

**THE EFFECTS OF SOIL AMENDMENTS ON SELECTED  
PROPERTIES OF TEA SOILS AND TEA PLANTS (*Camellia sinensis* L.)  
IN AUSTRALIA AND SRI LANKA**

Thesis submitted by

**Meragalge Swarna Damayanthi Luxmei De Silva**

**BSc, MPhil (Crop science) (University of Peradeniya, Sri Lanka)**

in March 2007

for the degree of Doctor of Philosophy in Tropical Plant Science within the  
School of Biological Sciences, James Cook University, QLD 4811, Australia.

## **STATEMENT OF ACCESS**

I, the undersigned author of this work, understand that James Cook University will make this thesis available for use within the University Library and, via the Australian Digital Theses network, for use elsewhere.

I understand that, as an unpublished work, a thesis has significant protection under the Copyright Act and;

I do not wish to place any further restriction on access to this work

---

Signature

---

Date

## STATEMENT ON SOURCES

### *Declaration*

I declare that this thesis is my own work and has not been submitted in any form for another degree or diploma at any university or other institution of tertiary education. Information derived from the published or unpublished work of others has been acknowledged in the text and a list of references is given.

.....  
(Signature)

.....  
(Date)

## ACKNOWLEDGEMENTS

A very special thanks goes to Tea Research Institute of Sri Lanka for granting funds for me to study in Australia and Sri Lanka as a split program. The encouragement and assistance I received from the former Director of Tea Research Institute Dr.W.W.D. Modder as well as present Director of Tea Research Institute Dr. M.T.Ziyad Mohamed are greatly appreciated.

I owe my sincere gratitude to my senior supervisor and Associate Professor R.J. Coventry and co-supervisor Adjunct Associate Professor J. A. Holt, James Cook University, Townsville, Australia, for their valuable comments, guidelines, and encouragement through out this study. Their assistance during the planning of experiments, and then criticisms and suggestion, painstaking detailed corrections are gratefully acknowledged. I greatly appreciate their intellectual support for their technical inputs as well as personal advises during my stay in Australia and while conducting and writing my thesis in Australia and Sri Lanka.

I sincerely thank Mr. Christopher Gardiner, Associate Lecturer, School of Tropical Biology, James Cook University, and his family for their kind support given me at all times.

Dr R.A.Congdon, Senior Lecturer and the Late Dr Peter Brownell, School of Tropical Biology, James Cook University, and Dr G.P.Gillman, CSIRO, Aitkenville, QLD 4814 for their kind co-operation during my study period in Australia are greatly appreciated.

I would like to express my sincere gratitude to Dr. Anandacumaraswamy, Head / Agronomy Division, TRI who constantly urged me towards completion of this study and advised me of correct paths. Special thanks go for my Sri Lankan friends in Australia who helped me in numerous ways during my stay in Townsville. The families who deserve special thanks are Bandara, Wijenayake, Jayaratne, Manatunge, Martin,

Natkunam, Obeysekera, Mohottie, Mallawaarachchi, Kulasooriya and friends Ishani, Anton and Saman. I appreciate the support given by fellow students Obed Lense, Indonesia, Margaret Burton, Australia, Brian Lengi, Tonga, Paul Ngaruiya, Kenya, throughout my study period.

I am indebted all my colleagues Amerasekera and Abesekera and students Sujitha, Uma Nishantha and Ganeshraj in the Agronomy Division at Tea Research Institute, Talawakelle who helped me in numerous ways during this study.

My heartiest gratitude goes to my parents, my brothers Senerath and family, and the Seneviratne family who looked after my children in my absence during the early part of the study.

I owe my dearest thanks to my husband Wijith who bore the heavy burden of caring for my daughters Thisuri and Sulani, and son Shashith in enabling me to devote my work during this study, and also for his continuous encouragement, and understanding.

***AFFECTIONATELY DEDICATED***

***TO***

***MY PARENTS, TEACHERS AND  
MY FAMILY***

## ABSTRACT

Organic matter transformations and nutrient cycling in soils depend on the activity of soil organisms. Deterioration of soil fertility lowers the biological activity and results in lower productivity. In the absence of adequate organic matter, the processes of conversion of nutrients to plant-available forms and their retention are very low. To enhance the activity of soil organisms especially that of beneficial microbial populations, the addition of high quality organic amendments is very important. Even though there are plenty of organic materials available in tea lands, there is inadequate information on their suitability and influence on the biological properties of soils.

The present research has attempted to determine the extent to which the microbial activity and productivity of tea soils in Australia and Sri Lanka can be manipulated by use of readily available soil amendments. Trials were conducted using grass and leguminous mulching materials with different C/N ratios, in combination with two pH amendments (dolomite and 'Minplus<sup>TM</sup>' – a finely ground volcanic rock dust - both applied at rates of 2500 kg ha<sup>-1</sup> only for the pot trials and 1000 kg ha<sup>-1</sup> for the other trials) and an inoculum of biologically active rain forest soil. The nursery stage of tea (*Camellia sinensis*) propagation was studied in a shadehouse at James Cook University, Townsville, Australia, and young tea (unpruned, 1 year after planting) and mature tea (pruned bushes, 5 years since planting) were studied in a field in Sri Lanka.

In the nursery trial, mulching materials consisting of finely chopped *Brachiaria decumbens* (a grass), *Calliandra calothyrsus* (a legume), and tea prunings were applied at a rate of 35 tonnes fresh weight ha<sup>-1</sup> year<sup>-1</sup> to pots with or without tea seedlings.

The grass mulch with Minplus improved soil organic carbon, CEC, soil pH, microbial biomass carbon, plant available phosphorus, and total nitrogen contents of the soil and enhanced the growth of plants when compared to the effects of *Calliandra* legume and tea mulch. All the combinations of mulches with dolomite reduced plant growth even though they enhanced some soil properties. Application of grass and legume mulches increased the beneficial population of gram positive bacteria, fungi, and mycorrhiza. Grass mulch also improved the growth of tea as measured by shoot weight and total biomass. The addition of a rainforest inoculum to the soils of the nursery tea plants increased the soil microbial biomass carbon and growth of tea plants even in the absence of any mulch.

The field trials in Sri Lanka demonstrated the extent of the changes induced by mulches and soil pH modifiers in soil microbial properties, including the abundances of functional groups of microbes (bacteria, fungi, mycorrhizae), soil microbial biomass carbon, and microbial respiration. In addition organic carbon, soil pH, nitrogen and mulch decomposition rate were measured. The mulching materials tested were: refuse tea (25 tonnes ha<sup>-1</sup> year<sup>-1</sup>), Mana grass (*Cymbopogon confertiflora*), and branches of Dadap (*Erythrina lithosperma*), a leguminous tree (35 tonnes fresh weight ha<sup>-1</sup> year<sup>-1</sup>). In addition to these treatments, lemon grass (*Cymbopogon nardus*) 20,000 plants ha<sup>-1</sup> as live mulch in young tea and a *Trichoderma* fungal culture in the mature tea were used. For young tea and mature tea, Mana and Dadap were applied four times and Refuse tea three times per study period and the lemon grass was planted at the start of the



trial on a 15 x 15 cm spacing in the young tea; *Trichoderma* was applied once to the mature tea trial at a rate of 500 g of spore culture / plant.

The results indicated that Dadap and Refuse tea raised the yield of tea significantly by 16% and 19% respectively in young tea, and by 14% in mature tea for both mulches. The mulches enhanced soil pH, microbial biomass carbon, soil respiration and also suppressed the most detrimental gram negative bacterial populations one year after the application of treatments in young tea and increased soil nitrogen by refuse tea in mature tea trial. The quality of tea increased in tea grown under the control and lemon grass mulch treatment in young tea and in *Trichoderma* fungus-treated plots in mature tea.

Minplus rock dust and the rainforest soil inoculum enhanced the growth of the nursery plants. The most suitable mulching materials to accelerate the biological activity were found to be those with C/N ratios below 20, and low in lignin and unoxidisable polyphenol. Therefore, the suitable materials for use as mulches on tea lands are *Brachiaria grass*, refuse tea, and Dadap legume. They also suppressed the development of pathogenic bacterial populations particularly gram negative bacteria. These materials also improved the biological properties of soil and thereby enhanced the growth and yield of tea.

## Table of Contents

	Page
Access to thesis	ii
Abstract	iii
Table of contents	vi
List of tables	xii
List of figures	xv
Glossary of terms	xvii
Statement on sources	xix
Acknowledgements	xx
Dedication	xxii

### CHAPTER 1

#### **THE EFFECTS OF SOIL AMENDMENTS ON SELECTED PROPERTIES OF TEA SOILS AND TEA PLANTS (*Camellia sinensis* L.) IN AUSTRALIA AND SRI LANKA**

1. Introduction	1
1.1 Aims of the research	1
1.2 Background	2
1.2.1 Tea soils	2
1.2.2 Soil acidity	4
1.2.2.1 Soil amendments used in tea soils of Sri Lanka	5
1.2.3 Microbial decomposition, utilisation and release of soil nutrients	6
1.2.4 Soil environmental factors affecting microbes	12
1.2.4.1 Moisture and aeration	13
1.2.4.2 Temperature	14
1.2.4.3 Soil properties	15
1.2.5 The effects of management practices on tea soils	17
1.2.5.1 Fertiliser	17

1.2.5.2	Mulching	20
1.2.5.3	Rock dust soil amendments	23
1.2.6	Pesticides	24
1.2.7	Increasing microbial activity and promoting soil quality	25
1.2.8	Conclusions	28
1.3	The tea plant	29
1.4	Scope of the thesis	31

## **CHAPTER 2**

### **NURSERY TRIAL AT JAMES COOK UNIVERSITY, AUSTRALIA**

2.1	Background	33
2.2	Aims of the study	34
2.3	Materials and methods	34
2.3.1	Soil	35
2.3.2	Plant materials	35
2.3.3	Experimental treatments	35
2.3.4	The pot experiment	39
2.3.5	Sample collection and analysis	41
2.3.5.1	Microbial biomass determination	42
2.3.5.2	FAME (Fatty Acid Methyl Ester) analysis	43
2.3.5.3	Statistical analysis	44
2.4	Results	
2.4.1	Changes in soil parameters – JCU Nursery Trial	46

2.4.1.1	Principal component analysis with plants	46
2.4.1.2	Factor analysis; JCU Nursery Trial	50
2.4.1.3	Factor analysis; JCU Nursery Trial- with tea plants-	52
2.4.1.4	Microbial dynamics; JCU Nursery Trial	60
2.4.2	Changes in soil microbial functional groups	62
2.4.3	Plant growth parameters	66
2.4.3.1	Principal components analysis of growth parameters: JCU Nursery Trial	66
2.4.3.2	Factor analysis of growth parameters JCU Nursery Trial	68
2.5	Discussion	75
2.5.1	Soil parameters	75
2.5.1.1	Soil organic carbon	75
2.5.1.2	Soil pH	77
2.5.1.3	Cation Exchange Capacity	79
2.5.1.4	Total nitrogen	80
2.5.1.5	Total phosphorus	80
2.5.1.6	Plant available phosphorus	81
2.5.1.7	Soil microbial biomass	82
2.5.1.8	Soil bacteria and fungi	83
2.5.2	Plant growth parameters	85
2.6	Conclusions	87

## **CHAPTER 3**

### **THE YOUNG TEA TRIAL , ST. COOMBS ESTATE, SRI LANKA**

3.1	Introduction	90
3.2	Aims of the study	93
3.3	Materials and Methods	93
3.3.1	Study site	93
3.3.2	Climate	94
3.3.3	Plant material	95
3.3.4	Experimental design	95
3.3.5	Treatments	96
3.3.6	Soil and plant analysis	100
3.3.6.1	Soil sample preparation	100
3.3.6.2	Plant sample preparation	100
3.3.6.3	Chemical and microbial analyses	100
3.3.7	Decomposition rate of mulching materials	101
3.3.7.1	Litter bag-technique	101
3.3.8	Tea quality analysis	102
3.3.9	Statistical analysis	102
3.4	Results	103
3.4.1	Mulch applications	104
3.4.3	Effect of mulches and pH amendments on soil properties	109
3.4.3.1	Relationship between organic carbon and microbial biomass carbon	110
3.4.4	Effects of mulches on soil microbial population structures	112

3.4.5	Effect of soil amendments on the growth of young tea	114
3.4.5.1	Chlorophyll content of leaves	114
3.4.6	Effect of soil amendments on the quality of made tea	114
3.5	Discussion	116
3.5.1	Soil microbial biomass	119
3.5.2	Soil respiration	122
3.5.3	Soil pH	122
3.5.4	Chlorophyll	123
3.5.5	Yield of tea	124
3.5.6	Tea quality	124
3.6	Conclusions	126

## **CHAPTER 4**

### **MATURE TEA TRIAL AT ST. COOMBS ESTATE, TALAWAKELLE, SRI LANKA**

4.1	Introduction	128
4.2	Aims of study	130
4.3	Materials and Methods	130
4.3.1	Study site	130
4.3.2	Soil and plant materials	130
4.3.3	Experimental treatments	131
4.3.4	Crop yield	133
4.3.5	Mulch decomposition rates	133
4.3.6	Soil and plant analysis	133

4.4	Results	134
4.4.1	Principal components analysis – mature tea, Sri Lanka	134
4.4.2	Factor analysis	136
4.4.3	Decomposition rates of mulches	137
4.4.4	Effects of mulches on soils and plant growth	138
4.5	Discussion	143
4.5.1	Tea yield	143
4.5.2	Total soil nitrogen	144
4.6	Conclusions	146
<b>CHAPTER 5</b>	<b>CONCLUSIONS AND RECOMMENDATIONS</b>	148
5.1	General conclusions	148
5.2	Recommendation for tea growers	151
5.3	Future studies	153
<b>CHAPTER 6</b>	<b>REFERENCES</b>	154

## List of Tables

		Page
2.1	Experimental treatments applied to 5 replicates of pots of Nerada Tea Plantation top soil (0-15 cm depth) in two randomised factorial blocks (with or without tea seedlings)	36
2.2	Chemical composition of oven dried (85 °C) mulch materials that were applied to the nursery trial at James Cook University	38
2.3	Treatment codes	39
2.4	Summary results of analyses of variance, Nursery Trials with or without plants at James Cook University, Australia, showing the effects of soil amendments on soil chemical, biological and plant growth parameters, 28 weeks after mulch emplacement	51
2.5	Effect of mulches on soil properties in the JCU Nursery Trial, with plants, 28 weeks after mulch emplacement	53
2.6	Effect of mulch on soil properties in the JCU Nursery Trial, with plants, 28 weeks after mulch emplacement	54
2.7	Effect of inoculum on soil properties in the J JCU Nursery Trial, with plants, 28 weeks after mulch emplacement	55
2.8	Effect of mulch x pH combination on soil properties at the JCU Nursery Trial, with plants, 28 weeks after mulch emplacement	56
2.9	Effect of pH x inoculum amendments on soil properties in the JCU Nursery Trial, with plants, 28 weeks after mulch emplacement	57
2.10	Effect of mulch x inoculum amendments on soil properties in the JCU Nursery Trial, with plants, 28 weeks after mulch emplacement	58
2.11	Effect of mulch x pH x inoculum on soil properties in the JCU Nursery Trial, with plants, 28 weeks after mulch emplacement	59
2.12	Abundances of bacteria, fungi, ratio of fungi/bacteria, and mycorrhizal components of the soil at the start of the Nursery Trial at the JCU	64
2.13	Abundances of bacteria, fungi, ratio of fungi/bacteria, and mycorrhizal components of the soil at the end of the 28 week Nursery Trial at the JCU	65



2.14	Effect of mulch on growth parameters in the JCU Nursery Trial, with plants, 28 weeks after mulch emplacement	69
2.15	Effect of pH on plant growth parameters in the JCU Nursery Trial, with plants, 28 weeks after mulch emplacement	70
2.16	Effect of an inoculum of rainforest soil on growth parameters of plants used in the JCU Nursery Trial, 28 weeks after mulch emplacement	71
2.17	Effect of mulch and soil pH amendments on plant growth parameters in the JCU Nursery Trial, 28 weeks after mulch emplacement	72
2.18	Effect of mulch x inoculum amendments on plant growth parameters in the JCU Nursery Trial with plants, 28 weeks after mulch emplacement	73
2.19	Effect of pH x inoculum amendments on plant growth parameters in the JCU Nursery Trial with plants, 28 weeks after mulch emplacement	74
3.1	Time of application of mulch and fertiliser, and of soil sampling of the young tea trial in Sri Lanka	98
3.2	The treatment combinations used on the young tea trial in Sri Lanka	99
3.3	Chemical compositions of oven dry (85 °C) mulch materials applied to the young tea trial, Sri Lanka	99
3.4	Summary of the response of treatments on soil chemical and biological parameters and plant growth parameters	103
3.5	Actual dry masses of mulch applied to the experimental plots (dry weight; tonnes ha <sup>-1</sup> and cumulative percentages of the nutrients included)	104
3.6	Decay constants and related parameters for mulch materials on the soil surface under the young tea, Sri Lanka	105
3.7	Effects of mulches on soil and plant properties in young tea, Sri Lanka	111
3.8	Nature of bacterial and fungal populations in Sri Lankan young tea soils, 14 months after application of mulch treatments	113
3.9	Effects of mulch materials and pH amendments on infusions of tea made from the young tea, Sri Lanka	115

4.1	The treatment combinations of mature tea trial in Sri Lanka	132
4.2	Time of application of mulch material and soil conditioners to mature tea in Sri Lanka	133
4.3	Summary results of an analysis of variance: mature tea trial at St. Coombs Estate, Talawakelle, Sri Lanka	137
4.4	Decomposition of mulching materials under mature tea at St Coombs, Sri Lanka from September 2001 to December 2001	138
4.5	The main effect of mulch on soil properties and yields of mature tea, Sri Lanka	139
4.6	The main effect of pH amendments on soil properties and yield of mature tea, Sri Lanka	140
4.7	Scores for quality (infused leaf) of tea in mulch and pH modifier treatments	142

## List of Figures

	Page	
1.1	The nitrogen cycle	11
2.1 (a)	Effects of mulches on soil parameters in the JCU Nursery Trial with plants: The analysed data include all soil pH modifier treatments	49
2.1 (b)	The analysed data exclude all soil pH modifier treatments	49
2.1 (c)	The analysed data embrace dolomite as the soil pH modifier treatment	49
2.1 (d)	The analysed data embrace Minplus as the soil pH modifier treatment	49
2.2 (a)	Changes in soil microbial biomass nitrogen over the 28 week period of the JCU Nursery Trial (with plants): Effect of mulches on microbial biomass nitrogen,	61
2.2 (b)	Effect of soil pH modifiers on microbial biomass nitrogen	61
2.2 (c)	Effect of rainforest soil inoculum on microbial biomass nitrogen	61
2.3	Principal component analysis of FAME profiles of microbial communities in soils collected after 28 weeks from the nursery trail at JCU in Australia.	63
2.4	Principal component analysis of bacterial communities in the soils used at the start of the Nursery Trial at the JCU, Australia	64
2.5 (a)	Effects of mulches on soil parameters in the JCU Nursery Trial with plants. Data exclude soil pH modifiers	67
2.5 (b)	The data include Minplus as the soil pH modifier	67
2.5 (c)	The data include dolomite as the soil pH modifier	67
2.5 a	Growth parameters changing with mulch materials with no pH modifier at the JCU nursery trial	68

3.1 a	The rainfall pattern at the experimental site at Talawakelle, over the period of the trial (August 2000 to October 2001)	94
3.1 b	The temperature pattern at the experimental site at Talawakelle, over the period of the trial (August 2000 to October 2001)	95
3.2	Residual oven dried mass of litter remaining in the litter bags after specific time intervals on the bare soil surface of experimental plots in young tea (% of original weight).	105
3.3	Dry biomass (tonnes ha <sup>-1</sup> ) of mulch remaining on the soil surface with time	106
3.4 (a)	Changes of organic carbon with remaining biomass of mulch material in the soil	107
3.4 (b)	Changes of rainfall within the study period of August 2000 to October 2001.	107
3.5	Changes in rainfall and organic carbon content of the soils under mulch-treated plots in young tea, Sri Lanka	108
3.6	Principal components analysis of the effects of various mulches on soil properties and on growth parameters with pooled pH modifiers in Young Tea, Sri Lanka	109
3.7	Relationship between soil organic carbon and the microbial biomass carbon content of the soil, 9 months after the application of treatments to the Young Tea, Sri Lanka.	112
4.1a	Effect of mulches on soil properties in mature tea, Sri Lanka The data exclude all soil pH modifier treatments	135
4.1 b	The data include dolomite as the soil pH modifier treatment	135
4.1 c	The data include Minplus as the soil pH modifier treatment	135
4.2	Organic carbon contents of soil vs yield of made tea	140
4.3	Changes with time in total nitrogen content of the soil to which no soil pH modifier was added under mature tea, Sri Lanka	141

## Glossary of terms

AP	Available phosphorus
CEC	Cation Exchange Capacity determined as the sum of the basic cations ( $\text{Ca}^{2+}$ , $\text{Mg}^{2+}$ , $\text{K}^+$ , $\text{Na}^+$ ) and the acidic cations ( $\text{H}^+$ , $\text{Al}^{3+}$ )
Dadap	The small leguminous tree <i>Erythrina lithosperma</i>
Dolomite	Calcium and magnesium carbonate: $\text{CaMg}(\text{CO}_3)_2$
FAME	Fatty Acid Methyl Ester
Guatemala grass	<i>Tripsacum laxum</i>
Immature tea	Young tea (1-2 yrs old)
JCU	James Cook University
Lemon grass	<i>Cymbopogon nardus</i>
Made tea	Black tea after processing
Mana grass	<i>Cymbopogon confertiflorus</i>
Mature tea	More than 20 years old tea
MBC	Microbial biomass carbon
MBN	Microbial biomass nitrogen
Minplus	Finely ground volcanic rock dust produced by Pacific Mineral Developments Pty Ltd, Innisfail.
N	Nitrogen
$\text{NH}_4^+$	Ammonium cation
Nursery tea	1-9 months old tea
OC	Organic carbon
P	Phosphorus
Plucking Table	Top part of the canopy where flush is harvested

$\text{PO}_4^{3-}$	Phosphate anion
Refuse tea	Waste product of the tea manufacturing process and is the partly ground, brown stalk and fibrous particles remaining after separating the commercial components of the manufactured tea
S	Sulphur
$\text{SO}_4^{2-}$	Sulphate anion
TRI	Tea Research Institute of Sri Lanka
Young tea	1-2 years old tea