Annals of Agri-Bio Research **28** (2): 437-442, 2023

Impact Score : 0.28 (Scopus)

Correlation between Grain Yield of Pearl Millet (*Pennisetum glaucum* L.) and Soil Quality Indices under Sudan Savannah Conditions

NURADDEEN ABDULLAHI ALIYU*, ROSLAN ISMAIL, MARTINI MOHAMMED YUSOFF[1], MOHD FIRDAUS MOHD ANUAR AND ADAMU GARBA K. NAISA[2]

Department of Land Management, Faculty of Agriculture, University Putra Malaysia, UPM Serdang, Selangor, Malaysia
**(e-mail: nuabdu2000@yahoo.com; Mobile: +234 80286 33035)*

(Received: February 20, 2023; Accepted: April 1, 2023)

ABSTRACT

For reasons of sustainable agriculture and land management, soil attributes have frequently been related to crop yields under various cropping systems. Grain yields of pearl millet and soil samples were collected from 36 plots at Kadawa and Dutsinma Research Farms for three consecutive wet seasons (2019, 2020 and 2021). The plots (under sole pearl millet cropping) were those that received full optimum fertilization (60 kg N/ha, 30 kg P_2O_5/ha and 30 kg K_2O/ha plus 5 t/ha FYM) annually for at least four years. Grain yield and soil data were obtained according to standard procedures. Data analysis was performed using the Pearson product moment correlation of statistical analysis system (SAS) package, version 9.4. Results indicated that available phosphorus (AP), cation exchange capacity (CEC), soil fertility index (SFI) and soil evaluation factor (SEF) correlated positively and significantly with grain yield of pearl millet. While surprisingly, soil organic carbon (SOC) recorded a non-significant relationship with the grain yield. Therefore, it was suggested that AP, CEC, SFI and SEF were potential soil health indicators for appropriate management of Sudan Savanna Inceptisols.

Key words: Nutrients, correlation, soil fertility index, soil evaluation factor, yield

INTRODUCTION

Population of Africa is expected to increase from 1.2 to > 2.5 billion by the year 2050 (UN, 2015). This can put more pressure on the fragile soils of Nigerian Sudan Savannah due to the need for increased food production through expansion of agricultural lands and intensification of farming practices in terms of fertilization and irrigation. These practices cause land degradation in the form of soil erosion and nutrient depletion (Oldfield *et al.*, 2019). In Sub Sahara Africa (SSA), C, N and P have been identified as the major nutrients that limit crop production (Stewart *et al.,* 2020). The relationship between soil fertility attributes and crop yield provides a better understanding of the sustainable management requirements of particular soil types (Khadka *et al.*, 2017). Also, potential soil health indicators are often soil properties that correlate well with crop yields (Sainju and Liptzin, 2022).

Pearl millet (*Pennisetum glaucum* L.) is ranked 4th (rice, maize, sorghum and millet) in many tropical regions of the world. It is a major source of food in areas of Africa and Asia, especially in the Sahel of Africa, where many people almost entirely depend on the crop for food (Kalaisekar *et al.*, 2017). The crop is a staple food for more than 100 million people in rural areas of Sub-Saharan Africa and India (Earl, 2018). Recently, pearl millet is gaining prominence as nutritious crop that promotes health and is climate resilient (Santosh *et al.*, 2016). The crop is easily grown in the dry Northern parts of Nigeria due to its ability to tolerate harsh conditions such as drought and flood. Essentially, the crop is well adapted to areas of high temperatures, drought and low soil fertility. It also performs well in soils with low pH or high salinity; hence, it is cultivated in places where other crops such as maize and wheat hardly survive. Pearl millet grain is very nutritious and contains 11 to 19% protein, 60 to 78% carbohydrate and 3 to 5% oil, as well as

[1]Department of Crop Science, Faculty of Agriculture, University Putra Malaysia, UPM Serdang, Selangor, Malaysia.
[2]Department of Geography and Regional Planning, Federal University Dutsinma, Nigeria.

good amounts of phosphorus and iron (Divya *et al.*, 2017). However, scarce economic and technological support have restrained increased production of the crop, so that low productivity as a result of little investment on pearl millet research programs has led to low use of agronomic techniques related to fertilizer management and mechanization (Macauley and Ramadjita, 2015). Proper nutrient management was reported to increase productivity of the crop (Bhuva *et al.*, 2018). Production data (FAO. 2017) indicated that the crop keeps recording the lowest global average yield (0.8 t/ha) in the last five decades in comparison to sorghum (1.5 t/ha), wheat (2.6 t/ha), rice (3.8 t/ha) and maize (4.0 t/ha). Soil properties have frequently been correlated with crop yields. For example, a positive correlation exists between crop yield and soil nitrate concentration in the top soil during the early cropping season (Yara, 2018). However, studies on the relationship between grain yield of pearl millet and soil attributes in the Sudan Savanna are few. Therefore, this study determined the relationship between soil fertility attributes and grain yield of pearl millet for sustainable management of Inceptisols under pearl millet cropping system.

MATERIALS AND METHODS

Field experiments were conducted during the 2019, 2020 and 2021 wet seasons within the Sudan Savanna of Nigeria. It is a zone that lies between latitude 09?3' and 12? N; longitude 04? and 14?3'E with altitude ranging between 500 to 605 m above MSL. The area is characterized by high temperature of 28 to 32°C (annual average), distinct wet season of 3 to 6 months and a relatively long dry season of 6 to 9 months. The abundant grasses are short (< 2 m tall), while trees are few and well scattered all over the region (Shehu *et al.*, 2015).

Experimental parameters taken were grain yield per hectare, cation exchange capacity (CEC), soil organic carbon (SOC), available phosphorus (AP), exchangeable K, soil fertility index (SFI) and soil evaluation factor (SEF).

Grain yield was taken after harvest by sun drying matured millet plants from net plot for three weeks followed by threshing and winnowing to obtain clean grains. Grain yield was then converted to kg/ha basis. Soil analysis was conducted using standard procedures as follows:

Soil samples were taken from research farms (Kadawa and Dutsinma) under pearl millet cultivation for >4 years consecutively. Plot size was 25 m by 4 m (100 m^2). The samples were those obtained from 36 plots that received full fertilization of 60 kg N/ha, 30 kg P_2O_5/ha and 30 kg K_2O/ha plus 5 t/ha FYM (Ajeigbe *et al.* 2020). Soil was sampled from the plots at a depth of 0-20 cm (zig-zag pattern). Thereafter, equal amounts of soil samples were mixed to form one composite soil sample per plot. Composite soil samples were air-dried, crushed and passed through 2 mm sieve. Three sub-samples from each composite sample were then analyzed for selected physical and chemical properties. Particle size distribution was by hydrometer method using calgon (5%) as a dispersant and the textural class determined with USDA textural triangle. Soil pH was determined by using pH meter in 1:2.5 soil/solution ratios. Organic carbon was by the wet oxidation method of Walkley and Black. Total nitrogen was by the microkjeldahl method after wet oxidation of organic matter. Free NH_3 was liberated from the digest by steam distillation in the presence of excess alkali. Thereafter, distillate was collected in a receiver with excess boric acid (indicator pH=4.5). Total nitrogen was then measured by titration. Available phosphorus was determined by the Bray No. 1 method (0.025N HCl +0.03N NH_4F). Exchangeable bases were extracted from the soil by leaching with 1 M ammonium acetate (pH 7) for > 2 h. 20 ml of the leachate was pipetted into 100 ml volumetric flask and then 20 ml lanthanum chloride solution was added. Potassium and sodium were determined by flame emission spectroscopy, while calcium and magnesium were measured by atomic absorption spectroscopy. The exchangeable acidity was determined by stirring the soil with 25 ml 1 M KCl and left for 30 min. The suspension was leached with five successive 25 ml aliquots of the 1 M KCl and then filtered. The filtrate was titrated with 0.1 M NaOH solution. Effective cation exchange capacity was determined by the sum of exchangeable bases and exchangeable acidity.

Soil fertility index and soil evaluation factors were determined as described by Perumal *et al.* (2017) as:

Soil Fertility Index (SFI): pH + organic matter (on % dry soil basis) + available P (mg/kg of dry soil) + exch K (cmol+/kg) + exch Ca (cmol+/kg) + exch Mg (cmol+/kg) - exch Al (cmol+/kg).
Soil Evaluation Factor (SEF): [exch K (cmol+/kg) + exch Ca (cmol+/kg) + exch Mg (cmol+/kg) – log (1 + exch Al (cmol+/kg)] × organic matter (%, dry soil) + 5
Both indices (SFI and SEF) were developed to assess the soil biomass and soil fertility status whereby SEF values of < 5 indicated extremely poor soil, while higher soil fertility was expected from values > 5. Data from the two sites were pooled and analyzed using Pearson product moment correlation based on statistical significance of $P < 0.05$. All data were analyzed by the Statistical Analysis System (SAS) package, version 9.4.

RESULTS AND DISCUSSION

The means of selected soil attributes in the study area are presented in Table 1.

Table 1. Initial physical-chemical properties of the soils at the experimental fields

Property	Kadawa	Dutsinma
Sand (%)	84±1.12	78±2.11
Silt (%)	10±0.92	18±0.97
Clay (%)	6±1.8	4±2.02
Textural class	Loamy sand	Loamy sand
pH (water)	6.3±0.07	6.5±0.7
pH (0.01M $CaCl_2$)	5.2±0.05	5.3±0.04
Organic carbon (%)	0.61±0.07	0.65±0.11
EC (dS/m)	0.05±1.15	0.05±1.13
Total nitrogen (%)	0.09±0.07	0.02±0.14
Available P (mg/kg)	5.8±0.22	4.1±0.17
Exch. Ca ($cmol_c$/kg)	4.0±0.09	6.6±0.09
Exch. Mg ($cmol_c$/kg)	1.08±0.22	1.78±1.01
Exch. K ($cmol_c$/kg)	0.08±0.12	0.17±0.09
Exch. Na ($cmol_c$/kg)	0.06±0.09	0.11±0.07
CEC ($cmol_c$/kg)	5.9±0.85	9.4±0.58
Exch. H+Al ($cmol_c$/kg)	0.6±0.55	0.8±0.09

Means ±SE of triplicate samples (n=3).

The soil texture was loamy sand having high amount of sand (78-84%) with low clay content (4-6%). The pH value was 6.3 to 6.5, while the organic carbon, total nitrogen and available phosphorus recorded values of 0.61-0.65%, 0.02-0.09% and 4.1-5.8 mg/kg, respectively. CEC ranged between 5.9-9.4 $cmol_c$/kg. Generally, fertility of the soil was low and as such soils were expected to respond highly to fertilization (Bary *et al.,* 2016). Many authors (Tully *et al.*, 2015; Adamty, 2016; Stewart *et al.*, 2020) have reported the low fertility status of the Sudan Savannah soils as a result of frequent mining and the lack of replenishment from external sources. There is need for proper action to control such soil degradation problem since many people in Africa depend on agriculture for their livelihood. Specifically, the Sudan Savannah soils are dominated by Entisols and Inceptisols (Adamty, 2016). The natural fertility of these soils was described as low to medium (Singh, 2015). To improve the fertility of such soils, there was need to apply large quantities of organic matter (Plant and Soil Science, 2018).
The results of grain yield, soil nutrients content and soil quality indices after harvest of pearl millet are presented in Table 2.

Table 2. Grain yield, soil nutrients content and soil quality indices

Attribute	Kadawa	Dutsinma
Grain yield (kg/ha)	3266.3±242.7	3039.5±406.9
Organic carbon (%)	0.48±0.11	0.52±0.13
Available phosphorus (mg/kg)	14.16±0.09	10.24±0.07
Exchangeable K ($cmol_c$/kg)	0.14±0.01	0.21±0.03
CEC ($cmol_c$/kg)	5.8±0.13	7.2±0.11
SFI	16.8±0.94	22.3±0.43
SEF	8.3±0.61	11.5±0.56

Means ±SE of triplicate samples (n=3).

Higher grain yield (3,266.3 kg/ha) was recorded at Kadawa compared to the yield (3,039.4 kg/ha) at Dutsinma despite the fact that Dutsinma recorded higher soil fertility attributes such as organic carbon, CEC, SFI and SEF. However, higher available phosphorus was recorded at Dutsima and it may be one of the major reasons for the relatively higher grain yield at Kadawa. Moreover, soil fertility was not the only factor that determines crop yield (Acquaah, 2015).
The correlation results (Table 3) among grain yield of pearl millet, soil nutrients and soil quality indices (SFI and SEF) showed that all the relationships were positive.
Organic carbon significantly correlated with AP (0.327), CEC (0.482), SFI (0.310) and SEF (0.652). Soil organic carbon (SOC) is the fraction of soil that contains carbon after decomposition of materials produced by various organisms. It is a major component of soil organic matter (SOM). A reduction of SOC indicated soil degradation (FAO and ITPS. 2017). However, SOC recorded a non-significant correlation with grain yield of pearl millet despite reports that showed crop yields frequently correlated

Table 3. Pearson correlation coefficient among grain yield, soil nutrients and soil quality indicators

	OC	AP	K	CEC	H+Al	SFI	SEF	GRAIN
OC	1.000							
AP	0.327*	1.000						
K	NS	0.385*	1.000					
CEC	0.481**	NS	0.389*	1.000				
H+Al	NS	0.435**	NS	NS	1.000			
SFI	0.310*	0.970**	0.398*	NS	NS	1.000		
SEF	0.652**	0.774**	0.417*	0.409*	0.518**	0.697**	1.000	
GRAIN	NS	0.601**	NS	0.371*	NS	0.323*	0.461**	1.000

Where, OC-Organic carbon (%), SEF-Soil evaluation factor, AP-Available P (mg/kg), GRAIN-Grain yield (kg/ha), K-Exchangeable K (cmolc/kg), CEC-Cation exchange capacity (cmolc/kg), H+Al-Exchangeable acidity (cmolc/kg), SFI-Soil fertility index, *-Significant at 5% level), **-Highly significant (at 1% level) and NS-Non-significant.

significantly and positively with SOC provided the concentration of SOC was between 1-2% (Oldfield *et al.,* 2019). Nevertheless, recent reports revealed that crop yields correlated poorly and non-significantly with SOC (Vonk *et al.*, 2020). In this study, the non-significant correlation between SOC and grain yield may be due to the very low level of organic carbon in the soils (Table 2). Also, there was more positive correlation between SOC and the yield of root or tuber crops than with cereal crops (Vonk *et al.*, 2020). In arid and semi-arid areas, increasing the SOC content from 0.5 to 0.8% was expected to increase crop yield by about 10% (Oldfield *et al.*, 2019). Moreover, plants assimilated carbon during grain production from atmosphere via photosynthesis instead of sourcing carbon from soil organic matter for grain production (Zhou *et al.,* 2016).

Significant correlation was observed between AP and all other attributes except CEC. The positive and significant correlation between grain yield and available phosphorus (AP) could be attributed to the high remobilization of phosphorus from source organs to sink organs during the reproductive phase of pearl millet development (Khwankaew *et al.*, 2022). Phosphorus was among the top three factors (C, N and P) that hindered crop production in the Sudan Savanna of West Africa (Stewart *et al.,* 2020). Phosphorus was also regarded as the most limiting nutrient in pearl millet production under the Sudan savannah conditions (Mason *et al.*, 2015). P root use efficiency was found to positively correlate with crop yields (Payne *et al.,* 2019).

Exchangeable K correlated significantly with CEC (0.389), SFI (0.398) and SEF (0.417). However, a non-significant correlation was observed between grain yield and exchangeable K probably due to low remobilization of K from source organs such as leaves to sink organs (grains) during grain production in cereals (Khwankaew *et al,* 2022). CEC was observed to correlate significantly with SEF (0.409). CEC was also among the most frequently used variables in determining soil fertility (Bunemann *et al.*, 2016). The grain yield recorded a positive and significant correlation with CEC. Yields of corn and wheat were found to correlate positively and significantly with soil CEC, AP and exchangeable K (Singh *et al.,* 2017), while Sainju and Liptzin (2022) recorded significant and positive correlations of crop yields with CEC, AP and exchangeable K under dry land conditions. Positive correlation between crop yield and CEC was attributable to the fact that higher CEC favoured the exchange and availability of nutrients to plants which consequently enhanced crop yields.

Grain yield of pearl millet correlated positively and significantly with both soil quality/fertility indices (SFI and SEF). Soil fertility was ranked among the major factors (low moisture, low soil fertility, poor stand, crop variety, poor soil structure, weeds, pest and diseases) that could limit crop production (Tiwari, 2021). Various SQIs were tailored to provide information related to the capacity of a soil to perform particular function(s) such as environmental protection, sustainable agricultural production or the promotion of human well-being (Weil and Brady, 2017). In this study, the significant relationship between grain yield and SQIs made the assessment tools valid for monitoring soil fertility in the study area. Moreover, the positive and significant relationship between grain yield with SFI and SEF suggested that improvement in soil fertility of the Sudan

Savanna soils could lead to higher grain yield of pearl millet. However, the values for SFI (r = 0.323) and SEF (r = 0.461) did not indicate a strong relationship between grain yield and soil fertility which suggested that other factors (crop variety, low moisture, soil depth, weeds, pest and diseases and poor stand) had great influence on the grain yield of pearl millet. Perhaps, stronger correlation (r = 0.601) was observed between grain yield and soil AP (Table 3). In fact, Perumal *et al.* (2017) concluded that AP was a better soil fertility indicator than SFI. Moreover, Biswas *et al.* (2019) reported a low relationship between the yield of wheat and SQI and attributed it to other factors (temperature, insects, disease, inputs and management system) that determined crop yield.

The relationship between soil fertility index (SFI) and soil evaluation factor (SEF) was positive and highly significant (0.697**). This suggested that any of the tools could be used to assess soil fertility in the study area (Table 3). Available P had a large and highly significant correlation with SFI, SEF and grain yield (0.943, 0.790 and 0.601, respectively). This suggested that AP was a critical determinant of the soil fertility of these soils. Moreover, Perumal *et al.* (2017) concluded that the available P was a better indicator of soil fertility than SFI in the forest soils of Malaysia. Meanwhile, phosphorus had also been described by Mason *et al.* (2015) as an important nutrient element that limited pearl millet production in the West Africa region. Both SQIs recorded positive and significant relationship with SOC, AP and exchangeable K. SOC was the most frequent variable used in determining SQIs (Bunemann *et al.*, 2016).

CEC correlated significantly (0.481) with organic carbon. It was well documented (Brown and Lemon, 2022) that organic matter had a very high CEC which contributed to soils, especially the fact that sandy soils relied much on the CEC of organic matter to retain nutrients on topsoil. The SEF recorded positive and significant correlation with all other measured variables (Table 3). It also recorded a superior relationship with the grain yield (0.461) when compared to SFI (0.323). This suggested that SEF was probably an improvement to SFI, as both tools were used to measure soil fertility of mineral soils (Perumal *et al.,* 2017).

CONCLUSION

The grain yield of pearl millet correlated positively and significantly with AP, CEC, SFI and SEF under Sudan Savanna conditions where Inceptisols were predominantly low in fertility and high in sand content. Surprisingly, SOC recorded a non-significant relationship with grain yield. However, SOC correlated positively and significantly with CEC, AP, SFI and SEF, while AP correlated positively and significantly with grain yield, exchangeable K, SFI and SEF. The positive and significant relationship among SQIs, soil nutrients and grain yield suggested that AP, CEC, SFI and SEF could be used as potential soil health indicators in low fertility Inceptisols of Sudan Savanna

REFERENCES

Acquaah, G. (2015). *Principles of Crop Production–Theory, Techniques and Technology*. Pearson Indian Education Services.

Adamty, N. (2016). Challenges for Organic Agriculture research in Tropical Zones. Soil Fertility and waste management in the Tropics. BIOFAC, Nurnberg, Germany.

Ajeigbe, H. A., Angarawai, I. I., Inuwa, A. H., Akinseye, F. M. and AbdulAzeez, T. (2020). *Handbook on Improved Pearl Millet Production Practices in North Eastern Nigeria*. Global Hunger and Security Initiative. *oar.icrisat.org.*

Bary, A., Cogger, C. and Sullivan, D. (2016). Fertilizing with Manure and Other Organic Amendments. Washington State University Extension. *http://pubs.wsu.edu.*

Bhuva, H. M., Detroja, A. C. and Khampara, M. D. (2018). Requirement of nutrients for Pearl millet (*Pennisetum glaucum* L.) production under Saurashtra conditions. *Int. J. Environ. Sci. Natural Res.* **9**. *Doi:10.19080/IJESNR-1119.*

Biswas, J. C., Kalra, N., Maniruzzamani, M., Nahar, U. A. and Haque, M. M. (2019). Soil health assessment methods and relationship with wheat yield. *Open J. Soil Sci.* **9**: 189-225.

Brown, K. and Lemon, J. (2022). Cations and Cation Exchange Capacity. Fact Sheet. *http://www.soilquality.org.au.*

Bunemann, E. K., Mader, P., Wohlfahrt, J. and Caspari, T. (2016). Concepts and indicators of soil quality: A review. International Soil Quality Assessment (ISQAPER) Report no. 4. FiBL. Wageningen University and

Research. *http://www.iSQAPER-project.eu.*

Divya, G., Vani, K. P., Badu, P. S. and Devi, K. B. S. (2017). Yield attributes and yield of summer pearl millet as influenced by cultivars and integrated nutrient management. *Int. J. Curr. Microbiol. Appl. Sci.* **6**: 1491-1495.

Earl, B. (2018). *Anatomics in Pearl millet–Future Food.* University of Nottingham.

FAO (2017). Food and Agricultural Organization of the United Nations Statistics Division. Data-Crops Production. *www.fao.org/faostat/en.*

FAO and ITPS (2017). *Global Soil Organic Carbon Map–GSOCmap version1.0.* Rome, FAO.

Kalaisekar, A., Padmaja, P. G., Bhagwat, V. R and Patil, J. V. (2017). *Insect Pests of Millet.* Academic Press. Elsevier Inc.

Khadka, D., Lamichhane, S., Shrestha, S. R. and Pant, B. B. (2017). Evaluation of soil fertility status of Regional Agricultural Station, Tarahana, Sunsari, Nepal. *Eur. J. Soil Sci.* **6**: 295-306.

Khwankaew, J., Bunnag, W., Pichakum, A., Songnuan, W., Dhammasamisorn, B., Narawatthana, S., Chotechuen, S., Chamarerk, V. and Meetam, M. (2022). Differences in nutrient remobilization characteristics and relationship to senescence and grain nutrient content among rice varieties. *J. Crop Sci. Biotech.* **25**: 407-419.

Macauley, H. and Ramadjita, T. (2015). In: *Cereal Crops: Rice, Maize, Millet, Sorghum and Wheat,* UNECF (ed). Feeding Africa. pp. 36. AbdouDiouf International Conference Centre.

Mason, S. C., Maman, N and Pale, S. (2015). Pearl millet production practices in semi-arid West Africa: A review. *Exp. Agric.* **1**: 11-21.

Oldfield, E. E., Bradford, M. A. and Wood, S. A. (2019). Global meta-analysis of the relationship between soil organic matter and crop yield. *SOIL* **5**: 15-32. *https://doi.org/10.5194/soil-5-15-2019.*

Payne, W. A., Hossner, L. R., Onken., A. B. and Wendt, C. W. (2019). Nitrogen and phosphorus uptake in pearl millet and its relation to nutrient and transpiration efficiency. *Agronomy J.* **85**: 425-431.

Perumal, M., Wasli, M. E., Ying, H. S., Lat, J. and Sani, H. (2017). Association between soil fertility and growth performance of plantedshoreamacrophylla (de Vriese) after enrichment planting at rehabilitation sites of Sampadi Forest Reserve, Sarawak, Malaysia. *Int. J. Forest Res.* **2017**. ArticleID6721354.

Plant and Soil Science (2018). Soil Classification and Geography. Plant and Soil Science e-library. USDA-NIFA (National Institute of Food and Agriculture).

Sainju, U. M. and Liptzin, D. (2022). Relating soil chemical properties to other soil properties and dryland crop production. *Front. Environ. Sci.* **10**: 1005114. *doi:10.3389/fenvs.2022.1005114.*

Santosh, K. P., Upadhyaya, H. D., Sangam, L. D., Mani, V. and Reddy, K. N. (2016). *Genetic and Genomic Resources for Grain Cereals Improvement.* pp. 253-289. Academic Press. Elsevier Inc.

Shehu, B. M., Jibrin, J. M. and Samndi, A. M. (2015). Fertility status of selected soils in Sudan Savanna biome of Nigeria. *Int. J. Soil Sci.* **10**: 74-83.

Singh, S. S. (2015). *Handbook of Agricultural Sciences*. Kalyani Publishers, New Delhi.

Singh, D., Sharma, R. P., Sankhyan, N. K. and Meena, S. C. (2017). Influence of long-term application of chemical fertilizers and soil amendments on physico-chemical soil quality indicators and crop yield under maize-wheat cropping system in acid Alfisol. *J. Pharm. Phytochem.* **6**: 198-204.

Stewart, Z. P., Pierzynski, G. M., Middendorf, B. J. and Prasad, P. V. V. (2020). Approaches to improve soil fertility in Sub-Saharan Africa. *J. Exp. Bot.* **71**: 632-641.

Tiwari, S. (2021). *Factors Affecting Crop Production Agronomy*. Agriculture Wales. *www.agriculturewales.com.*

Tully, K., Sullivan, C., Weil, R. and Sanchez, P. (2015). The state of soil degradation in Sub-Saharan Africa: Baselines, trajectories and solutions. *Sustainability* **7**: 6523-6552.

UN (2015). World population prospects: The 2015 revision, key findings and advance tables. *Worthy Paper Number ESA/P/WP.241,* New York, USA: United Nations.

Vonk, W. J., Van Ittersum, M. K., Reidsma, P., Zavattaro L., Bechini, L., Guzman, G., Pronk, A., Spiegel, H., Steinmann, H. H., Ruysschaert, G and Hijbeek, R. (2020). European survey shows poor association between soil organic matter and crop yields. *Nutrient Cycling in Agroecosystems* **118**: 325-334. *http://doi.1007/s10705-020-10098-2.*

Weil, R. R. and Brady, N. C. (2017). *The Nature and Properties of Soils,* 15^{th} edn. Pearson Educational.

Yara fertilizer (2018). *Yara Fertilizer Industry Handbook*. Knowledge Grows.

Zhou, B., Serret, M. D., Elasab, A., Pie, J. B., Araus, J. L., Aranjuelo, I. and Sanz-saez, A. (2016). Wheat ear carbon assimilation and nitrogen remobilization contribute significantly to grain yield. *J. Integrative Plant Biol.* **58**: 914-926. *https://doi.org/10.1111/jipb.12478.*