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Evaluation of Testing Kits for Routine Soil Analyses

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Abstract

Soil test results from commercial and university laboratories are normally accurate, affordable, and typically come with recommendations for fertilizing specific crops. Soil testing by these labs is easily accessed in developed countries making it difficult to replace with anything else. Three soil test kits were evaluated on 20 diverse soil samples to determine their potential as a replacement for standard laboratory tests. Of the three test kits included in the study (LaMotte, Luster Leaf, and Rapitest), all were capable of testing pH, nitrogen (N), phosphorus (P), and potassium (K). Results indicated that there were differences between the kits regarding their ability to accurately and reliably measure soil pH and plant available N, P, and K. The kit that demonstrated the most potential for these tests was the LaMotte soil test kit. It most closely correlated with test results of Oklahoma State University Soil, Water, and Forage Analytical Laboratory (SWFAL) for soil pH and P and correlated to a lesser extent for N. All test kits, however, were poor predictors of soil K levels when compared to the results using standard laboratory procedures. Those considering using soil test kits in lieu of soil testing laboratories should take into consideration that not all soil testing kits are accurate or reliable. Furthermore, results from standard laboratories will provide farmers and gardeners with reliable results and recommendations. When the option of using a soil testing laboratory is not available soil test kits can provide a substitute for standardized tests, but with much less accuracy and the results may misguide lime and fertilizer applications resulting in over or under fertilization and potential negative environmental effects.

Keywords: Soil testing, soil-testing kits, nitrogen, phosphorus, potassium, pH.

INTRODUCTION

Increasing food production is critical as populations around the world continue to grow and will require improvements in stewardship of all natural resources. Improvement of soil fertility is important, particularly in developing countries (Karlen et al., 2003). Soil fertility serves as the basis for all food production, both plant and animal, and is therefore pivotal to all aspects of food production within a given society. The fertility of soils is constantly changing as crops extract essential nutrients from the soil for their growth and nutrients are replenished through the addition of plant or animal residues and fertilizers. The process of extracting nutrients then returning them back to the soil is termed nutrient cycling (Magdoff and Van Es, 2009).

Soil is a complex matrix of mineral, organic, and biological materials that provide for the physical and chemical needs of plants. Nutrient shortages prevent crops from producing at their full potential and often result in poor plant stands, stunted growth, and low yields (Gruhn et al., 2000). The other aspect of nutrient mismanagement is excessive use of soil inputs including animal manures, composts, and commercial fertilizers which result not only in wasted resources, but also in degradation of the environment (Gruhn et al., 2000). Fertilizing of crops based on broad-based recommendations without soil testing or on inaccurate soil analysis can result in either over or under fertilization of crops and in poor crop performance and possible damage to the environment.

Accurate soil analysis is critical for improving efficiency in crop production and for reducing the potential for plant nutrient leaching and subsequent negative environmental effects. Soil test results are routinely used by farmers in developed countries to make decisions regarding adjustments to soil pH and supplying major plant nutrients. Once soil pH and nutrient levels in the soil are determined, recommendations can be made based upon test results and specific crop requirements since crops vary considerably in their needs for nitrogen (N), phosphorus (P), and potassium (K) (Brandenberger and Zhang, 2015). Soil testing can also provide information on secondary and micro nutrient levels and organic matter, a key component of soil health.

Managing soil fertility is also critical in developing countries, but its use has not been as widely adopted resulting in soil nutrient mining and an imbalance in the nutrient cycle of farmlands (Attanandana et al., 2008). Gyapong and Ayisi (2015) stated that poor soil fertility is the major cause of low productivity and profitability for small-holder farms in sub-Saharan Africa. Furthermore, in developing countries, limited access to soil testing facilities has resulted in farmers following broad-based fertility recommendations that do not take into account the site-specific soil conditions of their fields. This has resulted in either wasting expensive fertility improving amendments or not providing enough for the fertility of their crops, both of which reduce the profitability and sustainability of the farm (Attanandana et al., 2008).

Most farmers understand that soil testing can provide insight into the production potential of their soils (Nafiu et al., 2012) and provide a decision tool for improving crop production on their farms. Soil sampling and testing, when done ahead of crop establishment, will provide the basis for pre-plant fertilization, addition of organic soil amendments, and soil pH adjustment (Zhang and Arnall, 2013). The combination of proper sampling technique and soil testing is critical in making decisions that will affect soil fertility and crop yields. Soil samples need to be taken at a depth where crop roots will actively absorb nutrients and water, typically the plow layer or the top 15 cm. It is important to note that a soil sample represents a large amount of soil per hectare. Therefore, it is critical that multiple subsamples be taken and then adequately mixed together to form a composite sample for analysis. Zhang and Arnall (2013) suggested that a minimum of 20 subsamples are needed to adequately represent a given field area to overcome spatial variability; and if the field varies considerably for soil properties, then more than one sample will need to be analyzed to provide a true representation of the soil in the field.

One possible solution for farmers in developing countries would be to sample and test on site or set up a small testing facility locally. This can be a complex and expensive process due to the cost and experience needed to successfully train technicians and supply a laboratory. One potential for solving these issues is to train farmers and local agricultural consultants to use soil test kits that are more economical than the equipment and supplies used by standard soil testing laboratories. Currently, there are many soil test kits that are available from numerous sources, but their accuracy and precision, ease of use, and cost are all valid concerns that justify further exploration.

Numerous soil test kits are available both from local and internet vendors. A small sampling of internet vendors found soil test kits varying widely in cost and capabilities. Many soil test kits are capable of doing several test samples (10 to 50 samples) and cost per sample tested ranged from 0.5 to 14 U.S. dollars (USD). Some kits have only soil pH testing capability, but a majority of kits have the ability to test soil pH and levels of plant available N, P, and K. Cost-wise, this compares well to commercial and state-run laboratories in the Southern U.S. which ranged from a low of 6 to a high of 10 USD per sample for routine tests (Oldham et al., 2015). Although cost comparisons between state laboratories and soil test kits were in similar ranges, there are two questions that should be answered prior to deciding if soil test kits should be used and which testing kit to use. First, is the selected test kit accurate enough to provide valid results for making soil fertility assessment and fertilizer recommendations and second, how complicated are the test procedures regarding the process and time required to complete the tests?

Objectives

With these questions in mind, studies were carried out on three soil test kits for their potential use by farmers and agricultural consultants in developing countries compared with the results from standard laboratory procedures. Specifically to:

- Compare soil test kit results to those of a standard soil testing laboratory to determine the accuracy and reliability of soil testing kits; Evaluate the complexity of procedures for each soil testing kit;
- Determine the time required to test soil samples for pH, N, P, and K.

MATERIALS AND METHODS

The 20 soil samples used for evaluation were obtained from the Soil, Water, and Forage Analytical Laboratory (SWFAL) at Oklahoma State University. The samples represented a wide range of soil physical and chemical properties, and

Table 1. Soil test kit ranges and unit intervals for pH, soil nitrogen, phosphorus, potassium, and time utilized to determine soil pH and plant available N-P-K for 20 soil samples collected from locations throughout the state of Oklahoma in the U.S.

Test kit	pH unit intervals	N	P	K	Minutes per sample	
LaMotte	0.2	Lbs./acre 10-150	Lbs./acre 10-150	Lbs./acre 0->400	19.9	b[z]
Luster Leaf	0.5	Low-High 0-80 mg/l	Low-High 5-100mg/l	Low-High 0-900mg/l	32.2	a
Rapitest	0.5	Depleted-Surplus 0-4	Depleted-Surplus 0-4	Depleted-Surplus 0-4	18.5	b

[z]Differences based on analysis of variance P=0.0002

nutrient ranges collected from 20 different Oklahoma counties. Soil test kits that were evaluated included: LaMotte STH-5 Combination soil outfit (LaMotte Co., Chestertown, Md.); Luster Leaf 1665 Professional soil test kit (Luster Leaf Products, Inc. Woodstock, Ill.); Rapitest soil test kit #1601 (Luster Leaf Products, Inc. Woodstock, Ill.). The LaMotte kit was selected based on experience within the research group and the other two kits were selected based on cost and availability from internet vendors. The study restricted the number of kits selected for testing due to the large number of soil samples to test (20) and replication of tests (three replications x 20 samples = total of 60 tests per kit and 60 for SWFAL). Tests for pH, plant available N, P, and K were repeated three times for each of the three soil testing kits included in the study except for the Luster Leaf kit which was stopped at two replications due to difficulties with the filtering device. The same tests were also performed three times by SWFAL using standard laboratory procedures as benchmarks for comparisons with soil test kit results. SWFAL is a member of the Agricultural Laboratory Proficiency Program which is an inter-laboratory program for testing the proficiency of the lab (https://www.collaborativetesting.com/store/main.aspx?DepartmentId=40). SWFAL uses common soil test procedures utilized in North America (Gavlak et al., 2005), and is certified by the Minnesota Department of Agriculture for soil testing (the only certification program that exists in the U.S., http://www2.mda.state.mn.us/webapp/lis/soillabs.jsp). Samples with soil test P and K levels reported from SWFAL over 65 mg/kg of P (2 times the threshold level where no P fertilizer would be recommended) or above 250 mg/kg K (2 times the threshold K level) were not included for the comparison because they were too high to have any practical implications. Time from start to finish was recorded for three different replications for each of the three test kits. The light source for the color comparison tests utilized by the soil test kits included not only natural sunlight, but also ambient overhead lighting from 12 overhead florescent two-bulb lighting fixtures with each bulb providing 2400 lumens at 3000^oK.

Standard laboratory procedures were used by SWFAL to determine levels of nitrate-N (NO_3-N), plant available P and K, and soil pH (Gavlak et al., 2005). Soil pH was measured by a glass electrode in a 1:1 soil to water suspension (Sims, 1996). Soil NO_3-N was extracted with 1 M KCl solution and quantified by a Flow Injection Autoanalyzer (LACHAT, 1994) to represent plant available N. Plant available P and K were extracted using the Mehlich 3 solution (Mehlich, 1984). Phosphorus and K in the extract were quantified by a Spectro Blue ICP spectrometer (Soltanpour et al., 1996). Nitrate-N and extractable P and K are referred to N, P and K from here on.

A majority of tests by these kits were based on color comparisons using standardized color charts included with the kits for measuring. The LaMotte and Luster Leaf kits used precipitate cloudiness as an indicator for K. Test results for N (NO_3), P, and K were both numerical and categorical for the Luster Leaf and Rapitest kits and were numerical only for the LaMotte kit in lbs. per acre (Table 1). All pH results were numerical with Luster Leaf and Rapitest providing results in increments of 0.5 on the pH scale and LaMotte providing results in increments of 0.2. Nitrogen, P, and K results from the Luster Leaf (mg/L) and Rapitest (0 to 4 scale) kits were converted to mg/kg based on direct conversion for the Luster Leaf results and parts per million equivalencies provided by Rapitest. The conversions provided the same units of data from both test kits and lab results.

Test procedures provided with each kit by the manufacturers were closely followed. The LaMotte kit utilized deionized water for preparing a separate solution for pH testing and an extraction solution to prepare a single soil extract for testing of N, P, and K. Preparation of solutions for testing with the Luster Leaf kit included four separate extractions and test solutions for pH, N, P, and K. Rapitest used distilled water to prepare a separate solution for pH testing and also distilled water to prepare a single soil extract for testing of N, P, and K.

Experimental design included a randomized complete block design with three replications. The pH, N, P, and K results from test kits were plotted against those using standard lab procedures from SWFAL. To evaluate the accuracy of the three methods in question (relative to standard lab procedures) simple linear regressions were conducted utilizing standard lab results as the independent variable and each of the proposed methods as the dependent variable. This was repeated for each of the measures (pH, N, P, and K). Two criteria were used to assess the accuracy: a correlation significantly different from zero between the method in question and the standard method (to establish a linear relationship), and a slope not significantly different from one (to signify a one-to-one relationship). Slopes (with p-values for testing equality to 1) and R^2 values are reported. Differences in time were assessed using ANOVA methods and protected pairwise comparisons Least Significant Differences (LSD). Significance was determined for p-values less than 0.05.

RESULTS

Time needed for completion of pH and N-P-K tests differed significantly between kits (Table 1). The LaMotte and Rapitest kits averaged approximately 20 minutes per sample while the Luster Leaf kit averaged 32 minutes per sample. The Luster Leaf kit required considerably more time due to having to complete four separate extractions, one for each of the four analyses that were carried out and also difficulties with the filtration device that provided the filtered solution for each test. This was in contrast to the LaMotte and Rapitest kits which required only two extractions and either utilized filter paper/filtration funnels during extraction or utilized no filtration at all. Time may or may not be a consideration for workers using these kits, but based upon the study's findings it would require an extra four hours of time to complete the tests for 20 samples using the Luster Leaf kit compared to the other two test kits.

Soil pH ranged from 5.7 to 8.3 using standard electrode by SWFAL and the pH using Luster Leaf and Rapitest kits ranged from 6.0 to 8.0 while the LaMotte kit ranged from 5.4 to 8.3 (Figure 1). The pH results from the LaMotte kit were the most closely correlated to laboratory results, with a trend-line slope of 1.04 ($p=0.001$ for test of slope=1) and an R^2 of 0.69 indicating a nearly one to one relationship between LaMotte pH and lab pH. The Rapitest results had a slightly higher R^2 of 0.75, but the slope of the trend-line was only 0.57 ($p<0.001$). The Luster Leaf kit trend-line slope was considerably less than one and R^2 was much lower than that of the Rapitest and LaMotte kits, indicating that Luster Leaf would not be a reliable test for soil pH.

Nitrate-N using the standard lab procedure ranged from 0.5 to 53.5 mg/kg (Figure 2). Nitrogen levels measured by the three test kits ranged from 0 to 80 mg/kg N. The N results of Rapitest and LaMotte test kits reasonably reflected the results from SWFAL, but the LaMotte was over while the Rapitest under estimated soil plant available N. Rapitest results had a trend-line slope of 0.79 ($p=0.001$) while LaMotte had a trend-line slope of 1.52 ($p<0.001$). The Luster Leaf had a trend-line slope of 0.36 ($p<0.001$) indicating that it only detected 36% of the SWFAL results. Regarding correlation, LaMotte test results had the highest R^2 of 0.78; Rapitest was next with 0.64; followed by Luster Leaf with 0.60.

Phosphorus levels reported from SWFAL tests ranged from 5.5 to 64 mg/kg (after removing those recording more than two times the threshold level (32.5 mg/kg) above which no P fertilizer would be recommended). Test kit results for P from the same soil samples ranged from 0 to 100 mg/kg. The LaMotte kit correlated most closely to SWFAL results as indicated by its trend-line slope of 1.15 ($p<0.001$) and R^2 of 0.42 (Figure 3). Both Luster Leaf and Rapitest results did not correlate well with SWFAL results as their trend-line slopes were 0.34 ($p>0.05$), and 0.18 ($p>0.1$), and R^2 values were 0.07 and 0.04, respectively.

Potassium levels reported by SWFAL ranged from 46 to 248 mg/kg (after removing those recording more than two times the adequate level of soil K 125 mg/kg above which no potassium fertilizer would be recommended). Test kit results for potassium ranged from 50 to 1,800 mg/kg. Although the LaMotte test kit results were significantly correlated with SWFAL results as shown in Figure 4, the trend-line slope was only 0.19 ($p<0.001$), which indicates this test kit is not sensitive to soil K levels. Neither the Luster Leaf kit nor the Rapitest results were significantly correlated with SWFAL results. In summary, none of the test kits was able to accurately measure plant available K in the soils tested.

DISCUSSION

Working with soil testing kits to determine their potential as a replacement for laboratory analysis that uses state-of-the art analytical tools and techniques was enlightening. Results from these laboratories are regarded as accurate and affordable. In addition to test results for pH and nutrient levels, the reports from reputable laboratories are often

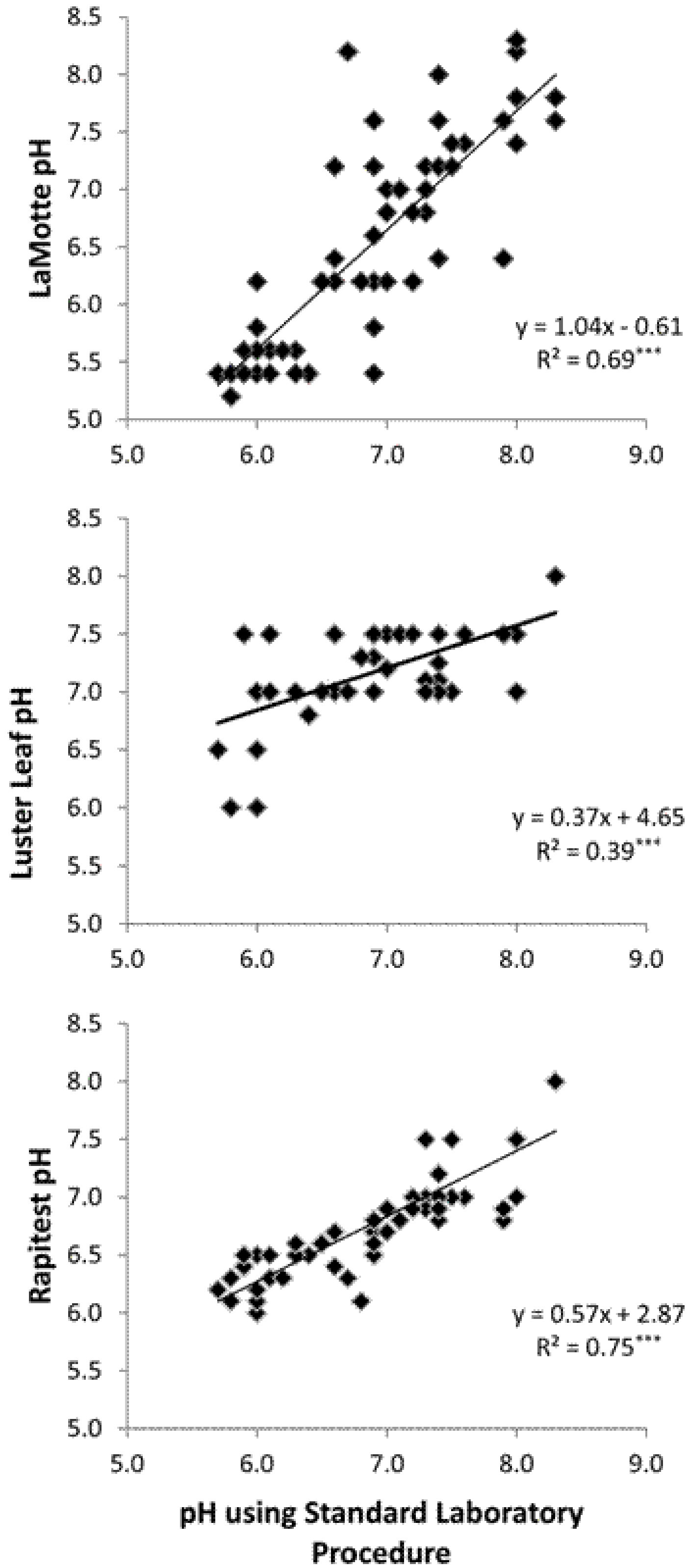

Figure 1. Comparison of soil pH using different test kits with standard laboratory practices. P=0.001 (***), NS=not significant at 0.05 level.

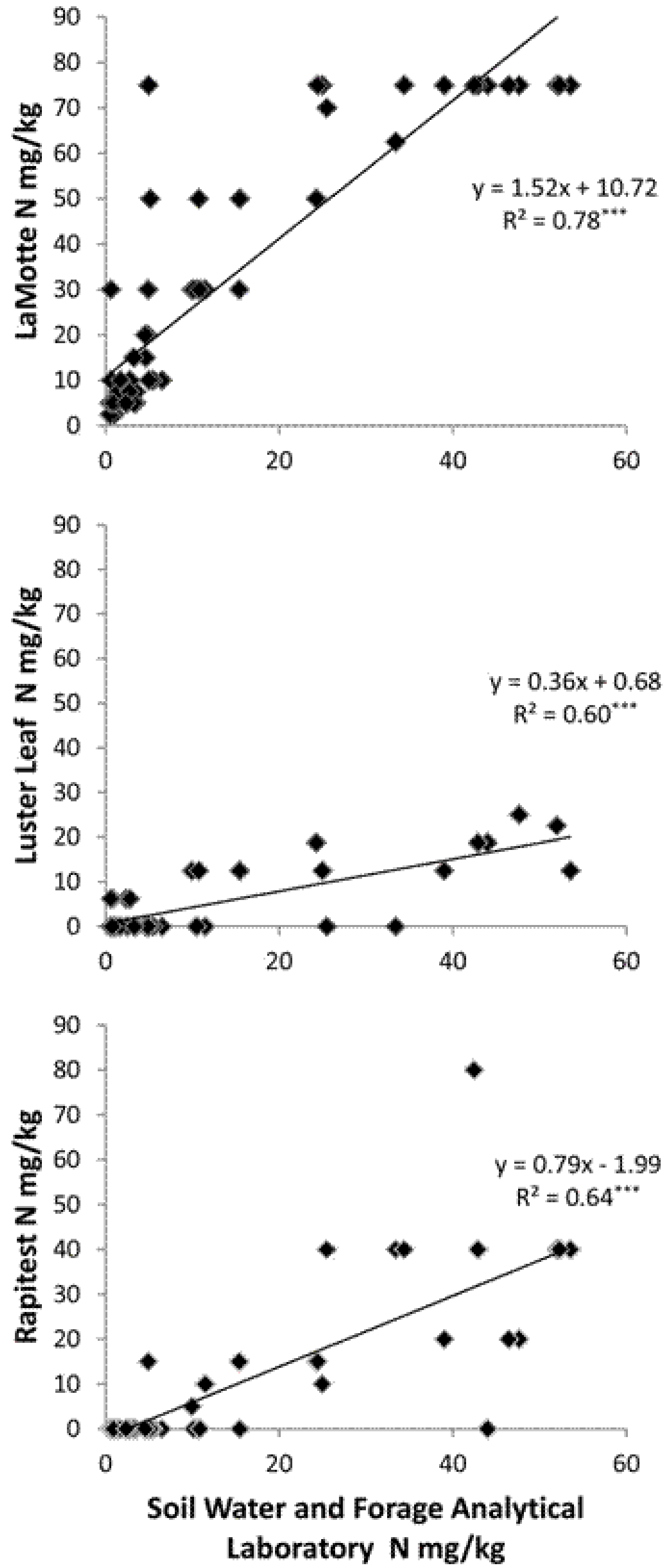

Figure 2. Comparison of soil N using different test kits with standard laboratory practices. P=0.001 (***), NS=not significant at 0.05 level.

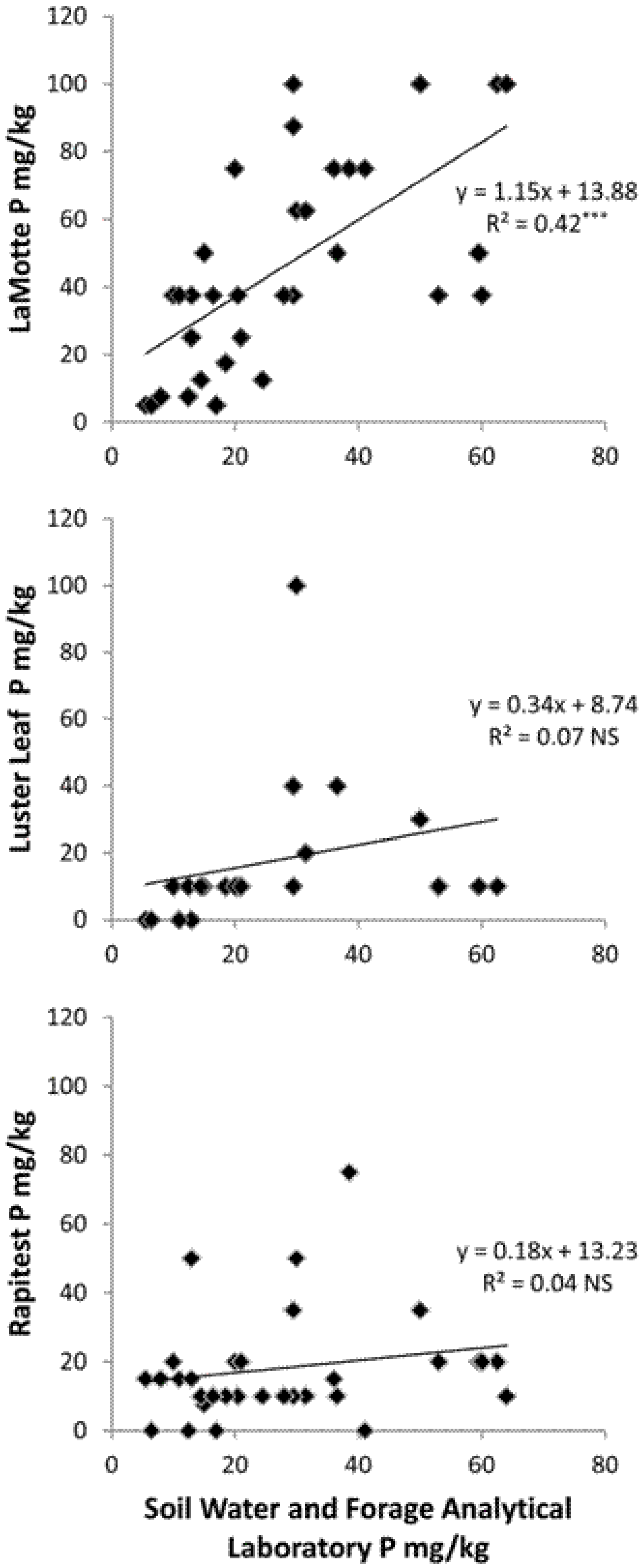

Figure 3. Comparison of soil test P using different test kits with standard laboratory practices. P=0.001 (***), NS=not significant at 0.05 level.

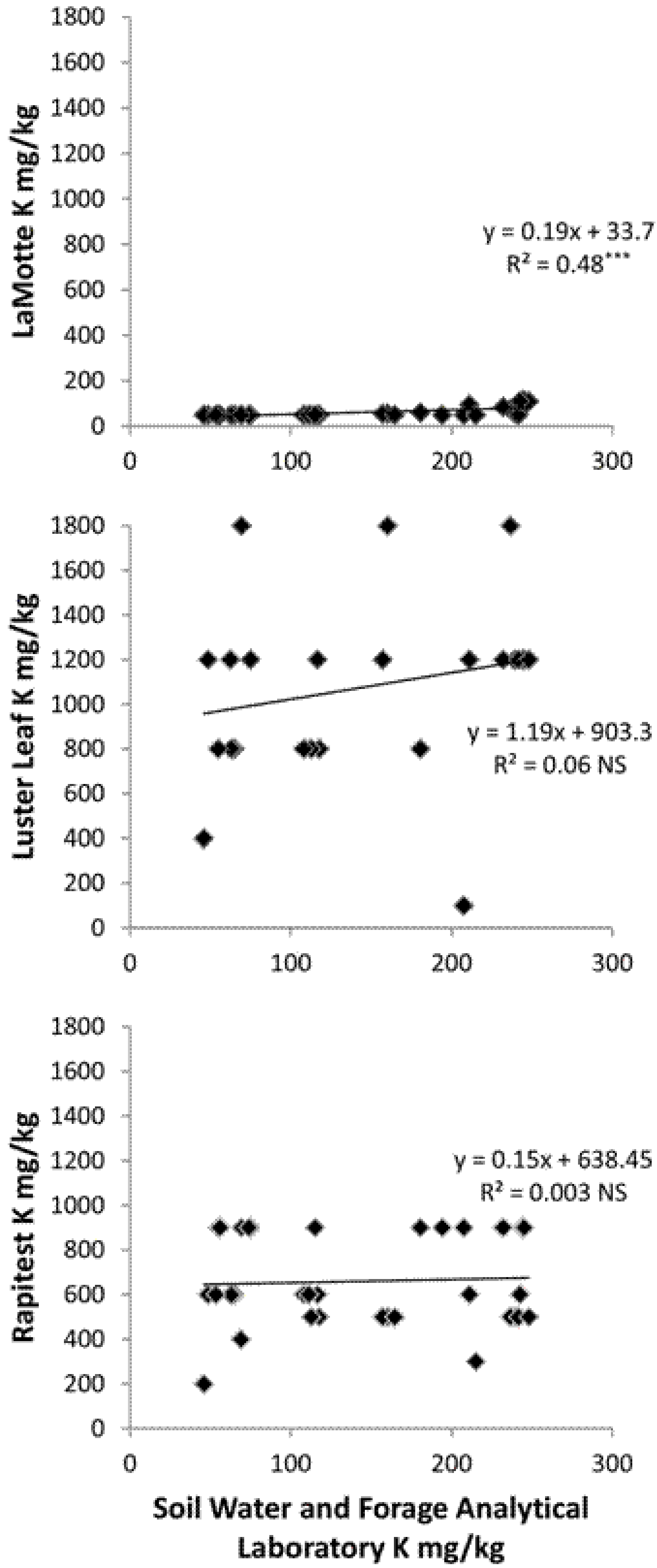

Figure 4. Comparison of soil test K using different test kits with standard laboratory practices. P=0.001 (***), NS=not significant at 0.05 level.

accompanied by recommendations for soil pH adjustments and crop-specific fertilizer recommendations. With all of these advantages, modern soil test laboratories are the standard of choice for soil analysis.

Of the three test kits included in the study all were capable of testing pH, plant available N, P, and K, but their accuracies for those different analysis were a major concern. In addition, the LaMotte kit was also capable of testing levels of humus, secondary and some minor nutrients, but these analyses should also be closely evaluated in the future. There were differences among the kits regarding their ability to accurately and reliably predict soil pH and N-P-K. The kit that demonstrated the most potential for these four tests was the LaMotte soil testing kit. It more closely correlated with laboratory test results for soil pH, N, P, and K. However, all test kits were poor predictors of soil phosphorous and potassium levels when compared to the results using standard analytical procedures from SWFAL ($R^2 < 0.5$).

Other aspects of selecting a soil test kit for on-site testing include cost, ease of use, and intricacies of shipping the kit to its intended use site. Costs of the test kits varied from a low of 1.60 to 9.00 USD per test (Rapitest-1.60, Luster Leaf-1.90, and LaMotte-9.00 USD/sample). The most expensive kit tested provided more reasonable results among the test kits evaluated compared to lab tests.

Ease of use varied considerably between the tests and was measured in time required to complete pH, N-P-K tests per soil sample. Both the LaMotte and the Rapitest kits required approximately 20 minutes per sample while the Luster Leaf kit required over 30 minutes per sample. This is a small difference per sample, but adds up considerably over the course of 20 or 40 samples.

Shipping test kits to remote locations is another consideration. Test kits in the study varied as to whether they could be carried by travelers or would need to be shipped separately by a shipper specializing in moving hazardous materials. Agricultural consultants and others that may use these soil test kits in countries other than their own would be wise to contact the manufacturer to determine the shipping requirements of the particular kit that they plan to use.

There is an alternative strategy to using soil test kits for providing soil analysis and fertility recommendations. Local government agencies or non-government organizations could work with farmers to train them how to collect soil samples properly then have them analyzed and report back results and recommendations directly to farmers. The authors have utilized this method in the past, but the challenging aspect of this strategy is finding a quality laboratory locally or shipping the samples to known labs out of country. Both approaches have been utilized successfully, but there are many steps to these strategies and opportunities for not completing the goal of providing farmers with accurate test results and fertilizer recommendations.

Based upon the results of the study, all three testing kits examined have some merit for testing soil samples without the benefit of a modern soil-testing laboratory. Of those tested, the LaMotte kit was more accurate and reliable than the other two, but was also more expensive. The Rapitest kit was inexpensive and provided reasonable results for pH and N. Both the LaMotte and Rapitest kits required less time to process each sample than the Luster Leaf kit. Only the LaMotte kit provided any level of confidence in the measurement of soil P, but none of the kits would be considered accurate enough to use for analysis of K levels in soil samples. Further study would be beneficial to investigate other soil test kits that are available. In conclusion, the authors would recommend that if state or private soil testing facilities are available for soil analysis then those should be used, but if not then the LaMotte kit would provide some useful information for fertility decisions.

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