AN OVERVIEW OF MALAYSIAN GUIDELINES ON SOIL TESTING AND ITS APPLICATION FOR NUTRIENT CLASSIFICATION

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ABSTRACT
Soil testing and plant analyses are essential tools in diagnosing nutritional deficiencies and problems related to plant growth. The information provided in this paper represents a summary of guidelines used in Malaysia on the use of soil testing and plant analysis as a diagnostic tool that enable farmers and plantation industries to assess the nutrient contents in soil and plants as a guide for fertilizer use and to obtain optimum yield. Discussions also include fundamentals of quality control and quality assurance applied for soil and plant testing including application of proficiency testing for laboratories accredited with the Malaysian Standard ISO/IEC 17025: 2017. A case study utilizing soil diagnosis, site-specific nutrient classification, and geographical information system tools are discussed as examples of soil and plant testing applications used for nutrient classification in Malaysian paddy cultivation.

Keywords: Guidelines, standards, proficiency testing, soil diagnosis, nutrient classification, geospatial interpolation, soil mapping

INTRODUCTION
Soil is one of the most important natural resources for crop production (Abdul Khalil et al., 2015). Soil testing and plant analyses are important tools in diagnosing nutritional deficiencies and problems related to plant growth. Soil testing is an integral part of modern farming especially in developing countries. Soil testing mainly focuses on analyzing nitrogen, phosphorus, and potassium that is most in demand by crops that are supplied by fertilizers. Secondary nutrients such as calcium, magnesium, and micronutrients including iron, zinc, copper, and boron as well as other soil properties such as texture, aggregate, pH, salinity, and organic matter are also measured to avoid deficiency problems and nutrient imbalance. Generally, there are four stages in soil testing (Estefan et al., 2013) that include (i) sample collection (ii) extraction or digestion and nutrient determination; (iii) interpretation of analytical results; and (iv) fertilizer recommendation: based on soil test calibrated for field condition and taking into considerations other factors such as crop nutrient requirement, optimum yield target, soil type, fertilizer application method, and environmental conditions. Meanwhile, plant analysis is often determined simultaneously with soil testing to facilitate management decisions in improving crop nutrition and formulating fertilizer recommendations (Memon et al., 2005). Plant analysis is commonly defined as the quantitative analysis of the total nutrient content in plant tissue that indicates the soil’s ability to supply nutrient that is directly related to the available nutrient status in soil (Kelling et al., 2000) at a particular time of sampling, often in time for any deficiencies to be remedied while the crop is still growing to maturity (Pusparajah, 1994). Both soil testing and plant analyses make it possible for farmers to assess the nutrient content in soil or plants, and to interpret the response of fertilizers on soil fertility improvement or to indicate appropriate rate of fertilizers to apply when there is a lack of nutrients in soil and plants. Thus, soil testing and plant diagnosis often help farmers in reducing fertilizer costs and environmental pollution arising from intensive fertilizer application.
In Malaysia, analytical services for soil and plant testing are carried out by government agencies, agricultural institutions, and commercial independent laboratories. The analytical services provided use strict standardized methods according to national quality standards that meet the requirement for research studies and nutrient management especially for agricultural activities. The Department of Standards Malaysia (STANDARDS MALAYSIA) is the national standards and accreditation body of Malaysia. The main function of STANDARDS MALAYSIA is to foster and promote standards, standardization and accreditation as a means of advancing the national economy, promoting industrial efficiency and development, benefiting the health and safety of the public, protecting the consumers, facilitating domestic and international trade and furthering international cooperation in relation to standards and standardization. Malaysian Standards (MS) are developed through consensus by committees that comprise balanced representation of producers, users, consumers and others with relevant interests, as may be appropriate to the subject at hand. In addition, MS are aligned to or are adoption of internal standards. The approval of a standard as a MS is governed by the Standards of Malaysia Act 1996 (Act 549). SIRIM, a national standards development agency that is under the purview of the Ministry of Science, Technology, and Innovation (MOSTI) Malaysia, is tasked with overseeing the national standards infrastructure on behalf of the Department of Standards of Malaysia. Some of the Malaysian national standards developed by SIRIM in relation to the agriculture sector include (i) quality management and quality assurance MS ISO/IEC 17025:2017 revised; (ii) management system certification schemes for food safety (ISO22000 and FSSC 22000) Good Manufacturing Practices (MS1514); (iii) MS2027:2018 (Good animal husbandry practice); (iv) Environmental management (MS ISO 14034:2018).

The two main government bodies involved in providing soil and plant testing services in the country is the Department of Agriculture Malaysia (DOA) and the Malaysian Agricultural Research and Development Institute (MARDI). Analysis Service Section under the purview of the Management and Conservation of Soil Resources Division, DOA Malaysia provide laboratory services to conduct analysis on nutrient content in soils, leaves, fertilizers, and water samples. The main objective of the service is to support the implementation of the development programmes conducted by the DOA Malaysia. The service provided by DOA Malaysia is also extended to other governmental agencies upon request where private bodies and individuals are charged at a reasonable fee. There are four types of analytical services provided by DOA Malaysia and these include (i) analysis of the soil physicochemical characteristics to describe soil properties, fertility, and conservation; (ii) analysis of leaf samples to determine plant nutrient level, soil fertility status, and fertilizer requirement; (iii) analysis of fertilizers to evaluate the quality of fertilizers supplied to farmers and other users; and (iv) analysis of water to determine the quality of water used for irrigation and the parameter of erosion for soil conservation purposes. The soil testing provided by DOA is not used to make fertilizer recommendations for individual smallholders. Other services provided by DOA include soil classification and general recommendations made according to soil and crop types. The laboratories under DOA provide highly experienced personnel in conducting soil and fertilizer testing, plant diagnosis, pesticide residue, and microbiological analysis.

The Malaysian Agricultural Research and Development Institute is a leading agricultural research center under the Ministry of Agriculture and Agro-based Industry of Malaysia. Established in 1969, MARDI is mandated to conduct research and promote efficient and innovative technologies towards the advancement of the agriculture, food and agro-based sectors. Moreover, MARDI provides consultancy and technical services, including laboratory analysis and quality assurance, to support the development of the food, agriculture and agro-based industries. Other than providing services to its own research personnel and other government agencies, MARDI’s Food and Agricultural Chemical Laboratory also provide services to individuals such as entrepreneurs, private companies and others. The laboratory is awarded with ISO/IEC 17025 certification from the Department of Standard Malaysia (DSM) to ensure that test results from analytical services complies with industry regulations and is equivalent to acceptable standards that global markets require.

**QUALITY CONTROL AND ASSURANCE**

Quality control and assurance are essential parts of good laboratory practices. According to the International Standardization Organization (ISO), quality control is defined as the operational techniques and activities that are used to satisfy quality requirements in which the main objective of quality controls is to prevent errors (Reeuwijk L.P. and Houba, V.J.G., 1998). Quality assurance is defined by the ISO as the assembly of all planned and systematic actions necessary to provide adequate confidence that a product, process, or service will satisfy given quality requirements. Regular assessment of quality control and assurance will document and measure both accuracy and precision.
Accuracy is generally defined as closeness of a measurement to known or expected value whereas precision is defined as the repeatability of multiple measurements on the same sample (Hoskins, 2009).

According to the United States Environmental Protection Agency (EPA), the distinct difference between quality control and quality assurance is that quality control is a system of activities to provide a quality product whereas quality assurance is a system of activities to provide assurance that the quality control system is performing adequately. Therefore, quality control activities should be implemented for all the steps of the measurement activities comprising sample collection to data reporting (ISAG, 2000). There are three main functions of quality assurance of data control. These functions include (i) assuring all sample data is stored adequately in databases; (ii) data in which accuracy and representativeness are doubted should be flagged; and (iii) recognizing and describing samples, that were measured without standard methods such as contamination, bulk sampling, and instrument breakdown.

For good laboratory practices in soil or plant testing, three precautions involving the use of blanks, repeats, and internal references are essential to be included among test samples as an assurance for quality control (Estefan et al., 2013). The procedures for quality control mainly monitor the accuracy of the work by checking the bias of data with the help of certified reference samples and the precision by means of replicate analyses of test samples as well as reference or control samples. Blanks are one of the common methods used to quantify analytical bias in soil and plant testing. Blank subtraction is used to correct for systematic sources of contamination in order to improve accuracy. Replicate analysis generally involved two or more analyses of routines sample unknowns at some specified frequency. Replicate testing of routine samples can be used to determine the precision of analytical results. Internal reference sample is often used as a daily quality control assessment used in soil testing labs. It is also an alternative approach to replicate analysis. An internal reference is typically an in-house homogenized sample that is run at regular or irregular intervals in routine sample stream. Internal reference sample is validated by running it in tandem with purchased standard reference material (SRM) samples.

The guidelines on soil testing and plant analyses comprised of several components that are dependent on chemical analysis are as follows (Nyit et al., 2017): (i) assessing compliance with fertilizers and bio-input quality standards; and (ii) determination of soil and plant nutrient concentrations. These dependencies require accurate and reproducible results that are independent of the laboratory providing the results. Thus, the function of quality control and quality assurance processes and procedures is to provide assurances by ensuring the following (i) standard operating procedures are documented and complied for each analytical method; (ii) chain of custody processes are followed to ensure sample integrity and confidentiality of results; (iii) active quality control procedures or processes are documented and implanted; (iv) laboratory participates in ISO/IEC 17025 accreditation scheme to validate laboratory quality assurance; and (v) laboratory participates in proficiency testing programme to verify robustness of test results.

Soil and plant proficiency testing (PT)

Food and agriculture products in markets need to have assurance in quality and safety. In order to make use of the values in predicting nutrient needs, the test must be calibrated by conducting nutrient response research, under local conditions with representative soils ranging from deficient to adequate for each nutrient of concern. To ensure uniformity, there is a need for standard samples and cross checking of results from different laboratories. The system of cross checking has been used in Malaysia since 1971.

In Malaysia, participation to proficiency testing (PT) exercise is considered mandatory for laboratories accredited according to Malaysian Standard MS ISO/IEC 17025: 2017 (General requirements for the competence of testing and calibration laboratories: second revision) (Figure 1). Proficiency testing is one of the essential elements of quality assurance (Sanusi et al., 2013). One of the main advantages of proficiency testing is to assess laboratories capabilities to perform routine test competently (Adni, 2013). The proficiency test carried out includes assessment by laboratories themselves, their clients, or accreditation and regulatory bodies. The proficiency test supplement laboratories own internal quality control procedures by providing an additional external measure of their testing capabilities to produce reliable and reproducible analytical data. Moreover, this proficiency test schemes also improves the techniques of on-site laboratory assessment by technical specialists normally used by laboratory accreditation bodies. In summary, the main objective of proficiency testing is to provide an independent assessment of the data quality and to improve the quality of the measurements (Sanusi et al., 2013). Furthermore, it provides valuable information on the performance of the laboratory to the laboratory management and the analysts.
The Agriculture Laboratory Association of Malaysia (AgLAM) organizes proficiency testing programmes on soil, plant, fertilizers, and compost analysis to improve laboratory testing accuracy and as well as ensuring standardized analytical methods among participating laboratories in Malaysia. The AgLAM was inaugurated on 28 May 2007 and was formerly known as Committee on Standardization of Soil, Plant, and Fertilizer Analysis. Recent efforts by AgLAM include improvement on speed, accuracy, and more environmentally friendly analytical techniques and methods. There are three main objective of the establishment of AgLAM that includes (i) to organize proficiency testing programmes of agriculture and related testing with the aim to improve laboratory performance; (ii) to function as a forum to promote good laboratory practices (GLP) through laboratory accreditation of ISO/IEC 17025; and (iii) to review and update on the latest development in the analytical techniques of agricultural testing in line with good agricultural practices (GAP).

Participation of proficiency testing organized by AgLAM is on a voluntary basis. At present, the number of participating laboratory in 2018 was more than 30 laboratories with participation mainly from government laboratories and plantation groups. The proficiency test scheme by AgLAM enables participating laboratories to regularly monitor their laboratory performance and taking adequate measures to investigate and repress problems associated with outlier results. Laboratories involved in the proficiency testing have found the programme to be useful in detecting analytical errors, and gentle drifts in results due either to inadvertent changes in analytical procedures by laboratory personal or equipment deterioration. In the proficiency testing schemes, standard samples are sent out every four months to be analyzed, and thereafter the committee compares the results from different laboratories. If any discrepancy arises, the laboratory in question will be asked to identify the problem and directly report to the committee (Adni, 2013).

![Logo of Laboratory Accreditation Scheme of Malaysia](image)

**Fig. 1. Logo of Laboratory Accreditation Scheme of Malaysia**

**DATA INTERPRETATION AND APPLICATION**

Descriptive statistics is an important tool that summarizes the quantitative data obtained from soil testing analysis. Regular assessment of quality control in data interpretation can be presented in terms of accuracy and precision. Accuracy is measured in terms of deviation of a measured value from the known or assumed value whereas precision is presented in terms of standard deviation from the mean of repeated measurements made on the same sample (Hoskins, 2009). Both accuracy and precision tabulate systematic and random errors that represent the analytical uncertainty in soil laboratory results. Furthermore, accuracy and precision statistics can be used as a performance indicator to determine whether quality assurance standards are complied over long-term period. A case study utilizing soil diagnosis, site-specific nutrient classification, and geospatial interpolation and processing tools are presented as examples of soil and plant testing applications used for nutrient classification in Malaysian paddy cultivation.
Utilization of soil diagnosis

It is widely known that the application of fertilizers is important to enhance yield and maximize long term soil productivity. Application of soil nutrient diagnosis enables farmers to make wise decisions and assess between fertilizer requirements of their crops, and the type and quantity of fertilizers to be applied for optimum yield. Assessment on the physical conditions of the soil and development of plant and soil analysis as diagnostic techniques has made it possible to assess the discriminatory fertilizer requirement for location specific area. The first stage of soil testing services consists of soil surveys and field trials. This is carried out to ensure that standard fertilizer recommendations can be established for important crops growing in different types of soils. For the case of Malaysia, utilization of soil diagnosis is limited to rice production. However, recommendations have also been developed for other crop types in recent years. Soil maps are also commonly used as the basis for fertilizer recommendations, supplemented by field-testing.

Paddy soils are naturally heterogeneous. Complex interrelationships existing between physical, chemical and biological soil properties have long been recognized. Apart from spatial variation, there is also temporal variation, such as nutrient status. The variation of soil properties in space and time implies that soils have varying capacity to retain and supply nutrients to rice crop. This makes it difficult to correctly manage field input applications. Studies have showed that rice productivity was strongly influenced by soil texture, acidity, nutrient concentration and its cation exchange capacity (Aminuddin et al., 2003). According to Rao and Srivasta (2000), soil test based application of plant nutrients helps to perceive higher response and cost benefit ratio as the nutrients are applied in proportion to the magnitude of the deficiency of a particular nutrient, and the correction of the nutrients imbalance in soil helps to harness the synergistic effects of balanced fertilization. In addition, location specific fertilizer recommendations are important for soils of varying fertility, resource conditions of farmers and levels of targeted yield to improve the yield production and reduce the cost of fertilizer input and wastage.

Soil nutrient classification

Four steps were involved to establish soil nutrient classification for paddy cultivation that includes (i) soil nutrient status; (ii) rating scheme; (iii) classification scheme; and (iv) classification map. Theeba et al. (2018) emphasized that soil chemical characteristics and nutrients in paddy cultivation must be done based according to site-specific location for soil pH, cation exchange capacity (CEC), and macronutrients of N, P, and K (NPK) status. For the first stage in determining soil nutrient status, soil was sampled based on selected grid points method provided by the Department of Agriculture (DOA) Malaysia. The values obtained for soil nutrients according to site-specific location for paddy cultivation is shown in Table 1.

Table 1. Soil chemical characteristics and nutrients for two site-specific paddy locations in Malaysia.

<table>
<thead>
<tr>
<th>Location</th>
<th>pH</th>
<th>CEC (cmol(+)/kg)</th>
<th>N (%)</th>
<th>P (µg/g)</th>
<th>K (cmol/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SPS</strong></td>
<td>Mean (average)</td>
<td>5.95</td>
<td>25.52</td>
<td>0.27</td>
<td>42.65</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>4.40</td>
<td>17.39</td>
<td>0.07</td>
<td>6.00</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>7.70</td>
<td>36.99</td>
<td>0.51</td>
<td>514.00</td>
</tr>
<tr>
<td></td>
<td>Std. Error</td>
<td>0.03</td>
<td>0.19</td>
<td>0.003</td>
<td>2.48</td>
</tr>
<tr>
<td><strong>IKS</strong></td>
<td>Mean (average)</td>
<td>4.74</td>
<td>10.34</td>
<td>0.23</td>
<td>39.95</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>3.20</td>
<td>0.69</td>
<td>0.01</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>6.91</td>
<td>34.40</td>
<td>7.00</td>
<td>424.00</td>
</tr>
<tr>
<td></td>
<td>Std. Error</td>
<td>0.03</td>
<td>0.23</td>
<td>0.014</td>
<td>2.60</td>
</tr>
</tbody>
</table>

Source: Muhammad Zamir et al. (2018)
The second stage of soil nutrient classification was to categorize the nutrients according to soil classification scheme (Muhammad Zamir et al., 2018) as illustrated in Figure 2. The classification scheme was conducted based on the results of the soil nutrient content for pH, CEC, N, P, and K as presented in Table 1. Soil characteristics and fertility status as listed in Table 1 were given ratings based on their value and category scheme according to the following classes: High (3); Medium (2); and Low (1) (Table 2). This step is then followed by the creation of NPK Classification Scheme based on the three identified classes: Class 1 (rating of 7 to 9); Class 2 (rating of 5 to 6); and Class 3 (rating of 3 to 4). For soil pH and CEC values, the soil properties were classified according to its actual mean value in which soil pH consisted of 4 classes whereas CEC comprised of 3 classes as shown in Table 3.

Fig. 2. Classification outline workflow for soil nutrient classification in paddy cultivation.

Table 2. Soil nutrient rating scheme for nitrogen, phosphorus and potassium for paddy cultivation

<table>
<thead>
<tr>
<th>Category</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>≥ 0.25</td>
<td>≥ 17</td>
<td>≥ 1.00</td>
<td>3</td>
</tr>
<tr>
<td>Medium</td>
<td>0.11 - 0.24</td>
<td>11 – 16</td>
<td>0.31 – 0.99</td>
<td>2</td>
</tr>
<tr>
<td>Low</td>
<td>≤ 0.10</td>
<td>≤ 10</td>
<td>≤ 0.30</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 3. Overall classification scheme for soil properties and nutrients for paddy cultivation

<table>
<thead>
<tr>
<th>Classification</th>
<th>NPK Rating</th>
<th>pH</th>
<th>CEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7 – 9</td>
<td>≥ 5.0</td>
<td>≥ 20</td>
</tr>
<tr>
<td>2</td>
<td>5 – 6</td>
<td>4.5 – 5.0</td>
<td>11 – 19</td>
</tr>
<tr>
<td>3</td>
<td>3 – 4</td>
<td>3.5 – 4.5</td>
<td>≤ 10</td>
</tr>
<tr>
<td>4</td>
<td>n.a.</td>
<td>≤ 3.5</td>
<td>n.a.</td>
</tr>
</tbody>
</table>

Geospatial interpolation and processing

The final stage in soil nutrient classification for paddy cultivation in Malaysia involves geospatial interpolation and processing. At this stage, collected data were analyzed and evaluated to determine the best course of action to overcome variability of soil nutrient content at the two site-specific locations. A geographic information system (GIS) tool was used to interpolate identified elements from each sampling points. For this purpose, inverse distance weighted (IDW) interpolation was utilized in which the rating values were converted into raster format. Once the raster is created, the classification value is re-adjusted accordingly to match the rating scheme. For soil macronutrients (NPK), each elemental layer was first created to produce separated rating layers. All of the separated elemental layers were then combined by adding N, P, and K layers to produce a new classification map for NPK ratings ranging from values 3 (lowest) to 9 (highest) (Muhammad Zamir et al., 2018).
Fig. 3. Nutrient classification map for two site-specific paddy location in Malaysia using inverse distance weighted (IDW) interpolation method for SPS (a), (c), (e), and for IKS (b), (d), (f).

CONCLUSION

Soil testing and plant analyses are important tools in diagnosing nutritional deficiencies and problems related to plant growth. Soil testing measures the level of nutrients available in the soil, and the extent to which these nutrients will be available to crops during the growing period. Both soil testing and plant analyses make it possible for farmers to assess the nutrient content in soil or plants, and to interpret the response of fertilizer on soil fertility improvement or to indicate appropriate rate of fertilizer to apply when there is a lack of nutrients in soil and plants. Quality control and assurance are essential parts of good laboratory practices. Participation to proficiency testing exercise is considered mandatory for laboratories accredited according to the Malaysian Standard ISO/IEC 17025: 2017 in Malaysia. Soil and plant analyses proficiency testing in Malaysia provides an independent assessment
of data quality to improve the quality of measurements. Laboratories involved in the proficiency testing have found the programme to be useful in detecting analytical errors, and gentle drifts in results due to either inadvertent change in analytical procedures by laboratory personal or equipment deterioration. Accuracy and precision statistics are used as a performance indicator to determine whether quality assurance standards are complied over a long-term period. Utilization of soil nutrient diagnosis in paddy plantation enables farmers to make wise decisions and assess between fertilizer requirements of their crops, and the type and quantity of fertilizers to be applied for optimum rice yield. Assessment on the physical conditions of the soil and development of plant and soil analysis as diagnostic techniques has made it possible to assess the discriminatory fertilizer requirement for location specific area. Soil nutrient classification for paddy cultivation in Malaysia involved four distinct stages comprising determination of soil nutrient status, nutrient rating scheme, nutrient classification scheme and soil classification mapping. Efficient and accurate soil testing and plant analyses will lead to more efficient nutrient management and sustainable crop production.

REFERENCES


