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Urea as the Nitrogen Source in NFT Hydroponic System

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ABSTRAK

Unsur nitrogen dalam larutan nutrien hidroponik cara NFT (nutrient film technique) menjalani proses hidrolisis dengan pengeluaran ammoniam. Hidrolisis urea berlaku dengan pesat dari hari ketujuh dan tamat pada hari keduapuluh. Dalam masa yang sama jumlah ammoniam dalam larutan meningkat dan mencapai tahap maksima pada hari keduapuluh. Penitratan berlaku serentak dan kepekatan nitrat mencapai maksima pada hari keduapuluh juga. Berat kering tanaman pada peringkat matang tidak berbeza antara larutan rawatan urea dan rawatan nitrat. Kepekatan ammoniam dalam daun dan akar rawatan urea adalah tinggi dari rawatan nitrat. Kepekatan nitrat dalam daun dan akar tidak berbeza diantara kedua dua rawatan tersebut. Kajian menunjukkan urea dapat menggantikan nitrat sebagai sumber unsur nitrogen untuk tanaman dalam sistem hidroponik cara NFT.

ABSTRACT

Urea as the source of nitrogen in the nutrient solution in NFT (nutrient film technique) hydroponic system undergoes hydrolysis which results in the release of ammonium in solution. Urea hydrolysis was rapid from the 7th day onwards and ended by the 20th day. At the same time, ammonium concentration in solution increased and reached its maximum on the 20th day. Nitrification occurred simultaneously and peaked also on the 20th day. Plant dry matter weight at harvest was similar for both urea and nitrate treatments. Ammonium concentration in leaves and roots was higher in urea than in nitrate treatments. Nitrate concentration in leaves and roots was similar for both treatments. The study showed that urea can be substituted for nitrate as the nitrogen source in the NFT hydroponic system.

INTRODUCTION

The source of nitrogen in the nutrient solution for the growing of crops under the hydroponic system has been in the forms of $Ca(NO_3)_2$ and KNO_3 (Cooper 1975). Even though urea is increasingly being used as the main source of nitrogen fertilizer for crops grown on soil (Gould *et al.* 1986), its use as the N source for crops grown under the hydroponic system has yet to be evaluated. One of the reasons which could hinder the use of urea in hydroponics is that urea has to undergo hydrolysis with the release of NH_4^+ and subsequent formation of NO_3^- through nitrificaton, forms that are utilised by the plants. Hydrolysis of urea proceeds through enzymatic catalysis of urease (Vlek *et al.* 1980). In soils urease activity is located in the soil biomass and solution originating from decaying organisms (Skujins 1976; Vlek *et al.* 1980). There is also evidence that soil urease activity may be derived from plants (Frakenberger and Tabatabai 1982). It has also been shown that floodwater of tropical lowland rice soils has measurable amounts of urease activity (Sahrawat 1980), which could possibly originate from the soil.

Since the presence of urease has always been associated with soil, its presence in the nutrient solution in the hydroponic system devoid of soil therefore is of interest. Since bacteria can proliferate in nutrient solution and urease originates from bacteria cells, the possible presence of urease in nutrient solution media and hydrolysis of urea in the solution therefore is great.

The objective of this study was to examine the possibility of using urea as the nitrogen source in the nutrient solution in the hydroponic system by following its transformation in the nutrient solution and the performance of *Brassica chinensis* grown in it.

MATERIALS AND METHODS

The NFT (nutrient film technique) of soilless culture with plants grown in channels fed with recirculating nutrient solution was used (Cooper, 1975). The container which held the recirculating nutrient solution had a capacity of 50 l. The channels were 3.7 m long, 30 cm wide and 5 cm high. These channels were constructed from 1 cm thick plywood. The inner surface of the channels was covered with polyethene sheets along which the solution flowed and bathed the plant roots. A submersible pump in the container delivered the solution through 2 cm (diameter) PVC pipes from the container to the top of the channel, discharging the solution through a 5 mm tube at the rate of 2 l/min. The channels were elevated at the top end (10 cm higher) so that the solution would flow in a thin film on the surface of the channel to the bottom end and into the container and then recirculated. Each replicate of a treatment consisted of the channel, a container and a pump. Three replicates were used for each treatment. The experiment was run in the greenhouse in a complete randomized design. Mini pak choy (*Brassica chinensis* var Ching Chiang -Taiwan) seeds were sown on rockwool blocks 6 cm^2 and 40 cm in length for each block; nine blocks were used for each channel.These blocks were placed at the centre of the channels. Three seeds were placed at each point, 8 cm apart. Each rockwool block had 5 plants. Thinning was done on the tenth day leaving one plant per point. The total number of plants per channel at the start of the experiment was 45. Since the concentration of urea in the solution had to be monitored continuously for the whole period of the plant growth, elemental nutrients were added to the solution for plant need, based on the electrical conductivity (E.C.) of the solution; the element content of the solution was analysed on the 20th day to ensure that all elements with the exception of N were adequate for plant need. Plants were observed for deficiency symptoms. Cooper and Charlesworth (1977) concluded that addition of nutrients under the NFT based on the readings of the E.C. and the solution pH was adequate to produce equivalent tomato yield compared to nutrient addition based on nutrient analysis.

Treatments

The standard nutrient formulation used was based on Cooper (1975) (Table 1). The other three treatments were 100% N-urea (No.2), mixture of 50%N-nitrate and 50%N- urea (No.3) and 75%N-urea and 25%N-nitrate (No.4). An accompanying treatment (No.5) similar to (No.2) but without plants grown was included. $CaCl_2$, KOH and K_2SO_4 were substituted for the $Ca(NO_3)_2$ and KNO_3 for treatments containing urea, resulting in some treatments having higher sulphur and chloride contents which, however, did not exceed toxic levels. pH of the solution was maintained at between 5.5-6.5 by adding HCl or NaOH. Electrical conductivity (E.C.) of the solution was maintained at 2.4 dS m^{-1} until the plants were harvested. Solution E.C. which fell below this value was replenished with the stock solution of the respective treatments. Amounts added to each treatment are given in Table 2. Water loss through evapotranspiration was replaced with tap water to the 50 l mark daily.

Sampling

Solution samples were taken daily for the first seven days and thereafter on the 10th, 20th,

TABLE 1
Chemical make-up of the various treatments

Source	Treatments (g/1000)				
	1	2	3	4	5
urea	–	480	240	360	480
KH_2PO_4	272	272	272	272	272
KNO_3	808	–	808	404	–
$Ca(NO_3)_2$	943	–	–	–	–
$CaCl_2$	–	588	588	588	588
$MgSO_4$	492	492	492	492	492
KOH	–	224	–	112	224
K_2SO_4	–	348	–	174	348
$MnSO_4$	5.27	5.27	5.27	5.27	5.27
H_3BO_3	3.03	3.03	3.03	3.03	3.03
Na_2MoO_4	.027	.027	.027	.027	.027
$ZnSO_4$	.22	.22	.22	.22	.22
$CuSO_4$	.05	.05	.05	.05	.05
EDTA-Fe	19.48	19.48	19.48	19.48	19.48

TABLE 2
Nitrogen supplement during the period of plant growth

Treatments	NO_3-N (g)	Urea-N (g)
T1	14.79	–
T2	–	6
T3	19.78	8.7
T4	7.38	10.8
T5	–	–

30th and the 40th day. Plants were harvested on the 40th day. PMA (phenylmercuric acetate) was added to samples to retard hydrolysis of urea before analysis of the samples was done. Samples were analysed for NO_3^- and NH_4^+ (Bremner 1965) and urea (Douglas and Bremner 1970).

Plant samples were taken on the 20th, 30th and the 40th day. For the first two samplings, 9 plants (one from each rockwool block taken at random) were harvested from each channel. The tops and roots were separated and weighed. The final harvest comprised 27 plants. They were oven dried, reweighed and ground. For analysis of NH_4^+ and NO_3^- in the samples, 1 g sample (oven dry) was shaken with 50 ml distilled water for 1 hr and the extract filtered. 10 ml of the extract was determined for NO_3^- and NH_4^+ (Woolley *et al.* 1960).

RESULTS AND DISCUSSION

Results of the analysis of the nutrient solution on the 20th day (Table 3) indicated that the macronutrient element content was adequate (Cooper and Charlesworth 1977). The elements content in the leaves at harvest also indicated that their concentration in plants were adequate (Table 3). Visual observation of the plants indicated no apparent nutrient deficiency except that the 100% N-urea treatment had darker green leaves than those in the other treatments.

Urea concentration in solution of treatments containing urea dropped rapidly from the 7th day onwards which showed that it had been hydrolysed. By the 20th day all the urea was depleted from the nutrient solution (*Fig. 1*). In soils urea is found to be fully hydrolysed within 3 days after application mostly in the form of NH_4^+ and by the 14th day most are in the NO_3^- form (Gasser, 1964; Bundy and Bremner 1974). Decrease in the urea concentration of the solution in treatments containing urea was rapid from the 7th day onwards. Loss of urea in the 100% N- urea with plant treatment was greater compared to the same treatment without plants on the 10th day. It is possible that the urease activity was greater in solution where plants were present. Elliott (1986) found hydrolysis of urea in cropped media more rapid than in uncropped media. Between the 1st and 7th day the urea loss was about 5%. Between the 7th and 10th day, urea in solution of cropped treatments decreased by 30%. Most of the urea was hydrolysed between the 10th and 20th day. Ammonium in the solution was detected as early as the first day after the start of the experiment in all the treatments receiving urea, indicating that hydrolysis of urea occurred immediately.

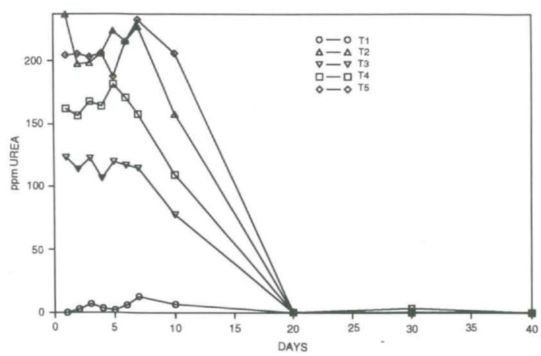

Fig. 1: Urea concentration in solution of the various treatments

Ammonium in Solution

Ammonium concentration in the nutrient solutions increased until the 20th day, thereafter its concentrations began to decline except in the treatment without plants (*Fig.2*). Plant uptake and the transformation of NH_4^+ to NO_3^- via nitrification are the possible reasons for the decline after the 20th day. Furthermore, its source, urea, had been depleted by that time. Ammonium concentration in solution depended on the amount of urea in the treatments. High urea levels resulted in high NH_4^+ concentrations. The highest NH_4^+ concentration was recorded in the 100% N-urea treatments. With plant growth the decrease was higher which could be due to plant uptake and increased nitrification. Decline in NH_4^+ concentration in the treatment without plants after the 20th day was slight. 75% and 50% N- urea treatments attained maximum NH_4^+ concentration on the 20th day and the NH_4^+ concentrations were in proportion to the amount of urea added. It can therefore be said that rate of hydrolysis of urea was not affected by the amount of urea present within the amounts of urea used in the experiment. This showed that urease was a non-limiting factor. Several researchers have found that in soils the rate of urea hydrolysed by soil urease increased with increase in urea concentration until the amount of urea added is sufficient to saturate the enzyme with the substrate (Douglas and Bremner 1971; Tabatabai and Bremner 1972; Dalal 1975).

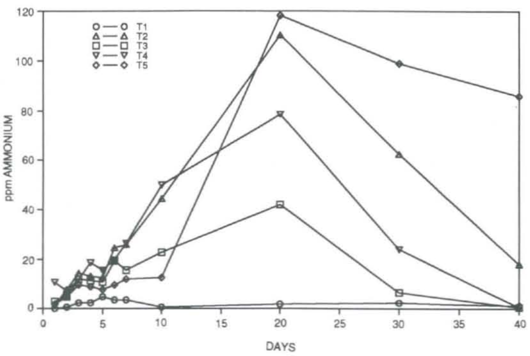

Fig. 2: NH_4^+ concentration in solution of the various treatments

Nitrate in Solution

The extent of nitrification occurring in the solution containing urea is shown in *Fig. 3.* Similar to the NH_4^+ buildup, NO_3^- increase in the nutrient solution was observed in the 100% N-urea treatments with and without plants; however the buildup started later (from the 7th day onwards). While treatments with 100% and 50% N-NO_3^- source declined for the period of 7- 10th day, treatments with 100%N-urea had NO_3^- concentration increased during the same period.

Maximum concentration of NO_3^- in the nutrient solution in the 100% N-urea treatments was attained on the 20th day. Subsequent periods showed no increase in nitrate concentration as shown by the 100% N- urea treatment without plants. At the 20th day the concentration of NH_4^+ was only one third of NO_3^-.

Ammonium buildup and nitrate formation in the treatments containing urea occurred simultaneously. While 100% N-urea treatment with plants had a NO_3^- concentration decrease after the 20th day, treatment without plants maintained the NO_3^- concentration until the 40th day. Nitrate concentration in treatments which contained urea decreased more sharply until the 40th day compared to plants in the 100% N-NO_3^- treatment.

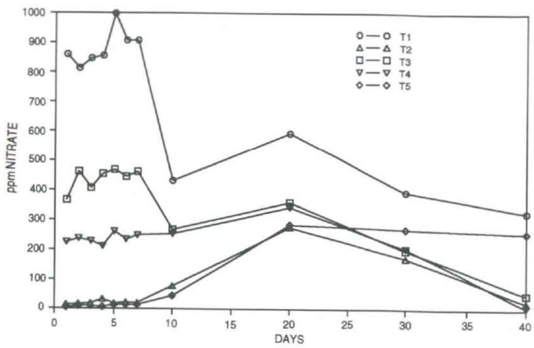

Fig. 3: NO_3^- concentration in solution of the various treatments

Total N in solution

Summation of the various forms of N (NO_3^-, NH_4^+ and urea) in the solution of the treatments is presented in *Fig. 4.* Total N remained the same for the first 7 days. From the 7th to 10th day total N of treatments 100% and 50% N-NO_3^- was lower compared to the others. From the 10th to the 20th day , 100% and 75 % N- urea treatments decreased in total N value. Further decline in total N occurred in all treatments except the one without plants from the 20th to the 30th day. At the 40th day, treatments which contained urea had lower values compared to 100% N- NO_3^- treatment. From the 20th day onwards the treatment without plants maintained its total N to the end.

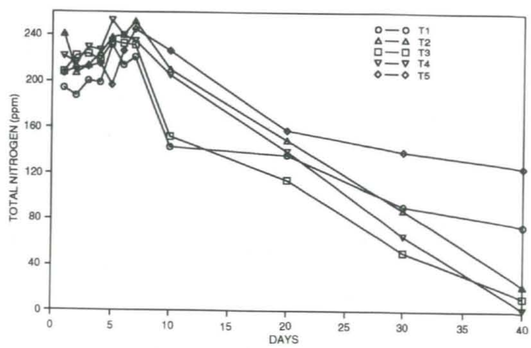

Fig. 4: Total N in solution of the various treatments

TABLE 3
Macronutrient concentrations in the solution (ppm) on the 20th. day and in the leaves at harvest (%)

Elements		Treatments			
		1	2	3	4
K	(solution-s)	306	332	249	263
	(leaves-l)	11.5	8.5	8.2	8.4
P	(s)	29	52	32	39
	(l)	1.33	1.10	1.04	1.22
Ca	(s)	175	214	227	200
	(l)	3.70	3.08	3.09	3.25
Mg	(s)	68	42	43	42
	(l)	.63	.56	.43	.50
N	(l)	4.97	5.51	5.18	4.4

Plant dry weight

Plant dry weight on the 20th day for 100% N-urea treatment was the lowest recorded and was significantly different ($P<0.05$) from those of 100% and 50% N-nitrate treatments (Table 4). This initial difference in the dry weight can be attributed to the time taken for urea to be hydrolysed before NH_4^+ and the subsequent release of NO_3^- in the solution for plant use. On the 30th day, the plant dry matter weight of the 100% N- nitrate treatment was not significantly different from that of 100%N-urea treatment. However, the two treatments with mixtures of urea and nitrate registered the highest value. Studies by Cox and Reisenauer (1973) have shown that mixtures of NH_4^+ and NO_3^- in solution give higher yield than those of NO_3^- or NH_4^+ supplied singly. Moneerat *et al.* (1982) reported that maximum dry weight was achieved with a ratio of 60: 40 (NH_4^+: NO_3^-) in the solution. Dry matter weight on the 40th day showed no significant difference among the four treatments (Table 4).

Total N Uptake by Plants

Total N uptake values normally follow dry matter weight figures. Total N uptake values of *Brassica* at harvest (40 days) were not significantly different among treatments. The 50% N-urea and 50% N-nitrate mixture recorded the highest N uptake value of 3.16 g. Baker and Maynard (1972) reported that maximum N absorption by plants was achieved when NH_4^+ and NO_3^- were combined in the nutrient solution. The amount of N taken up by the plants accounts for 80% of the N supplied in the solution.

Ammonium in Roots

The percent coefficient of variation (%C.V.) of the NH_4^+ content in the plant roots on the 20th day growth stage was high due to the problem of separating the roots from the rockwool media. At this stage the roots were very fine and were firmly embedded in the media making the task of separation difficult. At the 30th and 40th day, the roots were thicker and bigger and the rockwool was softer making the task of separation easier. This was reflected in the decreasing trend in the C.V. value as the plants matured. No significant difference in ammonium concentration in the plant roots of the 20- and 30-day-old plants of the various treatments was observed (Table 4). Plants treated with 100% N-nitrate did contain NH_4^+ in the roots. The reduction and assimilation of NO_3^- in the roots produce NH_4^+ as an intermediary product (Pate 1973). NH_4^+ concentration in the roots of the 30- and 40-day old plants treated with 100%N-urea was higher than those treated with 100%N-nitrate. Pill and Lambert (1977) noted that in general, plants supplied with NH_4^+ have a higher concentration of free NH_4^+ than plants grown at comparable levels of NO_3-. NH_4^+ accumulation in the roots of the 100% N-urea treatment could also be due to the slow conversion of NH_3^- into glutamine which is a function of the carbohydrate supply (Vickery *et al.* 1936).

Ammonium in Leaves

Ammonium concentration in the leaves of 20-day-old plants treated with 100% N-urea was higher than that in plants in the 100% N- nitrate treatments (Table 4). Pate and Wallace (1964) found that the bulk of the NH_4^+ absorbed by roots is converted to amino acids by the metabolic system of the roots and only a small percentage of the NH_4^+ is found in the xylem exudate presumably transported to the leaves for assimilation. It is possible that in leafy vegetables, the leaves play a major role in the assimilation of NH_4^+ which thus results in concentration of NH_4^+ in leaves being comparable to that in the roots. On the 30th day , NH_4^+ concentration in the leaves in all the treatments was similar.

TABLE 4
Dry matter yield, total N, NH_4^+ and NO_3^- content of pak choy

		C.V. (%)	Treatments 1	2	3	4
Dry matter yield (g/9 plants)						
D	20	21.89	1.26 a	0.75 b	1.26 a	1.21 ab
a	30	30.70	16.5 ab	10.77 b	21.61 a	19.43 ab
y	40	19.95	135.18 a	147.69 a	184.91 a	187.38 a
Total N uptake (g/9 plants)						
Day	40	23.86	2.20 a	2.75 a	3.16 a	2.76 a
NH_4 (roots) ppm						
D	20	91.58	824.6 a	803.6 a	200.0 a	304.3 a
a	30	29.72	570.0 b	1247.8 a	1470.0 a	1320.0 a
y	40	14.92	2010.0 b	2910.0 a	2610.0 ab	2610.0 ab
NH_4 (leaves) ppm						
D	20	43.66	324.5 b	693.8 a	330.0 b	360.0 ab
a	30	28.13	1260.0 a	1620.0 a	1680.0 a	1350.0 a
y	40	23.79	1680.0 b	2790.0 a	2100.0 ab	2340.0 ab
NO_3 (roots) %						
D	20	54.60	2.13 a	1.10 ab	0.90 ab	0.73 b
a	30	47.99	0.30 a	0.40 a	0.36 a	0.20 a
y	40	46.41	0.10 a	0.09 a	0.12 a	0.10 a
NO_3 (leaves) %						
D	20	46.30	3.27 a	2.27 a	2.73 a	2.38 a
a	30	33.78	2.48 a	1.63 ab	1.55 ab	1.21 b
y	40	46.93	1.01 a	0.99 a	1.21 a	0.89 a

Means with the same letter in a row are not significantly different at 0.05 using DMRT.

This period coincides with the high concentration of NH_4^+ in the nutrient media. As the concentration of NH_4^+ in solution started to fall by the 40th day, NH_4^+ concentration in leaves of 100%N-nitrate plants decreased. Since 100% N-nitrate treatment plants had less than 5% NH_4^+ content in the nutrient solution, we can deduce that the NH_4^+ present in the the leaves was from the reduction of NO_3^-. The NH_4^+ concentration in the leaves increased as the plant matured.

Nitrate in Roots

Nitrate concentration in roots was in contrast with that of NH_4^+. Whilst the concentration of NH_4^+ increased with plant growth, NO_3^- concentration decreased. NO_3^-: NH_4^+ concentration ratio was >20 in the 20-day-old plants and was <1 in the 40-day-old plants. Increased NO_3^- assimilation to amino acids in plants as they mature could be the reason for the fall in NO_3^- concentration. No significant difference in % nitrate in roots of plants treated with 100% N-nitrate and 100% N-urea at the 20th, 30th and 40th day was observed.

Nitrate in Leaves

NO_3^- concentration in the leaves of pak choy was higher than in the roots. Pate(1973) found that the reduction of NO_3^- concentration in the leaves is relative to the roots and varies widely among plant species. It is possible that NO_3^- assimilation in the leaves of pak choy is more intense than in the roots. In maize plants, the roots were found to reduce about 1/3 of the nitrate and the percentage of NO_3- reduction decreased as the plant aged (Raghuveer 1977). No significant difference in % nitrate in leaves between treatments was observed at the three plant growth stages (Table 4). The amount of NO_3^- in the leaves decreased as the plant growth increased. Percent NO_3^- was ten-fold higher than NH_4^+ in the leaves, the ratio being greater when plants were young.

CONCLUSION

Urea as the source of N used in nutrient solution in the NFT hydroponic system undergoes hydrolysis with the release of NH_4^+ and the subsequent formation of NO_3^-. The urea was completely hydrolysed by the 20th day. There was no difference in either the plant dry weight in the 100% N-urea or 100% N-nitrate treatments at harvest. NH_4^+ concentration in roots and leaves was higher in the 100% N-urea treatment than in the 100% N-nitrate treatment. No difference in NO_3^- concentration in roots and leaves of 100% N-nitrate and 100% N-urea treatments was detected. The study showed the possibility of using urea as the N source for the NFT hydroponic system in crop production.

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