RELIABILITY OF TECHNOLOGICAL AIDS IN AGRICULTURE: A CASE STUDY OF SOIL ANALYSIS IN SOUTH AFRICA

Van der Westhuizen, C. and Nell, F.J.J.

Department of Agriculture

Faculty of Health and Environmental Sciences

Central University of Technology, Free State

Private Bag X20539

Bloemfontein, 9301

South Africa.

Abstract:

Technology plays and increasingly important role in farm management worldwide. New technology includes, amongst others, automation and robotics, livestock technology, modern greenhouse practices, precision agriculture and artificial intelligence, Well-known technology such as soil moisture probes and soil chemical analysis still play and important role in effective and efficient farm management. The reliability of data and information provided by all these technological aids is of utmost importance. Soil chemical reports are used by farmers, advisors and fertilizer companies as the fundamental or core information to make recommendations on the types and quantities of inorganic fertilizer to be applied. Both under- and oversupply of fertilizers have meaningful implications. The objective was to determine the level of variation in soil analyses results amongst four different laboratories in South Africa. A large soil sample was taken, mixed, divided into 40 sub-samples, and periodically sent to four different soil laboratories in three different batches. Analysis indicated meaningful differences ($p < 0,05$) in the analysed levels of macro-elements (P) between laboratories, as well as between different batches within each laboratory, with less variation between microelements. Only with a reliable soil fertility record will the farmer be able to make important decisions regarding the fertilizer programme.

Keywords: soil analysis, macro-elements, microelements, soil laboratories, extraction methods, technology reliability

1. Purpose

1.1 Introduction

Innovation is more important in modern agriculture than ever before. The industry as a whole is facing huge challenges, from rising costs of supplies, a shortage of labour, and changes in consumer preferences for transparency and sustainability. In order for farmers to compete in the local and international market, they need to produce high quality food at a reasonable consumer price while making sustainable profit and also protecting the environment and ensuring the long-term sustainability of their farms. Major technology innovations have focused around areas such as precision agriculture (e.g. yield monitoring and differentiated spatial application of inputs like seed, fertilizer and pesticides), automation and robotics, livestock technology, vertical farming and other modern greenhouse practices, RFID Technology, and many more. Various apps can be used on smartphones and tablets, and is not only for the identification of problems, but also acts as a support tool for the modern-day farmer. The reliability of data and information provided by all these technological aids is of utmost importance to provide accurate information to the user.

However, a well-known technology such as soil chemical analysis still play an important role in effective and efficient farm management. In this case the variation between soils chemical reports (based on the same sample) were investigated in South Africa

1.2 Optimum yield and -production

The expected crop yield is determined by the soil (e.g. soil structure and texture, type, effective depth, restricting layers, chemical nutrient status, etc.) and climate (e.g. total precipitation and distribution, available heat units, humidity, wind, hail, etc.), and dictates the application levels of seed and fertilizer. Other inputs like cultivations, pest control (herbicides, insecticides and fungicides) and labour remain to some extent unaffected by slight variations in the target yield but still constitute a significant portion of the input costs. By reducing inputs like seed and fertilizer, the relative (percentage) contribution of the “yield-independent” costs (cultivations and pest control) towards total input costs, increases. Farmers will thus tend to align seed- and fertilizer inputs towards a realistic target yield, thus striving towards optimal production (Smith, 2006). Regarding fertilizer inputs, on the one hand, it is important to provide the required amount of nutrients needed by the plants to reach the target yield, also taking in consideration e.g. the yield of the previous season, if livestock utilized the stubble, and remembering that crop growth is limited by the most deficient nutrient (Yara, 2018). Since the Russia/Ukraine war started in February 2022, the price of most fertilizers almost doubled in South Africa. Due to the high cost of these fertilizers, it is also important not to oversupply fertilizer given the impact on financial feasibility (total input costs that also affects the total capital requirement for the season that, in most cases, also have an interest burden). In addition, incorrect application techniques influence the Carbon footprint, the environmental impact of leached nutrients (especially nitrate) in underground water resources, and ammonia volatilisation losses into the atmosphere (Yara, 2018).

1.3 Soil testing

For a farmer to enable optimal production and sustainable farming, the management program requires knowledge on the soil fertility status of the cultivable lands. Soil chemical analysis reports are used by farmers, advisors and fertilizer companies as the core foundation to make assumptions on soil fertility and, consequently, recommendations on the types and quantities of inorganic fertilizer to be applied to reach the target yield of a crop. Soil testing is used to determine nutrients already present in the soil and is the basis for P, K, Mg, B and Zn recommendations. This indicates what may be lacking and which should be supplemented through fertilizer application, thus providing guidelines as to the type and amount of fertiliser to be applied (Cornel University, n.d.). There are three basic steps that must be followed if meaningful results are to be obtained from soil testing. These are: 1) to take a representative sample of soil for analysis, 2) to analyse the soil using the accepted procedures that have been calibrated against fertiliser experiments in that particular region, and 3) to interpret the results using criteria derived from those calibration experiments.

1.4 Soil laboratories' accreditation and procedures

There are many soil analysing laboratories in South Africa – most of these are focused on civil engineering and agricultural needs. The Fertilizer Association of Southern Africa (FERTASA) administers a test and control programme for laboratories that use their standardised soil analysis methods to ensure the best possible quality analyses (FSSA, 2007). The South African National Accreditation System (SANAS) was established in 2006 and is the only national body responsible for carrying out accreditations in respect of conformity assessment, as mandated through the Accreditation for Conformity Assessment, Calibration and Good Laboratory Practice Act (Act 19 of 2006). They provide ISO/IEC 17025 accreditation, and also implement continued monitoring of accreditation status via surveillance assessments and re-assessments over a fixed accreditation cycle. A monitoring authority (on behalf of SANAS) inspects test facilities and conducts study audits to ascertain their degree of compliance to the Organisations for Economic Cooperation and Development (OECD) principles of Good Laboratory Practice (GLP) (SANAS, 2020). Furthermore, the National Laboratory Association also look after the interests of a large number of laboratories in South Africa. This includes measuring, testing, calibration and verification of equipment in laboratories which operate in well-defined areas of research and development in the natural and applied sciences (NLA, 2020). Some laboratories are also ISO 9001 accredited, indicating that they are compliant with international quality management systems requirements, though ISO/IEC 17025 includes additional technical requirements for laboratory personnel and operations. Such accreditation (ISO/IEC 17025) means the laboratory meets both the technical competence requirements and management system requirements that are necessary for it to consistently deliver technically valid test results and calibrations (SANAS, 2016).

1.5 Calibration of soil tests and soil analysis report

Soil analysing laboratories apply many different methods to analyse different elements and other characteristics of a soil sample. Soil tests seldom extract the total amount of nutrients or elements in a soil sample (Mallarino, 2005). Soil tests have been developed to measure a fraction of the total soil nutrient concentration that correlates with plant growth. Interpreting a soil-test value requires an understanding of the impacts on test results of the extractant used, method of soil sampling, sample handling, and the intended use for the result. Extraction involves shaking a sample of soil in a chemical solution (Kowalenko, 2004). The amount of nutrient measured by various soil tests can vary widely depending on the extractant used. Important extractant properties include the concentration of the chemical compounds and the reaction time with the soil (Mallarino, 2005).

Chemical solutions specific for each nutrient is ideal, but multiple element extracting solutions are popular as this increases efficiency for the laboratory. Multiple element extracting solutions employ a mixture of chemicals, which involves compromises for different soils and nutrients. The soil to chemical solution ratio, as well as the time and vigour of the shaking can also influence the amount of nutrient extracted from the soil. Some laboratories scoop a volume of the soil sample for the extraction, while others weigh the sample. This should be considered for interpreting the results or when comparing values for samples analysed in different laboratories (Kowalenko, 2004). The method used to measure the nutrient after extraction may be important for some nutrients (Mallarino, 2005). For example, colorimetric methods usually measure only orthophosphate P, while other methods may also measure other P forms. Also, the same soil test may measure widely different amounts of nutrients in soils with contrastingly different chemical and (or) mineralogical properties.

1.6 Interpretation of the soil analysis report

On completion of their analysis of soil samples, laboratories issue a Soil Analysis Report showing the results of each test and the units of measurement in each case (Loch, n.d.). The presentation and format vary, but it lists the methods used to derive each of the results shown, because independent interpretation is impossible without knowing how the individual tests were done (especially for phosphorus and pH). According to Loch (n.d.), if the methods differ from those routinely used in the region and have not been calibrated against fertiliser response trials in that region, independent interpretation is probably impossible. When seeking to establish trends in soil fertility over time, it is important to compare results that were obtained by using the same extraction methods.

2. Material and methods

The objective, as mentioned, was thus to investigate possible variations in soil analysis results (or reports) amongst different laboratories in South Africa. Under supervision of an independent agronomist, a large soil sample was taken from the topsoil (top 200 mm), clods were crushed, foreign matter removed, and the soil thoroughly mixed. It was also spread in a thin layer over a clean plastic sheet, mixed again and small scoops were taken evenly over the whole depth and area and placed into 40 unused plastic bags, thus 40 sub-samples each with a mass of ±1,0 kg (Nell, 2021).

The first batch were sent to four different soil laboratories (each containing 4 samples). The next batch (of 3 samples) were sent 6 days later, while the last batch of 3 samples were sent another 10 days later. The laboratories were unaware that the three batches (and respective samples) originated from the same source. By using an ANOVA, the results of the soil samples were statistically analysed. The four laboratories were numbered as Lab 1, Lab 2, Lab 3 and Lab 4.

3. Results

3.1 Variations in macro nutrients

The laboratories provided the results for each sample, i.e. ten from each laboratory. The first objective was, for each laboratory, to compare the variation between the respective element values of the 10 samples provided and analysed. In Table 1 each laboratory's mean value of the ten samples analysed are provided, as well as the p-value that was calculated for the ten samples of each laboratory.

Table 1 The mean values and the p value for soil analyses of macro elements conducted by each laboratory

Variable	Lab 1 mg/kg	Lab 2 mg/kg	Lab 3 mg/kg	Lab 4 mg/kg	Lab 1 P - value	Lab 2 P - value	Lab 3 P - value	Lab 4 P - value
P - Bray 1	45.70	57.05	69.79	46.60*	> 0.05	> 0.05	> 0.05	0.0095
P - Bray 2	76.17	95.08	116.32	77.67*	> 0.05	> 0.05	> 0.05	0.0095
P - Mehlich 3	68.30*	81.50	99.70	109.53*	0.0434	> 0.05	> 0.05	0.0002
K	454.70*	445.46	500.60*	560.37	0.0057	> 0.05	0.0499	> 0.05
Na	49.80*	36.83	-	60.11	0.0059	> 0.05	-	> 0.05
Ca	1168.60	1089.90	-	1402.89	> 0.05	> 0.05	-	> 0.05
Mg	449.60*	500.82	-	715.23	0.0027	> 0.05	-	> 0.05
Ca %	51.70*	49.70	47.96*	48.16	0.0006	> 0.05	<0.0001	> 0.05
Mg %	36.15*	36.20	39.79*	40.20*	0.0003	> 0.05	<0.0001	0.0190
K %	10.23*	12.70	10.69*	9.83	0.0150	> 0.05	0.0079	> 0.05
Na %	1.92*	1.50	1.56	1.81	0.0003	> 0.05	> 0.05	> 0.05

* Indicated significant differences in means ($p < 0.05$)

Significant differences occurred between the results of different labs, namely Lab 1 showed significant differences between samples for P - Mehlich 3, K, Na, Mg, Ca %, Mg %, K % and Na %, while the results of Lab 2 showed no significant differences between batches. Lab 3 showed significant differences between samples for K, Ca %, Mg % and K %, while Lab 4 showed significant differences between samples for P - Bray 1, P - Bray 2, P - Mehlich 3 and Mg %.

ANOVA was used to calculate the variations for the different batches within each laboratory. The results of each batch (e.g. the 4 samples of batch 1) were firstly averaged, e.g. the four phosphorus (Bray 1) values were averaged to reduce the variation within one batch. This was then compared to the average of the phosphorus (Bray 1) values of the second and third batches from the same laboratory.

For Lab 1, significant differences occurred between the results of the mean of some of the three different batches regarding P - Mehlich 3, K, Na, Ca, Mg, Ca %, Mg %, K % and Na %, especially between batches 1 and 2 and batches 1 and 3, with less variation between the analysis results between batches 2 and 3 where significant differences were only found between Ca % and Mg %. In assessing the results from Lab 2 , the values were very consistent with only two cases (Ca % and Mg %) whereby a significant difference between mean values of batches 1 and 2 can be observed. Meaningful differences were also found between similar samples tested within Lab 3 and also in Lab 4.

3.2 Variations in micro nutrients

The laboratories were also instructed to analyse the micro elements, however, not all of the laboratories were able to analyse all of the elements, which is the reason for the blank spaces in the data. Table 2 illustrates the data for the micro elements from the respective laboratories and the mean p–value calculated by means of ANOVA.

Table 2 The mean values and the p value for soil analyses of micro elements conducted by each laboratory

Variable	Lab 1 mg/kg	Lab 2 mg/kg	Lab 3 mg/kg	Lab 4 mg/kg	Mean p - value
Fe	78.86	-	80.70	104.68	> 0.05
Mn	164.22	-	190.31	189.19	> 0.05
Cu	2.59	-	3.77	3.51	< 0.0001*
Zn	15.92	-	16.28	17.92	> 0.05
S	9.70	6.84	-	9.01	> 0.05
B	0.75	-	1.06	1.67	0.0002*
Al	-	-	-	349.53	> 0.05

* Indicated significant differences in means ($p < 0.05$)

Table 2 reflects the results from the micro element soil analyses performed when the averages of all the laboratories are compared. Once again, the average of the ten samples were calculated and is presented as the value in the table, e.g. the Fe value of 78.86 mg/kg is the average value of all 10 samples analysed by Lab 1. As can be seen from the p-values in the mean column, there are only two elements that show a significant difference between the laboratories. The remaining five elements do not show a significant difference. However, it was necessary to compare individual laboratories against each other. After performing an ANOVA, significant differences between laboratories were only found for the analysed copper (Cu) contents in the soil between Lab 1 and Lab 3 ($p = <0.0001$) and between Lab 1 and Lab 4 ($p = 0.0003$), as well as regarding the analysed boron (B) contents in the soil between Lab 1 and Lab 3 ($p = 0.0129$), between Lab 1 and Lab 4 ($p = 0.0006$), and between Lab 3 and Lab 4 ($p = 0.0102$).

3.3 Percentage variation from the average

To get a better perception of the variation, the percentage variation from the average for a variable for each laboratory were calculated and documented Table 3.

Table 3 Average variation between the 10 samples for each variable, and the extent (%) to which the largest value differs from the average of the laboratory

	Lab 1		**Lab 2**		**Lab 3**		**Lab 4**	
	Average	**Largest difference**	**Average**	**Largest difference**	**Average**	**Largest difference**	**Average**	**Largest difference**
P - Bray 1	4.6%	10.3%	11.6%	49.7%	28.4%	71.9%	18.7%	29.4%
P - Bray 2	7.7%	17.1%	19.3%	82.8%	47.4%	119.9%	31.2%	49.0%
P - Mehlich 3	6.4%	15.7%	11.6%	49.7%	28.4%	71.9%	18.3%	30.8%
K	9.4%	13.8%	9.6%	32.3%	4.9%	15.3%	12.7%	20.3%
Na	12.4%	31.7%	23.6%	92.4%	-	-	14.6%	50.5%
Ca	3.8%	7.5%	16.7%	83.5%	-	-	9.1%	16.2%
Mg	6.4%	14.7%	18.1%	90.5%	-	-	10.4%	17.6%
Ca %	1.4%	3.1%	2.7%	13.5%	5.2%	8.9%	1.4%	2.7%
Mg %	2.0%	4.0%	9.5%	47.5%	5.1%	9.3%	1.5%	3.2%
K %	4.5%	10.5%	38.3%	191.3%	5.3%	11.8%	5.6%	16.1%
Na %	17.9%	32.3%	33.3%	33.3%	10.9%	23.0%	17.6%	39.6%
Fe	3.5%	9.8%	-	-	25.0%	61.1%	38.7%	71.1%
Mn	7.2%	28.3%	-	-	14.6%	26.7%	34.7%	54.3%
Cu	3.7%	9.1%	-	-	8.8%	15.1%	15.4%	26.3%
Zn	26.6%	132.8%	-	-	24.8%	62.2%	15.3%	29.4%
S	46.0%	229.9%	34.3%	89.6%	-	-	15.6%	32.4%
B	35.4%	46.3%	-	-	17.6%	26.1%	33.4%	60.6%
Al	-	-	-	-	-	-	22.5%	38.2%

From Table 3 it can be seen that for Lab 1, the P – Bray 1 values showed an average 4.6 % variation amongst the 10 samples tested. The value of one tested sample were 10.3% less or more than the average value for all the samples. When assessing all the values, it can be seen that the variation of some laboratories were much more than others, while the analysis result for some specific variables shows drastic differences from the average of the ten samples tested (e.g. a value for S at Lab 1 shows a 229.9% variation from the average). From Table 3 it can be calculated that the mathematical average variation for all the variables tested by Lab 1 is 11.7%, Lab 2 is 19.1%, Lab 3 is 17.4% and Lab 4 yielded a 17.6% differentiation.

4. Conclusion

When the variation in the analysis results of the ten samples for each laboratory were assessed, it was found that some laboratories had meaningful variations in almost all the variables tested, while others had very few. When the elements of the different batches are compared, some laboratories show less variation. Kowalenko (2005) indicated that a comparison study of 9 laboratories in the USA, involving 24 soil samples from 9 states using colorimetry, reported different variations from the mean for Mehlich-III, Bray-I and Olsen phosphorus tests. For this reason, variations in soil analysis results were also expected in the South African study. When the South African results is compared to the USA study, the average variation for all four laboratories for Mehlich-III was 16.2% (compared to the US's 10%) and for Bray-1 it was 15.8% (compared to the US's 13%), thus more variation in the South African laboratories.

Nevertheless, when assessing the mean values in the tables, it is obvious that it varies to almost 69% for certain variables amongst batches for the same laboratory, which is excessive. Examples of variable P values are Lab 3 where P - Bray 1 varies between 87.50 mg/kg and 53.43 mg/kg, thus a 38,9% variation, or Lab 4 where P - Mehlich 3 varies between 77.28 mg/kg (Batch 2) and 130.47 mg/kg (Batch 3), thus a 68,8% variation between the batch means. Should a fertilizer recommendation be made on these, a substantial difference in the recommended P will be expected. It will either be too low resulting in a crop yield limitation, or oversupply implicating an unnecessary expense for the farmer.

Sometimes farmers also tend to shift their soil analysis from one laboratory to another. The variations between laboratories (Table 1) indicate the vast difference in results, e.g. the P – Bray 2 value of 76.17 mg/kg by Lab 1 compared to the average of 116.32 mg/kg of Lab 3. As the samples analysed by the two respective laboratories are similar, the different results can be ascribed to different techniques applied within the laboratories. However, interpreting these different results may mislead the farmer (or advisor) resulting in incorrect fertilizer recommendations/applications.

It is recommended that farmers remain with the same laboratory when soil sample analysis need to be conducted. As seen in this paper, the extent of variations differs between laboratories, however, the farmer will not know the variation of the laboratory that is usually used. Consequently, the only solution is that laboratories upgrade their quality control by ensuring that procedures, as far as humanly possible, are consistently executed in the same manner as to ensure the least variation between consecutive analyses. Farmers should also check the accreditation status of the laboratory that is used to ensure that the practices applied by the people performing the analyses, are monitored. Accreditation agencies should also ensure that they stick to scheduled inspections to these laboratories to continuously monitor the quality standards of the staff and the condition of analysing equipment.

Users of soil analysis reports (farmers and advisors) rely heavily on these laboratories to provide them with unbiased and accurate scientifical information. Only with a reliable soil fertility record will the farmer be able to make important decisions regarding the fertilizer programme that impacts on the soil fertility and the long-term sustainability of resources.

Reference List

Cornel University. n.d. *Nutrient Management, Competency Area 3: Soil Testing and Plant Tissue Analysis*. https://nrcca.cals.cornell.edu/nutrient/CA3/CA3_SoftChalk/CA3_print.html. Assessed on 8 October 2020.

Fertilizer Society of South Africa (FSSA). 2007. *Fertilizer Handbook* (6th rev edn. FSSA: Lynnwood Ridge.

Kowalenko CG. 2004. "Determining Nutrients Available in Soils". In: Bittman S & Kowalenko CG (eds.), *Advanced Silage Corn Management: A Production guide for coastal British Columbia and the Pacific Northwest*. https://farmwest.com/node/942 Assessed on 8 October 2020.

Loch DS. n.d. *Soil Nutrient Testing: How to Get Meaningful Results*. Redlands Research Station: Cleveland (https://www.daf.qld.gov.au/__data/assets/pdf_file/0006/65985/Soil-Nutrient-Testing.pdf) Assessed on 9 October 2020.

Mallarino AP. 2005. "Testing of Soils". In: Hillel D (ed.), *Encyclopaedia of Soils in the Environment - Reference Work 2005*. Academic Press. pp 143-149 https://www.sciencedirect.com/topics/earth-and-planetary-sciences/soil-testing. Assessed on 8 October 2020.

National Laboratory Association (NLA). 2020. *The National Laboratory Association*. https://www.home.nla.org.za/ Assessed on 9 October 2020.

Nell, F.J.J., 2021. *Factors influencing farmers' fertilizer practices on irrigation schemes in the central parts of South Africa*. Unpublished master's thesis. Central University of Technology, Free State: Bloemfontein

Smith, B., 2006. *The farming handbook*. CTA: Wagenen.

South African National Accreditation System (SANAS). 2016. *Frequently asked questions – October 2016*. https://www.SANAS.co.za/Pages/website/documents/others/faq/FREQUENTLY%20ASKED%20QUESTIONS%20-%20Oct%202016-1.pdf. Assessed on 11 October 2020.

South African National Accreditation System (SANAS). 2020. *Welcome to SANAS*. https://www.SANAS.co.za/Pages/index.aspx. Assessed on 11 October 2020.

Yara Fertilizer Industry Handbook. 2018. *Knowledge grows*. October 2018. https://www.yara.com/siteassets/investors/057-reports-and-presentations/other/2018/fertilizer-industry-handbook-2018-with-notes.pdf/ Assessed on 12 October 2020.