# Prediction of Soil Nitrogen Content using E-nose and Radial Basis Function

Jigme Norbu[1], Theerapat Pobkrut[1], Treenet Thepudom[1], Thinley Namgyel[1], Teerayut Chaiyasit[1], Yu Thazin[1], Teerakiat Kerdcharoen[1,2,3,*]
[1]Materials Science and Engineering, Faculty of Science, Mahidol University, Bangkok 10400
[2]Department of Physics, Faculty of Science, Mahidol University, Bangkok 10400, Thailand
[3]NANOTEC Center of Excellence, Mahidol University, National Nanotechnology Center, Bangkok, Thailand
*Corresponding author: teerakiat@yahoo.com

*Abstract*—**Existing soil nutrient determining methods are still a concern as most of them entail arduous field sampling followed by rigorous testing procedures, both of which are time consuming and expensive. Conversely, farmers require cheap and instant information about the soil nutrient management for quick decision making or they will have to risk their crop. Electronic nose (E-nose) is an emerging technology that has potential application in monitoring of soil nutrient abundance. In this work, e-nose coupled with Radial Basis Function (RBF) is employed to determine the amount of nitrogen (N) which is one of the main nutrients in the soil. The results demonstrate that not only does the e-nose clearly discriminate the odors of soil with different N concentration, but also can evidently predict the total N content with accuracy of 96.2% using RBF. Hence, e-nose and RBF network could be a promising alternative to conventional soil testing methods.**

***Keywords— Electronic nose; radial basis function; nitrogen; volatile organic compounds***

## I. INTRODUCTION

Current farming paradigm demands extensive and robust automated systems capable of obtaining information to enable instant decision making by the farmers. Acquiring information on soil nutrient management is one of the main domains of precision farming method in realizing sustainable crop yields [1]. Soil is the main sink as well as sources of Volatile Organic Compounds (VOCs) that vary from simple to complex due to the vast features defined by soil profile parameters [2]. Monitoring soil VOCs has been an emerging approach for studying the soil nutrients variability in precision farming system. Beside many other soil VOCs determinants, studies have shown that a small variation of nutrients in the soil such as nitrogen [3] and organic matter [4] significantly varies the VOCs produced. The conventional soil nutrient assessments are based on arduous field sampling followed by rigorous soil testing, both of which are time-consuming and costly. For example in Thailand, testing the soil for total nitrogen in conventional laboratory costs Baht1000 per sample and takes about 3-4 weeks of time to run the test alone. This procedure is cumbersome for farmers because they need instant information for quick decision making or they will have to risk their crop.

Electronic nose is a potential device that can be employed for monitoring of soil nutrient abundance which directly

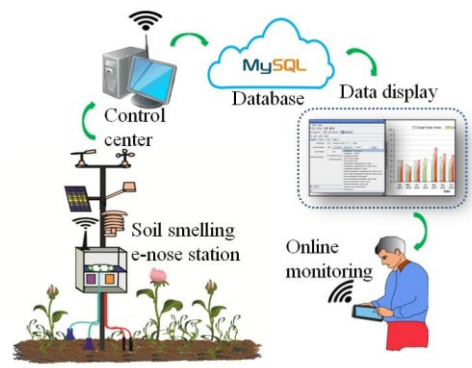


Figure 1. Future perspective of smart electronic nose

translates to soil fertility. As of now, there are very few literatures that investigated the potential of E-nose in soil monitoring purpose. Recently, E-nose technology was employed to evaluate the moisture status in various types of soil [5] and to monitor organic abundance in the soil [6]. Similarly, another paper reported application of E-nose to determine microbial activity in the soil through biogenic volatile organic compounds [7]. However, the authors did not come across any literature yet that reports application of E-nose to determine the level/amount of nutrients in the soil. This work reports a new approach in the field of agriculture whereby an E-nose system coupled with RBF is employed to determine the amount of nitrogen, which is one of the main nutrients in the soil.

## II. METHODOLOGY

### A. Electronic nose system

The E-nose system described in this work consists of sample delivery system, detection system, and data computing system. The sample delivery system consists of two channels for the delivery of sample and reference gas. The solenoid valve controlled by the microcontroller alternates the flow of reference and sample gas at the flow rate of 0.5 L/min. A total of seven cycles of test was performed for each sample with reference and sample time of 3 minutes and 1 minute respectively. The detection system consists of sensor chamber. It is equipped with six metal oxide semiconductor (MOS) gas sensors (see table I) and designed to uniformly dispense the gas flow through all the sensors. The sensors are connected using voltage divider method as shown in equation (1) to measure the resistance of the sensors, given by Ohm's law [8];

$$V_0 = V_s\left(\frac{R_2}{R_1 + R_2}\right) \quad (1)$$

Where Vs = 5V (input voltage), $R_1$ = 10KΩ and '$V_0$'and '$R_2$' are the output voltage and resistance of the sensors respectively.

The data is acquired by DAQ device while LabVIEW program helps visualize and analyze it. The sensor response percent was calculated employing equation (2)

$$R\% = 100\left(\frac{R_s - R_i}{R_i}\right) \quad (2)$$

Where $R_s$ is resistance of sensor for reference and $R_i$ is the resistance of sensor for sample.

### B. Radial Basis Function (RBF)

RBF is a nonlinear function with a symmetrical structure. It is suitable for implementing tasks with large sample, multi-class, and problems of high dimension because it has the benefit in local sensitivity, convergence rate, and prospect of reaching global points [9]. It primarily constitutes three layers namely, the input layer, the hidden layer, and the output layer as shown in fig.3. The input layer comprises input data and the hidden layer transforms input space data to the hidden space by means of a non-linear function, while the output layer yields the response of the network to the activation pattern of the input data [10].

In this paper, RBF was used to predict the amount of N present in the soil based on the sensing response data from E-nose and laboratory test.

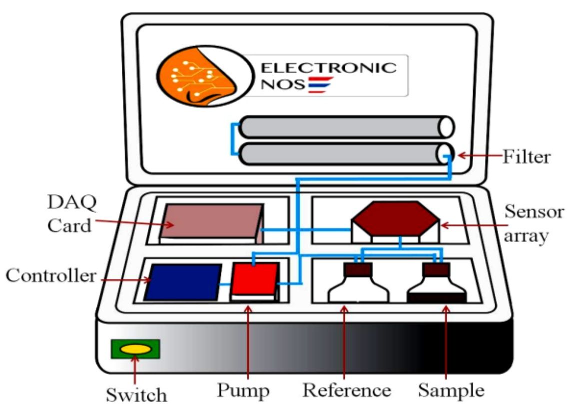


Figure 2. Schematic of portable e-nose

TABLE I

| Sensor no. | Sensors | Detection target |
|---|---|---|
| 1 | TGS 2444 | $NH_3$ |
| 2 | TGS 823 | Organic solvent vapors |
| 3 | TGS 2600 | Air contaminants |
| 4 | TGS 2602 | VOCs, ammonia and odorous gases |
| 5 | TGS 826 | Hydrogen, ammonia, and ethanol |
| 6 | TGS2620 | Solvent vapors |

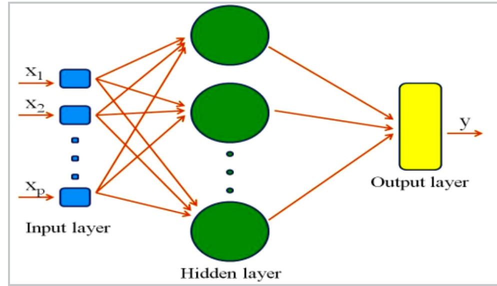


Figure 3. Schematic of RBF network

TABLE II

| Sl # | Samples | Description |
|---|---|---|
| 1 | Control | Soil only |
| 2 | $O_1$ | Soil 49 grams + OF 1 gram |
| 3 | $O_2$ | Soil 48 grams + OF 2 grams |
| 4 | $N_1$ | Soil 49 grams + N 1 gram |
| 5 | $N_2$ | Soil 48 grams + N 2 grams |
| 6 | $N_{0.25}$ - $O_{0.75}$ | Soil 49 gm + N 0.25gm + OF 0.75 gm |
| 7 | $N_{0.75}$ - $O_{0.25}$ | Soil 49 gm+ N 0.75 gm + OF 0.25 gm |
| 8 | $N_{1.5}$ - $O_{0.5}$ | Soil 48 gm + N 1.5 gm + OF 0.5 gm |

Out of two major methods to design and create RBF networks namely newrb and newrbe, the former method was employed as it requires lesser neurons compared to the latter. The network was created by identifying the function newrb (P, Tc, MSE, ip, SPREAD). The matrices of 27 data sets (3 samples x 9 rounds of test) were used as training sets of data P and the result from conventional laboratory test as Tc. An additional 7 sets of test for 3 selected samples (Control, $N_1$, and $N_2$) were performed to obtain the data to be used as prediction set. Having obtained the predicted amount of nitrogen level in the soil, the relative tolerance was calculated by the following formula;

$$\text{Relative tolerance } (\%) = \frac{LR - PR}{PR} X100 \quad (3)$$

Where LR is the lab result and PR is the predicted result. The accuracy percentage was then calculated by subtracting the relative tolerance from 100%.

### C. Specimen preparation

In this experiment, soil specimens were collected at the depth of 0-6 inches from Faculty of Science, Phyathai Campus, Mahidol University in December 2017. A total of 8 samples (see table II) with different amount of nitrogen(N) and Organic Fertilizer(OF) were prepared to be tested by the lab made E-nose. In the first experiment, five samples; Control, $O_1$, $O_2$, $N_1$, and $N_2$ were tested. For the second part, four samples; Control, $N_{0.25}$-$O_{0.75}$, $N_{0.75}$-$O_{0.25}$, and $N_{1.5}$-$O_{0.5}$ were examined. All the specimens were stored in a specimen bottle under ambient conditions and tested by the E-nose every 3 days for a period of 45 days.

## III. RESULT AND DISCUSSION

### A. PCA and sensing response result

Fig. 4.a and fig.4.b show three sets of PCA result and sensing response respectively for the first experiment.

As depicted in the figure, the soil samples with no added fertilizer (control) and the samples with added organic fertilizer ($O_1$ and $O_2$) are separated on the left hand side by PCA while the samples with added nitrogen fertilizer ($N_1$ and $N_2$) are on the right hand side. This implies that the E-nose is able to classify soil samples with and without nitrogen. Moreover, from the fig.4.b, it can be observed that all the gas sensors yield significantly different sensing response to the samples with and without nitrogen. There is no significant difference in PCA result as well as sensing response result amongst the sample with added OF.

Fig.5.a and Fig.5.b display the PCA and sensing response result respectively for the second part of experiment wherein the samples contained different concentration of added nitrogen fertilizer and OF. It is noticeable that the PCA can successfully classify the samples with varying nitrogen concentration. The shift in cluster dots to the right hand side can be assigned to the increasing concentration of added nitrogen (indicated by red arrow). Moreover, the sensing response graphs (see fig.5.b) indicate increased response percentage with increasing nitrogen concentration.

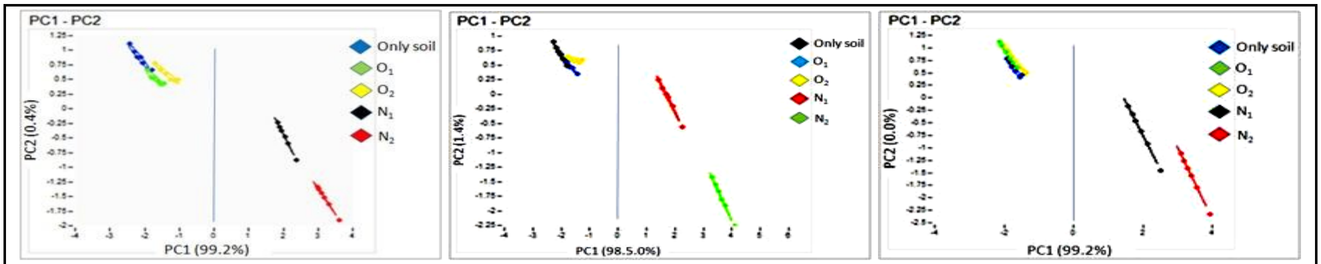


Figure 4.a. PCA result for first part

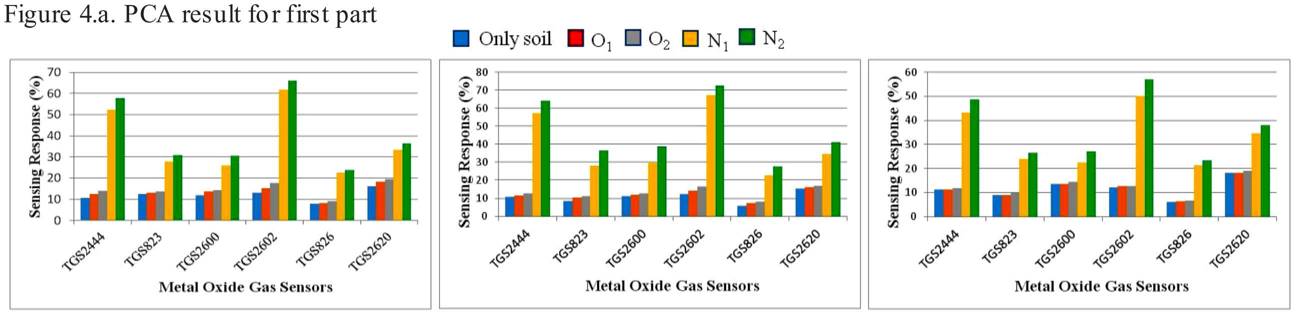


Figure 4.b. Sensing response result for first part

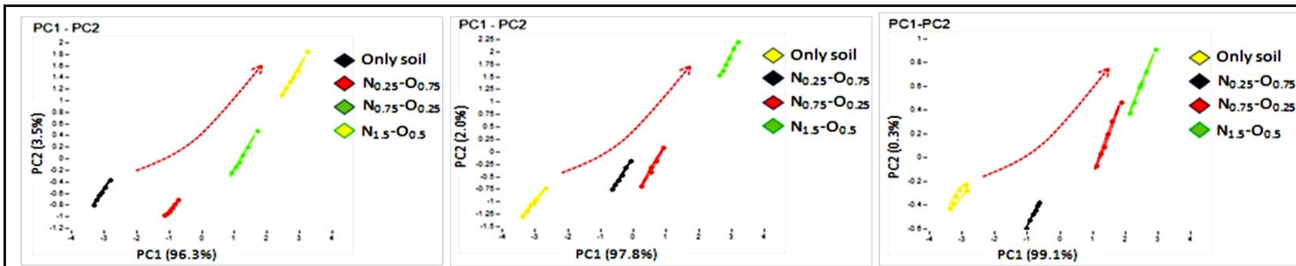


Figure 5.a. PCA result for second part

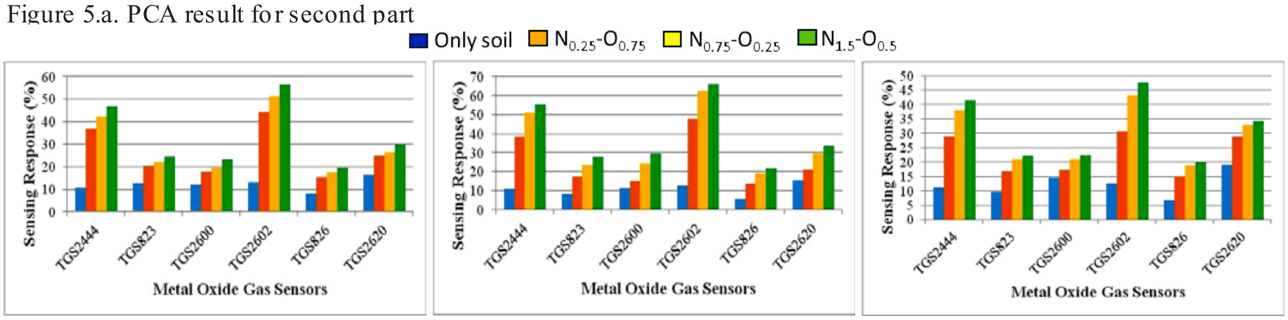


Figure 5.b. Sensing response result for second part

TABLE III

| Sample | Nitrogen | Organic matter |
|---|---|---|
| Control | 0.13% | 7.58% |
| $N_1$ | 0.50% | 7.36% |
| $N_2$ | 0.57% | 7.47% |
| $O_1$ | 0.33% | 7.24% |
| $O_2$ | 0.34% | 7.36% |

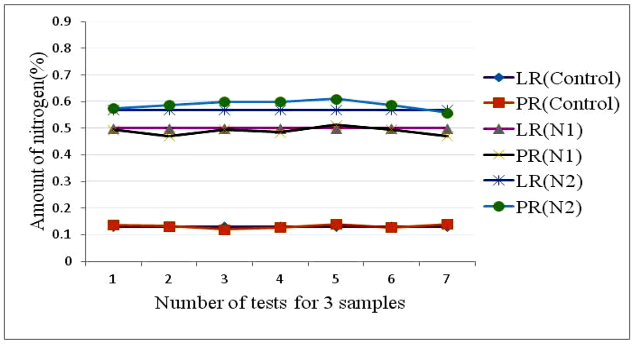


Figure 6. Fitting of laboratory and RBF results

Among six metal oxide gas sensors, sensor no.5 (TGS2602) yields highest sensing response while sensor 1 (TGS2444), yields second highest. This can be attributed to enhanced emission of ammonia ($NH_3$), VOCs, and odorous gases [11], due to higher concentration of nitrogen fertilizer in the soil samples.

### A. *Laboratory soil analysis report*

Table III shows percentage of nitrogen and organic matter content in the samples furnished by the conventional laboratory test. It can be observed that the total nitrogen content increased after the samples were treated with nitrogen fertilizer. The soil sample amended with 2 grams of nitrogen ($N_2$) show highest nitrogen of 0.57% while the sample with no added nitrogen (control) show the lowest of 0.13%. Therefore, the total nitrogen in the soil samples was found to be in accordance with the amount of nitrogen fertilizer added to the samples.

### B. *Predicted results by Radial Basis Function*

It was observed that the predicted nitrogen percentages are nearly the same as that of lab result. The prediction accuracy for Control, $N_1$, and $N_2$ were found to be 95%, 97%, and 96% respectively. The overall average prediction accuracy obtained is 96.2% which is adequately high. However, the accuracy could be further enhanced by increasing the number of training data sets. Fig.6 demonstrates lab test and prediction result of RBF for 3 samples and 7 rounds of test fitted together. The overlapping of lines in the graph indicates high similarity in results from lab test and RBF.

## IV. CONCLUSION

In this work, the electronic nose based on metal oxide gas sensors was employed for detection of soil odor. The experiment revealed that E-nose could clearly distinguish between the differences in soil odors due to varied amount of nitrogen content. Furthermore, the RBF network has optimistically predicted the nitrogen concentration in the soil samples with accuracy of 96.2%. The results undeniably affirm that E-nose coupled with RBF network has huge potential of offering an alternative to costly and time consuming conventional laboratory test. The E-nose did not uncover significant difference in odor amongst samples with added OF. The capability of E-nose and ANN in determining soil organic matter needs to be explored in future.

## ACKNOWLEDGMENT

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