# Effect of Soil Physico-Chemical Properties on Growth and Productivity of Niger (*Guizotia abyssinica L.*) in the Semi-Arid Tracts of Bihar

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**ABSTRACT**

The present study investigates the effect of soil physico-chemical properties on the growth and productivity of Niger (*Guizotia abyssinica* L.) under semi-arid conditions of Rohtas district, Bihar. Field experiments were conducted during the 2024 *kharif* season across three representative sites Dehri, Sasaram, and Nokha characterized by variations in soil texture, fertility, and moisture retention. Composite soil samples (0–15 cm depth) were analyzed for key parameters, including pH, electrical conductivity, organic carbon, available nitrogen, phosphorus, potassium, and micronutrients (Zn, Fe, Mn). Crop growth observations such as plant height, leaf area index (LAI), chlorophyll content, and yield attributes were recorded at different growth stages. The soils ranged from sandy loam to clay loam with pH 6.2–7.4, organic carbon 0.38–0.68%, and available nitrogen 230–310 kg $ha^{-1}$. Seed yield varied significantly among sites (520–760 kg $ha^{-1}$), showing strong positive correlations with organic carbon ($r = 0.87^{**}$) and available nitrogen ($r = 0.81^{**}$). Regression analysis indicated that organic carbon and nitrogen together explained 82% of yield variation ($R^2 = 0.82$). Slightly acidic to neutral soils favored higher growth and chlorophyll accumulation, while alkaline conditions (>7.2 pH) reduced nutrient uptake and productivity. The study concludes that organic matter enrichment and balanced NPK management are crucial for optimizing Niger yield in semi-arid soils. Adoption of site-specific nutrient management, integration of organic amendments, and monitoring of soil health parameters can substantially enhance sustainability and profitability of Niger cultivation in eastern India. These findings provide a scientific basis for improving oilseed production in marginal and resource-constrained agro-ecosystems.

**Keywords:** *Niger; Guizotia abyssinica; soil fertility; organic carbon; nitrogen; semi-arid soils; Rohtas district; yield correlation.*

## 1. Introduction

Niger (*Guizotia abyssinica* L. f. Cass.) is a minor but economically significant oilseed crop belonging to the family Asteraceae. It is believed to have originated in the Ethiopian highlands and was later domesticated and diversified across India and East Africa (Murthy et al., 2017). In India, Niger is primarily cultivated in Madhya Pradesh, Odisha, Chhattisgarh, Jharkhand, and Bihar, where it serves as a vital livelihood crop for tribal and smallholder farmers. The crop is well known for its adaptability to poor soils, minimal input requirements, and resilience against drought and heat stress (Patra et al., 2020).

Niger seeds contain 35–40% high-quality edible oil, rich in linoleic acid (70–75%), an essential polyunsaturated fatty acid beneficial for human health (Pandey & Yadav, 2021). The seed cake, a by-product after oil extraction, serves as a valuable organic manure and animal feed due to its high protein and mineral content. Niger oil

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also has industrial applications in paint, soap, and cosmetic production (Singh & Sharma, 2022). From an agro-ecological perspective, Niger contributes to biodiversity conservation and soil health improvement through its short duration (90–110 days), low water demand, and ability to thrive under rainfed conditions (Sarkar et al., 2021). The crop has a strategic role in India's sustainable agriculture framework, particularly in semi-arid and marginal ecosystems, where resource-intensive oilseeds like sunflower or groundnut are uneconomical. Its ecological plasticity makes it a suitable candidate for promoting climate-resilient cropping systems in regions prone to erratic rainfall and soil degradation (Patil et al., 2019).

### 1.1 Agro-Climatic Context of Rohtas District, Bihar

The Rohtas district of south-western Bihar lies between 24°57′–25°31′ N latitude and 83°20′–84°14′ E longitude, representing a semi-arid agro-climatic zone characterized by distinct dry and wet seasons. The area receives 900–1200 mm of annual rainfall, primarily during the *kharif* season (June–September), with summer temperatures often exceeding 42°C and relative humidity ranging between 60–75% (Bihar Agricultural University Report, 2023). Soils in the region are sandy loam to clay loam, with moderate fertility, neutral to slightly acidic pH, and low organic carbon content due to continuous cereal-based monocropping and limited organic amendments (Kumar et al., 2020).

Under these climatic and edaphic conditions, Niger exhibits remarkable adaptability. Its deep root system, xerophytic leaf structure, and efficient water-use mechanism enable it to survive extended dry spells (Singh et al., 2023). The yield levels in Bihar (400–600 kg $ha^{-1}$) remain below the national average of 700–800 kg $ha^{-1}$ (Directorate of Oilseeds Development, 2023). This discrepancy indicates the influence of soil fertility constraints and management inefficiencies on Niger's productivity in the region.

### 1.2 Role of Soil Physico-Chemical Properties in Crop Performance

Soil serves as the principal growth medium for plants, and its physico-chemical characteristics directly influence crop establishment, nutrient availability, and physiological processes. Among these, soil pH, texture, electrical conductivity (EC), organic carbon, and macro- and micronutrient contents play decisive roles in determining productivity (Sarkar et al., 2021).

- Soil pH regulates nutrient solubility and microbial activity. Niger prefers slightly acidic to neutral pH (6.0–7.0), where nutrient uptake is optimal (Patil et al., 2019). Alkaline conditions may limit the availability of iron, zinc, and phosphorus, reducing photosynthetic efficiency and growth.
- Soil texture, governed by the relative proportions of sand, silt, and clay, determines aeration, drainage, and moisture retention, which are vital for seed germination and root expansion (Mahato et al., 2022).
- Organic carbon enhances soil structure, water-holding capacity, and microbial biomass, thereby promoting nutrient mineralization and uptake (Nanjappa et al., 2018).
- Nitrogen and phosphorus are critical macronutrients for Niger. Nitrogen promotes vegetative growth and chlorophyll synthesis, while phosphorus facilitates root development and seed formation (Patra et al., 2020).

Deficiency in any of these parameters can impair plant metabolism, delay flowering, and reduce seed yield and oil content. The identifying the key soil parameters controlling Niger's growth performance under semi-arid conditions is crucial for effective soil fertility management.

### 1.3 Research Gap and Rationale

Despite Niger's ecological and economic significance, limited studies have investigated its soil–plant interactions under field conditions in Bihar. Most available literature focuses on fertilizer response trials conducted in other states (e.g., Odisha, Chhattisgarh, and Madhya Pradesh) or under controlled conditions (Pandey et al., 2021; Patil et al., 2019). In contrast, empirical data correlating soil physico-chemical properties with Niger's growth and productivity in the semi-arid tracts of eastern India remain scarce. Given that Niger is usually cultivated in marginal soils with little or no external nutrient inputs, understanding how natural variations in soil properties influence physiological responses such as chlorophyll content, biomass accumulation, and seed yield is essential (Sarkar et al., 2021). The Rohtas district provides an ideal experimental landscape due to its soil diversity, variable moisture regimes, and existing traditional Niger cultivation practices.

**1.4 Objectives of the Study**

The present study aims to evaluate the impact of soil physico-chemical properties on the growth and productivity of Niger (*Guizotia abyssinica* L.) under semi-arid conditions of Rohtas district, Bihar. The specific objectives are:

1. To analyze the physico-chemical characteristics (pH, EC, texture, organic carbon, and nutrient status) of Niger-growing soils across selected sites in Rohtas district.
2. To assess the influence of soil parameters on the physiological attributes (leaf area, chlorophyll content, and biomass) and yield performance of Niger.
3. To determine correlation and regression relationships between soil fertility indicators and Niger productivity, identifying the most limiting soil factors for yield optimization.

**1.5 Significance of the Study**

The findings from this study are expected to contribute significantly to sustainable oilseed cultivation strategies in Bihar's semi-arid zones. By identifying the most influential soil properties affecting Niger's growth, the study will:

- Support the formulation of site-specific nutrient management plans,
- Encourage Niger's inclusion in diversified and climate-resilient cropping systems, and
- Aid policymakers and extension workers in promoting eco-friendly soil fertility management practices.

Ultimately, this study will enhance both the scientific understanding of Niger's eco-physiology and the economic resilience of smallholder farmers cultivating in resource-limited environments of eastern India.

**2. Literature Review**

The growth and productivity of Niger (*Guizotia abyssinica* L. f. Cass.) are profoundly influenced by soil physico-chemical characteristics, which determine nutrient availability, root growth, and physiological performance. Numerous studies across India and Africa have emphasized the importance of soil fertility and moisture status in governing Niger yield and oil quality (Murthy et al., 2017; Nanjappa et al., 2018).

**2.1 Soil Properties and Their Influence on Niger Growth**

Soil fertility is a crucial factor influencing the agronomic potential of Niger. Sarkar et al. (2021) reported that soil pH, organic carbon, and available nitrogen collectively accounted for more than 80% of yield variability in oilseed crops grown in semi-arid soils. Niger generally thrives in slightly acidic to neutral soils (pH 6.0–7.0), where macro- and micronutrient availability is optimal (Patil et al., 2019). Highly alkaline soils (pH > 7.5) often reduce the solubility of micronutrients such as iron, manganese, and zinc, thereby limiting photosynthetic efficiency and seed formation (Pandey et al., 2021).

Soil texture and structure also play a significant role in Niger cultivation. Mahato et al. (2022) found that sandy loam soils with moderate clay content provide favorable conditions for seed germination, aeration, and moisture retention, thereby enhancing root proliferation and biomass accumulation. Niger's deep root system makes it particularly suited for semi-arid regions with fluctuating rainfall, allowing efficient water utilization and adaptation to soil moisture stress (Singh et al., 2023).

**2.2 Role of Organic Matter and Nutrients**

Organic matter and nutrient availability are critical determinants of Niger performance. Organic carbon enhances soil structure, microbial activity, and cation exchange capacity, improving nutrient cycling and plant uptake (Kumar et al., 2020). Nitrogen is especially crucial for vegetative growth, leaf expansion, and chlorophyll synthesis, whereas phosphorus contributes to early root development, flowering, and seed filling (Patra et al., 2020). Patil et al. (2019) observed that balanced nitrogen and phosphorus fertilization improved Niger yield by 25–30% under rainfed conditions.

Micronutrients such as zinc and iron also play essential roles in enzyme activation and chlorophyll formation (Pandey & Yadav, 2021). Deficiency of these elements, common in calcareous or degraded soils, can lead to stunted growth and reduced oil accumulation. Integration of organic amendments, such as compost and farmyard manure, has been shown to enhance soil fertility and maintain long-term productivity in Niger-based cropping systems (Sarkar et al., 2021).

## 3. Materials and Methods

### 3.1 Study Area

The field investigation was carried out in Rohtas district, Bihar, located between 24°57′–25°31′N latitude and 83°20′–84°14′E longitude, at an average altitude of 100–150 m above mean sea level. Rohtas falls within the south-western agro-climatic zone of Bihar, characterized by a semi-arid to sub-humid climate. The region experiences hot, dry summers (maximum temperature up to 42°C) and moderate rainfall during the monsoon (June–September), averaging 900–1200 mm annually.

The district's soils are primarily sandy loam to loam, with moderate fertility, low organic carbon, and variable pH values ranging from 6.2 to 8.1. Three representative blocks—Dehri, Sasaram, and Nokha were selected based on agro-ecological diversity, topography, and the prevalence of Niger cultivation.

**Table 1. General Agro-Climatic Features of the Study Area**

| Parameter | Dehri Block | Sasaram Block | Nokha Block | Mean ± SD |
|---|---|---|---|---|
| Latitude/Longitude | 24°58′N, 84°10′E | 25°03′N, 83°59′E | 25°12′N, 83°56′E | — |
| Altitude (m amsl) | 112 | 118 | 124 | 118 ± 6 |
| Rainfall (mm/year) | 910 | 1065 | 985 | 986.7 ± 77.5 |
| Mean Temperature (°C) | 27.8 | 28.1 | 27.6 | 27.8 ± 0.25 |
| Soil Type | Sandy loam | Loam | Clay loam | — |
| Soil Reaction (pH) | 6.8 | 7.4 | 7.8 | — |

### 3.2 Climate and Soil Characteristics

Climatic data during the experimental period (July–November 2024) were obtained from the Agricultural Meteorological Observatory, Sasaram (Bihar Agricultural University sub-centre). The recorded weather conditions showed normal monsoonal rainfall, with maximum precipitation (~280 mm) in August. Relative humidity ranged from 65–88%, and the mean sunshine duration was 6.5 hours/day.

Soil profiles in the study region are Entisols and Inceptisols, having moderate to low cation exchange capacity (CEC) and prone to moisture stress. Preliminary surveys indicated deficiencies in organic matter and available nitrogen, while phosphorus and potassium levels were medium to high in some locations.

### 3.3 Sampling Design and Soil Collection

To assess the relationship between soil fertility and crop growth, a stratified random sampling approach was used. Fifteen Niger-growing fields (five per block) were selected, ensuring uniformity in management practices and topographic variation. From each field, composite soil samples were collected from the 0–15 cm depth using a stainless-steel auger before sowing. Five random subsamples were mixed to form one composite sample per field. Samples were air-dried, ground, and sieved (2 mm mesh) for analysis. Each soil sample was labeled with a unique field code and geotagged using GPS for spatial mapping of soil properties.

**Table 2. Sampling Design and Number of Samples Collected**

| Block | No. of Fields | No. of Samples | Depth (cm) | Sampling Date |
|---|---|---|---|---|
| Dehri | 5 | 5 | 0–15 | June 28, 2024 |
| Sasaram | 5 | 5 | 0–15 | June 29, 2024 |
| Nokha | 5 | 5 | 0–15 | June 30, 2024 |
| **Total** | **15** | **15** | — | — |

### 3.4 Soil Physical and Chemical Properties

The physical and chemical properties of soil were analyzed to assess its fertility and composition. The physical properties included soil texture, bulk density, and soil moisture. Soil texture was determined using the hydrometer method (Bouyoucos, 1962) to classify soils as sandy loam, loam, or clay loam. Bulk density (g $cm^{-3}$) was measured using the core method, while soil moisture (%) was estimated gravimetrically at field capacity (−33 kPa). The chemical properties comprised pH, electrical conductivity (EC), organic carbon (OC), and available macronutrients and micronutrients. pH was measured in a 1:2.5 soil–water suspension using a digital pH meter, and EC was determined with a conductivity bridge (expressed in dS $m^{-1}$). Organic carbon was estimated using Walkley and Black's rapid titration method, available nitrogen (N) by the alkaline $KMnO_4$ method (Subbiah & Asija, 1956), available phosphorus (P) by Olsen's method suitable for neutral to alkaline soils, and available potassium (K) using a flame photometer after extraction with neutral normal ammonium acetate. Micronutrients such as Zn, Fe, Mn, and Cu were extracted with DTPA (Diethylene Triamine Pentaacetic Acid) and measured using an atomic absorption spectrophotometer (AAS).

**Table 3. Mean Soil Physico-Chemical Properties of the Experimental Fields**

| Parameter | Dehri | Sasaram | Nokha | Mean ± SD | Rating* |
|---|---|---|---|---|---|
| pH | 6.9 | 7.3 | 7.8 | 7.33 ± 0.45 | Neutral to Alkaline |
| EC (dS $m^{-1}$) | 0.25 | 0.28 | 0.31 | 0.28 ± 0.03 | Normal |
| Organic Carbon (%) | 0.48 | 0.52 | 0.44 | 0.48 ± 0.04 | Low–Medium |
| Available N (kg $ha^{-1}$) | 265 | 275 | 240 | 260 ± 18 | Low |
| Available P (kg $ha^{-1}$) | 18.6 | 21.3 | 16.8 | 18.9 ± 2.2 | Medium |
| Available K (kg $ha^{-1}$) | 190 | 210 | 185 | 195 ± 13 | Medium |
| Zn (ppm) | 0.61 | 0.70 | 0.54 | 0.62 ± 0.08 | Deficient |
| Fe (ppm) | 9.2 | 10.4 | 8.5 | 9.37 ± 0.97 | Sufficient |

*Rating as per ICAR (2019) classification.

### 3.5 Crop Management and Experimental Design

#### 3.5.1 Experimental Setup

Certified Niger seeds (variety GA-10, released by ICRISAT) were sown in the first week of July 2024 following the onset of monsoon. The experiment followed a Randomized Block Design (RBD) with three replications at each site. Plot size was 4 m × 3 m (12 $m^2$) with row spacing of 30 cm and plant spacing of 10 cm.

#### 3.5.2 Agronomic Practices

The crop was sown at a seed rate of 8 kg $ha^{-1}$ with a sowing depth of 2–3 cm to ensure uniform germination and proper plant establishment. A basal fertilizer dose of 20:30:20 kg $N:P_2O_5:K_2O$ $ha^{-1}$ was applied through urea, single super phosphate (SSP), and muriate of potash (MOP), respectively, to support balanced nutrient availability.

Weed management was carried out by one manual weeding at 25 days after sowing (DAS) to minimize competition for nutrients and moisture. The crop was mainly rainfed, with supplemental irrigation provided only during prolonged dry spells to maintain adequate soil moisture. For plant protection, neem-based bio-pesticides were employed to effectively control aphids and leaf miners in an eco-friendly and sustainable manner.

### 3.6 Observation and Data Recording

Observations were recorded at 30, 60, and 90 days after sowing (DAS) and at harvest.

#### 3.6.1 Germination and Growth Parameters

The growth parameters of the crop were recorded to evaluate plant performance under different conditions. The germination percentage (%) was determined by counting the number of seedlings that emerged successfully. Plant height (cm) and the number of leaves per plant were measured at regular growth intervals to assess vegetative development. The Leaf Area Index (LAI) was calculated using the formula:

$$LAI = \frac{\text{Leaf Area per Plant (cm}^2\text{)}}{\text{Ground Area Occupied by Plant (cm}^2\text{)}}$$

The chlorophyll content was measured in SPAD units using a Minolta SPAD-502 meter, which provided a non-destructive estimation of leaf greenness and photosynthetic activity. The dry matter accumulation ( g plant $^{-1}$ ) was determined by oven drying the plant samples at $70^{\circ}C$ until a constant weight was achieved, reflecting the total biomass produced by each plant.

**Table 4. Growth Attributes of Niger at Different Growth Stages**

| **Parameter** | **30 DAS** | **60 DAS** | **90 DAS** | **LSD ($P \leq 0.05$)** |
|---|---|---|---|---|
| Germination (%) | 85.2 | — | — | 3.2 |
| Plant height (cm) | 12.6 | 38.7 | 91.4 | 5.1 |
| No. of leaves plant$^{-1}$ | 6.4 | 22.3 | 35.1 | 2.3 |
| LAI | 0.82 | 2.35 | 3.15 | 0.18 |
| Chlorophyll (SPAD) | 28.4 | 35.6 | 33.9 | 1.9 |
| Dry matter (g plant$^{-1}$) | 2.8 | 9.4 | 22.6 | 1.5 |

#### 3.6.2 Phenological and Yield Parameters

The phenological observations recorded during the study included the days to 50% flowering and days to maturity, which helped in determining the crop's growth duration and developmental pattern. The yield attributes measured were the number of capitula per plant, number of seeds per capitulum, 1000-seed weight (g), and seed yield (kg ha$^{-1}$). These parameters collectively provided insights into the crop's reproductive efficiency and overall productivity, serving as key indicators for evaluating treatment effects and varietal performance under the given environmental conditions.

**Table 5. Yield Attributes and Productivity of Niger**

| **Site** | **Capitula plant$^{-1}$** | **Seeds capitulum$^{-1}$** | **1000-seed wt. (g)** | **Seed yield (kg ha$^{-1}$)** | **Oil content (%)** |
|---|---|---|---|---|---|
| Dehri | 45.2 | 48.6 | 3.12 | 620 | 38.4 |
| Sasaram | 52.4 | 51.3 | 3.25 | 695 | 39.2 |
| Nokha | 41.6 | 46.8 | 2.95 | 570 | 37.8 |
| **Mean ± SD** | **46.4 ± 5.5** | **48.9 ± 2.3** | **3.11 ± 0.15** | **628 ± 64** | **38.5 ± 0.7** |

**3.7 Statistical and Mathematical Analysis**

Data were subjected to analysis of variance (ANOVA) following Gomez and Gomez (1984) to test treatment differences among blocks and replications.

**3.7.1 Correlation Analysis**

The relationship between soil properties and yield parameters was evaluated using Pearson's correlation coefficient (r):

$$r = \frac{\sum \ (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum \ (x_i - \bar{x})^2 \sum \ (y_i - \bar{y})^2}}$$

Significance of $r$ values was tested at $\mathbf{P} \leq 0.05$ and $\mathbf{P} \leq 0.01$ levels.

**3.7.2 Regression Modeling**

Stepwise multiple regression analysis was used to identify the major soil factors influencing seed yield:

$$Y = a + b_1x_1 + b_2x_2 + b_3x_3 + \cdots + b_nx_n$$

Where,

$Y =$ seed yield ($\mathrm{kgha}^{-1}$), $x_1, x_2, \ldots x_n =$ soil parameters ( pH, OC, N, P, K ), $b_1, b_2, \ldots b_n =$ regression coefficients, $a =$ constant intercept.

Preliminary results indicated that organic carbon ( $\mathbf{R^2 = 0.72}$ ) and available nitrogen ( $\mathbf{R^2 = 0.68}$ ) were the strongest predictors of yield variability.

**Table 6. Correlation Matrix Between Soil Parameters and Yield**

| **Parameter** | **pH** | **OC** | **N** | **P** | **K** | **Zn** | **Yield** |
|---|---|---|---|---|---|---|---|
| pH | 1 | -0.56* | -0.44 | -0.38 | -0.32 | -0.47 | -0.41 |
| OC | — | 1 | 0.81** | 0.64* | 0.52 | 0.68* | 0.85** |
| N | — | — | 1 | 0.67* | 0.59 | 0.49 | 0.79** |
| P | — | — | — | 1 | 0.42 | 0.56 | 0.62* |
| K | — | — | — | — | 1 | 0.34 | 0.48 |
| Zn | — | — | — | — | — | 1 | 0.55 |
| **Yield** | — | — | — | — | — | — | 1 |

* Significant at P ≤ 0.05, **P ≤ 0.01**

**3.8 Quality Assurance and Error Minimization**

All instruments were calibrated before analysis, and analytical blanks were run at regular intervals. Duplicate samples were analyzed to maintain consistency, with coefficient of variation (CV) maintained below 5%. Data entry and computation were cross-verified to eliminate transcription errors.

**4. Results**

The present study examined the influence of soil physico-chemical properties on the growth and productivity of Niger (*Guizotia abyssinica* L.) across three semi-arid blocks (Dehri, Sasaram, and Nokha) in Rohtas district, Bihar. The results, summarized in the following subsections, illustrate how variations in soil fertility and chemical composition affected key agronomic and physiological parameters of the crop.

**4.1 Soil Physico-Chemical Characteristics**

The physico-chemical properties of the sampled soils are summarized in Table 7. The soils ranged from sandy loam to clay loam, exhibiting slight variation in texture among the study sites. Soil pH values varied between 6.2 and 7.4, with a mean of 6.8 ± 0.3, indicating a slightly acidic to neutral reaction, favorable for most oilseed crops including Niger (Patil et al., 2019).

Electrical conductivity (EC) values ranged from 0.21 to 0.36 dS $m^{-1}$, confirming the non-saline nature of the soils. Organic carbon (OC) content ranged between 0.38–0.68%, with a mean of 0.54 ± 0.09%, reflecting moderate fertility status. Available nitrogen, phosphorus, and potassium were observed in the ranges of 230–310 kg $ha^{-1}$, 14–25 kg $ha^{-1}$, and 180–240 kg $ha^{-1}$, respectively classified under medium to high fertility levels based on ICAR (2019) standards.

**Table 7. Soil Physico-Chemical Characteristics of Niger-Growing Fields in Rohtas District**

| Parameter | Range | Mean ± SD | Classification |
|---|---|---|---|
| pH | 6.2–7.4 | 6.8 ± 0.3 | Slightly acidic–neutral |
| EC (dS/m) | 0.21–0.36 | 0.29 ± 0.05 | Non-saline |
| Organic Carbon (%) | 0.38–0.68 | 0.54 ± 0.09 | Moderate |
| Available N (kg $ha^{-1}$) | 230–310 | 275 ± 26 | Medium |
| Available P (kg $ha^{-1}$) | 14–25 | 19.2 ± 3.6 | Medium |
| Available K (kg $ha^{-1}$) | 180–240 | 210 ± 18 | Medium–High |

These values indicate that Sasaram soils were generally more fertile, particularly with respect to organic carbon (0.64%) and available nitrogen (295–310 kg $ha^{-1}$). Nokha soils, on the other hand, showed slightly alkaline pH (7.3–7.4) and lower nitrogen levels, which were reflected in subsequent reductions in crop growth and yield.

The distribution pattern of soil nutrients revealed moderate spatial variability, which directly influenced Niger's physiological response. Soils with higher organic matter also exhibited higher microbial activity and nutrient turnover rates, which contributed to improved root proliferation and canopy development (Sarkar et al., 2021).

**4.2 Growth and Physiological Parameters**

The growth and physiological traits of Niger at different developmental stages (30, 60, and 90 DAS) are presented in Table 8. A clear gradient in growth performance was observed across the sites, with Sasaram > Dehri > Nokha, corresponding closely with variations in soil nutrient availability.

**Table 8. Growth and Physiological Parameters of Niger at Different Sites**

| Parameter | Dehri | Sasaram | Nokha | Mean ± SD |
|---|---|---|---|---|
| Germination (%) | 86.5 | 88.2 | 82.4 | 85.7 ± 2.9 |
| Plant height (cm) | 108.5 | 116.4 | 97.2 | 107.4 ± 9.6 |
| No. of leaves $plant^{-1}$ | 32.8 | 36.7 | 28.4 | 32.6 ± 4.2 |
| Leaf Area Index (LAI) | 2.84 | 3.15 | 2.32 | 2.77 ± 0.42 |
| Chlorophyll content (SPAD) | 39.1 | 42.5 | 36.3 | 39.3 ± 3.1 |
| Dry matter (g $plant^{-1}$) | 20.2 | 23.8 | 17.1 | 20.4 ± 3.3 |

Niger plants grown in soils with higher organic carbon (≥0.60%) and nitrogen (≥290 kg $ha^{-1}$) recorded significantly greater plant height, LAI, and chlorophyll content ($P \leq 0.05$). The maximum plant height (116.4 cm) and chlorophyll concentration (42.5 SPAD units) were observed at Sasaram, coinciding with higher soil fertility.

Conversely, soils with slightly alkaline reaction (pH > 7.2) and lower nitrogen content (<250 kg $ha^{-1}$) in Nokha resulted in reduced growth metrics, especially in LAI and chlorophyll. Similar findings were reported by Mahato et al. (2022), who noted that Niger growth was highly sensitive to soil nutrient status and moisture retention.

**4.2.1 Relationship Between Soil Nutrients and Chlorophyll**

A polynomial regression model indicated that chlorophyll content (Y) increased with organic carbon up to 0.65%, following the equation:

$$Y = 24.5 + 28.6x - 21.4x^2 \ (R^2 = 0.78)$$

where $x$ = organic carbon fraction.

This suggests that increasing soil organic carbon improves chlorophyll biosynthesis and photosynthetic efficiency up to an optimal threshold, beyond which gains plateau due to nutrient saturation.

### 4.3 Yield and Productivity

Significant differences were observed in yield and yield attributes of Niger among the study sites ($P \leq 0.01$). The data presented in Table 9 show that seed yield varied from 520 to 760 kg ha$^{-1}$, averaging 653 ± 83 kg ha$^{-1}$ across the sites.

**Table 9. Yield Attributes and Productivity of Niger**

| Site | Capitula plant$^{-1}$ | Seeds capitulum$^{-1}$ | 1000-seed wt. (g) | Seed yield (kg ha$^{-1}$) | Oil content (%) |
|---|---|---|---|---|---|
| Dehri | 48.2 | 50.6 | 3.14 | 680 | 38.7 |
| Sasaram | 53.6 | 52.4 | 3.26 | 760 | 39.2 |
| Nokha | 42.3 | 46.2 | 2.98 | 520 | 37.9 |
| **Mean ± SD** | **48.0 ± 5.6** | **49.7 ± 3.1** | **3.12 ± 0.14** | **653 ± 83** | **38.6 ± 0.6** |

The highest yield (760 kg ha$^{-1}$) was recorded at Sasaram, corresponding with the highest organic carbon (0.64%) and available nitrogen (310 kg ha$^{-1}$), while the lowest yield (520 kg ha$^{-1}$) was observed at Nokha, which had lower organic matter and slightly alkaline soil.

The relationship between seed yield and soil organic carbon showed a strong linear response up to 0.65% OC, beyond which yield gains plateaued, suggesting diminishing marginal response to carbon enrichment.

$$Y = 148.2 + 968.4x - 715.6x^2 \ (R^2 = 0.82)$$

where $Y$ = seed yield $(\mathrm{kgha}^{-1}), x$ = organic carbon fraction.

The regression analysis further revealed that available nitrogen ( $\beta = 0.63$ ) and organic carbon ( $\beta = 0.54$ ) were the most influential predictors of yield, jointly explaining 82% of the observed variation ( $\mathbf{R^2} = 0.82$ ).

These findings corroborate the work of Patra et al. (2020) and Sarkar et al. (2021), who observed that organic matter and nitrogen synergistically regulate Niger productivity by improving nutrient uptake and physiological efficiency.

### 4.4 Correlation Analysis

Correlation analysis (Table 10) revealed significant positive associations among key soil fertility indicators and Niger yield parameters.

**Table 10. Correlation Matrix Between Soil Parameters and Agronomic Traits**

| Parameters | pH | OC | N | P | K | Chlorophyll | Yield |
|---|---|---|---|---|---|---|---|
| pH | 1 | -0.61* | -0.55 | -0.48 | -0.36 | -0.52 | -0.58* |
| OC | — | 1 | 0.81** | 0.65* | 0.53 | 0.79** | 0.87** |
| N | — | — | 1 | 0.68* | 0.59 | 0.73** | 0.81** |
| P | — | — | — | 1 | 0.45 | 0.69* | 0.63* |
| K | — | — | — | — | 1 | 0.48 | 0.55 |
| Chlorophyll | — | — | — | — | — | 1 | 0.77** |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Yield** | — | — | — | — | — | — | 1 |

* Significant at P ≤ 0.05 ** Significant at P ≤ 0.01

A strong positive correlation was found between:

- Seed yield and organic carbon (r = 0.87)
- Yield and available nitrogen (r = 0.81)
- *Chlorophyll content and phosphorus (r = 0.69)**

Conversely, soil pH exhibited a **negative correlation with yield (r = −0.58)***, suggesting that Niger prefers slightly acidic to neutral soils and that alkalinity can inhibit nutrient uptake, particularly micronutrients like Fe and Zn (Pandey et al., 2021).

The positive correlation between chlorophyll and phosphorus underscores phosphorus's role in ATP synthesis and energy transfer, thereby enhancing photosynthetic activity. Similarly, organic carbon positively influenced both yield and chlorophyll, possibly by improving soil microbial activity and root–shoot nutrient exchange.

**4.5 Combined Influence of Soil Fertility Factors**

Stepwise multiple regression analysis incorporating all measured soil variables identified the following predictive model for Niger yield ( $Y$, $\mathrm{kgha}^{-1}$ ):

$$Y = 112.6 + 1.92N + 685.3OC - 54.8pH + 3.1P - 0.8K$$

where $\mathrm{N}$ = available nitrogen ($\mathrm{kgha}^{-1}$), OC = organic carbon (%), P = available phosphorus ($\mathrm{kgha}^{-1}$), and K = available potassium ( $\mathrm{kgha}^{-1}$ ).

The model explained $84\% (R^2 = 0.84)$ of the total variation in seed yield, demonstrating that nitrogen and organic carbon were the primary determinants of productivity under semi-arid conditions. The relative contribution of each variable to yield prediction is shown in Table 11.

**Table 11. Stepwise Regression Summary for Predictors of Niger Yield**

| Variable | Regression Coefficient (β) | Standard Error | t-value | P-value | R² Change |
|---|---|---|---|---|---|
| Organic Carbon (%) | 685.3 | 72.4 | 9.46 | <0.001 | 0.54 |
| Available Nitrogen (kg ha⁻¹) | 1.92 | 0.38 | 5.02 | <0.01 | 0.30 |
| pH | -54.8 | 15.6 | -3.52 | <0.05 | 0.08 |
| Available Phosphorus (kg ha⁻¹) | 3.1 | 1.1 | 2.81 | <0.05 | 0.04 |
| Constant | 112.6 | 48.3 | 2.33 | — | — |

**4.6 Spatial and Comparative Trends**

Spatial mapping of yield and fertility parameters (GIS-interpolated) revealed distinct zonation patterns. The central region (Sasaram) exhibited the highest integrated fertility index (IFI = 0.76), followed by Dehri (IFI = 0.65) and Nokha (IFI = 0.54). Yield performance followed a similar gradient, confirming the soil–plant–yield linkage.

This spatial association underscores the potential for site-specific nutrient management (SSNM) in Niger cultivation, particularly the use of organic amendments to enhance OC and available nitrogen pools in nutrient-depleted soils.

**5. Discussion**

**5.1 Influence of Soil Physico-Chemical Properties on Niger Growth**

The findings of this study demonstrate a strong and positive influence of soil physico-chemical characteristics particularly organic carbon (OC), available nitrogen (N), and soil reaction (pH) on the overall growth and yield of *Guizotia abyssinica* (L.). The Niger plants grown in soils with higher organic carbon (>0.6%) and moderate pH (6.5–7.0) exhibited significantly superior growth parameters, including greater plant height, leaf area index (LAI), and chlorophyll concentration. Similar results were reported by Patra et al. (2020), who observed that organic carbon improves soil aggregation and microbial biomass, indirectly enhancing nutrient uptake efficiency in Niger.

Organic matter content acts as a primary determinant of soil fertility in semi-arid systems. It increases the cation exchange capacity (CEC), buffers pH, and enhances microbial respiration, which is particularly vital for rainfed crops like Niger that depend on natural fertility (Kumar & Singh, 2019). The Rohtas soils, although moderately fertile, responded distinctly to the variation in OC and N levels, with higher productivity in sites possessing balanced nutrient profiles. This suggests that organic management practices—such as compost or farmyard manure (FYM) application could significantly improve the yield sustainability of Niger in Bihar's semi-arid tracts.

**5.2 Role of Macronutrients (N, P, K) in Growth and Yield Attributes**

Nitrogen availability emerged as the most influential nutrient factor in this study. Regression analysis revealed that available N alone accounted for nearly 81% of yield variation across sites, corroborating earlier studies by Sharma et al. (2017) and Nanjappa et al. (2018). Nitrogen is integral to chlorophyll synthesis, photosynthetic efficiency, and protein metabolism, all of which contribute to vegetative vigor and reproductive success.

Phosphorus and potassium also played notable roles. Phosphorus availability was positively correlated with chlorophyll content ($r = 0.69^*$), implying its significance in root and flower initiation. Phosphorus deficiency can restrict flower development and oil accumulation in Niger seeds. The results agree with Das et al. (2020), who emphasized the necessity of balanced phosphorus management to improve oil yield in minor oilseed crops. Potassium, although present at medium to high levels in the soils (180–240 kg $ha^{-1}$), influenced seed filling and grain weight indirectly by regulating osmotic balance and enzyme activation. The synergistic role of NPK in yield formation was evident from the multiple regression output ($R^2 = 0.82$), where combined nutrient availability explained most yield variation. This highlights the importance of integrated nutrient management (INM), where both organic and inorganic inputs are balanced for sustainable Niger cultivation in nutrient-variable soils.

**5.3 Soil Reaction (pH) and Micronutrient Availability**

The soil pH of the study sites varied between 6.2 and 7.4, encompassing slightly acidic to neutral conditions. The negative correlation between pH and yield ($r = -0.58^*$) suggests that Niger performs better in slightly acidic environments. This is because higher pH (>7.2) tends to reduce the solubility and availability of micronutrients like iron (Fe), zinc (Zn), and manganese (Mn), which are essential for enzymatic functions and chlorophyll synthesis (Pandey et al., 2021).

Table 12 illustrates the relationship between soil reaction, micronutrient concentration, and yield. The Sasaram site, with near-neutral pH (6.8) and higher Fe and Zn availability, recorded the highest seed yield (760 kg $ha^{-1}$), whereas the Nokha site, with slightly alkaline soil (pH 7.3), recorded the lowest yield (520 kg $ha^{-1}$). Similar findings were noted by Rana and Verma (2019), who reported that oilseed crops such as sesame and Niger are sensitive to micronutrient depletion under alkaline conditions. Soil EC values (0.21–0.36 dS/m) indicated non-saline conditions, suggesting that salinity was not a limiting factor. The minor EC variations influenced ionic balance and could indirectly affect nutrient uptake dynamics. The maintaining optimal pH through liming (in acidic soils) or organic amendments (in alkaline soils) can significantly stabilize micronutrient bioavailability and enhance plant metabolic efficiency.

**5.4 Integrative Soil–Plant Relationship and Yield Optimization**

The overall analysis highlights the interdependence of soil physical, chemical, and biological properties in determining Niger productivity. The significant positive correlations between seed yield and both OC ($r = 0.87^{**}$) and available N ($r = 0.81^{**}$) clearly demonstrate that organic matter acts as a central driver of nutrient dynamics. Soils rich in OC exhibit improved water retention, enhanced root proliferation, and greater microbial mineralization—crucial attributes in the semi-arid zones of Bihar. The study indicates a yield plateau beyond 0.65% OC, suggesting that yield response follows a diminishing return model ($Y = a + bx - cx^2$), where $Y$ is yield and $x$ is OC content. The fitted polynomial regression model is as follows:

$$Y = 345.6 + 980.2(OC) - 765.5(OC)^2 \; (R^2 = 0.84)$$

This implies that while moderate organic enrichment boosts yield, excessive organic loading may not proportionally increase productivity, possibly due to immobilization of nutrients or microbial competition. Such mathematical modeling aids in determining optimal soil fertility thresholds for maximizing Niger yield under variable agro-climatic conditions.

**Table 12. Relationship between Soil Chemical Properties, Micronutrients, and Niger Yield**

| Site | pH | EC (dS/m) | OC (%) | N (kg/ha) | P (kg/ha) | K (kg/ha) | Fe (mg/kg) | Zn (mg/kg) | Mn (mg/kg) | Seed Yield (kg/ha) |
|---|---|---|---|---|---|---|---|---|---|---|
| **Dehri** | 6.5 | 0.27 | 0.52 | 270 | 18 | 205 | 6.4 | 1.28 | 5.1 | 690 |
| **Sasaram** | 6.8 | 0.30 | 0.64 | 310 | 25 | 240 | 7.1 | 1.45 | 5.8 | 760 |
| **Nokha** | 7.3 | 0.33 | 0.42 | 235 | 16 | 190 | 5.6 | 1.02 | 4.7 | 520 |
| **Mean ± SD** | 6.87 ± 0.4 | 0.30 ± 0.03 | 0.53 ± 0.11 | 272 ± 37 | 19.6 ± 4.7 | 211.6 ± 25 | 6.37 ± 0.76 | 1.25 ± 0.22 | 5.2 ± 0.45 | 657 ± 98 |

*Note: Strong positive correlations observed between OC, N, and yield ($p < 0.01$); Fe and Zn availability decreased at pH > 7.0.*

### 5.5 Comparison with Regional and National Findings

The yield levels (520–760 kg $ha^{-1}$) observed in the current study align closely with national averages reported by ICAR-Directorate of Rapeseed-Mustard, (2021), indicating that Bihar's semi-arid tracts hold considerable potential for Niger expansion under improved soil management. In Madhya Pradesh and Odisha, similar yield trends were recorded where organic matter and nitrogen availability were the key determinants (Rana & Verma, 2019; Patra et al., 2020).

These comparative results reinforce the conclusion that Niger can serve as an efficient low-input oilseed crop adaptable to marginal lands if managed under balanced fertility and moisture conditions. The study also confirms that moderate soil fertility (OC 0.5–0.7%; N 250–300 kg $ha^{-1}$; pH 6.5–7.0) represents the optimal eco-physiological range for Niger productivity in the semi-arid landscapes of eastern India.

## 6. Conclusion and Future Scope

### 6.1 Conclusion

The present study clearly establishes that soil physico-chemical properties play a decisive role in determining the growth, physiology, and productivity of *Niger (Guizotia abyssinica L.)* in the semi-arid tracts of Bihar. The findings highlight that organic carbon and available nitrogen are the most influential factors affecting plant height, chlorophyll content, and ultimately seed yield. Soils with slightly acidic to neutral pH (6.5–7.0) and moderate fertility (OC 0.5–0.7%, N 250–300 kg $ha^{-1}$) provided the most favorable environment for optimal crop performance. The positive correlation between soil organic matter and yield (r = 0.87**) underscores the importance of maintaining adequate soil carbon through organic amendments and residue recycling.

The regression and correlation analyses revealed that nitrogen and organic carbon together explained more than 80% of yield variation, signifying the synergistic effect of nutrient availability and soil biological activity on Niger productivity. Slightly alkaline conditions (>7.2 pH) and reduced micronutrient availability, particularly zinc and iron, were associated with lower yields, indicating the sensitivity of Niger to soil chemical imbalances. The site-specific nutrient management strategies, integrating both organic and inorganic sources, are essential for enhancing soil fertility, improving nutrient use efficiency, and ensuring sustainable productivity in semi-arid conditions.

### 6.2 Future Scope

Future research should focus on long-term field trials integrating biofertilizers (e.g., *Azospirillum*, *PSB*) and organic manures to refine nutrient recommendations for Niger under varying agro-ecological conditions of Bihar.

Advanced modeling techniques, such as GIS-based soil fertility mapping and remote-sensing-driven crop growth prediction, can be used to delineate Niger suitability zones. Studies on genotype–environment interactions and physiological mechanisms underlying drought tolerance could support the development of location-specific high-yielding varieties. Investigations into micronutrient-enriched fertilizer formulations and organic carbon management under climate change scenarios will also be vital to ensure resilience and profitability of Niger cultivation. Overall, the integration of eco-physiological, soil chemical, and agronomic research will pave the way toward sustainable Niger production systems suited for resource-poor farmers in semi-arid landscapes of eastern India.

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