



**UNIVERSITI PUTRA MALAYSIA**

**NITROGEN EFFICIENCY OF UREA  
AMENDED WITH INHIBITORS AND CATIONS  
APPLIED TO RICE**

**SHREE CHANDRA SHAH**

**FH 1994 1**



**NITROGEN EFFICIENCY OF UREA  
AMENDED WITH INHIBITORS AND CATIONS  
APPLIED TO RICE**

**By**

**SHREE CHANDRA SHAH**

**Dissertation Submitted in Fulfilment of the Requirements for  
the Degree of Doctor of Philosophy in the Faculty of Agriculture,  
Universiti Pertanian Malaysia**

**March 1994**



**DEDICATED  
TO  
MY BELOVED MOTHER  
NIRASIA DEVI**



## ACKNOWLEDGEMENTS

I would like to express my profound gratitude, appreciation and indebtedness to Dr. Mohd. Khanif Yusop, Chairman of the Supervisory Committee, for his unstinted advice, constant guidance, healthy criticism, constant encouragement and persistent inspiration throughout the course of this study;

I owe my sincere gratitude and appreciation to Dr. Surjit Singh, member of the Supervisory Committee, for his invaluable comments, constructive suggestions and endless encouragement during the course of my dissertation work and also for providing necessary help in conducting the research work;

I express my sincere thanks to Dr. Aminuddin Hussin, member of the Supervisory Committee, for his counsel and guidance in all phases of my study;

I am thankful to Mr. Junaidi, Mr. Nasir (UPM) and Mr. Saidi (MARDI) for their tremendous help during the soil sampling sessions and field studies at the farmer's field in Besut, Terengganu. I am also thankful to Mdm. Zabedah Tumirin who briefed me on the  $^{15}\text{N}$  analysis techniques and other chemical analysis. I would like to express heartfelt appreciation to all the staff of the Soil Chemistry section for their cooperative attitude and their kind help during various phases of investigations;



I would also like to express my sincere thanks and deep sense of gratitude to the Institute of Agriculture and Animal Science (IAAS) Rampur, Nepal for not only nominating me for this scholarship and for granting me study leave but also providing me with the chance of self improvement in my field of specialisation;

I tender my sincere thanks to USAID/Nepal and Universiti Pertanian Malaysia (UPM) for their financial assistance which was rendered to me during the course of this study;

I warmly acknowledge the cooperation of all my friends especially, Dr. Fayyaz, Jasbir, Banik, Suresh, Thakur and Indu during the course of this research work. Without whom I would not have had the necessary motivation to complete my dissertation. I take my pleasure to thank Mr. Abdul Aziz Bahsir, Ms. Fadzlon Yusof and Mdm. Faridah Shamsuddin of Graduate School for their kind cooperation throughout this study;

I would also like to thank Miss Salmah Kassim for having the patience to type the manuscript again and again till this dissertation became a reality;

Finally my heartiest thanks to my wife, Pawan, and my children for their love, understanding, endurance, endless patience, and moral support which was absolutely necessary to complete my study.



## TABLE OF CONTENTS

<b>ACKNOWLEDGEMENTS</b> .....	iii
<b>LIST OF TABLES</b> .....	xi
<b>LIST OF FIGURES</b> .....	xv
<b>LIST OF ABBREVIATIONS</b> .....	xvii
<b>ABSTRACT</b> .....	xix
<b>ABSTRAK</b> .....	xxii
<b>CHAPTER</b>	
<b>I INTRODUCTION</b> .....	1
<b>II REVIEW OF LITERATURE</b> .....	4
Urea Fertilizer.....	4
Urea Hydrolysis in Lowland Rice Soils.....	5
Ammonia Volatilisation in Lowland Rice Soils.....	7
Nitrification-Denitrification in Lowland Rice Soils .....	10
Control of Urea-N Loss from Lowland Rice Soils .....	12
Inhibitors.....	13
Soluble Salts .....	19
Field Measurements of N Losses from Lowland Rice Soils .....	23
Field Measurement of Ammonia Volatilisation Loss in Lowland Rice Soils .....	23



	Page
Field Measurement of Denitrification Loss in Lowland Rice Soils .....	25
The <sup>15</sup> N Recovery Technique .....	26
Determination of <sup>15</sup> N in the Laboratory.....	27
<b>III MATERIALS AND METHODS.....</b>	<b>30</b>
Experiment I : Urea-N Transformations in Flooded Rice Soils .....	30
Experimental Design .....	30
Kinetics of Urea Hydrolysis.....	33
Statistical Analysis.....	33
Experiment II : Effects of Soils and Planting Methods on Urea-N Utilisation Efficiency and Nitrogen Balance.....	34
Experimental Design .....	34
Raising and Planting of Rice Seedlings.....	36
Fertilizer Application .....	37
Urea-N and Ammonium-N Determination in Floodwater .....	37
Yield and Yield Components .....	38
Statistical Analysis.....	39
Experiment III : Effects of Inhibitors on Efficiency of Urea-N Applied to Rice.....	40
Experimental Design .....	40



	Page
Transplanting of Rice Seedlings .....	41
Determination of Urea-N and Ammonium-N in Floodwater .....	41
Yield and Yield Components.....	41
Statistical Analysis.....	41
<b>Experiment IV : Use of Soluble Salts for Improving Efficiency of Urea-N Applied to Lowland Rice.....</b>	<b>42</b>
Experimental Design .....	42
Transplanting of Rice Seedlings .....	44
Determination of Urea-N and Ammonium-N in Floodwater .....	44
Yield and Yield Components.....	44
Statistical Analysis.....	44
<b>Experiment V : Field Evaluation of Nitrogen Efficiency of Inhibitors and Soluble Salts Treated Urea.....</b>	<b>45</b>
Experimental Design .....	45
Transplanting of Rice Seedlings .....	47
Yield and Yield Components.....	47
Statistical Analysis.....	48
<b>IV RESULTS AND DISCUSSION.....</b>	<b>49</b>
<b>Experiment I : Urea-N Transformations in Flooded Rice Soils .....</b>	<b>49</b>
Kinetics of Urea Hydrolysis.....	49





	Page
Urea-N and Ammonium-N.....	55
<b>Experiment II : Effects of Soils and Planting Methods on Urea-N Utilisation Efficiency and Nitrogen Balance.....</b>	<b>60</b>
Urea in Floodwater.....	60
Ammonium-N in Floodwater .....	63
Effects of of Planting Methods on Urea-N and Ammonium-N in Floodwater .....	65
Floodwater pH .....	67
Plant Uptake of Fertilizer Nitrogen .....	72
Fertilizer Nitrogen Recovery from Soils.....	78
Plant Nitrogen Uptake .....	80
Fertilizer Nitrogen Losses.....	85
Fertilizer Nitrogen Utilisation Efficiency .....	89
Yield Components .....	92
Dry Matter Production.....	92
<b>Experiment III. Effects of Inhibitors on Efficiency of Urea-N Applied to Rice.....</b>	<b>97</b>
Urea in Floodwater.....	97
Ammonium-N in Floodwater.....	99
Plant Uptake of Fertilizer Nitrogen.....	102
Fertilizer Nitrogen Recovery from Soils.....	106



	Page
Plant Nitrogen Uptake .....	108
Fertilizer Nitrogen Losses.....	112
Fertilizer Nitrogen Utilisation Efficiency .....	114
Yield Components .....	115
Dry Matter Production .....	117
 Experiment IV : Use of Soluble Salts for Improving Efficiency of Urea-N Applied to Lowland Rice .....	 120
Urea in Floodwater.....	120
Ammonium-N in Floodwater .....	125
Plant Uptake of Fertilizer Nitrogen .....	127
Fertilizer Nitrogen Recovery from Soils.....	131
Plant Nitrogen Uptake .....	134
Fertilizer Nitrogen Losses.....	138
Fertilizer Nitrogen Utilisation Efficiency .....	140
Yield Components .....	142
Dry Matter Production .....	144
 Experiment V : Field Evaluation of Nitrogen Efficiency of Inhibitors and Soluble Salts Treated Urea.....	 147
Plant Nitrogen Uptake .....	147
Yield Components .....	152
Dry Matter Production .....	154



	Page
<b>V SUMMARY AND CONCLUSIONS .....</b>	160
<b>BIBLIOGRAPHY.....</b>	168
<b>APPENDICES</b>	
<b>A Additional Tables.....</b>	181
<b>B Nitrogen and <sup>15</sup>N Analyses .....</b>	187
<b>BIOGRAPHICAL SKETCH .....</b>	201



## LIST OF TABLES

Table		Page
1	Physico-Chemical Properties of Soil Series Used for Urea Transformations Studies .....	31
2	Treatments Used in the Experiment II.....	35
3	Treatments Used in the Experiment IV.....	43
4	Treatments Used in the Experiment V.....	46
5	Lag Phase, Regression Coefficient, Half-Life and Rate Constants of Urea Hydrolysis in the Flooded Soils .....	53
6	Effects of Soils and Planting Methods on pH of Floodwater at Planting Following Urea Application.....	68
7	Effects of Soils and Planting Methods on pH of Floodwater at Maximum Tillering Stage Following Urea Application.....	69
8	Effects of Soils and Planting Methods on pH of Floodwater at Panicle Initiation Stage Following Urea Application.....	70
9	Influence of Soils and Planting Methods on Total Fertilizer Nitrogen Uptake by Plants at Maximum Tillering and at Maturity .....	73
10	Fertilizer Nitrogen Uptake by the Different Plant Parts as Affected by Soils and Planting Methods at Maximum Tillering Stage.....	75
11	Fertilizer Nitrogen Uptake by the Different Plant Parts as Affected by Soils and Planting Methods at Maturity .....	76
12	Fertilizer Nitrogen Recovery from Soil at Maximum Tillering and at Maturity in Different Soils and Planting Methods.....	79
13	Influence of Soils and Planting Methods on Total Nitrogen Uptake by Rice Plants at Maximum Tillering and at Maturity.....	82



14	Nitrogen Uptake by Stems, Leaves and Roots as Influenced by Soils and Planting Methods at Maximum Tillering Stage .....	83
15	Nitrogen Uptake by Grain, Stems, Leaves and Roots as Influenced by Soils and Planting Methods at Maturity .....	84
16	Effects of Soils and Planting Methods on Loss and Efficiency of Fertilizer Nitrogen at Maximum Tillering Stage .....	87
17	Effects of Soils and Planting Methods on Loss and Efficiency of Fertilizer Nitrogen at Maturity .....	88
18	Yield Components of Rice as Affected by Soils and Planting Methods .....	93
19	Effects of Soils and Planting Methods on Dry Matter Production at Maximum Tillering Stage.....	94
20	Effects of Soils and Planting Methods on Dry Matter Production of Rice at Maturity .....	95
21	Total Fertilizer Nitrogen Uptake by Rice Plants as Influenced by Inhibitors on Bakau and Cempaka Soils.....	103
22	Fertilizer Nitrogen Uptake by Grain, Stems, Leaves and Roots as Influenced by Inhibitors on Bakau and Cempaka Soils.....	105
23	Fertilizer Nitrogen Remaining in the Soils at Harvest of Rice Plants as Affected by Inhibitors.....	107
24	Total Nitrogen Uptake by Rice Plants as Affected by Inhibitors on Different Soils .....	109
25	Nitrogen Uptake by the Different Plant Parts of Rice as Influenced by Inhibitors on Bakau and Cempaka soils.....	111
26	Effects of Inhibitors on Loss and Efficiency of Fertilizer Nitrogen Applied to Different Rice Soils .....	113



	Page
27	Influence of Inhibitors on Yield Components of Rice Grown on Bakau and Cempaka Soils.. 116
28	Dry Matter Production of Rice as Influenced by Inhibitors on Different Soils..... 118
29	Plant Uptake of Total Fertilizer Nitrogen as Influenced by Soluble Salts on Bakau and Cempaka Soils..... 128
30	Fertilizer Nitrogen Uptake by Grain and Stems of Rice as Affected by Soluble Salts on Bakau and Cempaka Soils ..... 130
31	Fertilizer Nitrogen Uptake by Leaves and Roots of Rice as Affected by Soluble Salts on Bakau and Cempaka Soils..... 132
32	Recovery of Fertilizer Nitrogen from Bakau and Cempaka soils at Rice Harvest as Affected by Soluble Salts ..... 133
33	Total Nitrogen Uptake by Rice Plants as Affected by Soluble Salts on Bakau and Cempaka Soils ..... 135
34	Nitrogen Uptake by Grain and Stems of Rice as Influenced by Soluble Salts on Bakau and Cempaka Soils..... 137
35	Nitrogen Uptake by Leaves and Roots of Rice as Influenced by Soluble Salts on Bakau and Cempaka Soils ..... 139
36	Effects of Soluble Salts on Loss and Efficiency of Fertilizer Nitrogen Applied to Rice Grown on Bakau and Cempaka Soils..... 141
37	Yield Components of Rice as Affected by Soluble Salts on Bakau and Cempaka Soils..... 143
38	Influence of Soluble Salts on Dry Matter Production on Bakau and Cempaka Soils..... 145
39	Effects of Inhibitors and Soluble Salts on Nitrogen Uptake by Stems, Leaves and Roots at Maximum Tillering Stage ..... 148



	Page
40	Effects of Inhibitors and Soluble Salts on Nitrogen Uptake by Grain, Stems, Leaves and Roots at Maturity ..... 150
41	Effects of Inhibitors and Soluble Salts on Yield Components of Rice..... 153
42	Influence of Inhibitors and Soluble Salts on Dry Matter Production of Rice at Maximum Tillering Stage..... 155
43	Influence of Inhibitors and Soluble Salts on Dry Matter Production of Rice at Maturity ..... 157
44	Temperature of Floodwater at Planting Following the Application of Inhibitors Amended Urea ..... 182
45	Temperature of Floodwater at Maximum Tillering Stage Following the Application of Inhibitors Amended Urea ..... 183
46	Effects of Soils and Planting Methods on 1000- Grain Weight of Rice ..... 184
47	Effects of Soils and Inhibitors on 1000-Grain Weight of Rice ..... 185
48	Effects of Soils and Soluble Salts on 1000- Grain Weight of Rice ..... 186





## LIST OF FIGURES

Figure		Page
1	Hydrolysis of Solution Applied Urea Versus Time in Flooded Soils Fitted to First-order Kinetic Models.....	50
2	Hydrolysis of Solution Applied Urea Versus Time in Flooded Soils Fitted to First-order Kinetic Models.....	51
3	Urea Transformations in Flooded Soils .....	56
4	Urea Transformations in Flooded Soils .....	57
5	Changes of Urea-N Concentration in Floodwater of Different Soils after Urea Application at (A) Planting (B) Maximum Tillering and (C) Panicle Initiation Stages of Plant Growth .....	61
6	Changes of Ammonium-N Concentration in Floodwater of Different Soils after Urea Application at (A) Planting (B) Maximum Tillering and (C) Panicle Initiation Stages of Plant Growth .....	64
7	Effects of Planting Methods on Urea-N and Ammonium-N Concentrations in Floodwater at (A) Planting (B) Maximum Tillering and (C) Panicle Initiation Stages of Plant Growth.....	66
8	Nitrogen Losses at Different Stages of Growth on Six Soil Types.....	90
9	Changes of Urea-N and Ammonium-N Concentrations in Floodwater as Affected by Inhibitors Amended Urea Applied at (A) Planting (B) Maximum Tillering and (C) Panicle Initiation Stages of Plant Growth.....	98
10	Changes of Urea-N and Ammonium-N Concentrations in Floodwater as Affected by Soil Types after Inhibitors Amended Urea Applied at (A) Planting (B) Maximum Tillering and (C) Panicle Initiation Stage of Plant Growth .....	100





		Page
11	Changes of Urea-N and Ammonium-N Concentrations in Floodwater as Affected by Soluble Salts Together with Urea Applied at (A) Planting (B) Maximum Tillering and (C) Panicle Initiation Stages of Plant Growth .....	121
12	Changes of Urea-N and Ammonium-N Concentrations in Floodwater as Affected by Soil Types after Application of Soluble Salts Together with Urea at (A) Planting (B) Maximum Tillering and (C) Panicle Initiation Stages of Plant Growth.....	123
13	Changes of Urea-N and Ammonium-N Concentrations in Floodwater as Influenced by Soluble Salts Applied One Week After Urea at (A) Planting (B) Maximum Tillering and (C) Panicle Initiation S Plant Growth.....	124
14	Changes of Urea-N and Ammonium-N Concentrations in Floodwater as Influenced by Soil Types when Soluble Salts Applied One Week After Urea at (A) Planting (B) Maximum Tillering and (C) Panicle Initiation Stages of Plant Growth .....	126



## LIST OF ABBREVIATIONS

AE	=	Atom Excess
CRD	=	Completely Randomised Design
DCD	=	Dicyandiamide
DNMRT	=	Duncan's New Multiple Range Test
DS	=	Direct-seeded Rice
Eh	=	Redox Potential
HQ	=	Hydroquinone
IFDC	=	International Fertilizer Development Centre
IAAS	=	Institute of Agriculture and Animal Science
MARDI	=	Malaysian Agricultural Research and Development Institute
MOP	=	Muriate of Potash
MT	=	Maximum Tillering Stage
NBPT	=	N-(n-Butyl) Thiophosphoric Triamide
NdfF	=	Nitrogen derived from Fertilizer
OM	=	Organic Matter
PI	=	Panicle Initiation Stage
PAU	=	Punjab Agricultural University
PMA	=	Phenyl-Mercuric Acetate
P. Puteh	=	Pasir Puteh
PPD	=	Phenyl Phosphorodiamidate
PT	=	Planting Time



RCBD	=	Randomised Complete Block Design
SAS	=	Statistical Analysis System
T 1/2	=	Half Life
TP	=	Transplanted Rice
TSP	=	Triple Superphosphate
UPM	=	Universiti Pertanian Malaysia
USAID	=	United States Agency for International Development



Abstract of the Dissertation Submitted to the Senate of Universiti  
Pertanian Malaysia in Fulfilment of the Requirements for the Degree of  
Doctor of Philosophy

**NITROGEN EFFICIENCY OF UREA AMENDED  
WITH INHIBITORS AND CATIONS APPLIED TO RICE**

BY

**SHREE CHANDRA SHAH**

March, 1994

Chairman : Mohd. Khanif Yusop, Ph.D.

Faculty : Agriculture

Urea, the major source of nitrogen (N), is subjected to extensive gaseous N losses to the atmosphere. Ammonia ( $\text{NH}_3$ ) volatilisation and denitrification losses are important mechanisms for N losses from urea and are causes of poor fertilizer use efficiency by lowland rice. The study was undertaken in a series of five experiments to evaluate means of increasing the efficiency of urea-N under flooded rice soil conditions. A laboratory incubation experiment of different rice soils was conducted to study the kinetics and transformations of urea in flooded soils. A greenhouse experiment was carried out on marine and riverine alluvial soils to evaluate urea-N efficiency in direct-seeded (DS) rice and transplanted (TP) rice under similar N management practices using  $^{15}\text{N}$ -labelled urea. Two greenhouse and one field studies were conducted to evaluate the effectiveness of inhibitors and cations on marine and riverine alluvial rice soils on the efficiency of urea-N using  $^{15}\text{N}$  recovery techniques.



Urea hydrolysis followed the first-order kinetics and rate constants ranged from  $-0.032$  to  $-0.076 \text{ ha}^{-1}$ . A lag phase existed in flooded soil conditions and it varied from 6 to 15 hours. The half-life of urea ranged from 12 to 26 hours. Urea conversion to  $\text{NH}_4^+\text{-N}$  was initially rapid with about three-fourths being converted within 48 hours of incubation and total conversion completed within 108 hours.

Urea hydrolysis in the floodwater of marine and riverine alluvial soils was completed within five days after urea application. The rate of urea-N and  $\text{NH}_4^+\text{-N}$  disappearance from floodwater at MT (Maximum Tillering) and PI (Panicle Initiation) stages was faster than at PT (Planting Time). Urea-N and  $\text{NH}_4^+\text{-N}$  concentration in floodwater of DS rice was lower than of TP rice. Lower fertilizer N losses and higher fertilizer N use efficiency by DS rice in both soils gave significantly higher yield of rice than by TP rice at MT stage and at maturity. Fertilizer N losses occurred mainly before maximum tillering.

Significantly higher urea-N and lower  $\text{NH}_4^+\text{-N}$  concentrations persisted in the floodwater of Phenyl phosphorodiamidate (PPD) amended urea than of Hydroquinone (HQ), Dicyandiamide (DCD) and urea alone at PT, MT and PI stages. Hydroquinone was not effective in retarding urea hydrolysis in floodwater but it was probably very effective in retarding denitrification. Uptake of fertilizer N and total N were increased with the addition of HQ, PPD and DCD amended urea as compared to urea alone in both soils. Fertilizer N use efficiency was higher in Bakau soil than in Cempaka soil. Hydroquinone and PPD treated urea enhanced retention of



fertilizer N in soils. Higher fertilizer N use efficiency due to HQ and DCD treated urea increased grain yield over urea alone. However, PPD amended urea did not increase yield of rice despite increased fertilizer N uptake. Soluble salts amended urea increased  $\text{NH}_4^+$ -N concentration in the floodwater than urea alone or soluble salts applied one week after urea application. Additions of soluble salts amended urea increased plant uptake of fertilizer N by reducing fertilizer N losses in both soils. Bakau soil immobilised more fertilizer N than Cempaka soil. Grain yield obtained from urea amended with Ca and K was significantly higher than from urea alone under greenhouse and field studies. In the field study, inhibitors and soluble salts co-applied with urea significantly increased N uptake by plants.

Higher efficiency of fertilizer N use in DS rice could be further exploited to increase grain yields. Effect of HQ on denitrification in lowland rice soils needs further testing. Effects of PPD on the N uptake and metabolism of urea within the plant need to be tested. Urea amended with Ca and K may offer a significant advantage over urea alone in reducing  $\text{NH}_3$  losses from urea in flooded rice soil by Ca precipitation mechanism but further research to quantify those effects is needed.



Abstrak Disertasi Yang Dikemukakan Kepada Senat Universiti Pertanian Malaysia Sebagai Memenuhi Syarat Keperluan Untuk Ijazah Doktor Falsafah.

**NITROGEN EFFISIENSI UREA YANG DIRAWAT  
DENGAN BAHAN PENGHALANG DAN KATION YANG  
DIGUNAKAN KEPADA PADI**

OLEH

**SHREE CHANDRA SHAH**

Mac, 1994

Pengerusi : Mohd. Khanif Yusop, Ph.D.  
Fakulti : Pertanian

Urea ialah suatu baja pembekal nitrogen yang penting, mengalami kehilangan N yang tinggi ke atmosfera dalam bentuk gas. Pemeruapan ammonia dan denitrifikasi suatu mekanisme kehilangan N dari urea yang penting dan ia merendahkan efisiensi penggunaan baja N oleh padi. Kajian yang mengandungi lima ujikaji dijalankan bertujuan untuk menilai kaedah yang boleh meninggikan efisiensi N daripada urea dalam keadaan tanah sawah yang terendam. Satu kajian pemeraman di makmal ke atas berbagai jenis tanah sawah di jalankan bagi mengkaji kinetik dan transformasi urea dalam tanah terendam. Satu kajian di rumah kaca dijalankan ke atas tanah lanar laut dan sungai untuk menilai efisiensi N dari urea untuk padi tabur terus (TT) dan padi tanam semai (TS) dengan pengurusan N yang sama dengan menggunakan urea yang ditanda dengan  $^{15}\text{N}$ . Dua kajian rumah kaca dan satu kajian ladang, dijalankan bagi menilai keberkesanan bahan penghalang dan kation pada tanah lanar laut dan sungai ke atas efisiensi N dari urea dengan menggunakan teknik  $^{15}\text{N}$ .





Hidrolisis urea mengikuti kinetik tertib pertama dan pemalar kadar dalam julat  $-0.032 - -0.076 \text{ ha}^{-1}$ . Fasa lambat berlaku dalam tanah terendam air dan tempohnya di antara 6 hingga 15 jam. Nilai setengah hayat urea adalah di antara 12 hingga 26 jam. Kadar perubahan urea kepada  $\text{NH}_4\text{-N}$  adalah cepat pada peringkat awal dengan tiga suku daripadanya di tukarkan dalam masa 48 jam semasa pemeraman dan pertukaran kesemuanya berlaku dalam 108 jam.

Hidrolisis urea dalam air pada tanah lanar laut dan sungai tamat dalam masa 5 hari selepas penaburan urea. Kadar kehilangan urea dan  $\text{NH}_4$  daripada air pada pengeluaran anak maksimum (PM) dan permulaan pembentukan bulir (PB) adalah lebih cepat daripada mula menanam (MM). Kepekatan urea dan  $\text{NH}_4\text{-N}$  dalam air bagi padi TT adalah lebih rendah daripada padi TS. Padi TT mempunyai hasil yang lebih tinggi daripada padi TS, kerana kehilangan baja N yang rendah dan efisiensi penggunaan baja N yang tinggi. Kebanyakan kehilangan baja N berlaku sebelum PM.

Di dalam air yang menerima rawatan phenyl phosphorodiamidate (PPD), kandungan urea adalah lebih tinggi dan  $\text{NH}_4$  lebih rendah daripada kandungan dalam air yang dirawat dengan urea bersamaan Dicyandiamide (DCD) dan urea sahaja pada MM, PM dan PB. Hydroquinone (HQ) tidak berkesan menghalang hidrolis urea dalam air tetapi mungkin berkesan menghalang denitrifikasi. Jumlah penyerapan N dan penyerapan baja N bertambah dengan rawatan urea bersama HQ, PPD dan DCD berbanding dengan rawatan urea sahaja pada kedua-dua tanah yang dikaji. Efisiensi penggunaan baja N pada tanah Bakau adalah lebih tinggi daripada tanah



Cempaka. Hydroquinone dan PPD meningkatkan kehadiran baja N dalam tanah. Peningkatan efisiensi penggunaan baja N oleh urea yang dirawat dengan HQ dan PPD menambah hasil bijirin pada berbanding dengan rawatan urea sahaja. Urea yang dirawat dengan PPD tidak meningkatkan hasil padi walaupun pengambilan baja N meningkat.

Urea yang dirawat dengan garam larut meningkatkan kepekatan  $\text{NH}_4^+$  N dalam air berbanding dengan rawatan urea sahaja atau rawatan garam larut yang ditambah selepas satu minggu penambahan urea. Penambahan urea yang dirawat dengan garam larut meningkatkan pengambilan baja N dengan mengurangkan kehilangan N daripada kedua jenis tanah. Tanah Bakau mengikat lebih banyak baja N daripada tanah Cempaka. Di rumah kaca atau di ladang hasil bijirin yang diperolehi dari rawatan urea yang dirawat dengan Ca dan K adalah lebih tinggi daripada rawatan urea sahaja. Dalam kajian di ladang kimia penghalang dan garam larut yang dirawat bersama urea meningkatkan pengambilan N oleh tumbuhan.

Effisiensi penggunaan baja N yang lebih tinggi oleh padi TT boleh dieksploitasikan bagi peningkatan hasil. Kesan HQ terhadap denitrifikasi dalam tanah sawah perlu kajian lanjut. Kesan PPD terhadap pengambilan N dan metabolisme urea di dalam tumbuhan perlu kajian lanjut. Urea yang dirawat dengan Ca dan K memberikan kesan yang baik berbanding dengan rawatan urea sahaja dengan mengurangkan kehilangan  $\text{NH}_3$  dari urea dalam tanah sawah dengan mekanisma perecipitasi Ca tetapi kajian yang lebih lanjut diperlukan untuk mengkaji kesan tersebut secara kuantitatif.