

An algorithm based on electrical conductivity for accurate liquid nitrogenous fertiliser application

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ABSTRACT

For basal and foliar treatments, precise administration of nitrogenous fertilizers—primarily urea ammonium nitrate (UAN) and granular urea, both pure and neem-coated—in aqueous form is crucial. When designing a liquid fertiliser administration system, the physicochemical characteristics of these nitrogenous fertilisers' aqueous solution are crucial. In order to create algorithms for use in sensor-based systems for real-time monitoring of the available N content in the fertiliser solution before to application, the research was conducted in 2019–20 at the ICAR-Indian Agricultural Research Institute, New Delhi. The physicochemical characteristics of urea ammonium nitrate (UAN-28%), pure urea, and neem coated urea in diluted form (pre-selected N-concentrations i.e. 0.78, 0.9, 1.08, 1.33, 1.75, 2.54, and 4.67% corresponding to the dilution ratios of 1:35, 1:30, 1:25, 1:15, 1:10, and 1:05) were measured and their significance with N-concentration. N-concentrations were significantly correlated with electrical conductivity (EC) alone. Based on the EC and N-concentrations, prediction models were created for granular urea fertilisers and diluted UAN. With coefficients of determination (R^2) of 0.998, 0.998, and 0.999 for diluted UAN, pure urea, and neem coated urea with water, respectively, the regression models in terms of EC to predict N-concentration shown a remarkable promise for their sensor-based precision application. Sensing pertinent physicochemical properties allows for the regulated administration of diluted liquid fertilisers with water.

Keywords: Electrical conductivity, Liquid nitrogenous fertilizers, Regression model

Introduction

The productivity and output of agriculture are greatly influenced by nitrogenous fertilisers. During different phases of crop development, it is the most important input to provide nutritional needs (Zhai 2006, Zhao and Yu 2006). Because the pace, form, concentration, and frequency of fertiliser administration affect a plant's response (Fernández et al. 2013). Compared to solid fertilisers, nitrogenous fertilisers have greater nitrogen usage efficiency and effectiveness when diluted with water in an appropriate ratio, making nutrients easily accessible for plant uptake (Walsh et al. 2016). Extremely low concentrations of the nutrient solution cause growth inhibition in hydroponically grown plants. Conversely, very high concentrations result in growth limitation, ionic toxicity, and osmotic stress (Savvas et al. 1999). Furthermore, higher concentrations cause scorching when applied topically (Castro 1ICAR-Indian Agricultural Research Institute, New Delhi; 2Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra; 3ICAR-Indian Agricultural Statistics Research Institute, New Delhi). *Corresponding author email: satishiari@ gmail.com et al. 2022. Therefore, for any sustainable crop production system, the pace and kind of nitrogenous fertiliser application are equally crucial. Precision agriculture-based technologies make extensive use of the physicochemical characteristics (Othaman et al. 2019, Darmawan et al. 2023). Additionally, the majority of sensor-based flow control systems have shown their efficacy in detecting, monitoring, and regulating various chemical application systems by relying on physicochemical features (Sowmiya et al. 2017, Xu et al. 2019). The relationship between physicochemical characteristics and concentration is therefore crucial, as is the evaluation of the viability of nitrogenous fertilisers like urea ammonium nitrate (UAN), pure urea, and neem-coated urea for their basal/foliar application, especially with precision agro-machines. By examining the physicochemical characteristics of liquid nitrogenous fertilisers (UAN, pure urea, and neem-coated urea) at various nitrogen concentrations, this study seeks to close the current gap. It also develops an algorithm based on the observed relationships between electrical conductivity and N-concentration to be used in sensor-based metering systems. However, the volumetric calibration of nutrient treatment depends on the connection between levels of concentration and the corresponding electrical conductivity. This study will give valuable information for improving various nutrition management practices. It may also be very helpful to marginal and small farmers by enabling them to maximise inputs and encourage sustainable crop production.

MATERIALS AND METHODS

The ICAR-Indian Agricultural Research Institute in New Delhi conducted the research in 2019–20. For the research, three liquid fertilizers—UAN, pure urea, and neem-coated urea—were used. Supplementary Table 1 lists the physicochemical

characteristics and content of the chosen liquid fertilisers. The urea fertilisers were first diluted and transformed into aqueous solutions (28% N) that were comparable to the UAN (28% N) from solid form, which contained 46% N. It assisted in lowering the salt issues and keeping the three liquid fertilisers' N concentrations at the same level.

Sample preparation for laboratory research: The nitrogen content for basal and foliar treatment should not be more than 3%, per prior study results and agronomic practices (Walsh et al. 2016, Sundaram et al. 2018). In light of the aforementioned information, the liquid fertilizers—UAN, pure urea, and neem coated urea—were diluted with distilled water in the following ratios: 1:05, 1:10, 1:15, 1:20, 1:25, 1:30, and 1:35. This resulted in sample solutions with varying N concentrations, namely 4.67, 2.54, 1.75, 1.33, 1.08, 0.90, and 0.78%, respectively. The physicochemical characteristics of all three liquid fertilisers were then measured at each N concentration level, including specific gravity (SG), dynamic viscosity (DV), surface tension (ST), pH, electrical conductivity (EC), and percentage light absorbance (LA). Determining the impact of nitrogen concentration on physicochemical characteristics, their viability in metering system design, and identifying the most important one for the creation of a physicochemical properties-based N prediction model were the primary goals of the work.

Determination of physical properties

Specific gravity (SG): SG of liquid fertilizer solutions was determined by density bottle method and calculated as:

$$\text{Specific gravity} = \frac{W_3 - W_1}{W_2 - W_1}$$

where W_1 , Weight of empty density bottle along with stopper (g); W_2 , Weight of water filled density bottle with

where η_1 and η_2 represent the viscosity of the test liquid (fertiliser solution) and reference liquid (distilled water), respectively; ρ_1 and ρ_2 represent the density of the test liquid (fertiliser solution) and reference liquid (distilled water), respectively; and t_1 and t_2 represent the flow time of the test liquid (fertiliser solution) and reference liquid (distilled water), respectively.

Surface tension (ST): By using the drop weight technique (Tate 1864) to generate cylindrical drops at the tip of a stalagmometer nozzle in accordance with normal protocol, ST of liquid fertiliser solutions with varying N contents was determined. The surface tension (σ) was computed as follows:

$$\sigma \text{ (N/m)} = \frac{W}{2\pi r}$$

where r , Radius of the tip of the stalagmometer i.e. 0.75

$\times 10/\text{m}$; W (kg), Mean weight of the single drop of the liquid = $\frac{W_2 - W_1}{150}$

Determination of chemical properties

pH and electrical conductivity (EC): The fertiliser solution's pH and EC were measured using digital pH and EC meters, respectively, utilising potentiometric and electrometric techniques. Standard buffer solutions with pH values of 4 and 7 were used to calibrate the pH meter, and KCl (0.01 M) solution was used to calibrate the EC meter. Light absorbance (LA): A digital spectrophotometer was used to determine the percentage of LA. The reference liquid was distilled water with 0% LA. Light with a wavelength of 470 nm was transmitted through the solution after the sample to be analysed was placed between the spectrometer and photometer. The spectrophotometer recorded the percentage absorption of the light that was emitted. To minimise measurement error, every experiment was repeated three times and carried out according to conventional protocols.

Statistical analysis: Two phases of statistical analysis were conducted. First, Minitab software was used to conduct a one-way ANOVA for fully randomised block design (CRBD) in order to assess the treatment main effects on the physicochemical characteristics of the three liquid fertilisers. The significance of various answer combinations was examined using Tukey's test. Later on, Google Collaboratory's Python programming language was used to create polynomial regression models for each of the three fertilisers.

RESULTS AND DISCUSSION

Weight of fertiliser solution full density (W_3); urea (NH_4CONH_2), dissolved in waterstopper (g) bottle with a cork (g).

The term "dynamic viscosity" (DV) describes a fluid's resistance to flow. The time it took for the liquid to move from higher mark A of the right limb's bulb to lower mark B via the capillary tube was measured using Ostwald's viscometer technique. The fertiliser solution's viscosity (η_1) was calculated as follows:

$$\eta_1 = \frac{\rho_1 t_1}{\rho_2 t_2}$$

transformed into ammonium (NH_4) and cyanate (CNO) ions (Alexandrova and Jorgensen 2007), whereas urea

ammonium nitrate $[(\text{NH}_2)_2\text{CO}_3 \cdot \text{NH}_4\text{NO}_3]$ in aqueous form produces ammonium (NH_4^+) and nitrate (NO_3^-) ions (Wahab and Mahiuddin 4). These NH_4^+ and NO_3^- ions are crucial sources of nitrogen for plants. The physicochemical characteristics of the aqueous solution are impacted by changes in the ionic concentration when liquid fertilisers are diluted in water. For design, the shift in physicochemical characteristics with N concentration is crucial. of any foliar and basal spraying schemes, as well as in crops sheltered by green or poly houses. However, macro and micronutrients used in hydroponic farming methods via various fertiliser products became accessible to the plant in ionic form, such as NO_3^- , NH_4^+ , SO_4^{2-} , H_2PO_4^- , K^+ , and N concentration, and vice versa. UAN at 4.67% N concentration had the highest dynamic viscosity of 1.203 mPa-sec, while pure urea at 0.78% N concentration had the lowest dynamic viscosity of 0.850 mPa-sec (Table 1). Similar to specific gravity, differences I 2+ 2+ 2+ 4 4 2 4

Zn, Ca, and Mg (Sanchez et al. 2021). The physical and chemical characteristics of liquid and aqueous fertiliser solutions, such as pH and EC, are influenced by the degree of dynamic viscosity evaluated at various N concentrations and ionic concentrations of plant nutrients (Shawon et al. 2023). In light of this, it is actually feasible to create an algorithm for various nutrient application systems based on physicochemical attributes and concentration level. N concentration's impact on liquid fertilisers' physicochemical characteristics A substance's specific gravity is determined by comparing its density to that of water. As the N content rose, so did the SG of the aqueous solutions of all three liquid fertilisers. For UAN, pure urea, and neem-coated urea, the ranges were 0.99–1.056, 0.983–1.018, and 0.980–1.029, respectively (Table 1). The current study's findings are consistent with those of Makarov and Egorov (2018), who discovered that the density and specific gravity of an aqueous solution containing urea and UAN fertilisers rose as the concentration of N increased. Additionally, it was discovered that while the overall effect of N concentration on SG was significant for all three fertilisers, the variation of SG was not significant for each N concentration in the case of UAN and pure urea (Table 1). However, the overall effect was significant at the 5% level of significance (Table 2). The density and viscosity of urea solutions with varying concentrations varied similarly, according to Kawahara and Tanford (1966). Similarly, at the 5% level of significance, the surface tension of the neem-coated urea solution increased significantly when the N content increased from 0.78 to 4.67% (Table 1). The overall impact was substantial for all three liquid fertilisers, while ST values were non-significant at certain N concentration levels in the other two (Table 2). The surface tension of liquid fertiliser was found to be comparable to that of pure water at lower concentrations ($<1.33\%$ N). When examining the density, viscosity, and surface tension of a urea-water solution in an undersaturated solution, Helonen et al. (2017) discovered a similar fluctuation. The identical physical characteristics of the urea water solution were reported by Kapusta et al. (2019).

Impact of N content on liquid fertiliser chemical characteristics: pH, EC, and LA show the ionic concentration (NH_4^+ , CNO_3^- , and NO_3^-) in the aqueous solutions

4.3 at the significance level of 5% (Table 2). Additionally, SG was closer to water for all three liquid fertilisers and closer to each N dosage level.

The resistance of a fluid to flow is measured by its viscosity.

As the amount of liquid fertilisers increased, so did the dynamic viscosity. The findings showed that since NH_4^+ ions are acidic, the pH of the UAN aqueous solution dropped as the quantity of N increased. However, in the case of both urea, a little rise in the pH of the aqueous solution fertiliser was seen with an increase in N content.

Table 1 Specific gravity, dynamic viscosity and surface tension of the liquid fertilizers at different N-concentrations

N-concentration (%)	Specific gravity (SG)			Dynamic viscosity (DV) (mPa-sec)			Surface tension (ST) (mN/m)		
	UAN	Pure urea	Neem coated urea	UAN	Pure urea	Neem coated urea	UAN	Pure urea	Neem coated urea
0.78	0.996 ^a	0.983 ^a	0.980 ^a	0.903 ^a	0.850 ^a	0.877 ^a	72.334 ^a	72.220 ^a	72.150 ^a
0.9	1.007 ^{ab}	0.984 ^a	0.987 ^b	0.913 ^a	0.853 ^a	0.883 ^a	72.385 ^a	72.262 ^{ab}	72.224 ^a
1.08	1.014 ^{bc}	0.987 ^b	0.993 ^c	0.952 ^a	0.873 ^b	0.916 ^b	72.459 ^a	72.323 ^b	72.373 ^b
1.33	1.027 ^{bc}	0.996 ^c	0.999 ^d	1.031 ^b	0.944 ^c	1.003 ^c	72.613 ^a	72.502 ^c	72.667 ^c
1.75	1.022 ^{cd}	1.006 ^d	1.009 ^e	1.073 ^b	1.043 ^d	1.041 ^d	74.011 ^b	72.970 ^d	73.551 ^d
2.54	1.032 ^d	1.012 ^e	1.017 ^f	1.124 ^c	1.072 ^e	1.082 ^e	76.712 ^c	73.810 ^e	74.469 ^e
4.67	1.056 ^e	1.018 ^f	1.029 ^g	1.203 ^d	1.141 ^f	1.119 ^f	80.352 ^d	75.126 ^f	75.807 ^f

*Mean follows the same letter(s) within N-concentration are not significantly different at 5% level of significance. UAN, Urea ammonium nitrate.

Table 2 ANOVA for physicochemical properties of selected liquid fertilizers at different N-concentrations

Liquid fertilizer	SG		DV		ST		<i>p</i> H		EC		LA	
	F valu e	<i>P</i> valu e	F value	<i>P</i> value	F value	<i>P</i> value	F value	<i>P</i> value	F value	<i>P</i> valu e	F value	<i>P</i> valu e
UAN	77.8 7	<.05	113.5 0	<.05	604.3 9	<0.0 5	619.1 1	<0.0 5	136165. 26	<0.0 5	4370.0 0	<.05
Pure urea	1566 .83	<.05	1069. 03	<.05	3877. 01	<0.0 5	3989. 30	<0.0 5	4911.45	<0.0 5	32741. 75	<.05
Neem coated urea	494. 42	<.05	1537. 38	<.05	5688. 16	<0.0 5	372.5 9	<0.0 5	5599.38	<0.0 5	227836 .72	<.05

SG, Specific gravity; DV, Dynamic viscosity (mPa-sec); ST, Surface tension (mN/m); *p*H, Potential of hydrogen; EC, Electrical conductivity; LA, Light adsorbance (%).

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Table 3 The potential of hydrogen, electrical conductivity and light absorbance of the liquid fertilizers at different N-concentrations

N- concentration (%)	Potential of hydrogen (pH)			Electrical conductivity (EC) ($\mu\text{S}/\text{cm}$)			Light absorbance (LA) (%)		
	UAN	Pure urea	Neem coated urea	UAN	Pure urea	Neem coated urea	UAN	Pure urea	Neem coated urea
0.78	6.783 ^a	7.073 ^a	7.066 ^a	15.812 ^a	13.530 ^a	11.792 ^a	0.001 ^a	0.001 ^a	0.002 ^a
0.9	6.770 ^a	7.080 ^a	7.086 ^a	24.565 ^b	18.136 ^b	17.421 ^b	0.001 ^a	0.002 ^a	0.003 ^b
1.08	6.750 ^a	7.126 ^b	7.120 ^a	39.451 ^c	26.627 ^c	27.607 ^c	0.003 ^b	0.003 ^c	0.006 ^c
1.33	6.453 ^b	7.183 ^c	7.196 ^b	56.750 ^d	41.460 ^d	44.119 ^d	0.009 ^c	0.014 ^d	0.010 ^d
1.75	6.323 ^c	7.457 ^d	7.291 ^c	70.813 ^e	59.206 ^e	59.828 ^e	0.012 ^d	0.021 ^e	0.013 ^e
2.54	6.140 ^d	7.813 ^e	7.456 ^d	82.412 ^f	76.525 ^f	74.053 ^f	0.018 ^e	0.026 ^f	0.029 ^f
4.67	5.647 ^e	7.943 ^f	7.700 ^f	109.469 ^g	92.767 ^g	91.714 ^g	0.042 ^f	0.096 ^g	0.095 ^g

*Mean follows the same letter(s) within N-concentration are not significantly different at 5% level of significance. UAN, Urea ammonium nitrate.

(Table 3). The fundamental nature of urea fertilisers was the cause. According to Bull et al. (1964), urea raises the pH of an aqueous solution but decreases hydrogen ion activity at greater concentrations. The overall findings showed that although pH was not significantly impacted by lower N concentrations, all three liquid fertilisers showed substantial change at higher concentrations at the 5% level of significance (Table 2). All three liquid fertilisers showed a decrease in EC with increasing dilution (Table 3). According to Krishnan et al. (2023), EC and ionic concentration in an aqueous urea solution are directly correlated. Wahab and Mahiuddin (2001) showed a similar fluctuation in EC with concentration of ammonium nitrate aqueous solution. The EC of liquid fertilisers varies, i.e. More obvious than any other physicochemical property were UAN, pure urea, and aqueous neem coated urea with N concentration. N concentration has a considerable impact on it (Table 2), and for all three liquids, the overall effect of concentration was likewise significant. fertilisers at the significance level of 5% (Table 2).

The ranges for the percentage light absorption were 0.001–0.042%, 0.001–0.096%, and 0.002–0.095% for UAN, pure urea, and urea fertiliser coated with neem, in that order (Table 3). Similar to specific gravity, at the 5% level of significance, the differences in percentage light absorbance (LA) observed at various N concentrations were not significant (Table 2). The physical characteristics of the fertiliser solution are not significantly impacted within the chosen range of nitrogen content, according to the results. These were discovered to be similar to water, which made the creation of a flow control system possible. However, in the case of three fertilisers, EC is one of the properties that is greatly impacted by N concentration. It was most suited to use EC for the construction of algorithms for precise prediction of N concentration in the solution because of its bigger and more noticeable variation with N concentration (F value = 136165.26). This will provide the chance to apply liquid fertiliser more precisely.

in any application system that relies on accuracy

The algorithms were created utilising a polynomial connection between EC and various levels of N concentrations for each of the three liquid fertilisers that were chosen. An important

correlation was observed between EC and N concentration. The equations of this algorithm are as follows:

For the selected liquid fertilizers (Polynomial Regression Model)

Urea ammonium nitrate (UAN):

$$Y = 3.996 \times 10^{-6}X^2 - 0.0002X^2 + 0.0109X + 0.6703 \quad [R^2 = 0.998, \text{ Adjusted } R^2 = 0.995]$$

Aqueous urea:

$$Y = 1.786 \times 10^{-5}X^3 - 0.0021X^2 + 0.0917X - 0.1641 \quad [R^2 = 0.998, \text{ Adjusted } R^2 = 0.996]$$

Neem coated urea:

$$Y = 1.481 \times 10^{-5}X^3 - 0.0015X^2 + 0.0634X + 0.1983 \quad [R^2 = 0.999, \text{ Adjusted } R^2 = 0.999]$$

where R is the regression coefficient, X is the solution's electrical conductivity (EC) value ($\mu\text{S}/\text{cm}$), and Y is the percentage of N concentration. For UAN, pure urea, and neem-coated urea, the coefficients of determination for N

concentration were 0.998, 0.998, and 1.00. The results demonstrated that accurate information about the availability of N in the fertiliser solution could be obtained by entering the EC value into the equation that emerged from the connection between EC and N concentration. In order to evaluate the quality of water based on its constituent concentration, Khlaif et al. (2021) created linear regression models between the chemical characteristics of water and EC. They discovered a prediction accuracy of 0.834–0.979. According to Wu et al. (2019), an EC algorithm-based fertigation system offers an ideal method of managing water and fertiliser, which helps save water and fertiliser. One of the macronutrients that promotes plant growth and general productivity is nitrogen. When it comes to NUE and effectiveness, liquid nitrogenous fertiliser application is superior than solid application. But when it comes to liquid N fertiliser, it is crucial to fully understand the available N content in solution before applying it. Since the N concentration level has a major impact on the physicochemical characteristics of liquid fertilisers, such as UAN, pure urea, and neem-coated urea, ranging from Electrical Conductivity-Based Algorithm for Liquid Nitrogenous Fertilizers 899 1–5%. The physical characteristics of liquid fertilisers, such as SG, DV, and ST, which are thought to be the most crucial in the design of any flow control system, were shown to be similar to those of pure water. Conversely, methods to monitor the N concentration in real time in an automated and accurate liquid fertiliser administration system were developed using chemical characteristics such as pH, EC, and LA as indicators. The results of this investigation demonstrated a strong correlation between EC values and N concentration. Consequently, a third-degree polynomial equation provided the best description of the connection between EC and N concentration. The EC may now be used as an indication in any automated monitoring and controlled application system of liquid nitrogenous fertilisers thanks to the development of prediction models for all three liquid fertilisers: UAN, aqueous urea, and aqueous neem coated urea.

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