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Original Article

Impact of integrated soil nutrient sources on the growth and yield of sorghum raised in Rigachikun, Kaduna State, Nigeria

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ABSTRACT

This study evaluated the effects of different soil nutrient sources on the growth and yield of sorghum under rain-fed conditions during the 2023 and 2024 cropping seasons. Research was conducted at the National Open University of Nigeria Research Farm, Rigachikun, Kaduna. The experiment comprised fourteen treatments: (I) Control, (II) Soybean intercrop, (III) 2.0 t/ha of poultry manure (PM), (IV) 2.0 t/ha of PM + Soybean, (V) 3.5 t/ha of PM, (VI) 3.5 t/ha of PM + Soybean, (VII) 0.2 t/ha of compost manure (CP), (VIII) 0.2 t/ha of CP + Soybean, (IX) 0.4 t/ha of CP, (X) 0.4 t/ha of CP + Soybean, (XI) 30 kg N/ha of NPK fertilizer, (XII) 30 kg N/ha + Soybean, (XIII) 60 kg N/ha, and (XIV) 60 kg N/ha + Soybean. A Randomized Complete Block Design (RCBD) with three replications was employed. The study demonstrated that integrated soil nutrient management significantly influences the growth and yield of sorghum. Sole applications of compost manure at 0.4 t/ha (IX) improved leaf area. However, soybean intercropping (II, IV, VI, VIII, X, XII, and XIV) did not have a significant effect on sorghum growth variables. The highest grain yield was recorded in plots treated with 60 kg N/ha of NPK fertilizer intercropped with soybean (XIV), though this was not significantly different from plots treated with 60 kg N/ha of NPK fertilizer without soybean (XIII). Given its positive impact on growth and yield, the application of poultry manure should be promoted, especially among smallholder farmers looking for sustainable nutrient sources.

KEYWORDS: *Fertilizer, Sorghum, Manure, Nutrient*

INTRODUCTION

Food security remains a persistent challenge for many families across Nigeria, with land degradation and climate change being pivotal factors contributing to this crisis. Recent studies indicate that approximately 65% of Africa's farmland is degraded, significantly impacting agricultural productivity and food security

Climate variability, marked by erratic rainfall patterns, extended droughts, and rising global temperatures, continues to threaten agricultural productivity. These climatic challenges, combined with socio-economic constraints and poor soil conditions, necessitate the adoption of farming systems that integrate soil fertility management with effective crop management practices. As highlighted by Vanlauwe *et al*. (2010), such systems should combine organic and inorganic

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inputs to enhance food security while maintaining environmental sustainability. These integrated approaches aim to provide crops with a reliable and cost-effective nutrient supply, ensuring resilience against climate variability. Addressing the intertwined issues of declining soil fertility and extreme weather conditions is critical for achieving sustainable food security.

While inorganic fertilizers have been widely utilized to address soil nutrient depletion, their prolonged use can degrade soil health over time. In contrast, organic amendments such as animal manure and crop residues have been shown to improve soil structure, enhance nutrient availability, and promote water retention. However, with the growing adoption of high-yielding crop varieties, organic inputs alone are often insufficient to meet the nutritional needs of crops. Therefore, integrated nutrient management systems (INMS), which utilize both organic and inorganic inputs, have been recommended as a sustainable strategy to boost land productivity and improve crop yields.

Despite the potential of INMS, its adoption among farmers cultivating sorghum in northern Nigeria, particularly in the Guinea savannah zone, remains limited. The effects of climate change further highlight the importance of promoting drought-tolerant crops like sorghum to combat food insecurity. Sorghum, known for its resilience to poor soils and harsh environmental conditions, is a staple cereal crop that plays a significant role in food security. Recent data indicates that sorghum is among the most cultivated cereals in Sub-Saharan Africa, covering a substantial portion of the total cereal acreage.

In Kaduna State, particularly at the National Open University of Nigeria Research Farm in Rigachikun, there is increasing demand for sorghum due to its versatility and importance as a staple crop. However, yields per hectare have been declining in recent years, underscoring the need for improved agronomic practices to reverse this trend.

The objective of this study was to evaluate the effectiveness of integrated nutrient management systems in improving the growth and yield of sorghum at the National Open University of Nigeria Research Farm in Rigachikun, Kaduna, for sustainable management.

MATERIALS AND METHODS

Experimental Site Field trials were conducted at the National Open University of Nigeria (NOUN) research site in Rigachikun, Kaduna, during the 2023 and 2024 cropping seasons under rain-fed conditions. The site is located within Latitude: 10.6500º N, Longitude: 7.4500º E at an elevation of approximately 650 meters above sea level in the Northern Guinea Savanna Agro-Ecological Zone of Nigeria. The average annual temperature in Rigachikun, Kaduna State, Nigeria, is approximately 29.06°C (84.31°F), which is slightly below the national average.

Experimental Design

The treatments evaluated were: (I) Control, (II) Soybean intercrop, (III) 2.0 t/ha-1 of poultry manure (PM), (IV) 2.0 t/ha-1 of PM + Soybean, (V) 3.5 t/ha-1 of PM, (VI) 3.5 t/ha-1 of PM + Soybean, (VII) 0.2 t/ha-1 of compost (CP), (VIII) 0.2 t/ha-1 of CP + Soybean, (IX) 0.4 t/ha-1 of CP, (X) 0.4 t/ha-1 of CP + Soybean, (XI) 30 kg N/ha-1, (XII) 30 kg N/ha-1 + Soybean, (XIII) 60 kg N/ha-1, and (XIV) 60 kg N/ha-1 + Soybean. The experimental layout followed a Randomized Complete Block Design (RCBD) with three replications. Organic and inorganic amendments were incorporated into the soil during land preparation. Sorghum (a local variety) was planted using a spacing of 0.75 m x 0.5 m, with four seeds per hole, later thinned to two stands per hole two weeks after emergence.

Soil Sampling and Analysis Before the experiments commenced in 2022 and 2023, soil samples were collected from the surface (0-15 cm depth) at eight random points using a soil auger. These samples were bulked, air-dried, ground, and sieved (2 mm) for laboratory analysis. The parameters analyzed included: Soil pH: Determined in a 1:1 soil-water suspension using a glass electrode Particle size: Assessed by the hydrometer method (Bouyoucos, 1951) with sodium hexametaphosphate as the dispersant. Total organic carbon: Measured via the chromic acid oxidation method (Walkley & Black, 1934). Total nitrogen: Analyzed using the Kjeldahl method (Anderson & Ingram, 1996). Available phosphorus: Determined by the Molybdenum-blue method (IITA, 1979). Exchangeable bases: Measured using neutral ammonium acetate extraction. Sodium (Na) and potassium (K) were determined via flame photometry, while calcium (Ca) and magnesium (Mg) were analyzed using Atomic Absorption Spectrophotometry (AAS). Exchange acidity: Measured by 1 M KCl extraction and titration with 0.01 M NaOH.

Crop Data collected were measurements of leaf area (cm^2), plant height (cm), panicle length (cm), and grain yield (kg/ha). Leaf area and plant height were recorded at three-week intervals, while panicle length and grain yield were assessed at harvest. Data were subjected to analysis of variance (ANOVA), and mean differences were determined using Fisher's Least Significant Difference (LSD) test at a 5% probability level (Meier, 2006).

RESULTS AND DISCUSSION

Soil Properties of the Experimental Site

The results of selected soil properties of the experimental site prior to the application of fertilizer are summarized in Table 1. The particle size distribution analysis revealed that the soil was predominantly sandy, with a sand content of 76.64%, silt content of 14.36%, and clay content of 9.0% in 2016. Consequently, the textural class of the soil was classified as sandy loam. The soil's pH (measured in water) was 6.64, indicating a slightly acidic condition. Organic matter content during the 2016 cropping season was 1.18%. The total nitrogen (N) content was 0.21%, while available phosphorus (P) was

1.20 mg/kg. The exchangeable cations were measured as follows: potassium (K) at 0.20 cmol/kg, calcium (Ca) at 3.40 cmol/kg, magnesium (Mg) at 2.18 cmol/kg, and sodium (Na) at 0.15 cmol/kg. The cation exchange capacity (CEC) of the soil was 5.83 cmol/kg, reflecting the soil's moderate nutrient retention capacity.

Table 1. Soil Properties of the Experimental site, in NOUN Rigachikun, Nigeria.

Soil parameters 0-15	2023	2024
Soil (%)	76.65	78.35
Silt (%)	14.35	10.61
Clay (%)	9.1	11.59
Texture class	**Sandy loam**	**Sandy loam**
p^H (H_2O)	6.63	6.666
P^H (Kcl)	5.87	5.66
Organic matter (%)	1.18	1.80
Total Nitrogen (%)	0.21	0.23
Phosphorus (mg/kg^{-1})	1.20	1.65
K (mg/kg^{-1})	0.20	0.23
Ca (mg/kg^{-1})	3.41	4.75
Mg (mg/kg^{-1})	2.18	2.51
Na (mg/kg^{-1})	0.16	0.18
CEC	5.83	7.67

Chemical Composition of Poultry Manure and Organic NPK (Compost)

The results of the chemical analysis of poultry manure and organic NPK (compost) are presented in Table 2. The soil pH of the poultry manure was 7.4, with an organic matter content of 26.41%, nitrogen content of 2.25%, and phosphorus content of 12.10%.

Table 2. Chemical properties of poultry and organic NPK (compost).

Parameters	Poultry manure	Compost
pH	7.4	7.0
Organic matter (%)	26.41	48.65
Total nitrogen (%)	2.25	8.20
Phosphorus (mg/kg^{-1})	12.10	6.12
K (cmol kg^{-1})	1.15	3.80
Ca (cmol kg^{-1})	10.81	13.28
Mg ($cmol/kg^{-1}$)	0.53	8.13
Na (cmol kg^{-1})	1.78	0.62

The exchangeable cation composition of the poultry manure was as follows: potassium (1.15 cmol/kg), calcium (10.81 cmol/kg), magnesium (0.53 cmol/kg), sodium (1.78 cmol/kg), and cation exchange capacity (CEC) of 14.27 cmol/kg. Similarly, the nutrient composition of the compost was determined as follows: organic matter (48.65%), nitrogen (8.20%), phosphorus (6.12 mg/kg), potassium (3.80 cmol/kg), calcium (13.28 cmol/kg), magnesium (8.13 cmol/kg), and sodium (0.62 cmol/kg). These results highlight the relative potential of poultry manure and organic NPK (compost) to improve soil fertility and enhance crop production when incorporated into the soil.

Crop Data

The leaf area of sorghum as influenced by the application of various nutrient sources is presented in Table 3. The results indicate that leaf area was significantly affected by the application of integrated soil nutrients. A significant difference was observed between the control and soybean as a sole nutrient source at 6 and 12 weeks after planting (WAP) during the 2023 season. However, no significant difference was recorded between the sole application of poultry manure at 2.0 t/ha and the combined application of soybean with 2.0 t/ha of poultry manure across all intervals. Similarly, there was no significant difference between the sole application of poultry manure at 3.5 t/ha and the combination of soybean with 3.5 t/ha of poultry manure across all intervals.

The sole application of compost manure at 0.2 t/ha did not differ significantly from the combination of soybean with compost at 0.2 t/ha across all intervals. Likewise, compost manure at 0.4 t/ha showed no significant difference in leaf area compared to soybean combined with compost at 0.4 t/ha during the 2014 season (Table 3).

The application of 30 kg N/ha of mineral fertilizer showed no significant difference in leaf area compared to soybean combined with 30 kg N/ha of mineral fertilizer. Similarly, the sole application of 60 kg N/ha of mineral fertilizer did not significantly differ from the combination of soybean with 60 kg N/ha of mineral fertilizer.

In the 2024 season, no significant difference in leaf area was observed between the control and soybean as a sole nutrient source at 9 and 12 WAP. The sole application of poultry manure at 2.0 t/ha and the combination of soybean with 2.0 t/ha of poultry manure showed no significant difference in leaf area across all intervals. Similarly, poultry manure at 3.5 t/ha and the combination of soybean with 3.5 t/ha of poultry manure did not differ significantly in leaf area at 9 and 12 WAP. The sole application of compost at 0.2 or 0.4 t/ha also showed no significant difference in leaf area compared to soybean combined with compost at 0.2 or 0.4 t/ha.

As illustrated in Table 3, the leaf area of sorghum was not significantly affected by the soybean mixture in the two cropping seasons. However, there was a marginal improvement in leaf area with the soybean mixture compared to the control, sole fertilizer, and compost or manure treatments. This result highlights the potential benefits of incorporating soybean into a cropping system.

These findings align with the report by Ofori and Stern (1987), who found that the leaf area of sorghum increased significantly in a soybean-sorghum mixture. Similarly, Fuyita *et al*. (1990) observed significant improvements in leaf area in a cowpea-maize mixed cropping system. Bavec *et al*. (2005) also reported an increase in maize leaf area due to intercropping with climbing beans. In contrast, Mouneke and Okpara (2001) did not find significant effects on growth parameters in cereal-legume intercropping systems. The observed discrepancies may be attributed to variations in growth conditions, which could have influenced the growth patterns of the crops in these studies.

Table 3. Effect of nutrient sources on leaf area (cm2) of sorghum.

Treatment	3WAP		6WAP		9WAP		12WAP	
	2023	**2024**	**2023**	**2024**	**2023**	**2024**	**2023**	**2024**
Control	55.2	66.1	111.1	112.4	219.7	221.1	298.8	302.2
Sorghum/soybean	68.1	66.1	117.5	116.1	221.0	222.7	302.2	302.9
2.0 t/ha^{-1} PM	64.7	60.0	118.0	116.0	236.6	244.0	313.5	308.5
2.0 t/ha^{-1} PM + soybean	61.2	65.4	119.7	116.5	236.7	244.5	313.8	309.0
3.5 t/ha^{-1} PM	60.1	66.0	120.0	121.0	228.9	256.1	317.7	323.1
3.5 t/ha^{-1} PM + soybean	69.0	63.5	120.1	124.0	228.9	257.8	319.0	323.4
0.2 t/ha^{-1} CP	63.0	58.1	123.0	146.0	234.8	241.0	318.7	324.0
0.2 t/ha^{-1} CP + soybean	73.5	61.5	123.8	148.6	236.5	241.0	318.7	324.8
0.4 t/ha^{-1} CP	65.0	63.3	126.0	243.9	243.0	245.0	325.1	330.0
0.4 t/ha^{-1} CP + soybean	64.7	60.1	127.1	124.5	243.9	245.5	325.2	330.6
30 Kg N/ha^{-1}	62.0	60.7	128.0	135.0	361.0	356.0	414.0	416.1
30 KgN/ha^{-1} + soybean	67.0	57.8	128.1	117.6	361.3	359.8	418.8	420.7
60 Kg N/ha^{-1}	64.4	59.1	132.4	144.5	422.0	388.1	425.0	427.9
60 KgN/ha^{-1} + soybean	68.3	60.3	133.2	144.8	423.4	389.8	425.6	428.0
LSD (0.05)	NS	NS	2.91	2.04	2.88	2.03	2.25	1.56

Note: WAP = Weeks after planting; PM = Poultry manure; NS = No significant difference.

Table 4 presents the plant height as influenced by the application of nutrients from varying sources during the 2016 and 2017 cropping seasons. The tallest plants were recorded in plots treated with 60 kg N/ha of mineral fertilizer, either as the sole nutrient source or in combination with soybean, achieving a height of 359.7 cm at 12 WAP (weeks after planting) in the 2016 season. In contrast, the shortest plants were observed in the control plots at 6, 9, and 12 WAP.

Plant height was significantly affected by the application of varying nutrient sources at 6, 9, and 12 WAP in 2016. Similarly, during the 2017 cropping season, the application of 60 kg N/ha of mineral fertilizer produced the tallest plants, reaching 364.3 cm at 12 WAP. Once again, the control plots resulted in the shortest plant heights at 6, 9, and 12 WAP.

The introduction of soybean did not have a statistically significant effect on plant height in either season. However, a marginal improvement in plant height was observed with the soybean intercrop. This trend aligns with the findings of Bavec *et al*. (2005), who reported that the plant height of maize was significantly improved when intercropped with climbing beans.

Interestingly, plant height followed a pattern similar to that of leaf area in sorghum. The plant height of sorghum was not significantly influenced by the soybean intercrop in either cropping season, as shown in Table 4. Nevertheless, the slight improvement in plant height with soybean intercrop highlights its potential benefits.

The panicle length of sorghum was not significantly affected by the application of fertilizers from varying sources, even though marginal differences were observed concerning the levels of fertilizer and/or manure treatments (Table 5). The sole application of NPK fertilizer at 60 kg N/ha or in a soybean mixture resulted in the longest panicle length (30.6 cm) during the 2016 season. In contrast, the shortest panicle length (26.2 cm) was obtained from the application of poultry manure at 2.0 t/ha. Similarly, there was no significant difference in panicle length between manure or fertilizer treatments.

Unlike the 2023 season, panicle length in the 2024 season marginally increased with higher levels of fertilizer or manure application. The shortest panicle length (26.1 cm) was recorded in the control treatment, while the longest panicle length (33.3 cm) was achieved with the application of NPK at 30 kg N/ha in a soybean mixture.

The grain yield of sorghum, however, was significantly influenced by the application of fertilizer or manure in both seasons (Table 5). The highest grain yield (1035.7 kg/ha) was observed with the application of NPK fertilizer at 60 kg N/ha in a soybean mixture, whereas the lowest grain yield (372.7 kg/ha) was recorded in the control treatment. There was no significant difference in panicle length when soybean was included in the mixture with varying levels of fertilizer or manure. A similar trend was observed in the 2017 season, although the highest grain yield was obtained from the sole application of NPK at 60 kg N/ha.

Table 4. Effect of nutrient sources on plant height (cm^2) of sorghum

Treatment	3WAP		6WAP		9WAP		12WAP	
	2016	2017	2016	2017	2016	2017	2016	2017
Control	17.3	15.1	78.6	76.4	177.0	187.4	230.2	234.4
Sorghum/ soybean	15.1	15.7	78.7	77.2	178.0	189.6	230.8	235.0
2.0 t/ha^{-1} PM	20.5	20.1	113.0	120.0	308.0	320.0	344.0	350.2
2.0 t/ha^{-1} PM + soybean	17.0	16.0	116.3	120.3	311.2	323.7	345.6	351.6
3.5 t/ha^{-1} PM	19.0	21.6	116.5	122.9	312.0	324.3	348.0	360.1
3.5 t/ha^{-1} PM + soybean	17.8	15.0	118.9	123.2	318.4	327.0	348.5	360.4
0.2 t/ha^{-1} CP	21.0	22.0	106.0	123.6	308.0	316.0	349.0	360.0
0.2 t/ha^{-1} CP+ soybean	16.6	18.0	109.4	123.7	308.2	316.2	349.9	363.1
0.4 t/ha^{-1} CP	20.1	19.8	126.0	124.0	318.5	326.0	350.0	362.3
0.4 t/ha^{-1} CP + soybean	18.5	14.0	126.7	124.2	318.7	326.4	351.4	362.7
30 Kg N/ha^{-1}	20.0	21.3	112.0	114.0	309.0	311.0	354.1	361.2
30 Kg N/ha^{-1} + soybean	16.5	16.3	119.4	114.1	310.1	311.5	355.8	361.7
60 Kg N/ha^{-1}	19.8	21.6	130.0	138.0	333.0	340.0	359.7	364.0
60 Kg N/ha^{-1} + soybean	16.8	15.3	130.2	138.0	336.7	340.6	359.7	364.3
LSD (0.05)	NS	NS	8.51	3.62	3.97	1.16	3.41	5.75

Note: WAP = Weeks after planting; PM = Poultry manure; NS = No significant difference

Table 5. Effect of nutrient sources on panicle length and yield of sorghum

Treatment	Yield (kg/ha) length (cm)		Panicle	
	2023	2024	2023	2024
Control	372.7	367.0	27.0	26.1
Sorghum/soybean	373.0	367.7	27.0	26.4
2.0 t/ha PM	387.1	430.0	26.2	27.0
2.0 t/ha PM + soybean	386.3	438.3	27.2	27.6
3.5 t/ha PM	410.7	501.1	27.0	28.8
3.5 t/ha PM + soybean	415.6	508.9	27.9	28.8
0.2 t/ha CP	387.0	483.7	28.0	30.0
0.2 t/ha CP + soybean	481.3	490.6	30.1	30.2
0.4 t/ha CP	633.0	693.0	30.0	33.0
0.4 t/ha CP + soybean	634.3	694.7	30.4	33.0
30 Kg N/ha	1016.1	1112.0	30.4	33.1
30 Kg N/ha+ soybean	1016.5	1116.6	30.4	33.3
60 Kg N/ha	1035.0	1134.8	30.6	30.7
60 Kg N/ha+ soybean	1035.7	1138.4	30.6	30.7
LSD (0.05)	13.11	8.58	NS	NS

The inclusion of soybean in the sorghum mixture might have enhanced the efficient utilization of soil nutrients, resulting in higher yields. This finding aligns with the studies of Olufajo (1992), Agbeje *et al*. (2002), and Mbah *et al*. (2007). However, this trend contrasts with the findings of Mouneke and Okpara (2007), who reported reduced grain yields under intercropping compared to sole cropping. This discrepancy may be attributed to competition for available nutrients, especially phosphorus and potassium, as well as possible soil moisture constraints.

CONCLUSION AND RECOMMENDATION

The combination of organic and inorganic amendments, along with the inclusion of a legume component, enhances the growth and yield parameters of sorghum. Sorghum planted in a mixture with soybeans and treated with these soil amendments showed marginal increases in leaf area, plant height, and grain yield. The higher values of growth and yield parameters observed with the application of various nutrient sources demonstrate that integrated nutrient management is effective in promoting the growth and yield of sorghum. This approach suggests that the reliance on inorganic fertilizers can be significantly reduced by incorporating soybean and compost manure, thereby supporting sustainable crop production.

Farmers recommended to apply compost manure at 0.4 t/ha (IX) to improve sorghum growth, particularly in areas with limited access to chemical fertilizers. The application of 60 kg N/ha of NPK fertilizer (XIII and XIV) is recommended for maximizing sorghum yield. However, further studies should explore ways to improve nutrient use efficiency and reduce dependency on inorganic fertilizers. did not significantly enhance sorghum growth, the long-term benefits of soybean intercropping for soil fertility should be further investigated, particularly for nitrogen fixation and organic matter buildup. Given its positive impact on growth and yield, the application of poultry manure should be promoted, especially among smallholder farmers looking for sustainable nutrient sources.

REFERENCE

Adekiya, A. O., Ojeniyi, S. O., & Agbede, T. M. (2012). Poultry manure effects on soil properties, leaf nutrient status, growth and yield of cocoyam in a tropical Alfisol. *Nigerian Journal of Soil Science, 22*(2), 30–39.

Adepetu, J. A., Adetunji, M. T., & Ige, V. (2014). Soil fertility and crop nutrition. Jumak Publishers, Ibadan, 1st ed., 106–470 p.

Agegnehu, G., van Beek, C., & Bird, M. I. (2014). Influence of integrated soil fertility management in wheat and tef productivity and soil chemical properties in the highland tropical environment. *Journal of Soil Science and Plant Nutrition*, *14*(3), 532–545. https://www.doi.org/10.4067/S0718-95162014005000042

Anderson, J. M., & Ingram, J. S. I. (1996). Tropical soil biology and fertility: A handbook of methods, 2nd ed., CAB International, 57–74 p.

Ayensu, E. S., & Doggett, H. (1999). Sorghum and millet: Their botany, cultivation, and utilization. Academic Press, London, pp. 1–121.

Bationo, A., Kihara, J., Vanlauwe, B., Waswa, B., & Kimetu, J. (2006). Soil organic carbon dynamics, functions, and management in West African agro-ecosystems. *Agricultural Systems*, *94*(1), 13–25. https://www.doi.org/10.1016/j.agsy.2005.08.011

Bavec, F., Zivec, U., Mlakar, S. G., Bavec, M., & Radics, L. (2005). Competitive ability of maize in mixture with climbing bean in organic farming. Poster presented at *Researching Sustainable Systems: International Scientific Congress on Organic Agriculture, Adelaide, Australia, Sept 21–23.*

Black, C. A. (1965). Method of soil analysis. Part 2: Chemical and microbiological properties, 2nd ed., American Society of Agronomy, 1011–1018. https://www.doi.org/10.2134/agronmonogr9.1

Bouyoucos, G. H. (1951). Recalibration of the hydrometer for making mechanical analysis of soils. *Agronomy Journal*, *43*, 434–438. https://www.doi.org/10.2134/agronj1951.00021962004300090005x

Brady, N. C., & Weil, R. R. (2007). The nature and properties of soils, 13th ed., Prentice Hall, New Jersey, pp. 650.

Eswaran, H., Lal, R., & Reich, P. F. (2001). Land degradation: An overview. In Bridges, E. M., Hannam, I. D., Oldeman, L. R., Pening de Vries, F. W. T., Scherr, S. J., & Sompatpanit, S. (Eds.), *Responses to Land Degradation.* Proceedings of the 2nd International Conference on Land Degradation and Desertification, New Delhi, India.

Food and Agriculture Organization (FAO). (2015). FAOSTAT 2015. FAO, Rome. http://faostat.fao.org

Fujita, K., Ogata, S., Matsumoto, K., Masuda, T., Ofosu-Budu, K. G., & Kuwata, K. (1990). Nitrogen transfer and dry matter production in soybean and sorghum mixed cropping systems at different population densities. *Soil Science and Plant Nutrition*, *36*, 233–241. https://www.doi.org/10.1080/00380768.1990.10414988

Lal, R. (2010). Managing soils and ecosystems for mitigating anthropogenic carbon emissions and advancing global food security. *BioScience*, 60(9), 708–721. https://www.doi.org/10.1525/bio.2010.60.9.8

Mando, A., Stroosnijder, L., & Brussaard, L. (1997). Effects of termites on infiltration into crusted soil. *Geoderma*, *74*(1–2), 107–113. https://www.doi.org/10.1016/S0016-7061(96)00061-9

Meier, U. (2006). "A note on the power of Fisher's least significant difference procedure." *Pharmaceutical Statistics*, 5(4), 253-263.

Mbah, E. U., Mouneke, C. O., & Okpara, D. A. (2007). Effect of compound fertilizer on the yield and productivity of soybean and maize in soybean/maize intercrop in southern Nigeria. *Tropical and Subtropical Agroecosystems*, *7*, 87–95. http://www.redalyc.org/articulo.oa?id=93970203

Obi, U. I. (2001). Introduction to factorial experiment for agricultural, biological and social science research, 2nd ed., Optimal Computer Solution Ltd., Enugu, Nigeria, 63–75 p.

Ofori, F., & Stern, W. R. (1987). Cereal-legume intercropping systems. *Advanced Agronomy Journal*, *41*, 41–90. https://www.doi.org/10.1016/S0065-2113(08)60802-0

Olufajo, O. O. (1992). Response of soybean intercropping with maize on a sub-humid tropical environment. *Tropical Oil Seed Journal*, *1*(1), 27–33.

Palm, C. A., Myers, R. J. K., & Nandwa, S. M. (2001). Organic-inorganic nutrient interactions in soil fertility replenishment. In Buresh, R. J., Sanchez, P. A., & Calhoun, F. (Eds.), *Replenishing Soil Fertility in Africa.* SSSA Special Publication No. 51, Madison, WI, USA: SSSA and ASA, pp. 193–218.

Sanginga, N., & Woomer, P. L. (2009). Integrated soil fertility management in Africa: Principles, practices, and developmental process. Tropical Soil Biology and Fertility Institute of the International Center for Tropical Agriculture.

Steiner, C., Teixeira, W. G., Lehmann, J., Nehls, T., de Macêdo, J. L. V., Blum, W. E. H., & Zech, W. (2007). Long-term effects of manure, charcoal, and mineral fertilization on crop production and fertility on a highly weathered Central Amazonian upland soil. *Plant and Soil*, *291*(1–2), 275–290.

Tian, G., Kolawole, G. O., Kang, B. T., & Kirchhof, G. (1995). Changes in soil chemical properties under a long-term alley cropping system in Southern Nigeria. *Agroforestry Systems*, *30*(1), 51–63.

Vanlauwe, B., Diels, J., Sanginga, N., & Merckx, R. (2010). Integrated plant nutrient management in Sub-Saharan Africa: From concept to practice. CAB International.

Walkley, A., & Black, I. A. (1934). An examination of the digestion method for determining soil organic matter. *Soil Science*, *37*, 29–38. https://www.doi.org/10.1097/00010694-193401000-00003