# MEASUREMENT OF CARBON AND NUTRIENT DYNAMICS IN SOIL-PLANT SYSTEMS AND THE ROLE OF PLANT RESIDUES IN THE DEVELOPMENT OF SUSTAINABLE CROPPING SYSTEMS

BY

YOTHIN KONBOON
M.Sc. (Agricultural Systems)

A THESIS SUBMITTED FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

UNIVERSITY OF NEW ENGLAND

MARCH 1997

# ACKNOWLEDGMENTS

The work presented in this thesis has been possible through the support and assistance of many people and organisations. Financial support provide through a fellowship from the Australian Centre for International Agricultural Research (ACIAR). I also gratefully acknowledge the Ubon Ratchathani Rice Research Center, Rice Research Institute, Department of Agriculture of Thailand for my leave of absence to undertake this study.

I am indebted to my supervisors, Assoc. Prof. Graeme J. Blair and Dr. Rod D.B. Lefroy for their enthusiastic support and involvement in planning and carrying out the research work. Their enlightened guidance throughout, and helpful criticisms provided during the preparation of this thesis, are greatly appreciated.

I received substantial technical assistance in conducting soil and plant analyses from Mrs Leanne Lisle, who diligently provided willing and capable assistance during all phases of the experimental work. Technical assistance in taking soil samples, sample analyses and performing experiments from Mr. Michael Faint, Miss Sarah Williams, Mrs. Judi Kenny, Mr Michael Crestani and Mr. Allan Mitchell; and general assistance from Mrs Joan Hammond, Mrs Iidi Hall and Mr Walter Redlich is also appreciated.

I am also grateful to my postgraduate colleagues and many other members of the Department of Agronomy and Soil Science for their warm social relations and for the cheerful atmosphere that made my work at the Department a real pleasure. The support given to me by all Thai students in Armidale and the International Programs Office is also gratefully acknowledged.

I wish to sincerely acknowledge my grandmother, Mrs. Wan Thongtip; my uncle, Mr. Somboon Thongtip and aunties, Mrs Pornpit Pimpisarn and Mrs Liamthong Thongtip for their financial support during the period of primary school to undergraduate studying. I would humbly admit that without their support I would not have had the chance to continue my study. I am also grateful to my mother, Mrs Sukon Suwichian who supported and encouraged me in any way she could.

My love and thanks go to my wife, Sirikool and lovely son, Boom for their continual support and encouragement during the most difficult times during my study and giving me the patience to persevere through 4 years of study.

# Abstract


The decline in soil organic matter of many agricultural soils in many areas, which has resulted from cropping, has increased interest in using plant residues and other organic materials to improve soil productivity. To develop the effective use and management of residues, a detailed understanding of decomposition rate and nutrient release pattern is needed, and this requires techniques that can be used to monitor changes in decomposition and nutrient release of residues.

The UNE perfusion apparatus, which utilises a hospital drip bag and administration set, has been developed by modification of the apparatus of Nyamai (1992) which utilised a more elaborate glass device. Residues were perfused with 0.005M $CaCl_2$ solution, a concentration aimed to simulate a soil solution, the $CO_2$ released during breakdown trapped in KOH and the net $CO_2$ analysed by titration of KOH against HCl. A control treatment, with no residue, was included. A comparative study of the UNE apparatus and Nyamai apparatus indicated close agreement between the two techniques. The advantages of the UNE system are that it is easy and cheap to construct and operate, which means that sufficient units can be assembled to conduct valid comparisons.

The UNE perfusion apparatus was used to measure the rate of decomposition and nutrient release of 5 plant residues: wheat (*Triticum aestivum*) straw, residues of two legume crops - chickpea (*Cicer arietinum*) straw and medic (*Medicago truncatula*) hay, and leaf litter from two tree legumes - *Albizia chinensis* and *Flemingia macrophylla*. The decomposition study was carried out at 25 °C for 84 days in a controlled temperature laboratory. To verify the results from the perfusion study, a glasshouse experiment was conducted to measure the growth and nutrient uptake of wheat grown in an Alfisol soil amended with the five plant residues used in the perfusion study, applied at two rates, 3 and 15 t $ha^{-1}$. A no residue control was also included. Following the application of residues and a basal application of all nutrients except N, two consecutive wheat crops were grown for 10 and 12 weeks, respectively. Yields were expressed relative to the control and the apparent nutrient recoveries as [Nutrient content of treatment] - [Nutrient content of control] x 100 / [Nutrient content of added residue].

The results showed that the maximum decomposition rates of residues, as indicated by the UNE perfusion apparatus, ranged from 6 to 70 mg $CO_2$ $g^{-1}$ $day^{-1}$ between days 2 and 8, and were in the order chickpea straw> medic hay> *Albizia* leaf > *Flemingia* leaf > wheat straw. After 84 days the amount of carbon released ranged from 59 to 12% of the initial carbon added and in the order chickpea straw = medic hay > *Albizia* leaf > *Flemingia* leaf > wheat straw.

In the glasshouse experiment, at the 15 t $ha^{-1}$ application rate, the yields of the first crop were in the order medic hay> *Albizia* leaf > chickpea straw > *Flemingia* leaf > wheat straw, with application of *Flemingia* leaf and wheat straw resulting in a yield depression compared to the control and application of chickpea straw resulting in toxicity effects on the wheat crop. Wheat yields of the second crop (15 t $ha^{-1}$ application rate) were in the reverse order, with *Flemingia* leaf > *Albizia* leaf >

medic hay > chickpea straw > wheat straw. Application of wheat straw still resulted in a yield depression.

The growth response to residue application studied in the glasshouse experiment correlated well with the decomposition rate and nutrient release studied by the perfusion technique. This indicates that the UNE perfusion technique can be used to determine the potential rate of residue breakdown and therefore be used to design appropriate residue management systems.

A glasshouse experiment, using drained pots, was undertaken with some of the plant residues used in the previous experiment (*Flemingia* leaf, medic hay and wheat straw) labelled with $^{15}N$ and $^{35}S$. In addition, the $\delta^{13}C$ natural abundance technique was used to monitor changes in soil carbon. The objectives of the study were to study the impact of plant residue and inorganic fertiliser additions on the growth of Japanese millet (*Echinochloa frumentocea*), soil and on residue carbon and nutrient dynamics. The treatments consisted of three plant residues (*Flemingia* leaf, medic hay and wheat straw) applied at a rate of 3 t $ha^{-1}$, 2 fertiliser application rates (30 kg N $ha^{-1}$ with complete nutrients, and 10 kg N $ha^{-1}$) and 3 harvest times (27, 48 and 91 days after planting). A no residue control was included. A Soloth soil was added to pots and divided into 3 separated layers, namely top (0-8 cm), middle (8-16 cm) and bottom soil (16-24 cm). The residues and fertiliser solution were incorporated into the top soil one day prior to planting and Japanese millet was grown for approximately 12 weeks. A perfusion experiment was also conducted to study the decomposition rate and nutrient release from these three residues.

The results from the perfusion study showed that decomposition of medic hay was significantly higher compared to *Flemingia* leaf and wheat straw. The release of nutrients varied but the percentage nutrient release of N, S, K, Mg and Na, from medic hay and wheat straw was generally higher than that released from *Flemingia* leaf. The decomposition and nutrient release of residues in the perfusion experiment reflected the results obtained from the pot trial.

In the pot trial, there was no significant difference in millet yield among the three residues. However, application of plant residue significantly improved millet yield approximately 44% to 70% over the non-residue control. The dynamics of carbon and nutrient from different plant residues are varied. Addition of medic hay resulted in a higher percentage of residue N and S in the plant and in the leachate than from the other residues. Compared to the *Flemingia* leaf treatment, the percentage of leachate N and S observed from medic were approximately 3 and 6 fold higher, respectively, while plant uptake of N and S from medic were 3 and 2 fold higher, respectively, than those observed from the *Flemingia* leaf treatment.

Application of wheat straw led to a high percentage of residue S, but low residue N being recovered in the leachate with a significant amount of both residue N and S utilised by the millet.

In contrast to medic hay and wheat straw, addition of *Flemingia* leaf resulted in a higher percentage of residue S and N remaining in the soil with a lower amount found in the leachate and in the plant. The residue N and S remaining in the soil of the *Flemingia* leaf treatment were both 1.25 times higher than that observed from the medic hay treatment.

Residue application had a similar effect on soluble C as it did on nutrients. Application of medic hay and wheat straw resulted in a higher amount of soluble C lost through leaching. This loss was approximately 20% higher than that observed from the *Flemingia* leaf treatment. Losses of soluble C through leaching had an impact on the carbon content of the soil. After the 91-day harvest, the highest total C in the soil was observed in the *Flemingia* leaf treatment, followed by wheat straw, medic hay and control treatments. Increasing fertiliser application rate had no obvious effect on crop yields or movement of residue nutrients and C.

The use of the $\delta^{13}C$ technique to estimate and monitor the movement of residue C in soil was not completely successful in this study. The results obtained from this technique indicated the general pattern of residue C movement in the soil profile. Based on the calculation of $\delta^{13}C$ value, the percentage of residue C in top soil amended with *Flemingia* leaf was generally higher than those observed from wheat straw and medic hay. Conversely, the percentage of residue C in the lower soil layers observed from wheat straw and medic hay treatments was generally higher than in the *Flemingia* leaf treatment. It was concluded that the $\delta^{13}C$ technique was not appropriate to use as a tracer to monitor change the organic matter in an experiment with such a short time span. In order to obtain a better picture of C movement in the profile the enriched $^{13}C$ or $^{14}C$ labelling techniques are suggested.

It was concluded that the residues which breakdown more slowly, such as *Flemingia* leaf, are more suitable for building up soil C and nutrients to benefit the following crops than rapid breakdown residue. The response of crops to different types of applied legume residues suggests that management of residue breakdown, by choice of species and fertiliser application, can have significant effects on the short, medium and perhaps even long term availability of nutrients. Therefore, choice and management of residues can affect the input of carbon and other nutrients into the system and the rate at which soil organic matter turns over. This in turn will affect the size of soil organic matter pool and the fertility of soil, both of which contribute to the sustainability of the system.

# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES