Soil fertility evaluation of a 4-hectare fallow at UEM-ESUDER, Mozambique using factorial analysis of plant growth as an alternative to soil extract analysis

Author: VINE, P.N., Vilankulo, Mozambique *formerly docente of Universidade Eduardo Mondlane—Escola Superior de Desenvolvimento Rural (UEM-ESUDER), Vilankulo*
Email: vineesucessores@gmail.com
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ABSTRACT

Not only agricultural production, but moreso planning and interpretation of experiments, require prior soil fertility evaluation. Furthermore, without soil fertility description the results of an experiment cannot confidently be projected to any other location. Baseline soil fertility of a forest fallow area at UEM-ESUDER campus was measured before any future land use change could create a more complex pattern of smaller areas, each area acquiring different fertility. Short-term plantings were monitored using a composite 23-kg soil sample with and without added nutrient elements, in a 2x2x2 factorial design. From the results the soil was categorized as Very Low in plant-available N and P and Low to Very Low in plant-available K. The results being clear, and Coefficients of Variation being satisfactory at around 20%, the methodology was affirmed and was subsequently further refined by reducing the amount of soil and the duration of plant growth. This may make the methodology applicable to individual plots, both large and small. In conjunction with plot mapping and documentation of plot treatment histories this may lead to improved land management.

RESUMO

Não só produção por agricultores, mas mais ainda a planificação e interpretação de experiências, precisam de avaliação prévia de fertilidade do solo. Demais, sem descrição da fertilidade do solo os resultados de uma experiência não podem ser transferidos com confiança para qualquer outro local. Numa área de pousio florestal no campus da UEM-ESUDER foi medida a fertilidade basal do solo, antes de que, no futuro, alguma mudança do uso do terreno poderia criar uma configuração mais complexa de áreas mais pequenas, cada área adquirindo diferente fertilidade. Plantios de pequena duração foram monitorizados utilizando uma amostra composta de 23 kg do solo com e sem adição de elementos nutrientes, num desenho estatística factorial 2x2x2. Por os resultados, o solo foi categorizado como Muito Baixo em N e P disponíveis para plantas e Baixo a Muito Baixo em K disponível para plantas. Os resultados sendo claros, e os Coeficientes de Variação sendo satisfatórios, cerca de 20%, a metodologia foi ratificada e subsequentemente foi mais aperfeiçoada por reduzir a quantidade de solo e a duração de crescimento das plantas. Isto poderia tornar a metodologia aplicável para porções individuais de terra, podem ser grandes ou pequenas. Conjunto com mapeamento das porções individuais e documentação dos tratamentos delas isto pode levar à melhoria do manejo da terra.

Palavras-chaves: fertilidade de solo; análise factorial

INTRODUCTION

Just as fertilizer/manure recommendations for farmers require meaningful soil fertility evaluation, so too the planning and interpretation of any agricultural experiment requires prior analysis of the soil conditions (NGUNGULO *et al*., 2023). However, certain hindrances are recognized in the evaluation. Firstly, in many situations there is poor availability of soil chemical analysis (ZAVALE *et al*., 2020). Secondly, worldwide there is no exact correlation between soil chemical analysis results and crop response to added nutrient elements.

For those reasons soil fertility evaluation by 2x2x2 factorial short-term plantings has been attempted and developed in several trials in and around Vilankulo (appropriate publications in preparation). The factors are three different essential elements, *e.g*. N, P, and K; the two levels of each factor are zero addition and a certain measured addition of the element, giving rise to eight (2x2x2) treatment combinations:

N_0 P_0 K_0
N_0 P_0 K_1
N_0 P_1 K_0
N_0 P_1 K_1
N_1 P_0 K_0
N_1 P_0 K_1
N_1 P_1 K_0
N_1 P_1 K_1

The trials arose from having observed (by colour) varying signs of deficiency of essential elements in very young tomato seedlings grown in cups of differing local soils. GODINHO GOUVEIA *et al*. (1970) earlier observed plant growth effects in some missing-element pot trials in Mozambique and discussed the use of missing-element trials and also soil extract analysis in soil fertility evaluation. They found that analysis with some extractants agreed with the diagnosis of sufficiency/deficiency of particular elements by missing-element plant growth trials, while other extractants did not give good agreement.

The present article is construed to be of urgent applicability to planning the use of land of UEM-ESUDER (Universidade Eduardo Mondlane—Escola Superior de Desenvolvimento Rural), in particular a 4-hectare area currently under fallow at the main campus since about 2015. The fertility evaluation herein reported was done in 2021.

The methodology has been refined through the series of trials whose full publication is in preparation. The trial presently reported used a 23-kg composite soil sample which was subsampled into experimental units cropped for 30 days. However, the results of this trial were so clear that the method has since been refined and now (2025) successfully uses a composite sample mass of 6.5 kg or less and cropping for approximately 10 days (appropriate publication in preparation).

The concepts hereby enunciated to interpret results of such a 2x2x2 factorial fertility trial are as follows. There are two stages.

For the first stage of the interpretation, the size and significance level of the effect on early plant growth of adding a particular element to the soil is used to assign the soil to one of the following categories. These categories are used by, for example, the Instituto de Investigação Agrária de Moçambique (IIAM) (cited by MARIA & YOST, 2006), *viz* Very Low, Low, Moderate, High, Very High with respect to that element. To assign to a category, the concept is applied that:

- Very Low means there will very probably be a response by a crop to the addition of that element
- Low means that there will probably be a response
- Moderate means that there will possibly be a response
- High means that no response or a negative response is expected
- Very High means the level is toxic.

Second, as recognized in the standard literature, membership of one of the above categories does not indicate the <u>amount</u> of the element to be added to give a maximum or economically optimum response. The recommendation of amount will be calculated on the best available evidence of (i) crop uptake of the element for the intended yield of the crop; (ii) existing level of the element in plant-available form in the soil; and (iii) other losses and gains of the element in plant-available form in the soil, *e.g.* by leaching and mineralization. The recommendation will also consider socio-economic costs and benefits (CHIVENGE *et al*., 2022).

The 2x2x2 factorial fertility trial can fulfill the first stage of the interpretation. The second stage is a separate assignment.

It is suggested that, by giving results in terms of response of actual plants to addition of an element, categorization of fertility level by 2x2x2 plantings may sometimes be better correlated with crop response in the field than categorization by chemical analysis of soil extracts.

It is proposed that the 2x2x2 method can be attempted for any three essential elements simultaneously. For example, it has been used successfully for N, P, and Mo for groundnuts (*Arachis hypogea*) in and around Vilankulo (full publication in preparation). It is suggested that after completion of a trial with the three most probably deficient elements (*e.g.* N, P, and K) all the experimental units can be mixed together as a supposedly more fertile composite than the original and can then be used for a 2x2x2 trial with any three other elements.

The importance of monitoring soil fertility and of demarcating and recording uses of the land (and the treatments applied) is highlighted in the Discussion, with special reference to experimental lands of UEM-ESUDER.

MATERIALS AND METHODS

The area investigated was a fallow of approximately 4 hectares occupying the eastern third of the principal campus of UEM-ESUDER (Universidade Eduardo Mondlane – Escola Superior de Desenvolvimento Rural), Vilankulo. The area was in spontaneous fallow since the fenced enclosure of the campus in approximately 2015. The prior use of the area was observed to be locally-typical low-input farming of annual food crops with a few scattered cashew (*Anacardium occidentale*) trees. Since the enclosure, forest developed on the land such that in 2025 there was approximately 100% coverage by tree canopy and virtual absence of grasses (Fig.1). The trees appeared to be predominantly of the *Leguminosae* family.

In November 2021 the class of Fertilidade de Solo, which participated in all stages of the trial under the supervision of the author, sampled the top 20 cm of soil using a Dutch auger. This was done at approximately 20 locations systematically distributed over the 4-ha area but excluding a steep dip in the south-eastern corner where soil fertility might be expected to differ on account of its topography. NGUNGULO *et al*. (2023) showed that the soil of the whole campus was of uniform physical character. On the day of sampling, all the samples were mixed together (total 23 kg) and the composite sample was divided equally (700 g portions) into 32 perforated black plastic propagation bags. The filled bags were laid out on plastic sheeting on the ground in four rows constituting four blocks. The blocks were parallel to a North-South wall of a building such that the building provided shade in the afternoons. Each bag was planted with two pre-germinated local maize seeds and watered with a fixed amount of distilled water. After emergence the seedlings were thinned to one per bag and the following nutrient solutions were applied to the soil surface in the bags with the eight (2x2x2) treatment combinations randomized within each block. The soil in the bags was then mulched with pieces of expanded polystyrene.

Each solution was applied in a 5-mL dose uniformly over the soil surface using a different virgin medical syringe for each different stock solution. Thus was applied, per 5-mL dose, the equivalent of 30 kg/ha of the respective element calculated as follows:

Soil volume in 1 ha x 0.20 m depth = 2000 m^3.
Taking the soil density as 1000 $kg.m^{-3}$, soil mass = 2000 m^3 x 1000 $kg.m^{-3}$ =
2.0 x 10^6 kg in 1 ha.
30 kg of a nutrient element in 2.0 x 10^6 kg of soil is equivalent to
30 kg x 0.700 kg/(2.0 x 10^6 kg) = 10.5 mg of the nutrient element in 0.700 kg of soil.
We endeavoured to make 100 mL of each solution in distilled water, containing the required 10.5 mg of nutrient element in each 5 mL dose *i.e.* 0.210 g of the element in 100 mL.

- N: using commercial urea 46-0-0 (46%N-0%P-0%K), we needed 0.210 x 100/46 g urea = 0.457 g of urea in 100 mL of distilled water
- P: using a commercial 0-11.5-0 (0%N-5%P-0%K) fertilizer, we needed 0.210 x 100/5 g = 4.20 g of 0-11.5-0 in 100 mL of distilled water
- K: using commercial KCl 0-0-60 (0%N-0%P-50%K) fertilizer, we needed 0.210 x 100/50 g = 0.420 g of 0-0-60 in 100 mL of distilled water.

However, we had only enough 0-11.5-0 to complete two blocks, using 2.10 g of 0-11.5-0 in 50 mL of distilled water. This was used for Blocks 1 and 2. For Blocks 3 and 4 we used analytical phosphoric acid H_3PO_4 labelled by the manufacturer as having density 1.71 g/mL and concentration of 85%. There is 31.63% P by mass in H_3PO_4 so to obtain 0.210 g P in 100 mL of distilled water we needed 0.210 x (100/31.63) x (100/85) g of the stock acid *i.e.* 0.210 x (100/31.63) x (100/85)/1.71 mL, *i.e.* 0.457 mL. We measured 0.45 mL into 100 mL of distilled water.

After applying the nutrients in 5 mL doses the total volume of liquid added to each bag was increased to a uniform 20 mL as necessary using the appropriate volume of distilled water.

Daily during plant growth, distilled water was added to each bag equally in amounts that avoided both saturation and wilting, both in the morning and in the evening if necessary.

By 24 days after planting, all the plants looked somewhat N-deficient (by colour) so all bags to which N had been assigned were treated with the equivalent of a further 60 kg N/ha and the other bags received distilled water in equivalent amount. This extra N was intended to facilitate the recognition of deficiencies at the end of the experiment.

(Note: in subsequent refinement of the methodology, such *ad hoc* measures have been found unnecessary).

The experiment ended at 30 days after planting when measurements were made of plant height (tape measure), stem diameter just above ground level (caliper), maximum leaf width (ruler), leaf colour (chart from LAEGREID *et al*., 1999, p. 124), and shoot fresh mass (balance sensitive to $\pm$ 0.1 g).

Analysis of the measurements according to GOMEZ & GOMEZ (1984) included examination of the effects of applying P in the form of fertilizer 0-11.5-0 compared with H_3PO_4 .

RESULTS AND DISCUSSION

Effects of N, P, and K additions are reported only for shoot fresh mass. As in all the 2x2x2 experiments carried out in the series of trials, the other plant variables measured were found to have analogous, but less sensitive, response to the treatments than shoot fresh mass.

Whereas 0-11.5-0 as P source (Blocks 1 and 2) had a large effect on plants, H_3PO_4 as P source (Blocks 3 and 4) had negligible effect. This indicated that H_3PO_4 was not a realistic source of P for the experiment. Treatment effects reported below are from analysis of only the half of the experiment that involved Blocks 1 and 2.

Coefficient of variation (*CV*) for the half of the experiment involving only Blocks 1 and 2 was 22%, *CV* from analysis of the other half of the experiment separately was 16%, and *CV* from analysis of the four-block experiment as a whole was 23%, and this was taken to indicate that treatment effects based on only Blocks 1 and 2 were adequately precise.

The results (Table 1) showed significance at $P<0.01$ for the effect of adding N, at $P<0.01$ for P, and at $P<0.05$ for K. Effects in 30 days of growth were approximately 50% increase in shoot fresh mass due to the N addition, 68% increase due to the P addition, and 38% increase due to the K addition.

The size and significance of the effects put the soil of the 4-hectare fallow in the categories:

- Very Low in N and very probable response to N addition
- Very Low in P and very probable response to P addition
- Low to Very Low in K and probable to very probable response to K addition.

Future uses of the area described may benefit from this information.

As indicated in the Introduction, the choice of <u>amount</u> of N, P, or K to add for maximum or economically optimum yield of a crop is a separate process. An example of 2x2x2 fertility analysis with a consequent fertilization recommendation for a particular crop is a report on a relatively fertile soil near Vilankulo by VINE (2025).

In development of the fertility evaluation methodology to allow for unavailability of fertilizer containing P while not containing N or K, use of analytical NaH_2PO_4 was successfully adopted. This analytical chemical is available and affordable in the small quantities required and assuredly contains no S (sulphur). S is likely to be found in commercial P-containing fertilizers and may cause effects on plant growth that may be mistaken for effects of P.

Plants on soil nearby in Vilankulo responded positively to NaH_2PO_4 so such soil was definitely deficient in P and it is therefore probable that the response to 0-11.5-0 for the 4-hectare fallow was a response to P, not to any S that might have been in the 0-11.5-0 fertilizer. This induction may be tested on the 4-hectare fallow soil using, for example, a 2x2 trial with NaH_2PO_4 and Na_2SO_4 as factors.

Some farmers and experimenters have proceeded to plant land with neither prior fertility analysis nor accessible recording of the treatments they applied. Without soil fertility analysis, results of an experiment are only confidently applicable to the particular small parcel of land occupied by the experiment, and cannot validly be projected to any other location. Recording treatments and the exact boundaries within which they were applied is important for subsequent planning of the use of land, especially for experiments. Factorial 2x2x2 analysis is an alternative to chemical analysis of soil extracts, thus increasing the availability of fertility monitoring. Physical, pH, and salinity data (surface and subsoil) are already available for the UEM-ESUDER soils (NGUNGULO et al., 2023). FOLIGE (2021) has set up at the UEM-ESUDER library an updatable digital map record for land use at UEM-ESUDER and it may be recommended that its use and continuous updating be compulsory.

CONCLUSION

The soil of the forest fallow was Very Low in N and P and Low to Very Low in K. The method which was used to come to those conclusions (2x2x2 factorial short-term plantings) was adequately precise. The method is an alternative to soil extract analysis. Combined with plot mapping and documentation of treatment histories, land management may be improved, particularly for agricultural experimentation. Otherwise one may end up, undesirably, with land that physically resembles an *n*-dimensional Venn diagram (WIKIPEDIA, 2025) of overlapping plots with various known and unknown histories, where *n* is continuously increasing and maybe with n^n (who knows?) different fertility combinations at different spots.

Fig. 1 A view of the forest fallow in 2025

Table 1
Shoot fresh mass excluding Blocks where H_3PO_4 was used instead of 0-11.5-0

Source of variation	Degrees of freedom	Sum of squares	Mean square	$F_{calculated}$	$F_{tabulated}$ 5%	1%	Proba -bility
Blocks	1	0.4225	0.4225	0.77	5.59	12.25	ns
Treatments	7	25.0275	3.575	6.50	3.79	7.00	*
N	1	7.0225	7.0225	12.78	5.59	12.25	**
P	1	11.56	11.56	21.03	5.59	12.25	**
K	1	4.6225	4.6225	8.41	5.59	12.25	*
NxP	1	0.49	0.49	0.89	5.59	12.25	ns
NxK	1	0.7225	0.7225	1.31	5.59	12.25	ns
PxK	1	0.36	0.36	0.65	5.59	12.25	ns
NxPxK	1	0.25	0.25	0.45	5.59	12.25	ns
Error	7	3.8475	0.549642857				
Total	15	29.2975					

**significant at 1% level
*significant at 5% level
ns not significant at 1% or 5% level
Coefficient of variation = 22%

Mean shoot fresh mass (g)

	N_0	2.68	P_0	2.49	K_0	2.80
	N_1	4.00	P_1	4.19	K_1	3.88
$LSD_{.05}$		0.88		0.88		0.88
$LSD_{.01}$		1.30		1.30		1.30

REFERENCES

CHIVENGE, P., ZINGORE, S., EZUI, K.S., NJOROGE, S., BUNQUIN, M.A., DOBERMANN, A., SAITO, K. (2022). Progress in research on site-specific nutrient management for smallholder farmers in sub-Saharan Africa. *Field Crops Research* 281: 108503

FOLIGE, A.F.E. (2021). Criação de mapa actualizável de uso histórico do terreno da ESUDER. 58p. + mapa no CD. Trabalho de culminação de curso, UEM-ESUDER, Vilankulo, Mozambique

GODINHO GOUVEIA, D., GOUVEIA, J., CABRAL, E.A. (1970). Apreciação da fertilidade de solos dos Postos Agronómicos de Nampula e Chemba pelo método de Jenny. *Agron. moçamb.* 4 (4): 209-220

GOMEZ, K.A., GOMEZ, A.A. (1984). Statistical procedures for agricultural research. 2nd edn. New York: Wiley

LAEGREID, M., BOCKMAN, O.C., KAARSTAD, 0. (1999). Agriculture, fertilizers, and the environment. Wallingford, U.K.: CABI Publishing

MARIA, R.M., YOST, R. (2006). A survey of soil fertility status of four agroecological zones of Mozambique. *Soil Science* 171 (11): 902-914

NGUNGULO, I.D., CHUTUMIA, C.B., MAITE, C.J., MANJATE, F.A., REMANE, F.E.O., VINE, P.N. (2023). Soils of the experimental fields of UEM-ESUDER, Vilankulo, Mozambique. Available at www.vineesucessores.com

VINE, P.N. (2025). Machengue solo 'preto'. Available at www.vineesucessores.com

WIKIPEDIA (2025). Venn diagram. Google

ZAVALE, H., MATCHAYA, G., VILISSA, D., NHEMACHENA, C., NHLENGETHWA, S., WILSON, D. (2020). Dynamics of the fertilizer value chain in Mozambique. *Sustainability* 12: 4691