

Establishing a Viable Fertilizer Quality Detection System

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K. Perumal¹, J. Arunkumar¹, S. Ananthi¹, T.A. Sambanda Moorthy¹, B. Karthik¹, U. Singh², and P.S. Bindraban³

¹Shri AMM Murugappa Chettiar Research Centre (MCRC) Taramani, Chennai, 600113, India.
perumalk@mcrc.murugappa.org

² IFDC, International Fertilizer Development Center, Muscle Shoals, Alabama 35662, USA. usingh@ifdc.org

³ VFRC, Virtual Fertilizer Research Center, Washington, D.C., 20005. USA. pbindraban@vfr.org

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Executive Director
Virtual Fertilizer Research Center
1313 H Street NW
11th Floor
Washington, D.C. 20005
USA
E-mail: contact@vfrc.org

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Virtual Fertilizer Research Center

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List of acronyms and abbreviations

AAS	Atomic absorption spectrophotometer
AAT	Alternative Analytical Technology
AS	Ammonium Sulfate
CBR	Case Based Reasoning
CPC	Circular Paper Chromatogram
FAAT	Fertilizer Alternative Analytical Technology
IFDC	International Fertilizer Development Center
MCRC	Shri AMM Murugappa Chettiar Research Centre
SSP	Single Superphosphate
VFRC	Virtual Fertilizer Research Center

1 Abstract

The proof of concept project entitled “Establishing the Viability of a Fertilizer Quality Detection System Using Alternative Analytical Technology (FAAT)” is aimed at developing a quick and robust methodology to determine the nutrient content in fertilizers. The methodology comprises the use of circular paper chromatography (CPC) and digital characterization of the corresponding chromatographic images incorporated in a database for automated assessments. One hundred (from the United States) and 22 (from India) different types of fertilizers were procured from the United States and India, and their nutrient properties were analyzed following conventional methods. These fertilizer samples were further diluted in 100 mL of 1% NaOH to obtain 3800 fertilizer concentrations. For the Indian fertilizers, 2200 samples were obtained with all 22 fertilizers by generating 100 different samples in incremental dilutions of 0.050g, up to 5 g. For the IFDC fertilizers, 1600 samples were similarly obtained from 80 of the 100 fertilizers, diluted up to 1 g. These fertilizer concentrations were analyzed using CPC. Three databases were created to serve as reference, comprising (i) the Indian fertilizer database with 1500 reference fertilizer sample images, (ii) the IFDC database with 563 samples and (iii) a combined database of 2063 samples. Finally, an unknown fertilizer chromatographic image from unknown fertilizer sample types was used for testing the accuracy of the methodology by comparing the chromatographic images with the images contained in the reference databases.

Out of the 25 test samples from IFDC, 21 reported similarity between AAT methodology and conventional analytical methods for nutrient content determination, and hence on quality, implying that 84% were mimicked correctly. Out of the 18 fertilizers from India, 11 tested correctly when using the database with 1500 references, representing about 61% accuracy of retrieving the correct fertilizer type and quality. The consolidated database containing both IFDC and Indian fertilizer (2063) was tested and recorded 34 out of 43 test samples that were similar between the FAAT system and conventional analytical methods, indicating about 70% accuracy.

The existing AAT software was fine-tuned and integrated as unique stand-alone software for the FAAT system and used for fertilizer testing.

An investigation was also carried with two types of fertilizers: urea and single superphosphate (SSP), and deliberately adulterating them with low grade inputs. The urea fertilizer was adulterated with ammonium sulfate (AS) and single superphosphate in the ratios of 1:0, 1:1, 1:3 and 3:1. The adulterated fertilizers were blended using mortar and pestle and 0.500g and 1.000 g were taken for CPC image development. Both the urea fertilizer and SSP were adulterated with AS and gypsum and tested on the FAAT system based on CPC images. The adulterated samples were retrieved from the data base and indicated 100% and 71% accuracy, respectively. Our study shows that with further refinement, the use of AAT methodology for testing fertilizer nutrient content and the presence of contaminants, and hence quality of the fertilizer, is a promising technology.

2 Introduction – the challenge of fertilizer quality

In developing countries, agriculture is confronted with severe challenges due to low purchasing power of farmers, the large number of fragmented smallholdings, low literacy level among smallholders and paucity of resources

available to the farmers. These problems are exacerbated by the lack of competition in fertilizer trade, leading to malpractices.

Farmers generally face problems pertaining to purchasing the right quality of fertilizers, inadequate supply of fertilizer and high cost of supply. Thus, quality of fertilizer plays a key role in improving crop yield and farm livelihood. High upfront input cost raises expectations of higher return at the time of harvest. Moreover, farmers are not in a position to examine the quality of fertilizers at the dealers point. Adulterated fertilizers can cause serious damage to the soil and crops and to the livelihood of the farm family. The quality of fertilizers cannot be evaluated after application in farm fields and should therefore be determined prior to its application to ensure that farmers are protected from fertilizer adulteration and malpractices.

Fertilizer testing facilities are very expensive and hardly accessible to farmers or dealers. The fertilizer quality testing laboratories are established in factory sites or far away from farmer's fields with highly sophisticated equipment such as UV-Visible spectrophotometer, Kjeldahl for Nitrogen AAS and ICP-AES for micronutrients. These laboratories are not easily accessible by farmers. These tools and equipment require highly qualified manpower, calibration and maintenance (including easy access of spare parts) and good quality electricity (and genset if grid is not a regular supply source). Therefore, adulteration by fertilizer traders and retailers may have become commonplace. Government control is not successful as laboratories are located long distances from farms and testing procedures are time-consuming and costly. Hence, easy, quick and inexpensive methods to trace adulteration would help to improve fertilizer quality and with that yield and farm livelihood.

Based on MCRC's patented Alternative Analytical Technology (AAT) for soil analysis, VFRC and MCRC have jointly explored the extension of MCRC's IP on AAT for fertilizer analysis. The aim was to develop a quick and affordable methodology for on-site testing of fertilizer quality. MCRC is also working on making the AAT system completely portable to enhance the reach and ease of use by fertilizer dealers and controlling agents to enforce fertilizer quality regulations.

Therefore, the objective of the study was to provide the proof of concept as to whether AAT is viable as a Fertilizer Quality Detection System, by the accurate quantitative determination of nutrients in fertilizers, following a recommended testing protocol.

3 Methodology, results and discussion

MCRC modified the qualitative method of CPC and combined it with modern technologies of image processing and pattern recognition, using Case Based Reasoning (CBR, for simplifying and accelerating the speed of soil nutrient analysis). The design of appropriate methods and tools, and evaluation for its repeatability and accuracy for testing soil nutrients, was filed as an Indian patent during 2008 (652/CHE/2008). This methodology is defined as MCRC's AAT.

In this proof of concept project, MCRC proposed a methodology to detect the nutrient contents in fertilizers based on principles of CPC and CBR. This patented AAT technology is thus being extended for fertilizer analysis.

3.1 Sample collection and conventional analysis of synthetic fertilizers

MCRC procured 22 commercially available grades of fertilizers from local sources in Tamil Nadu, India (Table 1). Samples of these fertilizers were sent for analysis at an independent ISO-certified laboratory at M/s Coromandel International Ltd, Vishakhapatnam, India. Four macro, micro and secondary nutrients and four heavy metals were analyzed following standard analytical methods such as Kjeldahl, gravimetric, flame photometrically and Atomic absorption spectrophotometer (AAS) methods described by Fertilizer Control Order, India 2010 & FAO 2008 (Table 2). The results are presented in Tables 3a, 3b and 3c. All 22 fertilizers were selected for CPC analysis.

MCRC also received 100 different complex fertilizers from IFDC, Muscle Shoals, USA. The nutrient composition for 80 of these fertilizers was provided to MCRC by IFDC. The balance of 20 was to be tested by AAT methodology for nutrient analysis to prove the viability of the concept. The physicochemical properties of 22 Indian fertilizers with grades, and of the IFDC fertilizers, were used to build the database; more details are given under section 3.2.3.

3.2 Establishment of chromatographic image database

CPC images of 2820 samples of different concentrations of fertilizers were first created. Image processing (2063 CPC images processed out of 2820 CPC images) using advanced mathematical techniques was carried out to capture digital information for every image. The characteristics evaluated for digital information included zones, color hue, intensity of colors, patterns, spikes, band width and "Relative front" value.

3.2.1 Development of circular paper chromatogram

The 2820 fertilizer concentration derived from 22 Indian fertilizers and 100 fertilizer complex of IFDC were individually processed through Circular Paper Chromatogram (CPC) following the method described by Pfeiffer (1958) and modified by Perumal et al. (2003 and 2008). The outline of the method is described in Figure 1.

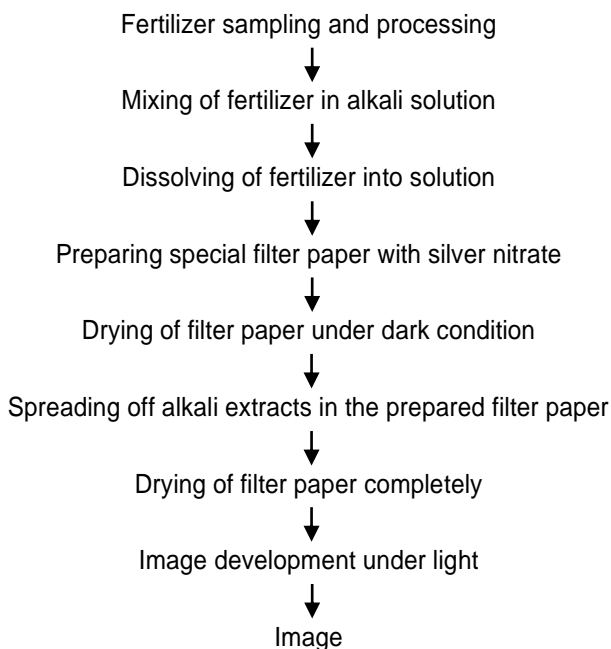


Figure 1. Sequential steps in developing Circular Paper Chromatograms

All samples are in duplicates, and it was ensured that images are visually similar. Only samples which give similar images are scanned for further image processing to extract its image features; more details are given under section 3.2.2.

Fertilizer samples were analyzed by CPC method. To establish a large sample size, the 22 commercially available fertilizers were diluted by dissolving them within the range of 0.050 g and 5.000 g (that is, 0.050, 0.10, 0.15, 0.20, 0.25, 0.30, 0.35, 0.40, 0.45, 0.50, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0 g) in 100 mL of 1% sodium hydroxide (NaOH), resulting in 3800 samples, and processed by the CPC method. Similarly, the 100 fertilizer samples received from IFDC were also subjected to dilution ranging between 0.050 and 1.000 g as sample weight for 1 IFDC to 80 IFDC for CPC analysis. The developed images were scanned by existing AAT system for capturing digital images.

3.2.2 Evaluation of images for extracting attributes and features using digital image processing techniques

An overview of the steps in the analysis of the CP Chromatograms/Images is provided in the below Figure 2.

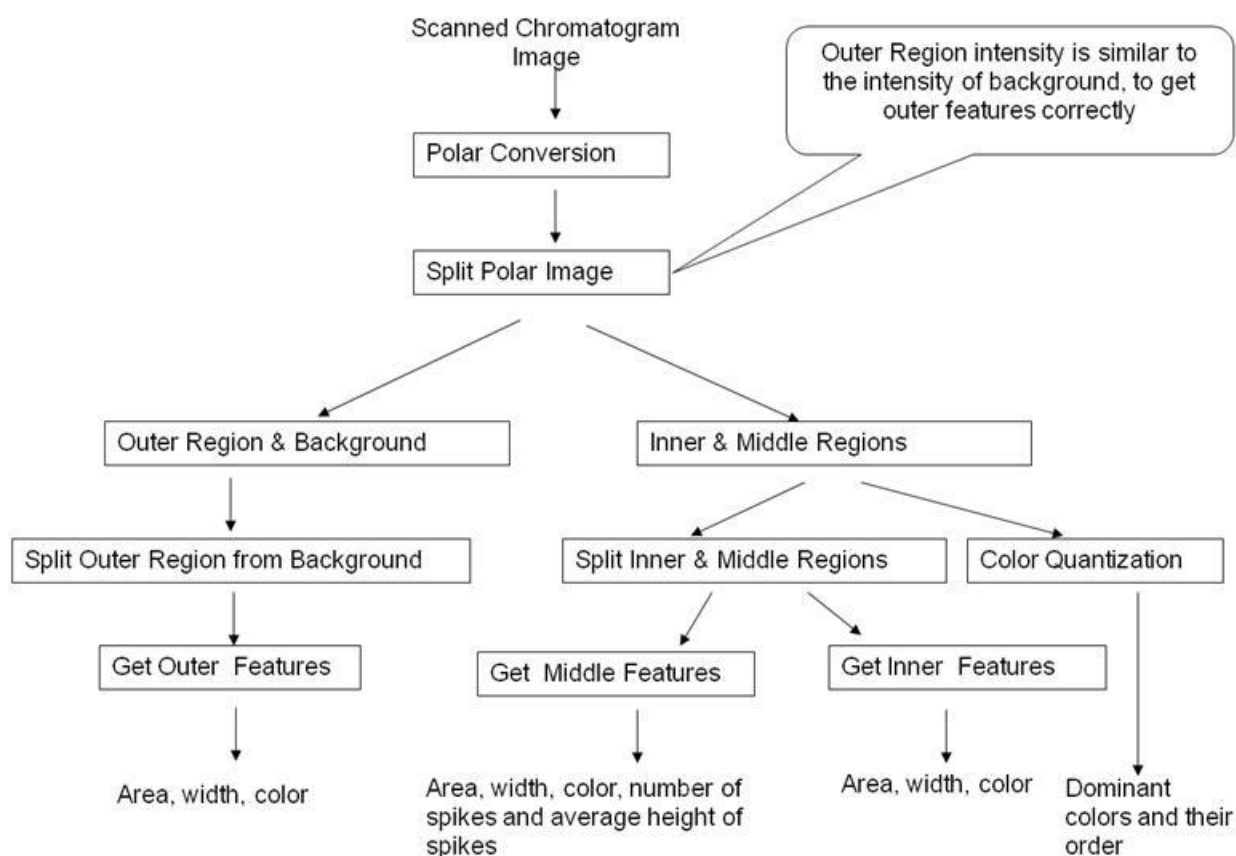


Figure 2. Flow chart of image processing by AAT system

These procedures and algorithms are the subject of patent application filed by MCRC in India in 2008 (652/CHE/2008). If required, this patent document can be made available.

3.2.3 Building the chromatographic image database

This project is attempting to prove the concept of extending the use of the MCRC's AAT methodology for soil samples for the simple and rapid analysis of fertilizer nutrients. For this limited proof of concept process, a small database and model algorithm was created. For higher repeatability and accuracy of results, MCRC recommends to develop a database of at least 25,000 to 50,000 CPC images with associated wet lab analysis for comparison.

In this project, the above-mentioned images of about 2820 samples were processed by AAT system for their digital image attributes. Among this, 2063 images were processed to obtain digital attributes that were then fed into the model database.

The decision algorithm thus incorporates a database with physicochemical properties from wet lab/conventional analysis of synthetic fertilizers (see under section 3.1) and digital image attributes of 2063 fertilizer concentrations from India and IFDC. This method, comprising the reference database and the decision algorithm for fertilizers, was installed in a new and stand-alone laptop computer.

The software was created using the Case Based Reasoning system to capture five best fit images identified by querying the test sample image in comparison with the reference database. From the best fit image which corresponds to the query image, the nutrient analysis for the test sample is derived. In cases where best fit images are difficult to obtain, the software yields five images similar to the query image. If required, the average nutrient analysis of the five similar images are used as the estimate (result) of the test sample (Annexes 1 and 2).

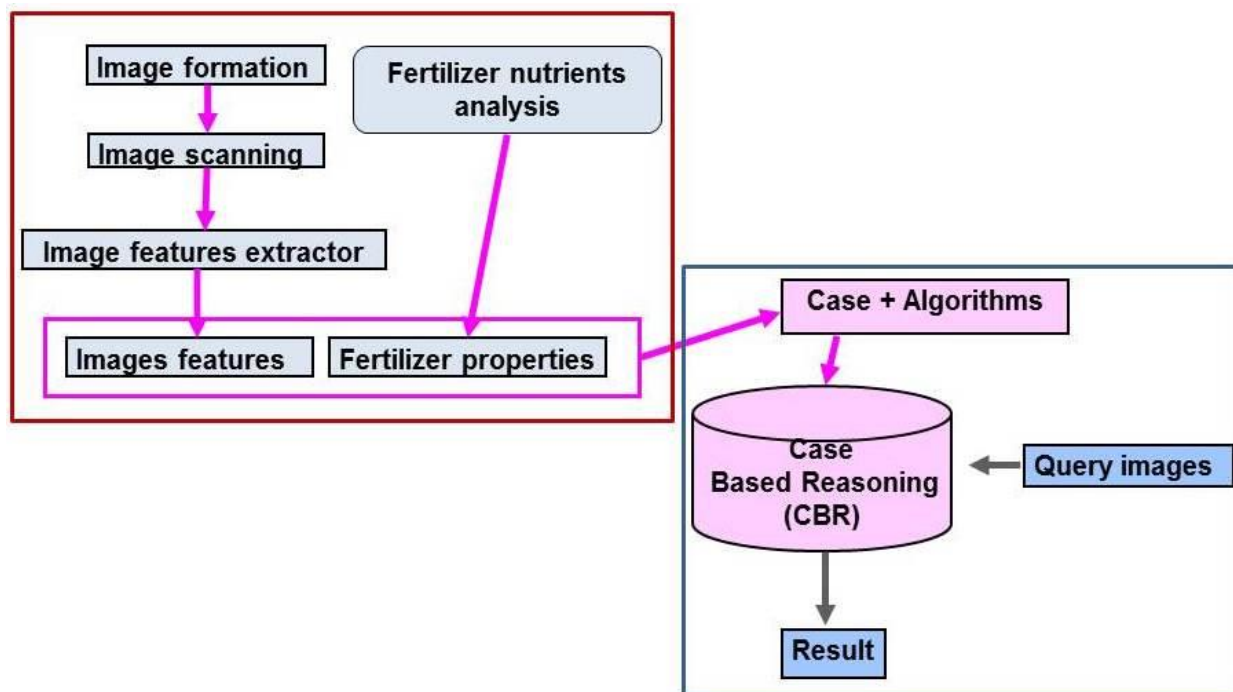


Figure 3. Schematic diagram of building a database and processing a sample

3.3 Determining the nutrient content in fertilizers

The database was divided into three sets of fertilizer CPC images consisting of 800 IFDC fertilizer CPC images, specifically images from IFDC fertilizer samples 1 to 80 of 0.050 to 1.000 g in 100 mL 1% alkaline solution and IFDC 1 to 100 of 0.500 g in 100 mL 1% alkaline solution. Among the 25 fertilizers from IFDC tested as query images, 19 matched with their wet lab analysis. Thus, the AAT system traced 76% of the samples from when using a full reference database that contained all the 25 fertilizers (Table 5 of test samples from IFDC).

For the remaining seven fertilizer samples, the CPC images were mismatched by the CBR, and the accuracy was estimated to be 61% (Tables 4a and 4b). The second set of database was created with 1500 CPC images of 22 Indian fertilizers with test sample weight of 0.050 g to 5.000 g of fertilizer in 100 mL 1% alkaline solution. Eleven out of 18 fertilizer CPC images retrieved closest fertilizer images consisting of both IFDC CPC images (800) and Indian fertilizer CPC images (1500). Thirty-seven fertilizer CPC images were tested to retrieve the best case image, and 22 query images retrieved the same fertilizer image as case images with an accuracy of 59% (Tables 6a and 6b). An image of urea was scanned 10 times and processed. The processed images retrieved the best five fits images of urea fertilizers from the Ferti tool software. The results mentioned above are revealing the right type of fertilizer identification.

The urea fertilizer was adulterated with AS and SSP with combinations ranging between 1:0, 1:1, 1:3 and 3:1 ratios. The adulterated fertilizers were blended with a mortar and pestle and 0.500 g and 1.000 g were used for CPC image development. This system picked the images of higher nitrogen samples as best fit (Table 7). SSP fertilizer was adulterated with gypsum (0.900 + 0.100 to 0.100 + 0.900 gm, respectively) and subjected to CPC analysis. The gypsum image was retrieved as best fit, which is revealing that adulteration could be determined through this system (Table 8 and Graph 12). The fertilizers CPC Images of similar pattern were selected, and its calculated nutrient values were compared for further improvement of software.

3.4 Nutrients identification and quantification by fractionation of chromatogram images

In addition to testing the proof of concept “Ferti tool,” studies were conducted to detect the deposited fertilizer nutrients in the CPC images by fractionation analysis. Thirteen different fertilizer images were dissected based on zones and colors and estimated by following standard method of nutrient analysis (Table 9).

3.4.1 Testing the adulterants through FAAT

Urea fertilizer was adulterated with AS in combinations ranging from 1:0, 1:1, 1:3 and 3:1 ratio. The adulterated fertilizers were blended with mortar and pestle and 0.500 g and 1.000 g were used for CPC image development. The images of the eight adulterated urea samples, including two samples without AS, were tested on the FAAT system. All eight samples were exactly retrieved from the database, indicating a 100% accuracy of detecting the adulterated urea. However, the adulterated urea samples reported high nitrogen content and thus required further fine-tuning to obtain the correct nitrogen content of the urea fertilizer.

SSP fertilizer was adulterated with gypsum at ratio ranging from 1:1 to 9:1. The adulterated fertilizers were blended with mortar and pestle, and 1.0 g was taken for CPC image development. The images of the seven adulterated

SSP samples were tested on the FAAT system and reproduced five similar images of the gypsum types, which indicated that the SSP fertilizer was adulterated with gypsum with an accuracy of 71%.

3.5 Software development

The AAT software needed to be installed with necessary accessories for establishing the FAAT system. A brainstorming session was organized to understand the function of AAT, core concept of the FAAT project, required algorithms, changes on C++ programming code, weighting machine learning and other necessary features to be adjusted among software engineers, IITM experts and project members. The input and output data formats and screens were modified based on fertilizer type and properties.

Machine learning, a branch of artificial intelligence, is a scientific discipline that primarily deals with computational intelligence techniques based on empirical evidences and provides useful predictions for unseen data. An important focus in machine learning has been to design and develop better algorithms for the regression analysis task. In statistics, this problem of predicting real valued target variables (soil nutrients, in our case) by modeling and analyzing a set of independent variables (features extracted from the chromatogram) is known as regression. The strong generalization ability of the models obtained by the application of these algorithms, coupled with the simplicity of their usage, has motivated scientists to resort to such techniques for complicated prediction tasks.

3.5.1 Developing database for fertilizer and chromatographic images

The goal of this project is to prove the concept of extending the use of MCRC's AAT methodology for rapid and simple analysis of fertilizers. This is a limited proof of concept process and hence a small database containing reference samples, and model algorithm has been created. MCRC recommends at least 25,000 to 50,000 CPC images with associated wet lab analysis for correlation, for higher repeatability and accuracy of results.

The modeling algorithm thus incorporates physicochemical properties (Annex 1) from wet lab/conventional analysis of synthetic fertilizer (see under section 3.1) and digital image attributes (Annex 2) of 2063 processed fertilizer concentrations from India and IFDC. These reference database and model algorithms for fertilizers were installed in a new and stand-alone laptop computer.

The software was created using a Case Based Reasoning system that captures the best fit and best five images between the test sample image and the images in the reference database. The nutrient content of the sample is obtained from the reference sample that fits best to the sample image. In cases where best fit images are difficult to obtain, the software yields five images similar to query image. If required, the average nutrient analysis of the five similar images is used as the estimate (result) of the test sample.

4 Conclusion

There have been instances of decline in the quality of fertilizer due to the marketing of adulterated and substandard fertilizer. Applying adulterated fertilizers will cause damage to soil health and crops. For determining the adulteration, a simple, cost-effective and easy-to-handle tool has to be developed for checking fertilizer quality and adulteration at the retailers. In this study, a reference database for about 2063 fertilizers with their physicochemical properties measured in conventional analytical laboratories was created with their corresponding chromatographic

images and digital characterization of these images based on selected attributes. The existing AAT software was adapted and integrated as a unique, stand-alone software for a FAAT system.

The consolidated database consisting of both IFDC and Indian fertilizers reported a similarity of about 70% in the results between the FAAT system and conventional analytical methods. Similarity between AAT methodology and conventional analytical methods for nutrient content and, hence, its quality, indicated an accuracy of 84% for IFDC database. The FAAT system also determined 100% accuracy of the adulteration. Broadly, it can be concluded that use of AAT methodology for fertilizer nutrients and adulterants (and hence quality) testing is a promising technology with room for improvement. This can be done by developing a parent database for 25,000 fertilizer concentrations, replacing the small dataset in the model fertilizer database.

Table 1. Procured fertilizers and agro-inputs from local market

S. No	Fertilizers	Source	Quantity (kg)
1	Urea	SPIC	3.0
2	Urea	Zuari	3.0
3	Urea	Kotari	3.0
4	Urea	Vijay	3.0
5	Ammonium sulfate (AS)	Zuari	1.0
6	Single superphosphate (SSP)	Rashtrya chemicals	1.0
7	Muriate of potash(MOP)	IPL	1.0
8	Muriate of potash(MOP)	Zuari	1.0
9	Sulfate of potash(SOP)	Kotari	0.5
10	Diammonium phosphate (DAP)	MFL	1.0
11	Monoammonium phosphate (MOP)	MFL	1.0
12	Potassium nitrate (PN)	Nagasree	1.0
13	20-20-0 (NPK)	CIL	1.0
14	14-35-14 (NPK)	Rashtrya chemicals	1.0
15	10-26-26 (NPK)	Rashtrya chemicals	1.0
16	15-15-15 (NPK)	CIL	1.0
17	12% ZnSO ₄	CIL	0.2
18	Borax 15%	Godavari – CIL	1.0
19	Zinc sulfate 21%	Zuari	2.0
20	Micronutrient mix	Dealer Taramani	1.0
21	20-20-0-13	Dealer mixed	1.0
22	Gypsum	Local market	1.0

Table 2. Fertilizer parameters and method of analysis

Fertilizers	Parameters	Methods (Motsara and Roy – Guide to laboratory establishment for plant nutrient analysis, FAO 2008)
Urea	Urea Nitrogen	Page No. 109
Ammonium sulfate	AN, S	Page No. 108
Single superphosphate	P ₂ O ₅ and moisture	Page No. 112
Triple phosphate	P ₂ O ₅	Page No. 112
MOP	K ₂ O	Page No. 119
SOP	K ₂ O, S	Page No. 119
DAP	Ammoniacal nitrogen, urea nitrogen and P ₂ O ₅	Page No. 109, 112
MAP	Ammoniacal nitrogen and P ₂ O ₅	Page No. 109, 112
Potassium nitrate	Nitrate nitrogen & K ₂ O	Page No. 119
20-20-0	Ammoniacal nitrogen, urea nitrogen and P ₂ O ₅ .	Page No. 109, 112
14-35-14	Ammoniacal nitrogen, urea nitrogen and P ₂ O ₅ & K ₂ O	Page No. 109, 112 & 119
10-26-26	Ammoniacal nitrogen, urea nitrogen and P ₂ O ₅ & K ₂ O	Page No. 109, 112 & 119
Custom NPK fertilizer with Zn micronutrient	N, P ₂ O ₅ , K ₂ O, Zn	Page No. 109, 112, 119 & 121
12 % Zn in Chelated Zn (Zn-EDTA), ZnSO ₄ or ZnO	Zinc	Page No. 121
Boron in Borax or Polybor or Granubor	Boron	Titration

Table 3a. Fertilizer physicochemical properties analyzed by conventional method at Coromandel International Limited

Sl. No.	Fertilizers	Compositions								
		AN (%)	UN (%)	NO ₃ – N (%)	TN (%)	T. P ₂ O ₅ (%)	WS P ₂ O ₅ (%)	K ₂ O (%)	SO ₄ (%)	H ₂ O (%)
1	Urea	Tr.	45.59	0.000	45.59	Tr.	0.000	Tr.	0.000	0.000
2	Ammonium sulfate (AS)	20.760	Tr.	0.000	20.76	Tr.	0.000	Tr.	0.000	1.06
3	Single superphosphate (SSP)	Tr.	Tr.	0.000	Tr.	0.000	16.34	Tr.	0.000	7.61
4*	Muriate of potash (MOP)	6.400	11.4	0.000	17.8	17.7	0.000	18.74	0.000	9.56
5	Sulfate of potash (SOP)	Tr.	Tr.	0.000	Tr.	Tr.	0.000	50.30	54.06	0.000
6	Diammonium phosphate (DAP)	18.300	0.000	0.000	18.3	44.8	0.000	0.000	0.000	0.000
7	Monoammonium phosphate (MAP)	11.91	0.000	0.000	11.91	60.4	0.000	0.000	0.000	0.000
8	Potassium nitrate (PN)	Tr.	Tr.	13.56	13.56	Tr.	0.000	45.840	0.000	0.000
9	20-20-0	18.5	1.15	0.000	19.65	19.8	0.000	Tr.	0.000	0.000
10*	14-35-14	8.3	1.9	0.000	10.2	11.9	0.000	24.08	0.000	0.000
11*	10-26-26	14.6	1.05	0.000	15.65	19	0.000	0.250	0.000	0.000
12	NPK (15-15-15)	6.45	0.000	8.10	14.55	14.9	0.000	14.530	0.000	0.000
13	12% Zn in chelated Zn (Zn-EDTA), ZnSO ₄ or ZnO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14	Boron 15%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15	Boron 20%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0900	0.000
16	20-20-0-13	19.300	0.000	0.000	19.300	19.800	0.000	0.000	15.020	0.000
17	Micronutrients	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
18	Gypsum	0.000	0.000	0.000	0.000	0.270	0.010	0.000	17.840	0.300
19	Urea -2	0.000	0.000	0.000	45.900	0.000	0.000	0.000	0.000	0.000
20	Urea -3	0.000	0.000	0.000	46.000	0.000	0.000	0.000	0.000	0.000
21	Urea -4	0.000	0.000	0.000	46.000	0.000	0.000	0.000	0.000	0.000
22	Monoammonium phosphate (MAP)	0.000	0.000	0.000	11.600	61.200	0.000	0.000	0.000	0.000

*The nutrient contents of fertilizers was found to be low due to impurities when we compare with actual claim of the fertilizer.

Table 3b. Fertilizer physicochemical properties analyzed by conventional method at Coromandel International Limited

Sl. No.	Fertilizers	Zn (Chelated) (%)	SO ₄ -S (%)	Minerals (ppm)						
				Boron (%)	Ca	Cu	Fe	Mg	Mn	Na
1	Urea	0.000	0.04738	0.000	1230.1	14.9	6.900	14.3	9.7	128.6
2	Ammonium sulfate	0.000	24.47	0.000	1458.3	11.1	29.50	52.5	12.1	191.2
3	Single superphosphate	0.000	8.98	0.000	20826.4	23.2	2280.0	2228.2	22.4	2124.6
4	MOP	0.000	0.709	0.000	2073.8	31.7	2359.3	1472.4	35.6	2845.5
5	SOP	0.000	0.000	0.000	1338.7	13.6	63.30	298.0	14.8	754.9
6	DAP	0.000	4.88	0.000	6692.0	26.5	4139.8	2197.3	170.5	742.8
7	MAP	0.000	0.12260	0.000	1478.4	13.8	29.60	52.8	15.2	191.7
8	Potassium nitrate	0.000	0.32450	0.000	2175.2	15.0	27.70	1124.5	14.3	917.6
9	20-20-0	0.000	2.07	0.000	6715.9	24.1	3408.8	11042.9	345.8	1615.7
10	14-35-14	0.000	1.21	0.000	35400	28.6	7085.4	7452.6	155.7	911.0
11	10-26-26	0.000	12.40	0.000	16100	24.2	2697.0	1754.4	190.6	1235.0
12	NPK (15-15-15)	0.000	1.60	0.000	17800	24.2	3325.4	7428.0	177.8	733.0
13	12% Zn in chelated Zn (Zn-EDTA), ZnSO ₄ or ZnO	11.9	0.10130	0.000	4600.00	9.6	12.80	38.7	13.2	0.000
14	Boron	0.000	0.10580	15.22	1413	63.6	42.70	108.5	12.6	0.000
15	Boron 20%	0.000	0.000	18.74	531.0	1.9	0.000	303.4	0.86	0.00197
16	20-20-0-13	0.000	0.000	0.31220	448.0	39.8	127.7	3424.0	23.90	353.0
17	Micronutrients	0.000	0.000	0.09871	21790.0	76.0	8452.0	4130.0	141.10	2649.0
18	Gypsum	0.000	0.000	0.05764	0.00225	0.000	49.80	59.2	0.69	290.4
19	Urea -2	0.000	0.000	0.000	1600	0.000	20.00	11	0.000	120.0
20	Urea -3	0.000	0.000	0.000	1500	0.000	7.000	148	0.000	178.0
21	Urea -4	0.000	0.000	0.000	2300	0.000	20.0	198	0.000	198.0
22	MAP	0.000	0.000	0.000	3300	0.000	20.0	217	0.000	4.000

Table 3c. Fertilizer physicochemical properties analyzed by conventional method at Coromandel International Limited

Sl. No.	Fertilizers	Minerals (ppm)							
		Zn	As	Cd	Cr	Co	Mo	Ni	Pb
1	Urea	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	Ammonium sulfate	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	Single superphosphate	10.00	0.000	6.800	22.2	0.000	0.000	6.800	0.000
4	MOP	0.000	0.000	0.000	26.2	0.000	0.000	3.100	0.000
5	SOP	0.000	0.000	0.000	0.300	0.000	0.000	0.000	0.000
6	DAP	0.000	0.000	23.10	177.7	0.000	0.000	11.10	356.6
7	MAP	0.000	0.000	0.000	9.300	0.000	0.000	0.000	0.000
8	Potassium nitrate	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9	20-20-0	0.000	0.000	0.000	8.000	0.000	0.000	0.000	2.900
10	14-35-14	0.000	0.000	0.000	22.00	0.000	0.000	2.800	2.000
11	10-26-26	0.000	0.000	2.000	49.00	0.000	0.000	4.300	0.000
12	NPK 15-15-15	3900.0	0.000	7.900	19.80	0.000	0.000	2.900	3.000
13	12% Zn in chelated Zn (Zn- EDTA), ZnSO ₄ or ZnO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	152.0
14	Boron	0.000	3.9	0.000	0.000	0.000	0.000	0.000	30.400
15	Boron 20%	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16	20-20-0-13	955.4	0.000	0.900	55.10	0.000	0.000	0.000	0.410
17	Micronutrients	85.400	0.000	0.000	68.90	4.300	0.000	9.100	0.000
18	Gypsum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.6
19	Urea-2	137.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	Urea-3	144.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
21	Urea-4	187.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
22	MAP	297.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 4a. Comparison of test sample (Indian fertilizers) with India fertilizer model database

S. No.	Sample ID	NPK Type Identification						Remark/ Outcome*
		Query Case			FAAT Result			
		N	P	K	N	P	K	
1	Urea	46	0	0	46	0	0	Correct
2	PN	13	0	46	13	0	46	Correct
3	Urea	46	0	0	46	0	0	Correct
4	Urea	46	0	0	46	0	0	Correct
5	DAP	18	46	0	13	0	46	Not correct
6	SSP	0	16	0	0	0	0	Not correct
7	10-26-26	10	26	26	10	26	26	Correct
8	15-15-15	15	15	15	15	15	15	Correct
9	20-20-0	20	20	0	20	20	0	Correct
10	MAP	12	61	0	18	46	0	Not correct
11	AS	21	0	0	21	0	0	Correct
12	PN	13	0	46	13	0	46	Correct
13	20-20-0-13	20	20	0	10	26	26	Not correct
14	SOP	0	0	50	0	0	0	Not correct
15	14-35-14	14	35	14	15	15	15	Not correct
16	14-35-14	14	35	14	0	0	60	Not correct

*Correct means identification of same type of fertilizer.

*Not Correct means identification of different type of fertilizer.

Table 5b. Comparison of test sample (Indian fertilizers) with India fertilizer model database

S. No.	Sample ID	NPK Type Identification						Remark/ Outcome*
		Query Case			FAAT Result			
		Zn			Zn			
1	Zinc	12	0	0	12	0	0	Correct
2	Zinc	12	0	0	12	0	0	Correct

Table 5a. Comparison of test sample (IFDC fertilizers) with IFDC fertilizer model database

S. No.	Sample ID	NPK Type Identification						Remark/ Outcome*
		Query Case			FAAT Result			
		N	P	K	N	P	K	
1	18 IFDC	25	0	5	25	0	5	Correct
2	23 IFDC	5	15	30	5	15	30	Correct
3	16 IFDC	6	6	18	29	0	5	Not correct
4	14 IFDC	3	15	30	3	15	30	Correct
5	20 IFDC	5	5	5	5	5	5	Correct
6	19 IFDC	10	10	10	10	10	10	Correct
7	15 IFDC	10	10	10	20	0	10	Not correct
8	1 IFDC	2	0	0	2	0	0	Correct
9	31 FDC	18	46	0	18	46	0	Correct
10	11 IFDC	13	0	0	13	0	0	Correct
11	10 IFDC	32	0	10	32	0	10	Correct
12	9 IFDC	8	16	24	8	16	24	Correct
13	10 IFDC	32	0	10	32	0	10	Correct
14	7 IFDC	7	9	25	7	9	25	Correct
15	22 IFDC	15	5	10	15	5	10	Correct

Table 5b. Comparison of test sample (IFDC fertilizers) with IFDC fertilizer model database

S. No.	Sample ID	NPK Type Identification						Remark/ Outcome*
		Query Case			FAAT Result			
		N	P	K	N	P	K	
1	11 IFDC	13	0	0	13	0	0	Correct
2	20 IFDC	5	5	5	5	5	5	Correct
3	27 IFDC	5	12	12	5	12	12	Correct
4	28 IFDC	19	1	19	19	1	19	Correct
5	30 IFDC	12	40	0	12	40	0	Correct
6	33 IFDC	32	0	10	32	0	10	Correct
7	34 IFDC	6	2	0	6	2	0	Correct
8	36FDC	18	3	16	6	6	18	Not Correct
9	31 FDC	5	20	20	5	15	30	Not Correct
10	14 IFDC	3	15	30	3	15	30	Correct

Table 6a. Comparison of test sample with fertilizer sample for combined database

S. No.	Sample ID	NPK Type Identification						Remark/ Outcome*
		Query Case			FAAT Result			
		N	P	K	N	P	K	
1	15-15-15	15	15	15	15	15	15	Correct
2	14-35-14	14	35	14	13	0	46	Not correct
3	3 IFDC	18	46	0	46	0	0	Not correct
4	7 IFDC	7	9	25	16	16	16	Not correct
5	15-15-15	15	15	15	15	15	15	Correct
6	10-26-26	10	26	26	10	26	26	Correct
7	20-20-0	20	20	0	0	0	60	Not correct
8	20-20-0-13	20	20	0	20	20	0	Correct
9	23 IFDC	5	15	30	5	15	30	Correct
10	14-35-14	14	35	14	0	16	0	Not correct
11	8 IFDC	8	3	5	46	0	0	Not correct
12	9 IFDC	8	16	24	2	0	0	Not correct
13	AS	21	0	0	21	0	0	Correct
14	2 IFDC	2	0	0	2	0	0	Correct
15	1 IFDC	2	0	0	2	0	0	Correct
16	13 IFDC	4	14	4	6	0	0	Not correct
17	IFDC 1	2	0	0	2	0	0	Correct
18	14-35-14	14	35	14	0	0	60	Not correct
19	MOP	0	0	60	0	0	60	Correct
20	MOP	0	0	60	0	0	60	Correct
21	PN	13	0	46	13	0	46	Correct
22	MOP	0	0	60	0	0	60	Correct
23	PN	13	0	46	0	0	60	Not correct
24	14-35-14	14	35	14	46	0	0	Not correct
25	14-35-14	14	35	14	0	0	60	Not correct
26	IFDC 71	29	0	5	29	0	5	Correct
27	MOP	0	0	60	0	0	60	Correct
28	SSP	0	16	0	0	16	0	Correct
29	Urea	46	0	0	46	0	0	Correct

Table 6b. Comparison of test sample with fertilizer sample for model database both India and IFDC

S. No.	Sample ID	NPK Type Identification						Remark/ Outcome*
		Query Case			FAAT Result			
		B	Zn		B	Zn		
1	Boron	15	0	0	15	0	0	Correct
2	Boron	15	0	0	15	0	0	Correct
3	Boron	15	0	0	15	0	0	Correct
4	Boron	15	0	0	15	0	0	Correct
5	Boron	15	0	0	15	0	0	Correct
6	Boron	15	0	0	0	0	0	Not correct
7	Zinc	0	12	0	0	12	0	Correct
8	Zinc	0	12	0	0	12	0	Correct





























Table 7. Comparison of test sample with adulterated fertilizer samples for N content (Refer-Graph 13)

S. No.	Code	Mixture of Fertilizers (g)				Nutrients Concentration (g)				Cal. Value				FAAT Result			
		Urea (g)	Ammonium Sulfate (g)	Single Superphosphate (g)	Total (g)	N	P	K	S	N	P	K	S	N	P	K	S
1	Ferti 0001	20	0	0	20	9.2	0.0	0.0	0.0	0.046	0.000	0.000	0.000	2.162	0.000	0.000	0.000
2	Ferti 0002	20	0	0	20	9.2	0.0	0.0	0.0	0.092	0.000	0.000	0.000	1.84	0.000	0.000	0.000
3	Ferti 0003	10	10	0	20	6.7	0.0	0.0	2.4	0.034	0.000	0.000	0.012	0.12	0.000	0.000	0.000
4	Ferti 0004	10	10	0	20	6.7	0.0	0.0	2.4	0.067	0.000	0.000	0.024	1.403	0.000	0.000	0.000
5	Ferti 0005	5	15	0	20	5.5	0.0	0.0	3.6	0.027	0.000	0.000	0.018	1.449	0.000	0.000	0.000
6	Ferti 0006	5	15	0	20	5.5	0.0	0.0	3.6	0.055	0.000	0.000	0.036	2.185	0.000	0.000	0.000
7	Ferti 0007	15	5	0	20	8.0	0.0	0.0	1.2	0.040	0.000	0.000	0.006	0.023	0.000	0.000	0.000
8	Ferti 0008	15	5	0	20	8.0	0.0	0.0	1.2	0.080	0.000	0.000	0.012	2.139	0.000	0.000	0.000

Table 8. Comparison of test sample with adulterated fertilizer samples for S content (Refer Graph-14, 15)

S. No.	Code	Composition in g/100 mL 1% NaOH							
		FAAT result				Cal. Value			
		N	P	K	S	N	P	K	S
1	SSP 150 mg + gypsum 850 mg	0	0.024	0	0.95	0	0	0	0.171
2	SSP 650 mg + gypsum 350 mg	0	0.104	0	1.75	0	0	0	0.315
3	SSP 100 mg + gypsum 900 mg	0	0.016	0	1.4	0	0	0	0.252
4	SSP 300 mg + gypsum 700 mg	0	0.048	0	0.9	0	0	0	0.162
5	SSP 500 mg + gypsum 500 mg	0	0.08	0	2.95	0	0	0	0.531
6	SSP 900 mg + gypsum 100 mg	0	0.144	0	0	0.3	0	0.15	0
7	SSP 800 mg + gypsum 200 mg	0	0.128	0	0	0.72	0.72	0.72	0

Table 9. Fractionation and analysis of fertilizer nutrient deposited in CPC

S. No	Fertilizer	Fractionized CPC Image	Nutrient Deposited (ppm)	RGB Values Generated by AAT System																								
1	Monoammonium phosphate		Three major rings/zones observed	<table border="1"> <tr> <td></td> <td>R145</td> <td>G157</td> <td>B85</td> </tr> <tr> <td colspan="4">Wheat colour</td> </tr> <tr> <td></td> <td>R102</td> <td>G139</td> <td>B139</td> </tr> <tr> <td colspan="4">Grey colour</td> </tr> </table>		R145	G157	B85	Wheat colour					R102	G139	B139	Grey colour											
		R145	G157	B85																								
	Wheat colour																											
	R102	G139	B139																									
Grey colour																												
Nitrogen	Inner most zone	700																										
Phosphorus	Next to inner zone	486																										
2	Diammonium Phosphate		Three major rings/zones observed	<table border="1"> <tr> <td></td> <td>R 145</td> <td>G157</td> <td>B85</td> </tr> <tr> <td colspan="4">Wheat colour</td> </tr> <tr> <td></td> <td>R102</td> <td>G139</td> <td>B139</td> </tr> <tr> <td colspan="4">Grey colour</td> </tr> </table>		R 145	G157	B85	Wheat colour					R102	G139	B139	Grey colour											
		R 145	G157	B85																								
	Wheat colour																											
	R102	G139	B139																									
Grey colour																												
Nitrogen	Inner most zone	1162																										
Phosphorus	Next to inner zone	381																										
3	Complex N:P:K 19:19:19		Three major rings/zones observed	<table border="1"> <tr> <td></td> <td>R145</td> <td>G157</td> <td>B85</td> </tr> <tr> <td colspan="4">Golden yellow</td> </tr> <tr> <td></td> <td>R245</td> <td>G222</td> <td>B179</td> </tr> <tr> <td colspan="4">Brown</td> </tr> <tr> <td></td> <td>R102</td> <td>G139</td> <td>B139</td> </tr> <tr> <td colspan="4">Grey</td> </tr> </table>		R145	G157	B85	Golden yellow					R245	G222	B179	Brown					R102	G139	B139	Grey			
		R145	G157	B85																								
	Golden yellow																											
		R245	G222	B179																								
Brown																												
	R102	G139	B139																									
Grey																												
Nitrogen	Inner most	200																										
Phosphorus	Next to inner	400																										
Potassium	Middle	231																										
4	Muriate of Potash		Four major zones observed	<table border="1"> <tr> <td></td> <td>R102</td> <td>G139</td> <td>B139</td> </tr> <tr> <td colspan="4">Dark grey outer ring</td> </tr> </table>		R102	G139	B139	Dark grey outer ring																			
		R102	G139	B139																								
Dark grey outer ring																												
Potassium	800																											

Annex 1. Screenshot of fertilizer composition in ferti tool



Annex 2. Screenshot of model fertilizer test report (printout form)

Fertilizer Composition Report

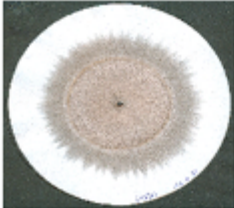
Zoom: 100%

Fertilizer Test Report

Sample ID: TF SP 0.850	Village: A	Collection Time: A
Farmer's Name: A	Tahik: A	Date of analysis: 05/11/13

Total Nitrogen: 0.38 %	Boron: 71.41 %
Total P₂O₅: 0 %	Sulphur: 0.02 %
Total K₂O: 255.42 %	Molybdenum: 0 ppm
Calcium: 155.69 %	Arsenic: 0 ppm
Magnesium: 12.35 %	Cadmium: 255.79 ppm
Sodium: 0 %	Chromium: 0 ppm
Iron: 35.1 %	Cobalt: 0 ppm
Manganese: 25.95 %	Nickel: 0 ppm
Copper: 7.77 %	Lead: 0 ppm
Zinc: 0 %	

Image of Fertilizer Chromatogram



* The physico-chemical properties of Fertilizer were determined by following an alternative analytical indigenous technology developed by MCRC, IT (M) with financial assistance from VFRC, USA.

Pages: 1

start | 6 W... | 3 M... | 5 M... | 5 M... | Mon... | Feb... | Sol... | Desktop | 2:43 PM

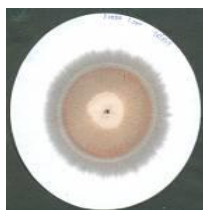
Annex 3. Similar fertilizer CPC images with respective N, Z and P values



A) N % 0.644



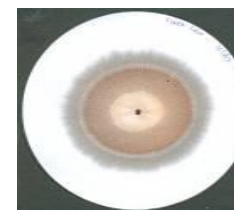
B) N % 0.667



C) N % 0.690



D) N % 0.713



E) N % 0.736



A) Z % 0.306



B) Z % 0.312



C) Z % 0.318



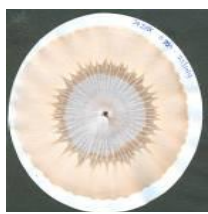
D) Z % 0.324



E) Z % 0.330



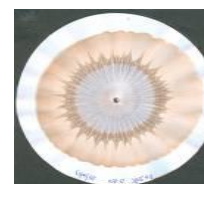
A) N% 0.042,P% 0.014



A) N% 0.045,P% 0.015



A) N% 0.048,P% 0.016

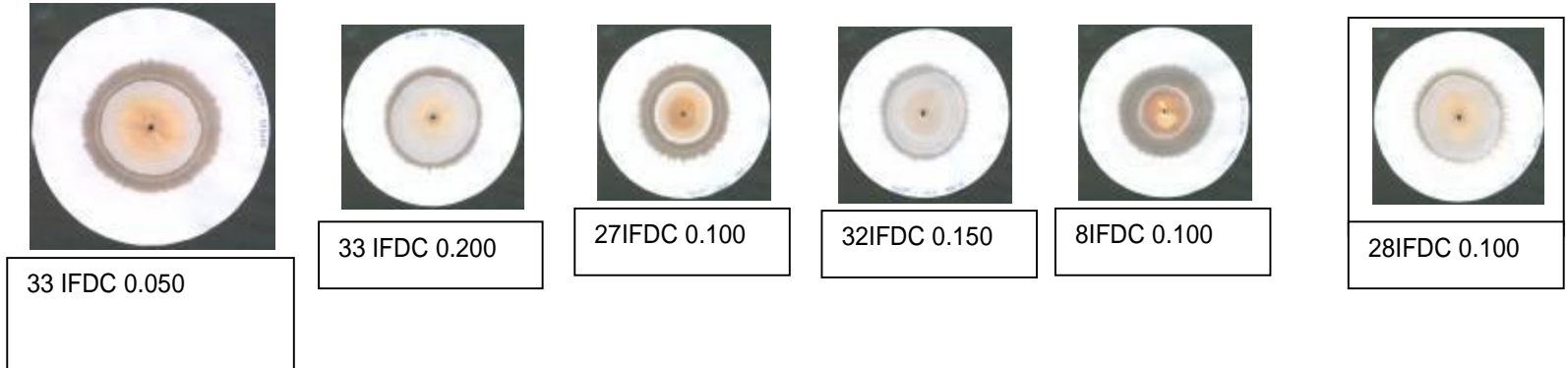


A) N% 0.051,P% 0.017

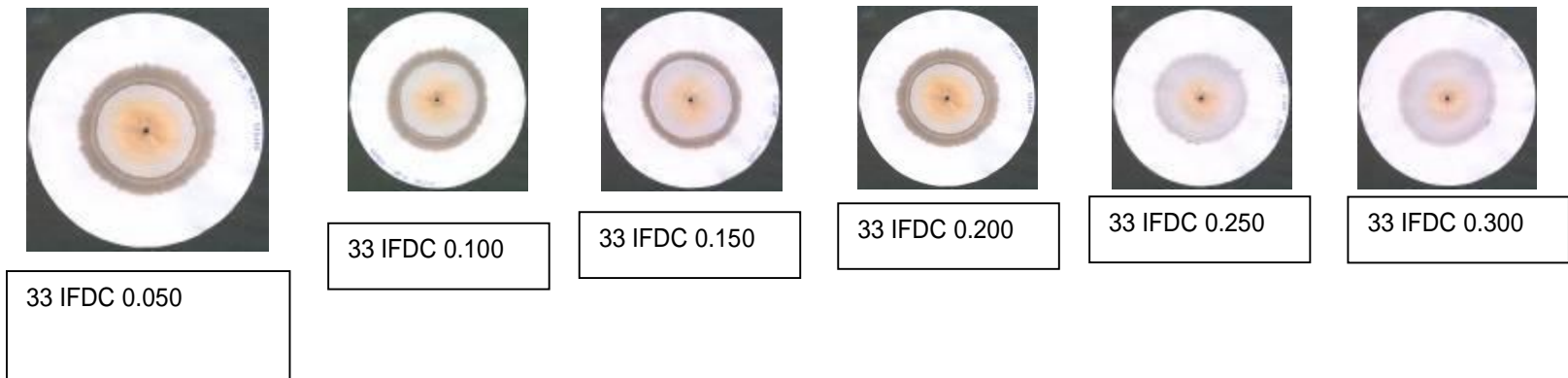


A) N% 0.054,P% 0.018

FAAT system retrieved images



Visual observation for query sample for similar CPC images



Annex 4. *Portable AAT kit (PAAT)*



5 Acknowledgments

The project team gratefully acknowledges the financial support received from the Virtual Fertilizer Research Center (VFRC), Washington, D.C., USA, and the International Fertilizer Development Center (IFDC), USA. We also thank M/s Coromandel International Limited, Vishakhapatnam, India, for their support on sampling fertilizers and its nutrient analysis. We sincerely thank Mr. K. Raghunandan, Chief Executive Officer, Shri AMM Murugappa Chettiar Research Centre (MCRC), for his technical and administrative support. Authors would also like to thank the Board of MCRC for their additional financial support (Rs. 300,000 approximately) for continuing research on the FAAT system.

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More information: www.vfrc.org

Virtual Fertilizer Research Center
1331 H Street, NW
11th Floor
Washington, D.C. 20005
USA
Email: contact@vfrc.org

