**RF-374**
**[1-6]**

RESEARCH ARTICLE Agricultural Reviews

# Comparative Phosphorus Calibration, based on Three Extractants for Maize (*Zea mays*) Production in an Alfisol

E.E. Oyomorua[1], S.A. Ojobor[1], G.O. Okogu[1], P.E. Umukoro[1]

**10.18805/ag.RF-374**

## ABSTRACT

**Background:** Effective phosphorus (p) in a particular soil depends on appropriate laboratory analytical method, of which soil extractant are pivotal. Comparative effects of P application to soil for maize production, based on prediction by three soil available P extractants were investigated in 2023 and 2024.

**Methods:** Phosphorus application to maize based on calculations from three extraction methods (Bray 1, Mehlich III and pressurized hot water at both maintenance level and sufficiency level) while evaluation of the residual effects was measured and the experiment was laid out in a randomized complete block design at a spacing of 75 cm by 25 cm and NPK 15:15:15 was applied at 3 and 6 weeks after sowing. Yield parameters were collected as well as soil samples. Data were subjected to analysis of variance using SAS software (version 9.0) and regression analysis while means were separated using Least Significant Difference at 5% level of significant.

**Result:** Phosphorus application based on Pressurized Hot Water Extraction (PHW) at maintenance level resulted in the most significantly ($P \leq 0.05$) better yield of dehusked maize (6.64 t/ha). Application of P based on Bray 1 at 5 mg/kg above the maintenance level, resulted into best significant fresh cob weight. There was a strong relationship ($r=0.7$ $P \leq 0.05$) between applied P based on PHW at the maintenance and dehusked weight of maize at the first planting. However, at residual planting (based on earlier applied P), PHW resulted into the optimum dehusked weight of maize ($r=0.7$ $P \leq 0.05$). Generally, increase in P application led to reducing extractible Zn in the experimental soils. Increase in P application also led to increase in soil pH, while it was the opposite in soil exchangeable acidity.

**Key words:** Alfisol, Extractant, Fertilizer, Maize production, Phosphorus extraction.

## INTRODUCTION

Fertilizer use in Nigeria is mostly by blanket application and such method does not consider the amount of nutrients fixed in the soil (Agbede, 2009). Often times, the situation leads to under or over application because, previous fertilizers input are not usually considered (Ritchie, 2021). Brady and Weil (2002) reported that plants use about 10-30% of applied phosphorus (P) while substantial amount are fixed in the soil. Such fixed nutrients may not be available to crops that are short duration unless the soil equilibrium is maintained to satisfy the fixation complex (Du *et al*., 2021). Blanket fertilizer application does not consider these residual nutrients. Moreover, appropriate soil nutrient extractants are needed to address the real nutrient needs by a particular crop.

Soil testing is a major tool needed for effective fertilizer application and it is usually conducted in the laboratories. This involve the use of chemicals which are often difficult to dispose of in an environmentally safety manner. Increasing awareness of safe environment is currently putting pressure on so many laboratories to explore the use of chemicals or methods that are environment friendly in disposing their waste. Large number of soil P tests are found in many laboratory manuals which includes Olsen, (Olsen *et al.,* 1954), Bray I (Bray and Kurtz, 1945), Mehlich III (Mehlich, 1984) and pressurized hot water (Ogundeji, 2013). Each method has unique characteristics and may have different interpretation index. At a given soil test level, the interpretation may be optimum for one test but may be interpreted as low or high for another test (Sawyer and Mallarino, 1999). Three categories are used: low, medium and high. A low soil test value offers a high probability of response to added fertilizer. A medium value offers a medium probability while a high value exhibits a low probability of getting a response (Pierre *et al.*, 2017). Interpretations and recommendations vary and attributed to differences in soil properties (Mallarino, 2009). It differs across states even with similar soil-test calibration data because the philosophy and assumptions of those making the recommendations are not similar. However, there is a difference in interpretation among Mehlich III, Bray I and Pressurized hot water (PHWE) soil test values for some

[1]Department of Agronomy, Faculty of Agriculture, Delta State University Abraka.

**Corresponding Author:** S.A. Ojobor, Department of Agronomy, Faculty of Agriculture, Delta State University Abraka.
Email: smartojobor@gmail.com
ORCID: https://orcid.org/0000/0002-6835-6797

**How to cite this article:** Oyomorua, E.E., Ojobor, S.A., Okogu, G.O. and Umukoro, P.E. (2025). Comparative Phosphorus Calibration, based on Three Extractants for Maize (*Zea mays*) Production in an Alfisol. Agricultural Reviews. 1-6. doi: 10.18805/ag.RF-374.

**Submitted:** 10-12-2024 **Accepted:** 11-06-2025 **Online:** 26-06-2025

soils in maize-growing region in Nigeria and unfortunately, there is little explanation for such inconsistency (Ebeling *et al*., 2006). Mehlich III which is a double acid extractant overestimate soil available P while Olsen underestimate it (Perrot *et al*., 1995). The PHWE uses an espresso machine to extract soil nutrients and has been evaluated with several soil extraction procedures across a broad range of soils, has been shown to be a practical alternative soil nutrient extraction procedure in Guatemala (Crane *et al*., 2004). It is economically more feasible for overhead cost reduction in laboratories and safe disposal. The procedure has been successfully taught in some countries (Crane *et al*., 2004). It was reported that PHWE was more effective in predicting boron (B) status of B fertilized soils and to be related to B content, uptake and yield of alfalfa (Schiffer *et al.,* 2005). There is little or no studies relating PHW extraction of P to maize production in Nigeria. Thus, a comparison of PHW extraction to other potential methods on Nigeria soils is needed.

Phosphorus is an important element in plant nutrition, it improves growth and yields of crops. Rasheed and Igbal (1995 and Ojobor *et al.*, 2021), observed that maize yield could be improved through balanced and timely use of phosphorus fertilizers. One of the most important life-supporting elements on Earth is phosphorus (Syers *et al*., 2008). It is one of the three crucial nutrients (N, P and K) for plant growth and fundamental for modern farming (Ulrich *et al.,* 2009). Therefore, there is need to compare maize yield using three P extractants (Bray 1, Mehlich III and PHW) and the effects of applied P on some soil properties. Maize (*Zea mays* L.) is an important cereal crop which ranks third after wheat and rice and also the third in Nigeria after sorghum and millet (Akanni and Adeniyi, 2020 and Ajeigbe *et al*., 2024). The annual maize production in the country is about 7 million tons (Wossen *et al*., 2023) though, US is the largest producer of maize (Ajeigbe *et al*., 2024). The crop requires adequate supply of plant nutrients mostly nitrogen, phosphorus and potassium for good growth and high yield. Farmers are often face with the challenges of knowing the exact quantity of P fertilizers to be used for optimum maize production and over application could lead to soil pollution. On this premise the study draws its objectives to calibrate site specific optimum P for maize production and compare maize yields on P recommendation by three extraction methods.

## MATERIALS AND METHODS

### Experimental site

The study plot was situated at Teaching and Research Farm, Parry Road, University of Ibadan with latitude 7°45’ N and longitude 3°89’ E, at elevation of 197 m higher than sea level. Temperature is generally high with mean monthly values that ranges 24-28°C, mean annual rainfall was 2100 mm. Rain start from April to November with bimodal distribution pattern then first peak in June and later at September though break in August follows immediately dry season by November and terminating by February with associated harmattan (NIMET, 2023).

### Land preparation and experimental design

P application was calculated using three phosphorus extractants (Bray 1, Mehlich III and pressurized hot water (PHW)). Maize was used the test crop. The land was cleared and ploughed before sowing. The experiment was laid out in a randomized complete block design (RCBD). Oba super 2 variety was used and was bought at premier seeds store in Ibadan. First planting was done in June, 2022 and three seeds were sown per hole with a spacing of 75 cm by 25 cm. Although, it was thinned to one per stand at two weeks after sowing. A split of NPK 15:15:15 at the rate of 30 kg P/ha in two periods (two and six weeks after sowing respectively). The soils were built up to maintenance P level of 20 mg/kg, based on both extraction with Bray 1 and Pressurized hot water, while all the soils were also built up to a sufficiency P level of 25 mg/kg, according to the different extractants. The residual evaluation was conducted in June, 2023 in same plots.

The extractant-based P treatments used are as follow:

a) Mehlich III for maintenance level (0 kg P/ha)
b) Mehlich III for sufficiency level (10 kg P/ha)
c) Bray 1 for maintenance level (8 kg P/ha)
d) Bray 1 for sufficiency level (18 kg P/ha)
e) PHW for maintenance level (38.4 kg P/ha)
f) PHW for sufficiency level (48.4 kg P/ha)

### Data collection and analysis

Parameters measured were; fresh weight of maize cobs, dehusked cobs (t/ha), dry weight of the dehusked cobs (t/ha), grain weight of maize (t/ha), empty cob weight of maize (t/ha), net 100 weight (t/ha), fresh stover weight of maize (t/ha), dry stover weight of maize (t/ha) and number of grains per cob. Data obtained from were subjected to analysis of variance (ANOVA) using SAS software (version 9.0) and regression analysis, the treatment means were separated using Least Significant Difference at 5% significant level of probability.

### Residual effects of applied phosphorus levels

Same agronomic procedures with no fertilizer application except those applied during first experiment.

### Soil sample preparation and analysis

Soil samples were air-dried, crushed with pestle and mortar, sieved using 2 mm sieve and were subjected to routine analyses at the University of Ibadan according to IITA (1997).

### Pre-planting soil analysis

The soil was an Alfisol, loamy sand texture, slightly acidic but organic carbon was very high above critical level (15 g/kg). Total nitrogen was below the critical value of 1.5 g/kg whereas, available phosphorus (Mehlich III - 20 mg/kg, Bray 1 - 17 mg/kg and Pressurized Hot Water extraction 1 mg/kg) were above the critical value (10 mg/kg) based on Mehlich

III and Bray 1 extractants but very low based on Pressurized hot water extraction. Exchangeable Ca (9.4 cmol/kg), K (0.1 cmol/kg) and Na were high whereas, Mg (1.8 cmol/kg) and ECEC (14 cmol/kg) were moderate (Table 1). The micronutrients were high most especially Mn and Fe.

**Pressurized hot water procedure -NO3-N, P and, K (Hanks, 1997 and )**

The machine was warmed up by running one to two runs of distilled water only. Tests were performed with an espresso machine that generates a pressure of 2.5 bars and a temperature of 93°C. Measured values were correlated with those obtained using standard nutrient extraction techniques.

## RESULTS AND DISCUSSION

**Influence of applied P and residual soil P on maize yield**

The Bray 1 for maintenance level resulted into the highest maize grain weight (3.14 t/ha) while Pressurized hot water for maintenance level led to the least (2.46 t/ha) at main planting (Table 2). Meanwhile, at residual planting, Bray 1 for sufficiency level had the highest grain weight (4.17 t/ha) while Pressurized hot water at the maintenance level had the least (1.54 t/ha). A similar significant trend was observed in both fresh and dry biomass weight. The Pressurized hot water for maintenance level resulted into the highest (14.52 t/ha) fresh biomass weight of maize while Mehlich III for sufficiency level had the least (8.99 t/ha). However, at residual planting Mehlich III for both maintenance and sufficiency level had the similar value (14.29 t/ha) followed by Pressurized hot water for maintenance level (13.60 t/ha). At the main planting, Bray 1 for sufficiency level had the highest value (4.59 t/ha) and Mehlich III for maintenance level resulted into the least (3.24 t/ha). However, Bray 1 for sufficiency and maintenance level had the highest (8.76 t/ha) and lowest (2.8 t/ha) mean value respectively. However, Mehlich III extractant for sufficiency had the highest value (15.58 g) and Pressurized hot water extractant for maintenance level had the least (12.22 g). The Bray 1 for sufficiency level resulted into the highest value (556) while Pressurized hot water for sufficiency level led to the least value (483) of number of grain per cob at the main planting. However, this was contrary at the residual planting where Pressurized hot water for sufficiency level resulted into the highest value (333) and Bray 1 for maintenance level had the least value (270).

**Table 1:** Pre planting soil analysis.

| Parameters | Value |
|---|---|
| pH (Water 1:1) | 6.23 |
| pH (KCl 1:1) | 5.23 |
| Organic C (g/kg) | 31.0 |
| Total N (g/kg) | 1.17 |
| **Available P (mg/kg)** | |
| Mehlich III | 20 |
| Bray 1 | 17 |
| PHWE | 1 |
| **Exchangeable cation (cmol/kg)** | |
| Ca | 9.4 |
| Mg | 1.8 |
| K | 0.1 |
| Na | 1.9 |
| **Exchangeable acidity** | 0.8 |
| ECEC | 14.0 |
| **Extractable micro nutrient (mg/kg)** | |
| Mn | 60 |
| Cu | 9 |
| Fe | 34 |
| Zn | 3 |
| **Particle size distribution (g/kg)** | |
| Clay | 100 |
| Sand | 880 |
| Silt | 20 |
| Textural class | Loamy sand |

Note: PHWE = Pressurized hot water extraction.

**Applied phosphorus and residual soil phosphorus on dehusked cob weight**

Fig 1 presents effects of applied P on dehusked weight of maize. It was revealed that P application rate had a significant influence on dehusked weight of maize, as more P was applied, the weight increases. This corresponds to Pressurized hot water extractant for maintenance level before the weight starts decreased. It was also revealed that there was a strong relationship between P application and dehusked weight at the first planting ($r=0.7$ $P\leq 0.05$).

Fig 2 shows a calibration curve between the effects of residual soil phosphorus on dehusked cob weight of maize. The data reflect that P application has influence on dehusked weight. There was an initial increase in weight of dehusked maize up to the critical level before a gradual decrease at extraction with Bray 1 for maintenance level. The optimum level was at extraction with Pressurized hot water for maintenance level. There was a strong relationship between fertilizer P application and dehusked weight of maize at residual planting ($r=0.7$ $p\leq 0.05$).

**Applied phosphorus and residual soil phosphorus on dry cob weight**

Fig 3 presents the effects of applied phosphorus on dry cob weight, as more P is applied, dry cob weight decline above the critical level thereafter gradually increased. The optimum level corresponds to Pressurized hot water for maintenance level. Dry cob weight had a low relationship with fertilizer P application ($r=0.1$ $P\leq 0.05$) at the main planting.

Fig 4 shows the residual effects of soil phosphorus on dry cob weight, it revealed that dry cob weight was significantly affected by residual soil P. Dry cob weight decreases after the critical level though, it has a strong correlation with residual soil P ($r=0.7$ $P\leq 0.05$). However, Pressurized hot water for maintenance level had optimum yield of dry cob weight of maize during residual planting.

**Phosphorus application (kg/ha) residual phosphorus**

Table 3 shows the influence of P application residual phosphorus content. Bray I extraction, Mehlich III and Pressurized hot water extracted soil available P between 45-51 mg/kg, 50-58 mg/kg and 7-23 mg/kg respectively for post planting soil.

**Table 2:** Influence of applied phosphorus and residual soil phosphorus on maize yield.

| Treatments | GW | FSW | DSW | NGC |
|---|---|---|---|---|
| | t/ha | | | |
| **Applied P** | | | | |
| Mehlich III ML | 2.72 | 13.83 | 3.24 | 519 |
| Mehlich 111 SL | 2.51 | 8.99 | 3.34 | 506 |
| Bray 1 ML | 3.14 | 13.60 | 4.35 | 553 |
| Bray1 SL | 3.02 | 11.07 | 4.59 | 556 |
| PHW ML | 2.46 | 14.52 | 4.43 | 490 |
| PHW SL | 2.64 | 9.73 | 4.51 | 483 |
| LSD (0.05) | NS | 2.86 | 0.90 | NS |
| **Residual P** | | | | |
| Mehlich III ML | 3.22 | 14.29 | 3.56 | 300 |
| Mehlich III SL | 2.25 | 14.29 | 4.04 | 328 |
| Bray 1 ML | 2.87 | 10.61 | 2.80 | 270 |
| Bray1 SL | 4.17 | 11.53 | 8.76 | 296 |
| PHW ML | 1.54 | 13.60 | 3.23 | 273 |
| PHW SL | 2.11 | 13.37 | 3.81 | 333 |
| LSD(0.05) | 0.57 | 2.52 | 0.94 | NS |

Legend: GW: Grain weight; NGC: Number of grain per cob; FSW: Fresh stover weight; DSW: Dry stover weight.

Mehlich III extractant of the initial soil revealed the P value to be 20 mg/kg upper limit for crop requirement (Chude *et al.*, 2012). Again, Bray 1 extractant revealed level to little below the upper critical range of P requirement while Pressurized hot water extraction of P revealed deficient of available P below the critical value ( Teo *et al.*, 2010). However, Bray 1 and Mehlich III extracting methods showed that the soil P was high. The disparity in the P values was in agreement with the report of Perrot *et al.* (1995) who reported that Mehlich III extractant could over estimate soil available P. This may also be due to the fact that both Mehlich III and Bray 1 are acidic extractants that could partly remove water-insoluble Ca-P and Mg-P compounds by the desorption process involved which PHWE method cannot remove. Bray 1 extractant for sufficiency level performed better in terms of fresh cob weight compared to that of Mehlich III extractant for maintenance level. Haque *et al.* (2024) have observed fresh cob weight increased after the application of phosphate fertilizer and the increase was in line with Liang *et al*. (2024) the reported maize dry cob increment as P application increases.

Significant increases observed on dehusked weight of maize with the levels of application may be due to increase in N and P released during the decomposition and probably increases in the vegetative growth due to cell division increased (Ariraman *et al*., 2020). Contrary to Du *et al.* (2021)

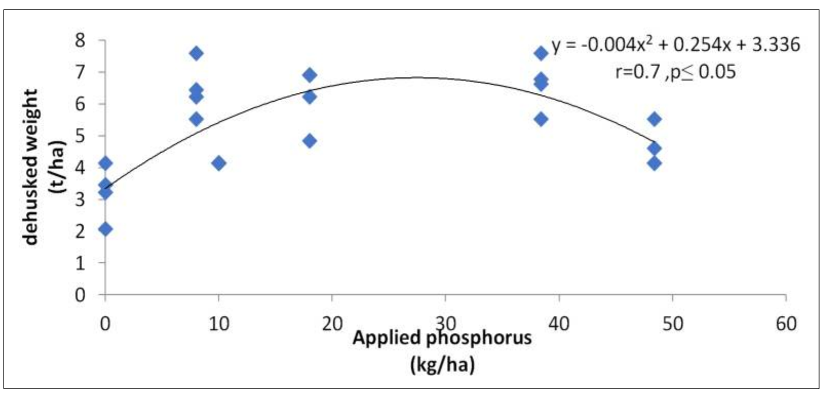


**Fig 1:** Effects of applied phosphorus on dehusked cob weight of maize.

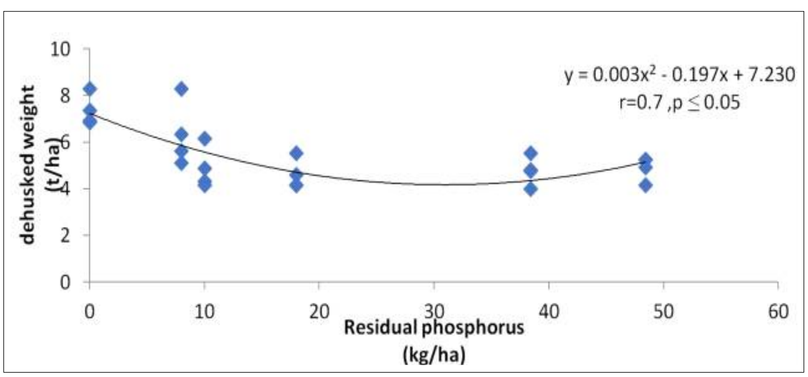


**Fig 2:** Effects of residual soil phosphorus on dehusked cob weight of maize.

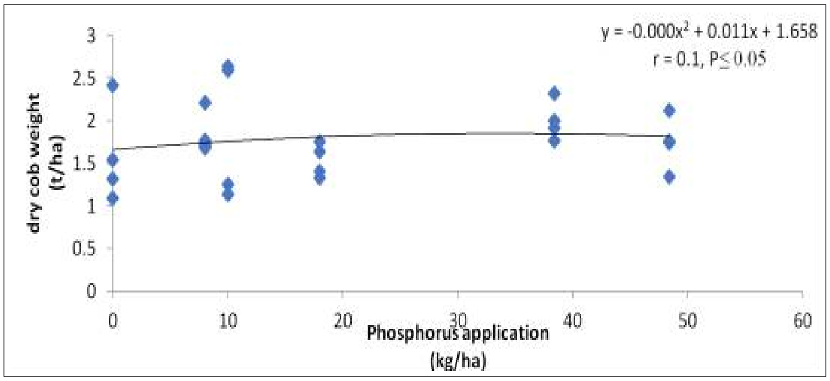


**Fig 3:** Effects of applied phosphorus on dry cob weight of maize.

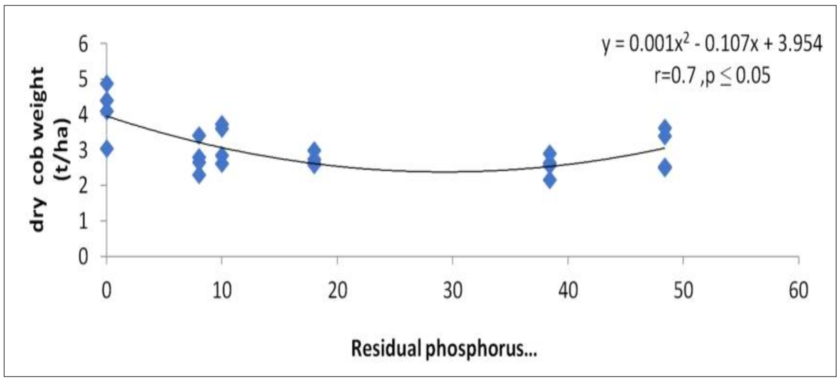


**Fig 4:** Effects of residual soil phosphorus on dry cob weight of maize.

**Table 3:** Phosphorus application (kg/ha) on residual phosphorus.

| P level | Available phosphorus (mg/kg) | | |
|---|---|---|---|
| ( kg/ha) | Bray 1 | Mehlich III | PHWE |
| Mehlich III ML | 51.00 | 52.00 | 9.00 |
| Mehlich III SL | 47.00 | 51.00 | 23.00 |
| Bray 1 ML | 45.00 | 58.00 | 13.00 |
| Bray1 SL | 49.00 | 50.00 | 7.00 |
| PHW ML | 46.00 | 57.00 | 16.00 |
| PHW SL | 47.00 | 51.00 | 18.00 |
| LSD (0.05) | Ns | Ns | 15.07 |

that observed maize stover increased significantly with the increasing level of P level up to 125 kg/ha. Dry cob weight had a low relationship with fertilizer P application ($r = 0.1$ $P \leq 0.05$) at the first season. However, this was contrary in residual planting where it had a strong correlation with residual soil P ($r=0.7$ $P \leq 0.05$).

## CONCLUSION

The result confirmed that PHW extractant successfully reflected the amount of P in the soil and it was best correlated with maize yield. Pressurized hot water extractant which is cheap, non-pollutant is as effective as Bray I and Mehlich III extraction methods for predicting maize yield.

## ACKNOWLEDGEMENT

The present study was supported by all the Authors.

### Disclaimers

The views and conclusions expressed in this article are solely those of us the authors and not the views of our affiliated institution. We are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

### Informed consent

No animal was used in this experiment.

### Conflict of interest

There are no conflicts of interest regarding the publication of this article. No funding or sponsorship.

## REFERENCES

Agbede., O.O. (2009). Understanding Soil and Plant Nutrition, first edition. Salman press Nigeria Limited, Keffi, Nasarawa.

Ajeigbe, H.A., Kamara, A.Y., Akinseye, F.M., Silwal, P.K., Faleti, O., Tofa, A.I., Kamai, N. Bebeley, J. and Solomon, R. (Editors). (2024). Matching cereal and legume crop varieties to production environments in Northeast Nigeria using Decision Support Tools (DST). International Institute of Tropical Agriculture (IITA). 92 pp.

Akanni, S.B. and Adeniyi, O I. (2020). On the forecast of cereals production in Nigeria. FUW Trends in Science and Technology Journal. 5(2): 331-335.

Ariraman, R., Prabhaharan, J., Selvakumar, S., Sowmya, S and Mansingh, M.D.I. (2020). Effect of nitrogen levels on growth parameters, yield parameters, yield, quality and economics of maize: A review. Journal of Pharmacognosy and Phytochemistry. 9(6): 1558-1563.

Brady, N.C. and Weil, R.R. (2002). Phosphorus and potassium. The nature and properties of soils. Prentice - Hall of India, Delhi. pp. 352.

Bray, R.H. and Kurtz, L.T. (1945). Determination of total, organic and available forms of phosphorus in soils. Soil Sci. 59: 39-45.

Chude, V.O., Olayiwola, C., Daudu, P. and Ekeoma, A. (Eds.) (2012) Fertilizer Use and Management Practices for Crops in Nigeria. 3rd Edition, Federal Fertilizer Department (FFD), Federal Ministry of Agriculture and Rural Development, Abuja. 204.

Crane, K.S. (2004). Pressurized hot water: An alternative methods of nutrient extraction and subsequent analysis for use in small scale agriculture. Theses and Dissertations. Pg 541.

Du, X., Wang, Z., Lei, W. and Kong, L. (2021). Increased planting density combined with reduced nitrogen rate to achieve high yield in maize. Sci Rep. 11: 358. https://doi.org/10.1038/s41598-020-79633-z.

Ebeling, A., Bundy, L., Kittell, A. and Ebeling, D. (2006). Evaluation of the Bray P1 soil test on eastern red soils in Wisconsin. Proc. of the 2006 Wisconsin Fertilizer, Aglime and Pest Management Conference. 45: 296-302.

Hanks, A.D., Webb, B.L and Jolley, V.D. (1997). A comparison of hot water extraction to standard extraction methods for nitrate, potassium, phosphorus and sulfate in arid zone soils, Communications in Soil Science and Plant Analysis. 28: 15-16, 1393-1402.

Haque, M.A., Sima, A.S., Jahiruddin, M. and Bell, R.W. (2024). Minimizing phosphorus mining through optimum phosphorus fertilization in maize. J Soil Sci Plant Nutr. 24: 5436-5448. https://doi.org/10.1007/s42729-024-01917-4.

IITA (International Institute for Tropical Agriculture) (1979). Laboratory Manual for Soil and Plant Analysis. Manual Series 7, IITA, Ibadan.

Liang, C., Liu, X., Lv, J., Zhao, F. and Yu, Q. (2024). The impact of different phosphorus fertilizers varieties on yield under wheat-maize rotation conditions. Agronomy. 14(6): 1317. https://doi.org/10.3390/agronomy14061317.

Mallarino, A.P., (2009). Long term phosphorus studies and how they affect recommendation philosophies. North Central Extension-Industry Soil Fertility Conference. 2009 25.

Mehlich, A. (1984). Mehlich III soil test extractant: A modification of Mehlich II extractant. Communications in Soil Science and Plant Analysis. 15: 1409-1416.

NIMET, (2023). Nigeria Meteorological Center, Abuja, Official Bulletin.

Ogundeji, A.O. (2013). Comparative evaluation of pressurized hot water, Mehlich III and Bray P 1, Extraction methods on phosphorus on two Nigerian soil. M.Sc. project submitted to the Department of Agronomy, University of Ibadan, Ibadan, Nigeria.

Ojobor, S.A., Egbuchua, C.N. and Onoriasakpovwa, R.A. (2021). Assessment of soil fertility status using nutrient index approach of Ovu Sub-Clan, Delta State, Nigeria: Agricultural Science Digest. 41(2): 282-288. doi: 10.18805/ag.D-294.

Olsen, S.R., Cole, C.V. Watatanabe, F.S. and Dean, L.A. (1954). Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate. USDA Circ 939. US Govt. Print. Office, Washington, DC.

Perrott, K.W., Saggar, S. and R.G. Menon (1995). Evaluation of soil phosphate status where phosphate-based fertilizers has been used. Fert. Res. 35: 67-82.

Pierre, G.T., Akponikpè, P.B.I., Agbossou E.K., Bertin P., Bielders, C.L. (2017). Fertilizer microdosing enhances maize yields but may exacerbate nutrient mining in maize cropping systems in northern Benin. Field Crops Research. 213: 130-142 https://doi.org/10.1016/j.fcr.2017.08.003.

Rasheed, M. and Igbal, M. (1995). Factor affecting yield of maize. Annual Progress Report, Agriculture Research Institute, Tarnab, Peshawar.

Ritchie, H. (2021). “Excess fertilizer use: Which countries cause environmental damage by over applying fertilizers?” Published online at OurWorldinData.org. Retrieved from: ‘https://ourworldindata.org/excess-fertilizer [Online Resource].

Sawyer, J.E. and Mallarino, A.P. (1999). Differentiating and Understanding the Mehlich 3, Bray and Olsen Soil Phosphorus Tests. 19th Annual Crop Pest Management Short Course, University of Minnesota.

Schiffer, J.A., Basta, N.T. and Storm, D.E. (2005). Correlation of soil extraction methods with boron response in field grown alfafa. Soil science society of America. 69(4): 1026-1035.

Syvers, J.K., Johnston, A.E. and Curtin, D. (2008). Efficiency of soil and fertilizer phosphorus use: Reconciling changing concepts of soil phosphorus behaviour with agronomic information. FAO Fertilizer and Plant Nutrition Bulletin. 18: pg 123.

Teo, C.C., Tana, S.N., Yonga, J.W.H., Hewb, C.S. and Ong, E.S. (2010). Pressurized hot water extraction (PHWE). Journal of Chromatography A. 1217(16): 2484-2494.

Ulrich, A., Malley, D. and Voora, V. (2009). Peak Phosphorus: Opportunity in the Making. Why the Phosphorus Challenge Presents a New Paradigm for Food Security and Water Quality in the Lake Winnipeg Basin.

Wossen, T., Menkir, A., Alene, A., Abdoulaye, T., Ajala, S., Badu-Apraku, B., Gedi, M., Mengesha, W. and Meseka, S. (2023). Drivers of transformation of the maize sector in Nigeria. Global Food Security. 38: 1-12.