



**UNIVERSITI PUTRA MALAYSIA**

**EFFICACY OF CONTROLLED-RELEASE UREA FERTILIZERS  
AND NITROGEN UPTAKE BY RICE**

**KIRAN JEET KAUR AMBRA SINGH**

**FP 2008 19**

**EFFICACY OF CONTROLLED-RELEASE UREA FERTILIZERS AND  
NITROGEN UPTAKE BY RICE**

**By**

**KIRAN JEET KAUR AMBRA SINGH**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in  
Fulfillment of the Requirements for the Degree of  
Masters of Science**

**June 2008**



**DEDICATED TO**

*Mr. Ambra Singh Sundara Singh - papa*

*Mrs. Bran Kaur Dalip Singh - ma*

*Mr. Karam Jeet Singh - brother*

*Mr. Kaljeet Singh - brother*



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Masters of Science

**EFFICACY OF CONTROLLED-RELEASE UREA FERTILIZERS AND  
NITROGEN UPTAKE BY RICE**

By

**KIRAN JEET KAUR AMBRA SINGH**

**June 2008**

**Chairman : Professor Mohd Khanif Yusop, PhD**

**Faculty : Agriculture**

The efficiency of urea fertilizer as Nitrogen (N) source is uncertain as found in many laboratory studies. It is subjected to rapid hydrolysis and  $\text{NH}_3\text{-N}$  volatilization. Ideal urea fertilizer should be soluble in soil and continuously regulated in amount that coincides with the rate of plant uptake. Controlled Release Urea (CRU) is a fertilizer that has been amended in such a way that the N is released over a period of time that coincides with plant requirement. This is achieved by coating the urea granule with material such as polymer that regulates the N releases to the soil solution. The CRU releases nutrients during the entire growing-season, reduces N loss and increases yield. Studies of behavior of CRU under tropical condition are limited. With this in view, this study was carried out with the main objective; to identify efficient CRU on selected soils. Laboratory and field studies were undertaken to evaluate the physical and



chemical properties of CRU, to quantify the N transformation of CRU on selected Malaysian soils and to determine yield and N uptake by rice from CRU. Six types of CRU used were CDU Uber-10, Meister-20, Meister-27, Humate Coated Urea, Duration Type-V, Sulfur Coated Urea (Gold N) and Urea fertilizer as control. Laboratory evaluation was carried out on seven types of soil series; Serdang series (Typic Paleudult), Munchong series (Typic Hapludox), Segamat series (Typic Hapludox), Selangor series (Typic Tropaquept), Rengam series (Typic Kandiudult), Holyrood series (Typic Kandiudult) and Bakau series (Typic Tropaquept).

The measurements of thickness of CRU coating and microphotographic observation of the coating were performed using Scanning Electron Microscope. The thickness of fertilizer coatings was in the range from 16.7  $\mu\text{m}$  – 73.2  $\mu\text{m}$  depending on the coating type. Humate Coated Urea has the highest value (73.2  $\mu\text{m}$ ) while the lowest value (16.7  $\mu\text{m}$ ) was obtained from Gold-N. No coating was found in Urea granule and CDU Uber-10.

Experiment results showed, there were significant differences among treatments in percentage of coating. Highest coating percentage was found in Meister-27 (11.23%) followed by Gold-N (11.20%), Meister-20 (10.53%) and Duration Type-V (6.69%). No coating was found in CDU Uber-10 and Humate Coated Urea, therefore are categorized as composite fertilizers. Fertilizer N analyses were carried out and compared with the total N content given by the manufacturers. Total N content of all the CRU analyzed were similar to the manufacturer's values.



Treatments with CDU Uber-10, Meister-20, Meister-27 and Duration Type-V had lower  $\text{NH}_4^+$ -N and  $\text{NO}_3^-$ -N content in soil. However, no significant difference was found in the Urea, Humate Coated Urea and Gold-N fertilizers. The treatments in Bakau series soil showed the highest concentration of  $\text{NH}_4^+$ -N while  $\text{NO}_3^-$ -N was negligible in soil. The lowest concentration of  $\text{NH}_4^+$ -N and  $\text{NO}_3^-$ -N in soil was found in Holyrood series.

Results indicate that, Humate Coated Urea and Gold-N fertilizers showed reduction in  $\text{NH}_3$ -N volatilization with 45% and 42% loss respectively. These CRU treatments did not significantly reduced loss. However, the other CRU treatments were effective in reducing  $\text{NH}_3$ -N volatilization as compared to urea with 49% loss. The other CRU fertilizer; CDU Uber-10, Meister-20, Meister-27 and Duration Type-V showed significant decreased of  $\text{NH}_3$ -N volatilization with 6.5%, 7.4%, 6.3% and 10.7% loss respectively.

In the field study using Bakau series soil and rice variety MR220 as the test crop, there were no significant effects using different fertilizers treatments on total N in grain, total N in straw and N uptake by straw. However, there were significant effects on straw yield, grain yield and N uptake by grain. The highest grain yield was recorded from CDU Uber-10 ( $5.9 \text{ t ha}^{-1}$ ) followed by Meister-20 ( $5.7 \text{ t ha}^{-1}$ ), Meister-27 ( $5.5 \text{ t ha}^{-1}$ ) and Duration Type V ( $5.0 \text{ t ha}^{-1}$ ). The grain yield from Humate Coated Urea was  $4.5 \text{ t ha}^{-1}$ , followed by Gold-N ( $3.8 \text{ t ha}^{-1}$ ) and Urea ( $3.7 \text{ t ha}^{-1}$ ). The highest N uptake by grain was recorded from Meister-20 with  $77 \text{ kg ha}^{-1}$ , followed by CDU Uber-10 ( $70 \text{ kg ha}^{-1}$ ), Duration Type-V ( $59 \text{ kg ha}^{-1}$ ), Meister-27 ( $58 \text{ kg ha}^{-1}$ ) and Urea ( $54 \text{ kg ha}^{-1}$ ). Meister-20

had significantly lowered  $\text{NH}_4^+$ -N and  $\text{NO}_3^-$ -N content in soil, reduced  $\text{NH}_3$ -N volatilization, increased grain yield and N uptake, therefore, the effectiveness of these CRU is given in the following order; Meister-20 > CDU Uber-10 > Meister-27 > Duration Type-V > Gold-N > Humate Coated Urea > Uncoated Urea.

The manufacturer claims that the CRU studied; Meister-20, Meister-27 and CRU Duration Type-V; can provide N for 200, 270 and 180 days respectively. The laboratory experiments done in this study proved that these CRU can last for the duration mentioned and it is suitable under Malaysian condition. In a field (culvert) experiment, Meister-20, Meister-27, CDU Uber-10 and CRU Duration Type-V can be used as single application for 2 seasons in rice planting; approximately 226 days. These findings suggest that there is a prospect of using CRU to increase rice yield and N efficiency and can be used for two season planting with single application of CRU.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Master Sains

**KEBERKESANAN BAJA 'CONTROLLED-RELEASE UREA' DAN  
PENYERAPAN NITROGEN OLEH PADI**

Oleh

**KIRAN JEET KAUR AMBRA SINGH**

**Jun 2008**

**Pengerusi : Professor Mohd Khanif Yusop, PhD**

**Fakulti : Pertanian**

Keberkesanan baja urea sebagai sumber Nitrogen (N) kebiasaannya kurang seperti yang diperolehi dari banyak penyelidikan di makmal. Ia sering dikaitkan dengan proses hidrolisis yang cepat dan pemeruapan  $\text{NH}_3\text{-N}$ . Baja urea yang idel sepatutnya boleh larut dalam tanah dan dapat membekalkan N secara berterusan untuk penyerapan oleh tanaman. Controlled Release Urea (CRU) merupakan sejenis baja yang mampu membebaskan N untuk satu tempoh waktu yang panjang mengikut keperluan tanaman. Keunikan ini dikecapi dengan granul urea disalut dengan lapisan seperti polimer yang mampu mengawal pembebasan N dalam larutan tanah. Controlled Release Urea membebaskan nutrien sepanjang tempoh pertumbuhan, mengurangkan kehilangan N serta meningkatkan hasil pertanian. Kajian terhadap sifat CRU dikawasan tropika masih berkurangan. Dengan mengambil kira keadaan ini, penyelidikan ini telah dijalankan dengan objektif utama; untuk mengkaji keberkesanan CRU ke atas jenis tanah yang





terpilih. Penyelidikan makmal dan ladang telah dijalankan bagi menentukan sifat fizikal dan kimia CRU, untuk menjumlahkan transformasi N dari CRU ke atas jenis tanah yang terpilih serta mengkaji hasil dan penyerapan N oleh padi. Enam jenis baja CRU telah digunakan iaitu CDU Uber-10, Meister-20, Meister-27, Humate Coated Urea, Duration Type-V, Sulfur Coated Urea (Gold-N) dan baja Urea sebagai kawalan. Penyelidikan makmal telah dijalankan ke atas tujuh siri tanah iaitu Siri Serdang (Tipik Paleudult), Siri Munchong (Tipik Hapludox), Siri Segamat (Tipik Hapludox), Siri Selangor (Tipik Tropaquept), Siri Rengam (Tipik Kandiudult), Siri Holyrood (Tipik Kandiudult) dan Siri Bakau (Tipik Tropaquept).

Pengukuran ketebalan lapisan salutan CRU dan pemerhatian mikrofotografik telah dijalankan dengan menggunakan 'Scanning Electron Microscope'. Ketebalan lapisan salutan baja berkenaan adalah diantara  $16.7 \mu\text{m}$  –  $73.2 \mu\text{m}$  bergantung kepada jenis lapisan salutan yang digunakan. Humate Coated Urea mempunyai ketebalan lapisan salutan yang paling tinggi iaitu  $73.2 \mu\text{m}$  manakala Gold-N mempunyai lapisan ketebalan yang paling kurang ( $16.7 \mu\text{m}$ ). Tiada lapisan salutan didapati untuk granul Urea dan CDU Uber-10.

Berdasarkan keputusan eksperimen, terdapat perbezaan bererti antara jenis baja bagi peratusan ketebalan lapisan salutan baja. Peratusan lapisan salutan pada Meister-27 adalah tertinggi (11.23%) diikuti Gold-N (11.20%), Meister-20 (10.53%) dan Duration Type-V (6.69%). Didapati CDU Uber-10 dan Humate Coated Urea tidak mempunyai salutan yang meyelaputi baja urea justeru dikategorikan sebagai baja komposit. Analisis

jumlah N dalam baja dijalankan dan dibandingkan dengan jumlah kandungan N yang dibekalkan oleh pengilang. Nilai jumlah N baja CRU yang dianalisis adalah sama dengan nilai yang diberikan oleh pengilang.

Rawatan menggunakan CDU Uber-10, Meister-20, Meister-27 dan Duration Type-V mempunyai kandungan  $\text{NH}_4^+\text{-N}$  dan  $\text{NO}_3^-\text{-N}$  yang lebih rendah dalam sample tanah. Tiada perbezaan bererti dikenalpasti pada baja Urea, Humate Coated Urea dan Gold-N. Tanah siri Bakau mempunyai kepekatan  $\text{NH}_4^+\text{-N}$  yang tertinggi manakala kepekatan  $\text{NO}_3^-\text{-N}$  tidak diperolehi dalam tanah. Namun begitu, kepekatan  $\text{NH}_4^+\text{-N}$  dan  $\text{NO}_3^-\text{-N}$  didapati paling rendah bagi tanah Siri Holyrood.

Keputusan yang diperolehi mencatatkan pengurangan dari segi peratusan pemeruapan  $\text{NH}_3\text{-N}$  bagi baja Humate Coated Urea dan Gold-N iaitu masing-masing pemeruapan sebanyak 45% dan 42%, tetapi tidak seelok rawatan baja CRU yang lain dalam pengurangan pemeruapan  $\text{NH}_3\text{-N}$  dibandingkan dengan pemeruapan baja Urea sebanyak 49%. Baja CRU; CDU Uber-10, Meister-20, Meister-27 dan Duration Type-V menunjukkan peratusan pengurangan pemeruapan  $\text{NH}_3\text{-N}$  yang ketara dengan nilai pemeruapan masing-masing sebanyak 6.5%, 7.4%, 6.3% dan 10.7%.

Penyelidikan ladang menggunakan tanah siri Bakau dan variti padi MR220 sebagai tanaman ujian telah dijalankan. Tiada kesan ketara dikenalpasti dengan menggunakan baja yang berlainan ke atas jumlah kandungan N dalam benih padi, jumlah kandungan N dalam jerami dan juga jumlah N yang diserap oleh jerami. Tetapi, terdapat perbezaan

bererti untuk hasil jerami, hasil padi dan jumlah N yang diserap oleh benih padi. Jumlah hasil benih padi yang tertinggi diperolehi dari rawatan CDU Uber-10 ( $5.9 \text{ t ha}^{-1}$ ), diikuti dengan Meister-20 ( $5.7 \text{ t ha}^{-1}$ ), Meister-27 ( $5.5 \text{ t ha}^{-1}$ ) dan Duration Type-V ( $5.0 \text{ t ha}^{-1}$ ). Hasil padi yang diperolehi dari Humate Coated Urea adalah sebanyak  $4.5 \text{ t ha}^{-1}$  diikuti dengan Gold-N ( $3.8 \text{ t ha}^{-1}$ ) dan Urea sebanyak ( $3.7 \text{ t ha}^{-1}$ ). Jumlah penyerapan N tertinggi oleh padi adalah dari penggunaan baja Meister-20 dengan nilai  $78 \text{ kg ha}^{-1}$ , diikuti CDU Uber-10 ( $70 \text{ kg ha}^{-1}$ ), Duration Type-V ( $59 \text{ kg ha}^{-1}$ ), Meister-27 ( $58 \text{ kg ha}^{-1}$ ) dan Urea sebanyak  $54 \text{ kg ha}^{-1}$ . Penggunaan Meister-20 menunjukkan pengurangan kandungan  $\text{NH}_4^+\text{-N}$  dan  $\text{NO}_3^-\text{-N}$  dalam tanah, mengurangkan pemeruapan  $\text{NH}_3\text{-N}$ , meningkatkan hasil padi dan penyerapan N oleh benih padi. Maka, keberkesanan CRU adalah mengikut urutan berikut; Meister-20 > CDU Uber-10 > Meister-27 > Duration Type-V > Gold-N > Humate Coated Urea > Urea.

Pengilang memberi jaminan bahawa baja CRU yang dikaji; Meister-20, Meister-27 dan CRU Duration Type-V; boleh membekalkan N masing-masing untuk 200, 270 dan 180 hari. Penyelidikan makmal telah dilakukan dan terbukti bahawa baja CRU ini boleh membekalkan N dalam tempoh masa yang telah diberikan dan sesuai dengan keadaan cuaca di Malaysia. Penyelidikan 'culvert' yang telah dijalankan, didapati Meister-20, Meister-27, CDU Uber-10 dan CRU Duration Type-V boleh ditabur sekali dan akan membekalkan N sehingga dua musim penanaman padi; anggaran 226 hari. Kajian ini mengesyorkan bahawa penggunaan baja CRU boleh meningkatkan hasil padi dan keberkesanan N dan baja CRU hanya ditabur sekali dan boleh membekalkan N sehingga dua musim penanaman padi.

## **ACKNOWLEDGEMENTS**

The author would like to express her profound gratitude, appreciation and indebtedness to Professor Dr. Mohd Khanif Yusop, Chairman of the Supervisory Committee for his valuable suggestions, guidance and encouragement during the course of research work and the improvement of the manuscript.

The author acknowledges PETRONAS for providing grant for this research.

Besides that, the author appreciate the help and guidance given by Associate Professor Dr. Anuar Abdul Rahim and Associate Professor Dr. Aminuddin Hussin as members of the Supervisory Committee for their suggestion and encouragement during all phases of study.

Furthermore, the author would also like to thank the lecturers who helped her to gain a better understanding and knowledge in the field of Agriculture and other related field.

Moreover, the author is very grateful to the Laboratory Assistants, Department of Land Management, Faculty of Agriculture, UPM; Mrs. Umi Kalthum Asmaon, Mr. Aziz Abdullah and Mr. Alias Tahar for their guidance and assistance during the author's laboratory analysis.



Finally, the author expresses appreciation to her parents and brothers for their endless patience, constant support, encouragement and assistance who have been there during her days of glory and trials. Lastly but not least, the author thanks her friends for their inspiration.



I certify that an Examination Committee met on 16 June 2008 to conduct the final examination of Kiran Jeet Kaur Ambra Singh on her Master of Science thesis entitled "Efficacy of Controlled-release Urea Fertilizers and Nitrogen Uptake by Rice" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree.

Members of the Examination Committee were as follows:

**Shamsuddin Jusop, PhD**

Professor  
Faculty of Agriculture  
Universiti Putra Malaysia  
(Chairman)

**Ahmad Husni Mohd Hanif, PhD**


Associate Professor  
Faculty of Agriculture  
Universiti Putra Malaysia  
(Internal Examiner)

**Siva Kumar Balasundram, PhD**

Lecturer  
Faculty of Agriculture  
Universiti Putra Malaysia  
(Internal Examiner)

**Zin Zawawi Zakaria, PhD**

Lecturer  
Biology Division  
Malaysian Palm Oil Board  
(External Examiner)

  
\_\_\_\_\_  
**HASANAHT MOHD. GHAZALI, PhD**  
Professor and Deputy Dean  
School of Graduate Studies  
Universiti Putra Malaysia

Date: 26 August 2008



This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master Science.

The members of the Supervisory Committee were as follows:

**Mohd Khanif Yusop, PhD**

Professor  
Faculty of Agriculture  
Universiti Putra Malaysia  
(Chairman)

**Aminuddin Hussin, PhD**

Associate Professor  
Faculty of Agriculture  
Universiti Putra Malaysia  
(Member)

**Anuar Abdul Rahim, PhD**

Associate Professor  
Faculty of Agriculture  
Universiti Putra Malaysia  
(Member)



---

**AINI IDERIS, PhD**  
Professor and Dean  
School of Graduate Studies  
Universiti Putra Malaysia

Date: 11 September 2008

## **DECLARATION**

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledge. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.



---

**KIRAN JEET KAUR AMBRA SINGH**

Date: 20 August 2008



## TABLE OF CONTENTS

	<b>Page</b>
<b>DEDICATION</b>	ii
<b>ABSTRACT</b>	iii
<b>ABSTRAK</b>	vii
<b>ACKNOWLEDGEMENTS</b>	xi
<b>APPROVAL</b>	xiii
<b>DECLARATION</b>	xv
<b>LIST OF TABLES</b>	xix
<b>LIST OF FIGURES</b>	xx
<b>LIST OF PLATE</b>	xxiii
<b>LIST OF ABBREVIATION</b>	xxiv
<b>CHAPTER</b>	
<b>I INTRODUCTION</b>	<b>1</b>
<b>II LITERATURE REVIEW</b>	<b>5</b>
Role of Nitrogen	5
Role of Nitrogen in Rice	6
Nitrogen Use Efficiency	7
Ammonium Salts	8
Nitrates	9
Urea	9
Urea Hydrolysis in Soil	13
Reaction of Urea in Soil	13
Reactions of Ammoniacal-N in Soil	15
Urea Concentration	17
Factors Affecting the Rate of Urea Hydrolysis	18
Soil Urease Concentration	18
Soil Temperature	19
Soil Water Content	19
Soil pH after Urea Application	20
Loss of Nitrogen	21
Ammonia Volatilization	21
Mechanism of NH <sub>3</sub> Volatilization	22
Nitrification – Denitrification	25
Leaching	29
Microbial Activity	30
Organic Matter and Clay Fixation of N	31
Controlled Release Urea	31
Mechanism of Controlled Release	37



<b>III</b>	<b>MATERIALS AND METHODS</b>	<b>39</b>
3.1	<b>Physical and chemical properties of CRU Studied</b>	<b>39</b>
	Appearance of Fertilizers	40
	Thickness of Coating Materials of CRU using Scanning Electron Microscope (SEM)	41
	Percentage of Coating (insoluble)	42
	Total N Content in CRU Fertilizers	42
3.2	<b>Laboratory Evaluation of CRU Fertilizers in Selected Inland soils and Rice soil</b>	<b>42</b>
	Soils Collection	43
	Soil Analytical Procedures	45
	Treatments	45
	Experimental Design	45
	Nitrogen Mineralization	46
	Ammonia Volatilization	47
	Soil pH	48
3.3	<b>Effect of CRU on N uptake of Rice</b>	<b>49</b>
	Soil Collection and Analysis	49
	Treatments	49
	Experimental Design	49
	Crop Management	50
	Sowing Rice Seeds	50
	Irrigation Management	50
	Fertilizer Application	51
	Straw Yield	51
	Grain Yield	52
	Analyses of Total N in Grain and Plant Tissue	52
	Analyses of Total N in Soil	52
	Nitrogen Uptake	53
	Ammonium-N Content in Soil	53
	Soil pH	54
	Statistical Analysis	54
<b>IV</b>	<b>RESULTS AND DISCUSSION</b>	<b>55</b>
4.1	<b>Physical and Chemical Properties of CRU fertilizers</b>	<b>55</b>
	Thickness of Coating Materials of Coated Fertilizers	55
	Percentage of Coating (insoluble)	59
	Total N Content in CRU Fertilizers	60
4.2	<b>Laboratory Evaluation of CRU Fertilizers in Soils</b>	<b>62</b>
	Nitrogen Transformation of CRU Fertilizers in Soils	62

	Changes in $\text{NH}_4^+$ -N and $\text{NO}_3^-$ -N	62
	Nitrification of $\text{NH}_4^+$ -N	63
	Total Mineral-N in Soil Released from CRU Fertilizers	70
	Volatilization of $\text{NH}_3$ -N	74
	Changes in pH	82
<b>4.3</b>	<b>Effect of CRU on N uptake by rice</b>	<b>87</b>
	Yield	87
	Straw Yield	87
	Grain Yield	88
	Nitrogen Concentration in Straw and Total N Uptake by Straw	89
	Nitrogen Concentration in Grains and Total N Uptake by Grains	90
	Total N Uptake by Plant	91
	Ammonium-N Content in Soil	93
	Soil pH	95
	Total N in Soil	97
<b>V</b>	<b>SUMMARY AND CONCLUSION</b>	<b>98</b>
	<b>RECOMMENDATION</b>	<b>102</b>
	<b>REFERENCES</b>	<b>104</b>
	<b>APPENDICES</b>	<b>115</b>
	<b>VITAE</b>	<b>124</b>



## LIST OF TABLE

<b>Tables</b>	<b>Page</b>
1 Fertilizer treatments	39
2 Appearance of CRU	40
3 Physical and chemical properties of soils	44
4 Amount of fertilizers used in field (culvert) study	51
5 Thickness of the coating materials on the fertilizers granules using SEM	58
6 Total N content in CRU fertilizers	61
7 Release of $\text{NH}_4^+$ -N and $\text{NO}_3^-$ -N of incubation	63
8 Release of $\text{NH}_4^+$ -N and $\text{NO}_3^-$ -N	65
9 Total ammonia loss over 70 days of incubation	81
10 Total ammonia loss in soil series over 70 days of incubation	82
11 Changes in pH with addition of urea in 10 days of incubation	82
12 Changes in pH with addition of urea in 10 days of incubation in soil series	84
13 The effect of CRU on straw yield	87
14 The effect of CRU on grain yield	89
15 Nitrogen concentrations in straw and total N uptake by straw	90
16 Nitrogen concentration in grain and total N uptake by grain	91
17 Total N uptake by plant	92
18 Ammonium-N released from CRU in Bakau Series soil	93
19 Total $\text{NH}_4^+$ -N content in Bakau series for 12 weeks	94
20 Total pH in Bakau series soil	96
21 Total N in Bakau series soil	97



## LIST OF FIGURES

<b>Figure</b>		<b>Page</b>
1.0	SEM micrograph of urea granule	55
1.1	SEM micrograph of CDU Uber-10	56
1.2	SEM micrograph of Meister-20	56
1.3	SEM micrograph of Meister-27	56
1.4	SEM micrograph of Humate Coated Urea	57
1.5	SEM micrograph of Duration Type-V	57
1.6	SEM micrograph of Gold-N	57
2	Percentage of coating of CRU fertilizers	60
3	Cumulative Mineral-N released from urea and CRU fertilizer in Serdang series	67
4	Cumulative Mineral-N released from urea and CRU fertilizer in Munchong series	68
5	Cumulative Mineral-N released from urea and CRU fertilizer in Segamat series	68
6	Cumulative Mineral-N released from urea and CRU fertilizer in Selangor series	68
7	Cumulative Mineral-N released from urea and CRU fertilizer in Rengam series	69
8	Cumulative Mineral-N released from urea and CRU fertilizer in Holyrood series	69
9	Cumulative Mineral-N released from urea and CRU fertilizer in Bakau series	69
10	Total Mineral-N in Serdang series	70
11	Total Mineral-N in Munchong series	70
12	Total Mineral-N Segamat series	71

13	<b>Total Mineral-N in Selangor series</b>	71
14	<b>Total Mineral-N in Rengam series</b>	71
15	<b>Total Mineral-N in Holyrood series</b>	72
16	<b>Total Mineral-N in Bakau series</b>	74
17	<b>Ammonia volatilization in Serdang series</b>	75
18	<b>Ammonia volatilization in Munchong series</b>	75
19	<b>Ammonia volatilization in Segamat series</b>	75
20	<b>Ammonia volatilization in Selangor series</b>	76
21	<b>Ammonia volatilization in Rengam series</b>	76
22	<b>Ammonia volatilization in Holyrood series</b>	76
23	<b>Cumulative ammonia volatilization from urea and CRU fertilizers in Serdang series</b>	78
24	<b>Cumulative ammonia volatilization from urea and CRU fertilizers in Munchong series</b>	79
25	<b>Cumulative ammonia volatilization from urea and CRU fertilizers in Segamat series</b>	79
26	<b>Cumulative ammonia volatilization from urea and CRU fertilizers in Selangor series</b>	79
27	<b>Cumulative ammonia volatilization from urea and CRU fertilizers in Rengam series</b>	80
28	<b>Cumulative ammonia volatilization from urea and CRU fertilizers in Holyrood series</b>	80
29	<b>Soil pH after CRU application in Serdang series</b>	85
30	<b>Soil pH after CRU application in Munchong series</b>	85
31	<b>Soil pH after CRU application in Segamat series</b>	85
32	<b>Soil pH after CRU application in Selangor series</b>	86

33	Soil pH after CRU application in Rengam series	86
34	Soil pH after CRU application in Holyrood series	86
35	Soil pH after CRU application in Bakau series	87
36	Cumulative $\text{NH}_4^+$ -N content in Bakau series	95
37	Changes in pH in Bakau series	96



## LIST OF PLATE

1	Ammonia volatilization determination	48
---	--------------------------------------	----





## LIST OF ABBREVIATIONS

CRU	= Controlled Release Urea
C	= carbon
Ca	= calcium
CEC	= cation exchange capacity
CO <sub>2</sub>	= carbon dioxide
H <sup>+</sup>	= hydrogen ion
HBC	= hydrogen buffering capacity
H <sub>2</sub> SO <sub>4</sub>	= sulphuric acid
H <sub>2</sub> O	= water
HCl	= hydrochloric acid
ha	= hectare
K	= potassium
kg	= kilogram
km	= kilometer
MOP	= Muriate of Potash
N	= nitrogen
Na	= sodium
NH <sub>3</sub> -N	= ammonia nitrogen
NH <sub>4</sub> <sup>+</sup> -N	= ammonium nitrogen
NO	= nitrogen oxide
NO <sub>2</sub>	= nitrogen dioxide
NO <sub>2</sub> <sup>-</sup>	= nitrite