle and mixed well. An ignition tube with 3ml of 1N NaOH was hung in bottle and reagent bottle was sealed using Para film. Three replicates were used for each sample. Forty eight hours after treatment the content of each ignition tube was washed into a 200 ml beaker using a wash bottle. Then 7.5 ml of $BaCl_2$ was added into the beaker and three drops of phenolphthalein indicator was added. Titrated with 0.5 N HCl acid until pink color was disappeared. The burette reading was used to calculate the CO_2 evolution rate are described below.

Table 3 - Selected soil pesticides and their application rates:

Type	Active ingredient	Rate of application
Soil fumigants	Dazomet	500 g/cube of soil
	Metham Sodium	600 ml/cube of soil
Insecticides	Carbofuran	94.5 kg per ha
Nematicides	Cadusafos	94.5 kg per ha
	Phenamiphos	94.5 kg per ha
Herbicides	2,4 - D	Mix 25-43 ml /18 l of water 550 l/ha
	Diuron	Mix 1.2 kg /50 l of water 550 l/ha
	Glufosinate Ammonium	Mix 30 ml /14 l of water 550 l/ha
	Glyphosate	Mix 1 l /50 l of water 550 l/ha
	Paraquat	Mix 25-37 ml /18 l of water 550 l/ha

Amount of CO_2 released was measured using this formula.

$HCl_{(aq)} + NaOH_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(aq)}$

$N1 \times V1 = N2 \times V2$
V2- Volume of HCl
V1- Volume NaOH
N1- Normality NaOH
N2- Normality HCl

Amount of CO_2 released = (3 - (N2xV2) / N1 x 22 x 0.001) g per 10g of soil.

The data were represented as CO_2 evolution per day basis.

C. Statistical analysis

The data were analyzed as two factor factorial design. Mean comparisons were done by Duncan's New Multiple Range Test (DNMRT). Data was analyzed by using SAS package.

RESULTS AND DISCUSSION

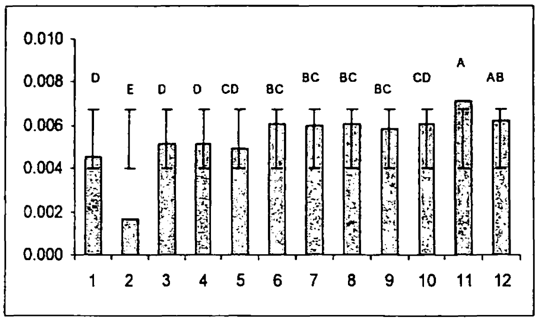
1. Soils of Agro Ecological Regions

The overall results revealed that there was a significant ($P<0.05$) effect by the soil pesticides on tea soils of the different agro ecological regions recommended for tea in Sri Lanka.

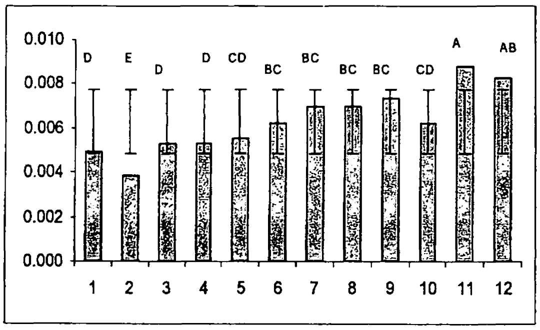
Among the soil types, TLW and HNT showed the lowest and the highest microbial activity respectively. According to Gunaratna, (2003) TLW posses clay loamy texture and has higher amount of organic carbon (3-4%). Soil pesticides could be highly adsorbed by organic matter and clay particles in the soils. Soil with more clay and organic matters tend to hold water and dissolved chemicals longer. These soils also have far more surface area on which pesticides can be adsorbed. Therefore, soil pesticides can be highly adsorbed by TLW as compared to other soils. Microbial activity was significantly low in this soil as the microorganisms would probably be highly affected by clay particles and organic matter adsorbed soil pesticides. Figure 1 (a) shows mean microbial activity of TLW treated with soil pesticides. Microbial activity TLW was significantly different from all the soils except DNY. On the other hand, microbial biomass is theoretically greater under high organic matter levels. Therefore in TLW soils, a comparatively greater microbial degradation could also be expected as per Büyüksönmez *et al.*,(1999).

HNT soils exhibits sandy clay loam texture and low organic carbon content. The coarser the texture of the soils, the greater the chance of the pesticides reaching ground water. Therefore, adsorption of pesticide in to the soils could be significantly low in HNT. Therefore microbial activity of HNT was significantly different from RTN, DNY and TLW. Figure 1 (e) shows mean microbial activity of HNT treated with soil pesticides. PSR showed comparatively higher microbial activity although not significantly different from KTW, RTN, DNY and HNT. PSR is similar to HNT because of their similar soil series. Figure 1 (f) shows mean microbial activity of PSR treated with soil pesticides. Microbial activity of KTW was significantly different from TLW and not significantly different from other soil types. Microbial activity of KTW was lesser than PSR. It has sandy clay loam texture with comparatively higher organic carbon percentage than PSR and HNT soils. Due to sandy soil texture and the little amount of soil organic matter could affect adsorption of pesticides than PSR and HNT soils. The low microbial activity was caused by organic matter adsorbed pesticides. Figure 1 (b) shows mean microbial activity of KTW treated with soil pesticides. RTN showed similar activities more than TLW. These soils have gravely loam texture and higher amount of organic carbon than the other soils tested. Higher organic matter leads to lower microbial activity in soils. Pesticides adsorbed by organic matter shows lower microbial activity. Mean soil microbial activity of RTN was significantly different from TLW and HNT and of DNY significantly different from HNT. Microbial activity of RTN showed little higher microbial activity than DNY. Figure 1 (c) and (d) show mean microbial activity of DNY and RTN treated with soil pesticides.

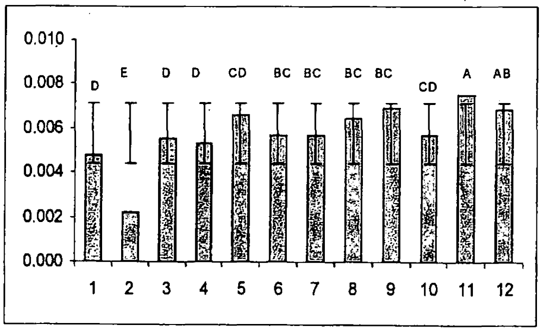
Soil pesticides had significant effect on reducing the microbial biomass in soil caused by Metham Sodium, Dazomet, Carbofuran, Cadusafos, Phenamiphos and Glufosinate Ammonium. Diuron, Glyphosate, 2,4- D and Paraquat did not significantly reduce the microbial activity in soils. Metham Sodium treated soils showed the lowest microbial activity regardless of the soil type and it was significantly different from all the other soil pesticides used. Metham Sodium and Dazomet is used as soil fumigants in nurseries exhibit their total killing of all living organisms. Carbofuran has insecticidal as well nematicidal properties.



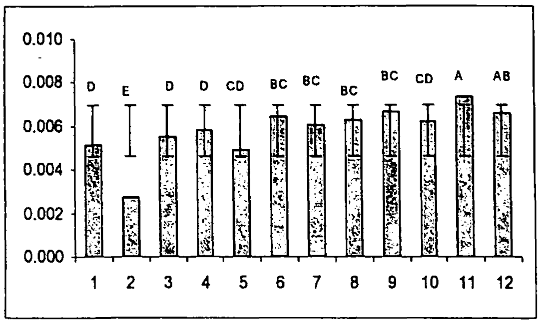
(a)TLW



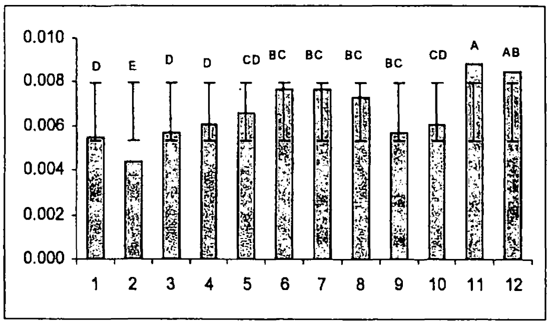
(b)KTW



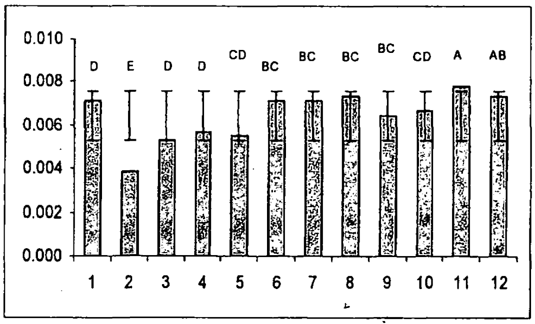
(c)DNY



(d)RTN



(e)HNT



(f)PSR

Figure 1 - Mean microbial activity of tea soils of different agro ecological regions treated with soil pesticides:

Note: X axis – Soil pesticides Y axis – Mean CO_2 evolution rate (g/10 g of soils/day) **Treatments;Fumigants** (1- Basamid, 2- Metham Sodium) **Insecticides** (3- Carbofuran) **Nematicides** (4- Cadusafos, 5- Phenamiphos) **Herbicides** (6- 2, 4-D, 7- Diuron, 8- Glufosinate Ammonium, 9-Glyphosate, 10- Paraquat, 11- Compost, 12- Untreated

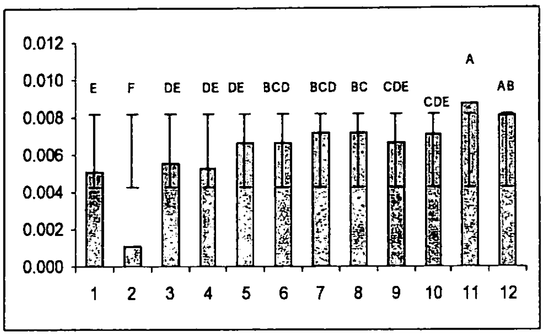
Table 4 - Mean percentage changes in microbial activity of tea soils after pesticides applications:

Type of pesticide	Active Ingredient	TLW	KTW	DNY	RTN	HNT	PSR	Mean	SD
Fumigants	Dazomet	-26.5	-40.0	-29.7	-22.2	-34.8	-2.5	-30.6	13.1
	M.Sodium	-73.5	-53.3	-67.6	-58.3	-47.8	-47.5	-60.1	10.7
Insecticides	Carbofuran	-17.6	-35.6	-18.9	-16.7	-32.6	-27.5	-24.3	8.2
Nematicides	Cadusafos	-17.6	-35.6	-21.6	-11.1	-28.3	-22.5	-22.8	8.5
	Phenamiphos	-20.6	-33.3	-2.7	-25.0	-21.7	-25.0	-20.7	10.2
Herbicides	2,4-D	-2.9	-24.4	-16.2	-2.8	-8.7	-2.5	-11.0	9.0
	Diuron	-4.4	-15.6	-16.2	-8.3	-8.7	-2.5	-10.6	5.6
	G Ammonium	-2.9	-15.6	-5.4	-4.2	-13.0	0.0	-8.2	6.1
	Glyphosate	-5.9	-11.1	1.4	1.4	-32.6	-12.5	-9.4	12.6
	Paraquat	-2.9	-24.4	-16.2	-5.6	-28.3	-8.8	-15.5	10.4
Compost		14.7	6.7	10.8	11.1	4.3	6.3	9.5	3.9

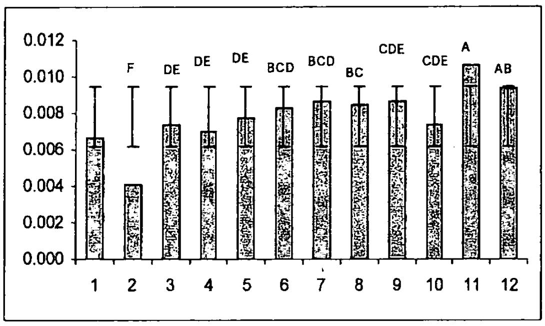
Results revealed its affect on beneficial organisms in the tea soils. Cadusafos and Phenamiphos used to suppress the nematodes in soils, also adversely affect the beneficial organisms in soil. Herbicides except Paraquat did not show significant effects on reduce the microbial biomass in the soil. Therefore, herbicides seem to posses less biocidal properties compared to other types of soil pesticides. Compost treated soil showed the highest microbial activity. It was caused by higher microbial biomass in compost due to considerably high organic matter content and soil physical properties. Mean microbial activity of compost added soil was significantly different from all the pesticides. Results clearly explain that, lower microbial activity caused by various soil pesticide applications and inorganic fertilizers etc., could be rectified by adding compost. Table 4 shows summaries of the mean percentage changes in microbial activity of the different agro ecological regions after soil pesticide applications. Similar observations were made with these soils and soil pesticide application by Abeykoon (2002).

2. *Forest and rehabilitated soils*

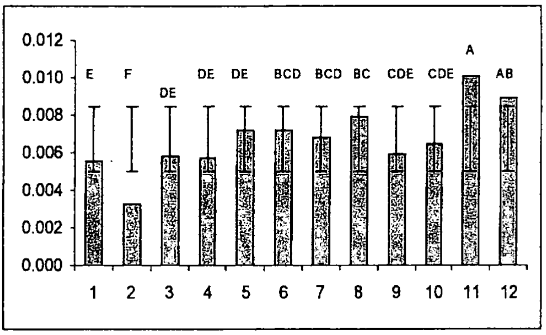
The overall results revealed that there was a significant effect on rehabilitated soils with GTM and MN and undisturbed FRT by different soil pesticides. Mean microbial activity of rehabilitated soil with GTM showed significant differences to that of MN and FRT Figure2 (a) shows mean microbial activity of GTM treated with soil pesticides. Highest and lowest microbial activity was seen in GTM and MN respectively. GTM grass rehabilitation encourages soil organic matter and soil microbial activity than MN. MN grass roots are also known to secrete chemical compounds that are biocidal. In addition, such chemical shall degrade synthetic chemical residues. Figure 2 (c) shows mean microbial activity of MN treated with soil pesticides. MN and FRT did not show significant differences But FRT showed higher microbial activity than MN. Figure 2 (b) shows mean microbial activity of FRT treated soil



(a) GTM



(b) MN



(c)FRT

Figure 2 - Mean microbial activity of rehabilitated and forest soils treated with soil pesticides:

Note: X axis – Soil pesticides Y axis – Mean CO_2 evolution rate (g/10 g of soils/day) **Treatments; Fumigants** (1- Basamid, 2- Metham Sodium) **Insecticides** (3- Carbofuran) **Nematicides** (4- Cadusafos, 5- Phenamiphos) **Herbicides** (6- 2, 4-D, 7- Diuron, 8- Glufosinate Ammonium, 9- Glyphosate, 10- Paraquat) 11- Compost 12- Untreated

Table 5 - Mean percentage changes in soil microbial activity pesticides applications on rehabilitated and forest soils:

Type of pesticide	Active Ingredient	FRT	MN	GTM	Mean	SD
Fumigants	Dazomet	-38.1	-36.4	-29.4	-34.6	4.6
	M. Sodium	-62.9	-86.4	-55.9	-68.4	16
Insecticides	Carbofuran	-35.1	-31.8	-21.6	-29.5	7
Nematicides	Cadusafos	-36.1	-34.1	-25.5	-31.9	5.6
	Phenamiphos	-19.6	-18.2	-17.6	-18.5	1
Herbicides	2,4-D	-19.6	-18.2	-11.8	-16.5	4.2
	Diuron	-23.7	-11.4	-7.8	-14.3	8.3
	G. Ammonium	-11.3	-11.4	-9.8	-10.8	0.9
	Glyphosate	-34	-18.2	-7.8	-20	13.2
	Paraquat	-27.8	-12.5	-21.6	-20.6	7.7
Compost		13.4	8	13.7	11.7	3.2

pesticides. Data suggests the importance of improving the microbial activity of soil in old tea fields by grass rehabilitation.

Metham Sodium treated soil showed lowest microbial activity regardless of the type of rehabilitation. It was significantly different from all the other used soil pesticides. Compost treated soil showed highest microbial activity and it was not significantly different from untreated soils and significant from pesticides polluted soils. Dazomet, Cadusafos, Carbofuran, Phenamiphos, Paraquat and Glyphosate significantly affected the soil microbial activity. Glufosinate Ammonium, 2, 4 – D, and Diuron did not significantly affect soil microbial activity. Table 5 shows mean percentage changes in soil microbial activity after pesticide applications in rehabilitated and forest soils.

CONCLUSIONS

All soil pesticides tested, significantly reduce microbial activity in different agro ecological regions, MN and GTM rehabilitated soils and undisturbed forest soils. The fate of soil pesticides was different with inherent organic matter content in the soils. Organic matter seems to adsorb pesticides and resultantly suppress the microbial biomass in soils. TLW soils with more organic matter showed lowest microbial activity while HNT soils showed the highest microbial activity. Among the rehabilitated soils GTM soils showed the highest microbial activity compared to MN soils but less than FRT soils. Among the selected soil pesticides, Metham Sodium reduces soil microbial activity regardless of the soil type. Soil fumigants, insecticides, nematicides and among the herbicides Paraquat, and Glyphosate showed significant effect on soil microbial biomass. According to the results there is a trend where pesticides with low half life and adsorption and water solubility leading in significant reduction of soil microbial activity. Organic matter addition to soil through compost application and grass rehabilitation improved the microbial activity. Therefore, these three methods could be used to rectify lower soil microbial activity caused by applying soil pesticides in tea soils. These could be effectively applied especially for mature and old tea fields and young fields which were continuous exposed to various soil pesticides. Attempt of present study was to examine the fate of soil pesticides in tea soils using soil microbial activity as the indicator. Results suggest that soil microbial activity seems to explain the effect of soil pesticides and its fate under different soil conditions. However residual chemical analysis as demonstrated by Watawala *et al.*, (2005) and bio assays with certain indicate plants as presented by Abeykoon (2002) would elaborate additional and confirmative information.

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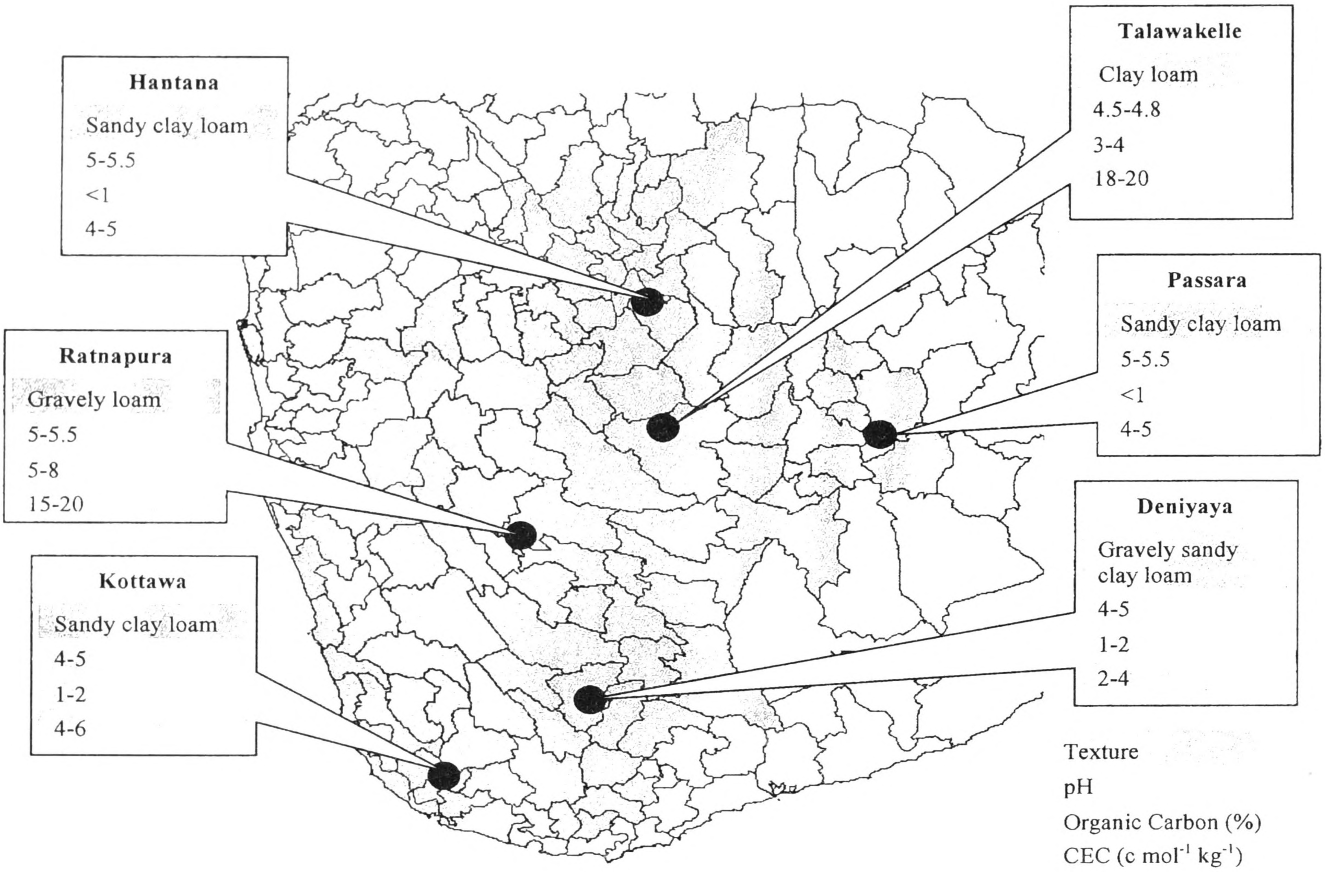
ANNEX 1



Some important properties of tea soils of different Agro Ecological Regions of Sri Lanka