FERTIGATION WITH A UREA SOLUTION OF SUGARCANE IN A CLAY SOIL

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ABSTRACT

The movement and transformation of N and the effect of urea on pH in the fertigated soil volume were investigated in a heavy-textured soil of a sugarcane field. The practice of fertigation involved the urea solution being pumped into the irrigation water by means of an automatic fertilization apparatus and transported into the field through an underground pipeline system. Nitrogen transformation was confined to the 200 mm surface layers of soil and pH changed for a short period of about two weeks and then returned to the initial value. The ammonium level reached a maximum three days after fertigation thereafter it declined with time by the process of nitrification. The decreasing patterns of NH$_4^+$-N after urea hydrolysis could be described by the first-order reaction kinetics. The rate constant ranged from 0.0033 to 0.0018 h$^{-1}$ and decreased with soil depth. Nitrate accumulation reached a maximum in the topsoil layers five days after fertigation and then declined. Substantial difference in nitrate redistribution and infiltration patterns in the subsoil layers was observed, but no evidence of loss by leaching was found. These results show that the use of fertigation for sugarcane on a clay soil is feasible.

Key words: Ammonium, fertigation, furrow irrigation with underground pipeline, nitrate, nitrogen, urea.

INTRODUCTION

The application of fertilizer N should receive more attention in its overall management because of its transient nature in soil, and its potential for becoming a pollutant of air and water. Investigation of the soil N budget indicated that only 16% to 25% of the added N was recovered during the entire growing season of sugarcane. The remainder might be lost by volatilization, denitrification and leaching. The most efficient use of fertilizer N may result when N application coincides with the period of rapid plant uptake. For maximum fertilizer efficiency N application should be divided into two or more periods during the long term (12-18 months) growing season, depending on the soil and climatic conditions. However this method will increase operation costs and the use of field equipment is usually limited to the early stages (0-4 months) of crop growth.
In order to overcome technical problems in mechanical cultivation of sugarcane and to apply N to meet the crop demand, a method of fertigation has been developed for sandy soils . The fertigation practice requires that the dissolved urea solution be pumped into irrigation water by an automatic fertilization apparatus and then transported via an underground pipeline system to the irrigation furrows. Fang et al. described the method and construction of the irrigation system and fertilization layout and discussed the characteristics and advantages of the method. The use of fertigation on a sandy loam resulted in a fairly even distribution of N in the soil and permitted more efficient and profitable than the conventional methods.

In the foreseeable future economic factors and labor-saving strategies will be the major considerations for sugarcane production in Taiwan. Fertigation appears to be one of the methods that may achieve a reduction in production costs. The purpose of this study was to monitor the lateral and vertical movements and the transformation of N after fertigation, and also to investigate the effect of urea on soil pH for elucidating the feasibility of fertigation in a clay soil.

**MATERIALS AND METHODS**

**Experimental site and field treatments**

The experiment was conducted at Nankunshui Farm, Kaohsiung Sugar Mill, from July 1989 to January 1991. A 7.5 ha sugarcane field with clay soil was divided into four plots of equal size for the fertigation and control treatments. Each plot received 40 kg/ha of N-P-K granular fertilizer before the sugarcane was planted. Sugarcane variety ROC 1 was planted in August 1989 to obtain an initial density of about 24,000 plants/ha.

The control plots were top-dressed mechanically with granular urea on 4 January 1990. The fertigated plots received a urea solution applied with the irrigation water on 29 May 1990. In both treatments the fertilizer N was applied at a rate of 160 kg/ha.

The fertigated plots were irrigated for 22 h on 19 May 1990 with 50 mm water containing the dissolved urea solution. The control plot was irrigated with the same quantity of water on 30 May 1990. Mean daily minimum and maximum air temperatures during the fertigation period were 20°C and 30°C, and soil temperatures (100 mm depth) were 25°C and 29°C respectively.

**Soil sampling and analysis**

The humic clay soil is slightly acid (initial pH = 6.3) and the texture of the topsoil (0-200 mm) and subsoil (200-500 mm) is silty clay loam and silty clay respectively.
Before and after fertigation, soil samples were taken with a 30 mm auger at depths of 0-50, 50-100, 100-150, 150-200, 200-350, 350-500, 500-650, 650-800 and 800-1000 mm from each of 3 sampling sites in the fertigation and control plots. The samples were collected before fertigation (day 0), and subsequently at days 1, 2, 3, 4, 5, 7, 11, 17 and 22 after fertigation to investigate the fate of the fertilizer N applied.

The concentrations of ammonium, nitrate and urea-N in the soil samples from each depth and sampling time were measured. Fifteen grams soil (dry weight basis) were shaken in 100 ml of 2M KCl containing 50 μM phenylmercuric acetate for 1 hr and then filtered. The exchangeable ammonium of the filtered extracts was determined by the indophenol blue method, urea concentration was analyzed by a modified diacetyl monoxime method, and nitrate content by the Brucine method. Soil moisture content of each soil sample was determined gravimetrically by drying for 24 hr at 105°C to calculate the quantity of mineral-N on an oven-dry soil basis (mg N/kg soil).

### RESULTS

#### Fertigation and nitrogen in irrigation water

Fertilization and irrigation were synchronized by an apparatus designed to automatically control the water applied and the concentration of urea in the water. The urea solution and irrigation water sampled before fertigation. Fertigation water containing urea was sampled at random sites during fertigation. Table 1 shows the chemical properties of urea solution and water samples. The concentrations of mineral-N in the fertigation water samples did not differ significantly, indicating that the urea solution was evenly mixed with irrigation water during fertigation.

#### TABLE 1. Chemical properties of urea solution, irrigation and fertigation water.

<table>
<thead>
<tr>
<th>Sample</th>
<th>pH</th>
<th>EC (mS/cm)</th>
<th>Ammonium-N (mg/L)</th>
<th>Nitrate-N (mg/L)</th>
<th>Urea-N (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urea solution</td>
<td>8.9±0.1</td>
<td>1.92±0.02</td>
<td>310±12</td>
<td>0.4±0.2</td>
<td>139371</td>
</tr>
<tr>
<td>Irrigation water</td>
<td>7.1±0.0</td>
<td>1.29±0.03</td>
<td>0.5±0.1</td>
<td>0.4±0.1</td>
<td>-</td>
</tr>
<tr>
<td>Fertigation water</td>
<td>7.2±0.1</td>
<td>1.30±0.03</td>
<td>1.2±0.1</td>
<td>0.4±0.1</td>
<td>348±37</td>
</tr>
</tbody>
</table>

* Three samples of urea solution and nine samples of irrigation and fertigation analyzed.

* Electrical conductivity.
Effect of urea on soil pH

Throughout the sequence of urea hydrolysis and subsequent nitrification, the soil pH altered appreciably in the upper 200 mm of soil (Figure 1). Soil pH increased from 6.8 to a maximum of 7.0 in the surface 50 mm zone of the furrow 3 days after fertigation, and slight soil acidification was observed at the depths of 100 to 200 mm. The movement and spatial redistribution of fertigated urea in clay soil was largely limited to the upper 100 mm layer. The effect of fertigated urea on soil pH lasted for only about two weeks when the pH returned to the original level. Soil pH below 200 mm did not change during the experiment period.

FIGURE 1. Soil pH change in 0-200 mm layers of soil following fertigation with urea solution.

Transformation of urea after fertigation

Extractable-N shown in Figure 2 is the summation of urea, ammonium and nitrate-N. The mean value of urea-N in fertigation water was 348 ppm (Table 1). The urea applied was concentrated in the upper 200 mm of soil and completely hydrolyzed within two days of fertigation. A significant content of urea-N was detected on the first day after fertigation and the amount declined with increasing soil depth. At the second day following fertigation a little urea-N was traced only in the 0-100 mm zone of the furrow.
The dominant N species present in the topsoil on the third day after fertigation was \( \text{NH}_3\text{-N} \) and on the fifth day was \( \text{NO}_3\text{-N} \) (Figure 2). Ammonium-N increased in the furrow during the first three days and thereafter decreased markedly with time. The increased amount of \( \text{NH}_3\text{-N} \) was approximately equivalent to the urea-N hydrolyzed and no significant nitrification had occurred during the first three day period. Thereafter \( \text{NH}_3\text{-N} \) in the soil was nitrified rapidly and a temporary accumulation of \( \text{NO}_3\text{-N} \) occurred in the upper soil layers (Figure 2).

![Figure 2: Distribution of ammonium, nitrate, and extractable N in 0-200 mm layers of soil following fertigation with urea solution.](image)
The pattern of decreasing NH$_4^+$-N in the topsoil layers showed a consistent trend with time (Figure 2) and the data fitted very well with the first-order kinetic equation. The value of rate constant, $k$, was determined from the semilogarithm plot of NH$_4^+$-N concentration and time. As shown in Table 2, the values of $k$ ranged from 0.0019 to 0.0033 h$^{-1}$ (with an average of 0.0025 and a standard deviation of 0.0005) and decreased with soil depth.

### TABLE 2. Parameters describing the first-order reaction kinetics for ammonium alteration after fertigation.

<table>
<thead>
<tr>
<th>Soil layer (mm)</th>
<th>Initial conc. of NH$_4^+$-N (mg/kg soil)</th>
<th>Rate constant, $k$ (h$^{-1}$)</th>
<th>Half-life (days)</th>
<th>Correlation coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 50</td>
<td>38.05</td>
<td>0.0033</td>
<td>8.7</td>
<td>0.9517</td>
</tr>
<tr>
<td>50 - 100</td>
<td>20.68</td>
<td>0.0026</td>
<td>11.1</td>
<td>0.9719</td>
</tr>
<tr>
<td>100 - 150</td>
<td>19.87</td>
<td>0.0021</td>
<td>13.8</td>
<td>0.9260</td>
</tr>
<tr>
<td>150 - 200</td>
<td>17.42</td>
<td>0.0019</td>
<td>15.5</td>
<td>0.9464</td>
</tr>
</tbody>
</table>

*a Relationship between ammonium concentration and time.*

### Distribution of mineral-N after fertigation

The distribution pattern of mineral-N in the topsoil layers after fertigation with urea solution is shown in Figure 2. At the third day, the proportions of mineral-N recovered in the ammonium form at 0-50, 50-100, 100-150 and 150-200 mm soil depth were 86, 79, 72 and 67% respectively. By five days approximately 50% of the recovered mineral-N was present as nitrate. The results shown in Table 3 indicate a fairly even distribution of mineral-N in the surface 200 mm of soil along the field after fertigation.

Distribution and infiltration of extractable-N between the 200 and 800 mm layers of soil following fertigation with urea solution are shown in Figure 3. The concentrations of NH$_4^+$-N below the 200 mm depth were higher in the layers from 200 to 650 mm after the first three days. However, it was significantly lower than the levels observed in the upper layers, indicating that the diffusion of surface applied urea solution was much slower as clay content increased. It is apparent from Figure 3 that the major component of N transformation in these layers was present in the nitrate form. Substantial leaching of NO$_3^-$-N in the deeper soil layers was observed. The increase of downward movement of NO$_3^-$-N was probably due to the heavy precipitation during the experiment period in which 311 mm of rainfall was measured in 8 days, but no evidence of leaching loss was found by sampling soil to a depth of 1000 mm and analyzing for nitrate.
TABLE 3. Distribution of mineral-N in the upper 200 mm of soil along the field at the third day after fertigation.

<table>
<thead>
<tr>
<th>Distance from point of application (m)</th>
<th>Extractable mineral-N in 0-200 mm layer (mg/kg soil)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-50 mm</td>
</tr>
<tr>
<td>30</td>
<td>48.8</td>
</tr>
<tr>
<td>60</td>
<td>42.9</td>
</tr>
<tr>
<td>90</td>
<td>41.4</td>
</tr>
<tr>
<td>Mean</td>
<td>44.4± 3.2</td>
</tr>
</tbody>
</table>

FIGURE 3. Distribution of extractable-N in 200-800 mm layers of soil following fertigation with urea solution.
DISCUSSION

The rapid hydrolysis of urea in the soil as described by Freney et al. probably occurred because it was applied as solution and permeated rapidly through the soil profile depositing the urea to the action site of urease in a large volume of soil. Most ammonium in the topsoil will be converted biologically to nitrate within two to three weeks at soil temperature of 25° to 30°C. Soil pH initially increased because of NH₄⁺CO₂-H₂O evolution after biological hydrolysis of urea, then decreased as nitrification proceeded. Microbial oxidation of fertilizer NH₄⁺ to NO₃⁻ results in liberation of 2 moles of H⁺ ion for each mole of NH₄ oxidized. The addition of H⁺ to the soil causes the pH of the soil solution to decrease until a buffer system becomes active. The pattern of changing soil pH observed in this study was quite different from the previous experiment conducted in a sandy soil in which the fertilizer N was probably evenly into the deep soil layers and changes of pH below 200 mm was obvious. However the changes in soil pH observed in this study reflected the balance between hydrolysis, nitrification and soil buffering capacity.

Weather conditions may influence the effect of fertigation in sugarcane fields. Excessive water supplied by unexpected rain after fertigation might result in nitrate leaching. Another potential problem with fertigation is that application of fertilizer may be delayed when irrigation is not necessary. Adoption of the fertigation practice however will depend primarily on economic considerations. It is less expensive (in terms of operation and labour costs) which is the focus of concern in sugarcane field management in Taiwan. Moreover, it provides an excellent opportunity for improving efficiency of N use, because N can be supplied whenever it is required by sugarcane throughout the growing season.

CONCLUSION

The use of fertigation for sugarcane grown in a heavy-textured soil is feasible. Nitrogen transformation was chiefly restricted to the topsoil and there was no deleterious impact on soil pH during fertigation. Under this management system, fertilizer N was evenly distributed in the field and leached into the root zone.
Further studies of application rates and timing of N fertilizer applied by this method will be made to determine the greatest benefits from the fertigation of sugarcane.

REFERENCES


LA FERTIGATION DE LA CANNE A SUCRE DANS UN SOL ARGLILEUX AVEC UNE SOLUTION D'UREE

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RESUME

Le mouvement et la transformation de l'azote ainsi que l'effet de l'urée sur le pH du volume de sol fertilisé furent étudiés dans un sol à texture lourd. La "fertigation" fut pratiquée au moyen d'une pompe doserue automatique pour l'envoi d'une solution d'urée dans l'eau d'irrigation qui est ensuite dirigée vers les champs dans une tuyauterie souterraine. La transformation de l'azote était limitée à la couche supérieure (200 mm) du sol et une alteration du pH fut observée pour une courte durée de deux semaines avant de retourner à sa valeur initiale. Le niveau d'ammonium atteignit un maximum trois jours après la fertigation et déclina par la suite dans le temps par la nitrification. La façon dont décroît le NH₄⁺-N après l'hydrolyse de l'urée pourrait être décrite par une réaction cinétique de premier ordre. Le coefficient de la réaction varient de 0.0033 à 0.0018 h⁻¹ avec une décroissance en profondeur du
sol. L’accumulation de nitrate dans la couche supérieure du sol était à son maximum sept jours après la fertigation et déclina par la suite. On observa une différence prononcée dans la redistribution du nitrate et son infiltration dans les couches inférieures du sol mais sa perte par lessivage n’était pas évident. Ces résultats démontrent que la fertigation de la canne est possible dans un sol argileux.

Mots clés: ammonium, fertigation, irrigation à la raiue avec tuyauterie enfuie, nitrate, azote, urée.

FERTIGACION EN CAÑA DE AZUCAR CON UNA SOLUCION DE UREA EN UN SUELO ARCILLOSO

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RESUMEN

Se investigó el movimiento y transformación de N y el efecto de la Urea en el pH de un suelo arcilloso dedicado al cultivo de la caña de azúcar. La fertigation se realiza mediante el bombeo de una solución de Urea al agua de riego por medio de un aparato automático que lleva la solución al campo a través de una tubería subterránea. La transformación de N estuvo supeditada a una capa de 200 mm, y el cambio de pH a un corto período de tiempo de aproximadamente 2 semanas. El nivel de amonio alcanzó su mayor límite durante los tres días después de la fertigation, declinando posteriormente debido al proceso de nitrificación. Esta declinación del NH$_4^+$-N, después de la hidrólisis de la Urea, puede ser debido a la reacción cinética de primer orden. La diferencia siempre osciló entre 0.0033 a 0.0018 h$^{-1}$, y disminuyó con relación a la profundidad del suelo. La acumulación de nitratos alcanzó su máximo, en la capa arable, 5 días después de la fertigation; declinando más tarde. Se observaron diferencias significativas en la redistribución de nitratos y los grados de infiltración en el subsuelo, pero ningún indicio de perdidas por percolación. Los resultados demuestran que la fertigation en caña de azúcar, en un suelo arcilloso, es una práctica factible.