



EFFECTS OF SOIL SOLARIZATION AND FARMYARD MANURE ON IRRIGATED RICE PRODUCTIVITY IN THE SAHEL SAVANNA OF NIGERIA

Rufai, S. and Shittu, E. A.

Department of Agronomy, Bayero University, Kano P.M.B 3011, Kano, Nigeria
Corresponding Author's Email: seabraham.agr@buk.edu.ng, **GSM:** +2348024695219

ABSTRACT

This study was carried out to assess the effects of soil solarization and farm yard manure (FYM) on the growth and productivity of irrigated rice during the 2019 and 2020 dry seasons at the Teaching and Research Farm of the Federal University Gashua, Yobe State, Nigeria. The experiment was arranged in a split-plot design with three replications. The main plots consisted of three soil solarization treatments (uncovered soil, single-layer polyethylene, and double-layer polyethylene), while the subplots received FYM at 0, 15, and 30 t ha⁻¹. The study revealed that, soil solarization and FYM significantly ($p \leq 0.05$) improved soil temperature, plant height, tiller production, dry matter accumulation, panicle length, effective tillers, and grain yield. The result further indicated that, combination of double-layer polyethylene solarization and 15 t ha⁻¹ FYM produced the tallest plants, the highest tiller number, and the greatest grain yield (5.53 t ha⁻¹). The study demonstrated that integrating double-layer soil solarization with 15 t ha⁻¹ FYM provides an effective and sustainable management strategy for improving irrigated rice productivity in the Sahel Savanna of Nigeria.

Keywords: Irrigated, Rice, Soil-solarization, Crop Productivity, Nutrition.

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the world's most important cereal crops and serves as a staple food for millions of people, particularly in sub-Saharan Africa, where its demand continues to increase. In Nigeria, rice plays a critical role in food security and rural livelihoods; however, productivity in the Sahel Savanna remains below its potential due to declining soil fertility, severe weed infestation, and the inherently low nutrient- and water-holding capacity of the predominantly sandy soils (Fukagawa & Ziska, 2019). Addressing these constraints requires sustainable soil management practices capable of improving soil productivity while reducing dependence on costly external inputs. Among the available soil management options, soil solarization has received increasing attention as an environmentally friendly technique that utilizes transparent polyethylene sheets to capture solar radiation, thereby increasing soil temperature and creating conditions that favour improved crop establishment and productivity. According to Gebreegziher (2024) and Cucu *et al.* (2025), soil solarization has been reported to suppress many soil-borne pests and weeds while improving soil conditions for crop growth. Likewise, the application of farmyard manure (FYM) contributes organic matter and essential nutrients that enhance soil fertility and support sustainable crop production (Kumari *et al.*, 2024; Sheoran *et al.*, 2024). Consequently, integrating soil solarization with FYM has the potential to provide a complementary approach to improving rice productivity under irrigated conditions.

Despite these reported benefits, information on the combined application of soil solarization and FYM under the Sahel Savanna conditions of Nigeria remains scarce. Most previous studies have evaluated either soil solarization or organic amendments independently, with limited evidence on their interactive effects on rice growth and productivity under the hot, semi-arid conditions of northern Nigeria. This knowledge gap limits the development of locally adapted and sustainable soil management strategies for irrigated rice production in the region. The present study was therefore undertaken to evaluate the combined effects of soil solarization and farmyard manure on the growth and productivity of irrigated rice in Gashua, located within the Sahel Savanna of Nigeria. The findings are expected to contribute to the development of sustainable and climate-resilient soil management practices that improve rice productivity while reducing reliance on synthetic agricultural inputs (Anisuzzaman *et al.*, 2021; Sheoran *et al.*, 2022).



The general objective of this study was to evaluate the effects of soil solarization and farmyard manure on the growth and productivity of irrigated rice in the Sahel Savanna of Nigeria.

The specific objectives were to:

- i. evaluate the effect of soil solarization on soil temperature and selected physicochemical properties of the experimental soil; and
- ii. determine the effects of soil solarization and farmyard manure on the growth and yield of irrigated rice.

MATERIALS AND METHODS

Experimental Site

Field experiments were conducted during the 2019 and 2020 dry seasons at the Teaching and Research Farm of the Federal University Gashua (12°52.585'N, 11°00.773'E; 348 m above sea level) in Yobe State, Nigeria. The experimental site is located within the Sahel Savanna agroecological zone, characterized by low annual rainfall, high solar radiation, high evaporative demand, and predominantly sandy loam soils typical of the semi-arid regions of northern Nigeria.

Meteorological Data

Meteorological data comprising daily minimum, maximum, and mean air temperature, relative humidity, rainfall, and wind speed were obtained from the Digital Weather Station of the Centre for Irrigation and Desertification Studies (CIDS), Federal University Gashua, throughout the experimental period. These data were used to characterize the prevailing weather conditions during the study.

Treatments and Experimental Design

The experiment consisted of two factors: soil solarization and farmyard manure (FYM). Soil solarization comprised of three levels: uncovered soil (control), single-layer polyethylene cover, and double-layer polyethylene cover, while FYM was applied at three rates (0, 15, and 30 t ha⁻¹). The treatments were arranged in a split-plot design with three replications, giving a total of 27 experimental units. Soil solarization treatments were assigned to the main plots, whereas FYM rates were allocated to the subplots. Each plot measured 3 × 2 m (6 m²), with 1.0 m and 0.5 m spacing between main plots and subplots, respectively, resulting in a total experimental area of approximately 10 × 23 m.

Soil Sampling and Laboratory Analysis

Before land preparation, composite soil samples were collected from the 0-15 cm depth using a soil auger. The samples were air-dried, gently crushed, passed through a 2-mm sieve, and analyzed at the Soil and Water Laboratory, Federal University Gashua, to determine particle size distribution, soil pH, electrical conductivity (EC), organic carbon, organic matter, total nitrogen, available phosphorus, exchangeable cations (Ca, Mg, K, and Na), cation exchange capacity (CEC), and bulk density using standard laboratory procedures described by Black (1956). The physicochemical properties of the soil before and after solarization, together with the chemical composition of the farmyard manure, are presented in Table 1.

Farmyard Manure incorporation

The farmyard manure consisted of a mixture of cattle dung, urine, bedding materials, and feed residues collected from the Livestock Unit of the Teaching and Research Farm, Federal University Gashua. The manure was thoroughly mixed before application, and representative samples were analyzed for selected physicochemical properties before incorporation into the experimental plots.

Nursery Establishment, Land Preparation and Soil Solarization

A nursery was established on a 4 × 4 m seedbed using the rice variety FARO 60. Fertilizer was uniformly applied at the recommended rate of 80 kg N ha⁻¹ using NPK (20:10:10) fertilizer (Ibrahim, 2017). Three-week-old healthy seedlings were used for transplanting.

The experimental field was ploughed, harrowed, and levelled before being laid out into three blocks according to the experimental design. Prior to solarization, the field was irrigated to near field capacity to facilitate heat transfer within the soil profile. Transparent polyethylene sheets (30 µm; 0.03 mm thick) were spread over the designated main plots, with the edges buried in the soil and secured with stones to minimize heat loss. Soil solarization was maintained for six weeks before transplanting.



Following the solarization period, the polyethylene sheets were removed and the designated FYM treatments (0, 15, and 30 t ha⁻¹) were incorporated into the respective subplots before transplanting.

Crop Establishment and Field Management

Three-week-old seedlings were transplanted during the evening to minimize transplanting shock at a spacing of 20 cm × 20 cm. Five representative plants were tagged in each plot for periodic observations. Irrigation was applied immediately after transplanting and subsequently every three days until panicle initiation and every two days thereafter to maintain adequate soil moisture throughout the growing period.

Manual weeding was carried out at 3, 6, and 9 weeks after transplanting (WAT) to maintain weed-free conditions throughout the experiment. At physiological maturity, plants from the net plot area were harvested manually by cutting approximately 10–15 cm above ground level using a sickle. The harvested plants were sun-dried for five days, manually threshed, and cleaned by winnowing before yield determination.

Data Collection and Analysis

Growth parameters recorded included soil temperature during the solarization period, and dry matter accumulation at 6 and 9 WAT.

Yield and yield-related parameters included panicle length, number of panicles per hill, effective tillers m⁻², panicle density, 1000-grain weight, grain yield per plant, harvest index, and grain yield per hectare. Panicle length was measured from the panicle base to the tip, while grain yield per hectare was computed from the net plot yield, adjusted to 14% grain moisture content, and converted to a hectare basis using standard agronomic procedures.

Data generated were subjected to analysis of variance (ANOVA) appropriate for a split-plot design using GenStat (17th Edition). Treatment means were separated using the Student–Newman–Keuls (SNK) test at the 5% level of probability.

RESULTS AND DISCUSSION

Soil Characteristics and Profiling

The physicochemical properties of soil before and after solarization, together with the chemical characteristics of the farmyard manure (FYM), are presented in Table 1. The soil remained sandy loam before and after solarization, indicating that the treatment did not alter the soil textural class. According to Zubairu *et al.* (2023) and Gambo *et al.* (2025), sandy loam soils are typical of the Sahel Savanna and are characterized by good drainage but relatively low nutrient- and water-holding capacity. The slight decrease in sand content and corresponding increase in silt following solarization were minimal and did not modify the overall soil texture.

Solarization resulted in a slight increase in soil pH from 6.81 to 7.00, while electrical conductivity remained virtually unchanged (0.014–0.015 dS m⁻¹), indicating that the treatment had no adverse effect on soil salinity. Bogati *et al.* (2023) reported that soil solarization may induce slight improvements in soil chemical properties under warm climatic conditions without causing undesirable changes in soil quality. Similarly, Huang *et al.* (2023) observed modest increases in soil pH following solarization, reflecting favourable changes in the soil environment.

Organic carbon and organic matter changed only marginally after solarization, suggesting that the treatment-maintained soil organic status under the prevailing field conditions. In contrast, the FYM contained substantially higher organic carbon (15.1 g kg⁻¹) than the experimental soil, highlighting its potential as an important source of organic matter for sustaining soil fertility. Similar observations were reported by Ndung'u *et al.* (2021), who demonstrated that farmyard manure contributes significantly to improving soil organic matter and overall soil quality.

Available phosphorus increased slightly from 0.49 to 0.56 mg kg⁻¹, while total nitrogen increased from 0.62 to 0.64 g kg⁻¹ after solarization. Although these increases were relatively small, they suggest slight improvements in soil nutrient status. According to Zhou *et al.* (2025), soil solarization can enhance phosphorus availability under suitable soil conditions, while Mgolozeli *et al.* (2022) and Tang (2025) reported similar improvements in nitrogen availability in soils managed with solarization and organic amendments.



Exchangeable calcium and magnesium remained relatively stable following solarization, whereas exchangeable potassium declined slightly from 0.48 to 0.22 cmol kg⁻¹. Nevertheless, the FYM contained appreciable levels of exchangeable potassium (1.31 cmol kg⁻¹), calcium (2.41 cmol kg⁻¹), and other essential nutrients, indicating its potential to supplement soil nutrient reserves. Likewise, cation exchange capacity increased slightly from 5.1 to 5.3 cmol kg⁻¹, suggesting a marginal improvement in the soil's capacity to retain nutrients. Futa *et al.* (2024) similarly reported that integrating soil solarization with organic amendments can improve soil fertility while maintaining favourable chemical properties.

Overall, the results indicate that soil solarization had no detrimental effect on the physicochemical properties of the experimental soil. When considered alongside the favourable nutrient composition of the FYM, the findings suggest that the integrated use of soil solarization and farmyard manure provides a suitable soil management approach for irrigated rice production in the Sahel Savanna. This observation is consistent with the findings of Musei *et al.* (2024) who reported that integrated soil management practices contribute to sustainable soil fertility and improved crop productivity under semi-arid conditions.

Table 1: Physicochemical Properties of the Experimental Soil before and after Solarization and of the Farmyard Manure (FYM) Used in the Study.

Soil parameters	Pre-Solarization	Post-Solarization	Farm Yard Manure
Particle size distribution (g kg⁻¹)			
Clay	160	170	-
Silt	280	310	-
Sand	560	520	-
Textural class	Sandy loam		
Chemical properties			
pH	6.81	7.00	6.70
ECE (dsm ⁻¹)	0.014	0.015	-
Organic carbon (g kg ⁻¹)	3.7	3.5	15.1
Organic matter (g kg ⁻¹)	5.2	5.2	-
Available phosphorus (mg/kg)	0.49	0.56	0.83
Total Nitrogen (g kg ⁻¹)	0.62	0.64	0.36
Bulk density (g cm ⁻³)	1.38	1.38	1.29
Exchangeable cations (c mol kg⁻¹)			
Mg	0.92	0.94	0.86
K	0.48	0.22	1.31
Ca	8.85	8.88	2.41
Na	0.87	0.92	0.98
CEC	5.1	5.3	-

Soil Temperature during the Solarization Period

Soil temperature differed significantly ($p \leq 0.05$) among solarization treatments throughout the eight-week solarization period (Table 2). Double-layer polyethylene consistently recorded the highest maximum (52-56°C) and minimum (34-36°C) soil temperatures, followed by the single-layer polyethylene treatment, whereas the uncovered soil maintained the lowest temperatures (41-45°C maximum and 24-27°C minimum). These findings demonstrate the greater effectiveness of double-layer polyethylene in trapping solar radiation and increasing soil temperature under the hot, dry conditions of the Sahel Savanna.

According to Al-Madani *et al.* (2024), the use of multiple polyethylene layers enhances heat retention by reducing heat loss, resulting in higher soil temperatures than those achieved with a single layer. Similarly, Nwagwu *et al.* (2023) reported that double-layer polyethylene provides a more efficient thermal barrier, thereby improving the effectiveness of soil solarization. The soil temperatures recorded under the solarized treatments in the present study exceeded 45°C during most of the solarization period,



a threshold reported to be effective for suppressing many weed seeds and several soil-borne pests and pathogens (Kanellou *et al.*, 2023; Omotayo & Eegunranti, 2023).

The higher temperatures achieved under solarization may have contributed to the improved crop growth observed in the subsequent stages of the experiment. Bárcenas-Moreno *et al.* (2022) reported that elevated soil temperatures during solarization can improve soil conditions for crop establishment, while Futa *et al.* (2024) observed that integrating soil solarization with appropriate soil management practices enhanced crop performance under field conditions. The superior thermal performance of the double-layer polyethylene treatment therefore highlights its suitability as an effective solarization practice for irrigated rice production in the Sahel Savanna.

Table 2: Soil Temperature during the Solarization Period at FUGA during the 2019 and 2020 Dry Seasons

Treatment	Temperature (°C) at 2 Weeks Interval							
	Weeks after treatment (WAT)							
	1-2		3- 4		5- 6		7- 8	
Depth	T max	T min	T max	T min	T max	T min	T max	T min
Uncover	42 ^b	26 ^b	43 ^b	27 ^b	45 ^b	24 ^c	41 ^d	25 ^c
Single	48 ^a	27 ^b	50 ^a	29 ^b	52 ^a	30 ^b	50 ^b	30 ^b
Double	52 ^a	34 ^a	53 ^a	36 ^a	52 ^a	36 ^a	56 ^a	34 ^a
SE±	5.12		4.8		4.1		3.4	

Means followed by the same letters in a column are not significantly different at $p \leq 0.05$ using Student Newman Keuls (SNK).

Effect of Solarization and Farmyard Manure on Vegetative Growth Attributes of Irrigated Rice

Dry matter accumulation of irrigated rice was significantly ($P \leq 0.05$) influenced by soil solarization at both 6 and 9 weeks after transplanting (WAT) during the 2019 and 2020 dry seasons (Table 3). At 6 WAT, the highest dry matter accumulation was recorded under single-layer polyethylene solarization (279 and 292 g in 2019 and 2020, respectively), whereas at 9 WAT, double-layer polyethylene solarization produced the greatest dry matter accumulation (350 and 349 g in 2019 and 2020, respectively). Farmyard manure (FYM) significantly affected dry matter accumulation only at 6 WAT in 2020, where 30 t ha⁻¹ produced the highest biomass (304 g), while no significant differences were observed at the other sampling periods. The interaction between soil solarization and FYM was significant at 9 WAT in both seasons, indicating that the response of dry matter accumulation to FYM depended on the level of soil solarization.

The greater dry matter accumulation under solarized treatments suggests that soil solarization created more favourable conditions for vegetative growth, particularly during the later stages of crop development. Previous studies have shown that soil solarization enhances the soil environment by suppressing weeds and soil-borne pathogens while improving nutrient availability, thereby promoting crop biomass accumulation and overall plant growth (Lessmann & Rudolph, 2026; Cucu *et al.*, 2025). The significant interaction observed at 9 WAT further indicates that combining soil solarization with FYM enhanced vegetative growth more effectively than either practice alone. Similar synergistic responses have been reported where farmyard manure improved soil fertility and biomass production, particularly under integrated soil management systems in rice-based production environments (Asai *et al.*, 2025; Kugedera *et al.*, 2025). The lack of a consistent response to FYM across all sampling periods suggests that the effectiveness of organic amendments was influenced by the prevailing soil conditions and their interaction with soil solarization, rather than by FYM application alone.

Table 3: Effects of Soil Solarization and Farmyard Manure on Dry Matter Accumulation of Irrigated Rice at 6 and 9 WAT during the 2019 and 2020 Dry Seasons

Treatment	2019		2020	
	6 WAT	9 WAT	6 WAT	9 WAT
Solarization (S)				
Uncovered soil	224 ^c	254 ^b	214 ^c	241 ^b
Single-layer polyethylene	279 ^a	311 ^a	292 ^a	301 ^a
Double-layer polyethylene	234 ^b	350 ^a	251 ^b	349 ^a
p- value	0.035	0.045	0.049	0.032
SE±	33.00	40.01	41.98	40.05
FYM (t ha⁻¹)				
0	209	315	200 ^b	312
15	234	349	230 ^b	345
30	244	323	304 ^a	331
p-value	0.128	0.115	0.019	0.112
SE±	40.00	41.01	41.98	40.05
Interaction				
S x FYM	0.2118	0.00032	0.2118	0.00012

Means followed by the same letter in a column are not significantly different at $p \leq 0.05$ using Student Newman Keuls (SNK).

Effects of Soil Solarization and FYM on Yield Components of Irrigated Rice

Soil solarization significantly ($P \leq 0.05$) influenced panicle length and the number of effective tillers m^{-2} in both the 2019 and 2020 dry seasons (Table 4). Single-layer polyethylene solarization produced the longest panicles (15.21 cm) in 2019, whereas double-layer polyethylene solarization resulted in the longest panicles (14.97 cm) in 2020. In contrast, both single- and double-layer polyethylene solarization produced significantly more effective tillers than the uncovered control in both seasons. However, soil solarization had no significant effect on the number of panicles $hill^{-1}$ or panicle density. Farmyard manure (FYM) significantly affected panicle length, effective tillers m^{-2} , and panicle density in both seasons. The application of 30 $t ha^{-1}$ FYM produced the longest panicles and the highest number of effective tillers, whereas 15 $t ha^{-1}$ FYM consistently resulted in the greatest panicle density. Significant interactions between soil solarization and FYM were observed for panicle length, panicles $hill^{-1}$, and panicle density, indicating that the response of these reproductive traits depended on the combined application of both management practices.

The improvement in panicle length and effective tiller production under solarized treatments suggests that soil solarization created a favourable condition for rice growth and reproductive development. Similar responses have been reported where soil solarization improved crop establishment and reproductive performance through enhanced soil conditions and reduced weed interference (Lessmann & Rudolph, 2026; Cucu *et al.*, 2025). Likewise, the positive response to FYM confirms the importance of organic nutrient inputs in supporting reproductive growth through improved soil fertility and sustained nutrient supply (Asai *et al.*, 2025). Although soil solarization alone did not significantly influence panicle density, the significant soil solarization $\times$ FYM interaction indicates that the response of panicle density depended on the combined application of both practices. This finding suggests that integrating soil solarization with FYM created more favourable conditions for reproductive development than either practice applied independently under the irrigated conditions of the Sahel savanna (Kugedera *et al.*, 2025).

The S $\times$ FYM significantly ($p \leq 0.05$) affected the number of panicles per hill and panicle density during the 2020 dry season (Figures 1 and 2), where the highest number of panicles per hill (16.00) was recorded under double-layer polyethylene solarization combined with 15 $t ha^{-1}$ FYM, whereas the lowest values (11.90-12.00) occurred in the uncovered soil with 0 or 15 $t ha^{-1}$ FYM and under single-layer polyethylene without FYM. Similarly, the greatest panicle density (245.00 m^{-2}) was obtained with double-layer polyethylene plus 15 $t ha^{-1}$ FYM, although it was statistically comparable to uncovered soil with 15 $t ha^{-1}$ FYM and single-layer polyethylene with 15 or 30 $t ha^{-1}$ FYM. These results



indicate that the response of reproductive traits depended on the combined application of soil solarization and FYM rather than either practice alone. Similar interactive benefits of integrating soil management practices with organic nutrient amendments have been reported to enhance rice reproductive growth and stand establishment under irrigated conditions (Iqbal *et al.*, 2022; Liang *et al.*, 2025).



Table 4: Effects of Soil Solarization and FYM on Panicle Length, Number of Panicles per hill, Effective Tillers m⁻², and Panicle Density of Irrigated Rice during the Dry Seasons of 2019 and 2020

Treatment	2019				2020			
	Panicle Length (cm)	Number of panicles hill ⁻¹	Effective tillers m ⁻²	Panicle Density	Panicle Length (cm)	Number of panicles hill ⁻¹	Effective tillers m ⁻²	Panicle Density
Solarization (S)								
Uncover	14.62 ^a	13.67	235 ^c	218.56	13.54 ^b	13.33	233 ^c	201.78
Single polythene sheet	15.21 ^a	14.00	282 ^a	223.22	14.62 ^a	13.67	279 ^b	222.29
Double polythene sheet	14.83 ^b	12.67	280 ^a	203.78	14.97 ^a	12.67	282 ^a	218.00
p-value	0.0156	0.2778	0.0428	0.2136	0.0154	0.493	0.0480	7.659
SE±	0.29	0.591	0.873	7.823	0.247	0.3645	0.821	0.1820
FYM (t ha⁻¹)								
0	14.23 ^c	13.22	226 ^c	192.11 ^b	14.06 ^b	13.22	229 ^c	191.33 ^b
15	14.79 ^b	12.78	259 ^b	244.67 ^a	15.49 ^a	13.67	272 ^b	243.89 ^a
30	15.59 ^a	14.33	261 ^a	208.78 ^b	14.59 ^b	12.78	279 ^a	208.44 ^b
p-value	0.0135	0.1882	0.0390	0.0005	0.0024	0.943	0.028	0.0004
SE±	0.29	1.591	0.873	7.823	0.247	0.4589	0.821	7.659
Interaction								
S x FYM	0.0232	0.0463	NS	0.0411	0.0345	0.0168	NS	0.0409

Means followed by the same letters in a column are not significantly different at $p \leq 0.05$ using Student Newman Keuls (SNK).

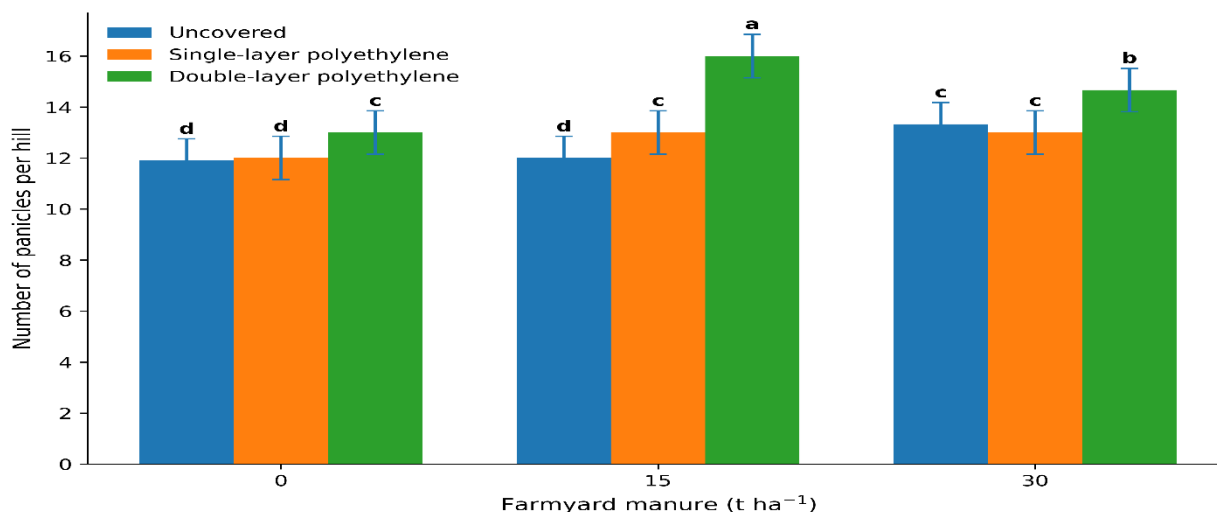


Figure 1: Interaction of Soil Solarization and FYM on Number of Panicles per Hill of Rice at FUGA during 2020 Dry Season

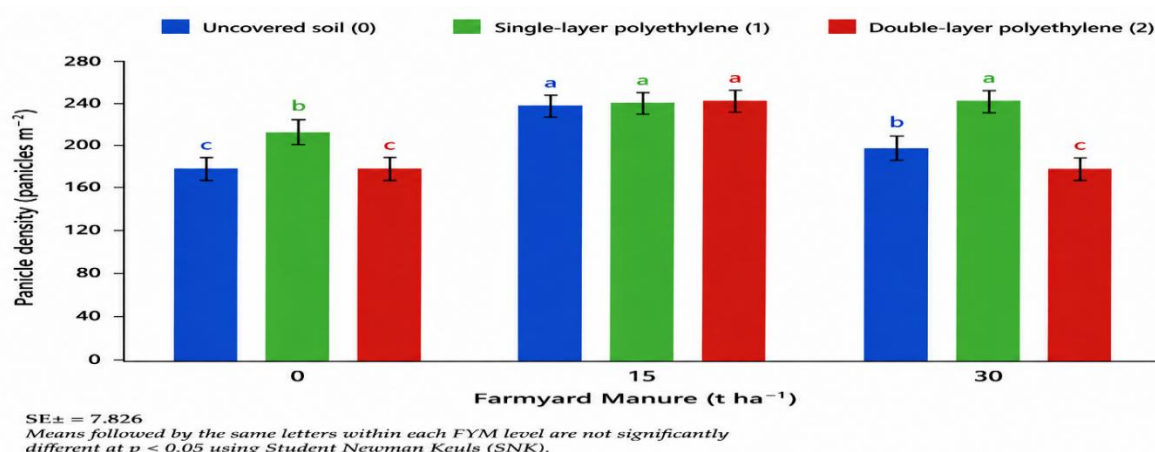


Figure 2: Interaction of Soil Solarization and FYM on Panicle Density of Rice at FUGA during 2020 Dry Season

Effect of Soil Solarization and Farmyard Manure on Yield and Yield Attributes of Irrigated Rice

Table 5 revealed that, soil solarization and FYM significantly ($p \leq 0.05$) influenced grain yield per plant and grain yield during the 2019 and 2020 dry seasons, whereas 1000-grain weight and harvest index were not significantly ($p \geq 0.05$) affected. Double-layer polyethylene solarization consistently produced the highest grain yield (4.33 and 4.11 t ha⁻¹ in 2019 and 2020, respectively), while the uncovered plots recorded the lowest yields. Likewise, solarized plots produced higher grain yield per plant than the control. Farmyard manure also significantly affected grain yield, with 15 t ha⁻¹ consistently producing the highest grain yield (5.17 and 4.60 t ha⁻¹) and grain yield per plant across both seasons. In contrast, increasing the FYM rate to 30 t ha⁻¹ did not result in additional yield benefits.

The interaction between soil solarization and FYM further demonstrated that the response of grain yield depended on the combined application of both practices. Double-layer polyethylene solarization integrated with 15 t ha⁻¹ FYM produced the highest grain yield per plant (21.50 g) and grain yield (5.53 t ha⁻¹), whereas the untreated combinations generally recorded the lowest yields (Figure 3). The superior performance of this treatment combination was consistent with the greater dry matter accumulation, and effective tiller formation observed under the same treatments, indicating that



improved vegetative growth was associated with enhanced grain production. The positive response to integrated soil solarization and FYM agrees with previous studies showing that combining soil management practices with organic nutrient amendments can improve rice growth and yield more effectively than applying either practice alone (Abid *et al.*, 2020; Urmi *et al.*, 2022). Similarly, soil solarization has been reported to improve crop performance by creating favourable soil conditions and reducing weed interference, thereby supporting better crop establishment and productivity (Kanellou *et al.*, 2023). The present findings therefore demonstrate that integrating double-layer soil solarization with 15 t ha⁻¹ FYM provides an effective and sustainable soil management strategy for enhancing irrigated rice production under the Sahel Savanna conditions of Nigeria.



Table 5: Effects of Soil Solarization and Farmyard Manure on 100 Grain Weight, Grain Yield per Plant and Grain Yield per Hectare of Irrigated Rice during the 2019 and 2020 Dry Seasons

Treatment	2019				2020			
	1000 grain weight (g)	Grain yield plant ⁻¹ (g)	Grain yield (t ha ⁻¹)	Harvest index	1000 grain weight (g)	Grain yield plant ⁻¹ (g)	Grain yield (t ha ⁻¹)	Harvest index
Solarization (S)								
Uncovered soil	22.00	16.06 ^b	3.32 ^b	34.46	23.00	16.21 ^b	2.84 ^c	34.23
Single-layer polyethylene	22.11	17.54 ^b	4.36 ^a	38.23	23.00	16.23 ^b	3.62 ^b	38.46
Double-layer polyethylene	21.56	18.43 ^a	4.33 ^a	38.88	23.22	18.09 ^a	4.11 ^a	38.55
p- value	0.2269	0.0147	0.0500	4.04	0.9519	0.0114	0.0026	4.04
SE±	0.57	0.52	0.054	0.300	0.58	0.45	0.381	0.300
FYM (t ha⁻¹)								
0	22.44	16.96 ^b	3.50 ^b	38.63	22.56	15.43 ^b	3.08 ^b	38.59
15	22.33	19.78 ^a	5.17 ^a	39.30	24.22	19.90 ^a	4.60 ^a	39.20
30	21.89	15.30 ^c	3.36 ^b	39.95	22.44	15.20 ^b	2.90 ^b	39.95
p-value	0.7720	<0.0001	0.0018	0.25	0.7649	<0.0001	<0.0001	0.95
SE±	0.57	0.52	0.576	0.293	0.58	0.48	0.381	0.290
Interaction								
S x FYM	NS	0.0020	0.0017	0.1232	NS	0.0016	<0.0001	0.1223

Means followed by the same letter in a column are not significantly different at $p \leq 0.05$ using Student Newman Keuls (SNK).

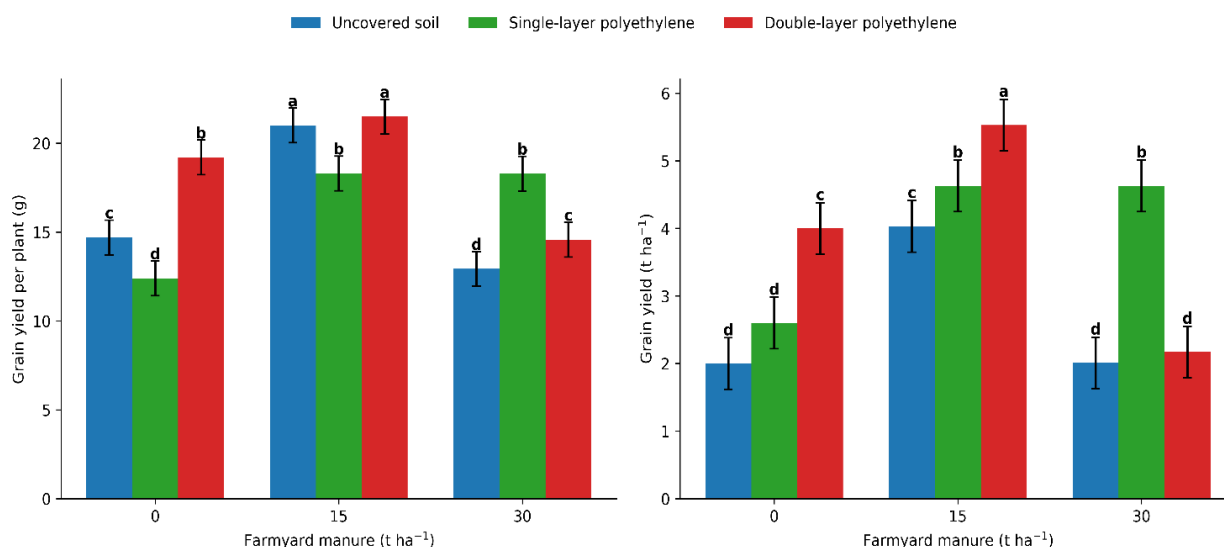


Figure 3: Interaction of Soil Solarization and FYM on Grain Yield per Plant and Grain Yield per Hectare of Rice at FUGA during 2020 Dry Season

CONCLUSION AND RECOMMENDATION

Soil solarization and farmyard manure (FYM) significantly improved the growth, yield components, and grain yield of irrigated rice under the Sahel Savanna conditions of Nigeria. Double-layer polyethylene solarization consistently enhanced crop performance, while the application of 15 t ha⁻¹ FYM produced superior results compared with the control and the higher FYM rate. The integration of double-layer polyethylene solarization with 15 t ha⁻¹ FYM was the most effective treatment, resulting in the highest overall rice performance. Therefore, integrating double-layer soil solarization for six weeks before transplanting with the application of 15 t ha⁻¹ FYM is recommended as a sustainable soil management strategy for improving irrigated rice productivity in the Sahel Savanna. Further multi-location and multi-season studies are recommended to validate these findings across different agroecological conditions.

REFERENCES

- Abid, M., Batool, T., Siddique, G., Ali, S., Binyamin, R., Shahid, M. J., Rizwan, M., Alsahli, A. A., and Alyemeni, M. N. (2020). Integrated Nutrient Management Enhances Soil Quality and Crop Productivity in Maize-Based Cropping System. *Sustainability*, **12**(23): 10214. <https://doi.org/10.3390/su122310214>
- Al-Madani, A. A., Al-Helal, I. M., and Alsadon, A. A. (2024). Assessing the Effectiveness of Reflective and Diffusive Polyethylene Films as Greenhouse Covers in Arid Environments. *Agronomy*, **14**(5): 1082. <https://doi.org/10.3390/agronomy14051082>
- Anisuzzaman, M., Rafii, M. Y., Jaafar, N. M., Izan Ramlee, S., Ikbal, M. F., and Haque, M. A. (2021). Effect of Organic and Inorganic Fertilizer on the Growth and Yield Components of Traditional and Improved Rice (*Oryza sativa* L.) Genotypes in Malaysia. *Agronomy*, **11**(9): 1830. <https://doi.org/10.3390/agronomy11091830>
- Asai, H., Andriamananjara, A., Rabenarivo, M., Rakotonindrina, H., Tsujimoto, Y., Nishigaki, T., Takai, T., and Okamoto, T. (2025). Selective application of farmyard manure to phosphorus-deficient soils improves rice yields in sub-Saharan Africa: Insights from field trials and literature review. *Field Crops Research*, **330**: 109932. <https://doi.org/10.1016/j.fcr.2025.109932>
- Bárcenas-Moreno, G., Jiménez-Compán, E., San Emeterio, L. M., Jiménez-Morillo, N. T., and González-Pérez, J. A. (2022). Soil pH and Soluble Organic Matter Shifts Exerted by Heating



- Affect Microbial Response. *International Journal of Environmental Research and Public Health*, **19**(23): 15751. <https://doi.org/10.3390/ijerph192315751>
- Black, C.A. (1965). Method of soil analysis, Agronomy No.1 part 2, American Society of Agronomy, Madison Wisconsin, **53**.
- Bogati, K. A., Sewerniak, P., and Walczak, M. (2025). Unraveling the Effect of Soil Moisture on Microbial Diversity and Enzymatic Activity in Agricultural Soils. *Microorganisms*, **13**(6): 1245. <https://doi.org/10.3390/microorganisms13061245>
- Cucu, M. A., Choudhary, R., Trkulja, V., Garg, S., and Matić, S. (2025). Utilizing Environmentally Friendly Techniques for the Sustainable Control of Plant Pathogens: A Review. *Agronomy*, **15**(7): 1551. <https://doi.org/10.3390/agronomy15071551>
- Fukagawa, N. K., and Ziska, L. H. (2019). Rice: Importance for Global Nutrition. *Journal of nutritional science and vitaminology*, **65**(Supplement), S2–S3. <https://doi.org/10.3177/jnsv.65.S2>
- Futa, B., Gmitrowicz-Iwan, J., Skersienė, A., Šlepetienė, A., and Parašotas, I. (2024). Innovative Soil Management Strategies for Sustainable Agriculture. *Sustainability*, **16**(21): 9481. <https://doi.org/10.3390/su16219481>
- Gambo, A., Fullen, M., and Baldwin, T. (2025). Characterization and classification of soils on a toposequence around Dutse Jigawa State, Nigeria. *Discover Soil*. **2**: 97. <https://doi.org/10.1007/s44378-025-00126-4>
- Gebreegziher, W.G. (2024) Agronomic use of solarization technology on soil fertility and pest management in dryland agriculture. *Cogent Food & Agriculture*, **10**: 1, 2306692, <https://doi.org/10.1080/23311932.2024.2306692>
- GenStat (2015). Release 16.3DE. VSN International, 5 The Waterhouse, Waterhouse Street, Hemel Hempstead, Hertfordshire HP1 1ES, UK.
- Huang, K., Li, M., Li, R., Rasul, F., Shahzad, S., Wu, C., Shao, J., Huang, G., Li, R., Almari, S., Hashem, M., and Aamer, M. (2023). Soil acidification and salinity: the importance of biochar application to agricultural soils. *Frontiers in plant science*, **14**: 1206820. <https://doi.org/10.3389/fpls.2023.1206820>
- Iqbal, A., Ali, I., Yuan, P., Khan, R., Liang, H., Wei, S., and Jiang, L. (2022). Combined Application of Manure and Chemical Fertilizers Alters Soil Environmental Variables and Improves Soil Fungal Community Composition and Rice Grain Yield. *Frontiers in microbiology*, **13**: 856355. <https://doi.org/10.3389/fmicb.2022.856355>
- Kanellou, E., Papafotiou, M., Economou, G., and Ntoulas, N. (2023). Soil Solarization as an Alternative Weed Control Method for Archaeological Sites in the Mediterranean Region. *Sustainability*, **15**(14): 11324. <https://doi.org/10.3390/su151411324>
- Kugedera, A. T., Trivedi, A., Nandeha, N., and Biswas, A. (2025). Agroforestry and integrated nutrient management as climate-smart agro-technologies for soil health and climate change mitigation: A review on African and Asian regions. *Discover Agriculture*, **3**: 272.
- Kumari, M., Sheoran, S., Prakash, D., Yadav, D. B., Yadav, P. K., Jat, M. K., Ankit, and Apurva (2024). Long-term application of organic manures and chemical fertilizers improve the organic carbon and microbiological properties of soil under pearl millet-wheat cropping system in North-Western India. *Heliyon*, **10**(3): e25333. <https://doi.org/10.1016/j.heliyon.2024.e25333>
- Lessmann, P. L., and Rudolph, R. E. (2026). Soil solarization efficacy for pathogens, nematodes, weeds, and arthropod pests in vegetable production systems: A review. *Journal of the American Society for Horticultural Science*, **151**(3): 188–201. <https://doi.org/10.21273/JASHS05590-26>
- Liang, X., Yu, S., Ju, Y., Wang, Y., and Yin, D. (2025). Integrated Management Practices Foster Soil Health, Productivity, and Agroecosystem Resilience. *Agronomy*, **15**(8): 1816. <https://doi.org/10.3390/agronomy15081816>
- Mgolozeli, S., Nciizah, A. D., Wakindiki, I. I. C., & Mudau, F. N. (2024). Nitrogen Mineralization of Selected Organic Materials and Their Combined Effects with Nitrogen Fertilizer on Spinach Yield. *Plants (Basel, Switzerland)*, **13**(14): 1974. <https://doi.org/10.3390/plants13141974>



- Musei, S. K., Kuyah, S., Nyawira, S., Ng'ang'a, S. K., Karugu, W. N., Smucker, A., and Nkurunziza, L. (2024). Sandy soil reclamation technologies to improve crop productivity and soil health: a review. *Frontiers in Soil Science*, **4**: <https://doi.org/10.3389/fsoil.2024.1345895>.
- Ndung'u, M., Ngatia, L. W., Onwonga, R. N., Mucheru-Muna, M. W., Fu, R., Moriasi, D. N., and Ngetich, K. F. (2021). The influence of organic and inorganic nutrient inputs on soil organic carbon functional groups content and maize yields. *Heliyon*, **7**(8): e07881. <https://doi.org/10.1016/j.heliyon.2021.e07881>
- Nwagwu, F. A., Obok, E. E., Umunnakwe, O. C. and Akpan, J. F. (2023). Influence of polyethylene film colour and soil solarisation duration on weed dynamics and performance of hybrid maize (*Zea mays* L.). *International Journal of Agricultural Technology*, **19**(2): 555-580.
- Omotayo, O.E., & Eegunranti, A.M. (2023). Effect of soil solarization on tomato (*Solanum lycopersicum* L.) growth and impact on native microbial diversity of farm soil in Nigeria. *Egyptian Journal of Biological Pest Control*, **33**: 6-18. <https://doi.org/10.1186/s41938-023-00653-8>
- Sheoran, S., Prakash, D., Yadav, P. K., Gupta, R. K., Al-Ansari, N., El-Hendawy, S., and Mattar, M. A. (2024). Long-term application of FYM and fertilizer N improve soil fertility and enzyme activity in 51st wheat cycle under pearl millet-wheat. *Scientific reports*, **14**(1): 21695. <https://doi.org/10.1038/s41598-024-72076-w>
- Tang, K. H. D. (2025). Biochar Amendments for Soil Restoration: Impacts on Nutrient Dynamics and Microbial Activity. *Environments*, **12**(11): 425. <https://doi.org/10.3390/environments12110425>
- Țopa, D.-C., Căpșună, S., Calistru, A.-E., and Ailincăi, C. (2025). Sustainable Practices for Enhancing Soil Health and Crop Quality in Modern Agriculture: A Review. *Agriculture*, **15**(9): 998. <https://doi.org/10.3390/agriculture15090998>
- Urmi, T. A., Rahman, M. M., Islam, M. M., Islam, M. A., Jahan, N. A., Mia, M. A. B., Akhter, S., Siddiqui, M. H., and Kalaji, H. M. (2022). Integrated Nutrient Management for Rice Yield, Soil Fertility, and Carbon Sequestration. *Plants (Basel, Switzerland)*, **11**(1): 138. <https://doi.org/10.3390/plants11010138>
- Zhou, C., Dun, X., Tang, Q., Long, Y., Du, J., and Bao, M. (2025). Elevation-dependent shifts in soil phosphorus forms and phosphorus-solubilizing microbial diversity suggest enhanced bioavailable phosphorus cycling with rising temperatures. *Microbiology spectrum*, **13**(8): e0130024. <https://doi.org/10.1128/spectrum.01300-24>
- Zubairu, A. M., Michéli, E., Ocansey, C. M., Boros, N., Rétháti, G., Lehoczky, É., and Gulyás, M. (2023). Biochar Improves Soil Fertility and Crop Performance: A Case Study of Nigeria. *Soil Systems*, **7**(4): 105. <https://doi.org/10.3390/soilsystems7040105>