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Effect of Different Mulching Materials on Growth Parameters and Yield of Okra (*Abelmoschus esculentus)* Production in Minna, Nigeria

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Abstract

During the 2022 growing season (August to November) at the Federal University of Technology, Minna School farm, Niger State, an experiment was conducted to investigate the influence of mulching on Okra's growth, yield, and moisture content was examined across four distinct growth stages (initial, development, mid, and late) and at varying soil depths (0 - 30 cm and 30 - 60 cm). The study employed a randomised complete block design with four replications, encompassing control (T0), groundnut shells mulch (T1), black polythene mulch (T2), and white polythene mulch (T3) as treatments. The highest average Okra fresh pod yield, amounting to 23.4 t/ha, was achieved by implementing white plastic mulch, contrasting with the control treatment, which yielded the lowest at 22 t/ha. Notably, the control plots exhibited yield reductions of up to 32% compared to the plots employing white plastic mulching. The utilisation of mulch had a notable impact on the overall crop yield, with the superior quality evident in the treatment employing white plastic mulch (26 t/ha). The control treatment exhibited the lowest quality at 24.3 t/ha. Groundnut shell mulch influenced moisture conservation, but no significant variance was observed compared to the control plots. Therefore, the study suggests that polythene mulch may be the most suitable type to enhance the quality of okra production by conserving soil moisture. Among the biodegradable and non-biodegradable mulches used in this study, white polythene mulch was the most effective.

Keywords

Crop, Groundnut Shell, Mulch, Plastic, Pod, Soil

1. Introduction

Agriculture in Nigeria is a critical sector, contributing about 35% to the GDP. Okra (*Abelmoschus esculentus*) plays a significant role in the Nigerian agricultural landscape, serving as a primary source of employment (Ibrahim et al., 2020; Anyaoha et al., 2023), including Minna, Niger State accounting for 70% - 80% of employment opportunities, and making a substantial contribution of up to 30% to foreign exchange earnings. This vegetable crop is extensively cultivated across various regions of Nigeria (Anyaoha et al., 2023). However, the productivity of okra cultivation is often constrained by inadequate moisture content in the soil, particularly during the dry season (Patra et al., 2023). Mulching is a common practice that helps conserve soil moisture by reducing water loss through evaporation from the soil surface (El-Beltagi et al., 2022). The variability in annual rainfall significantly impedes the sustainability of rain-fed farming systems in economically disadvantaged tropical regions, particularly in certain areas of Nigeria (Chukwuone & Amaechina, 2021). Essential climate parameters influence crop growth and productivity, including temperature, relative humidity (RH), and light intensity (Mgolozeli et al., 2020). Addressing rural farmers' challenges can be achieved by adopting conservation agriculture, which safeguards the soil and mitigates erosion (Rodenburg et al., 2021; Strauss et al., 2021). Among the methods employed, mulching emerges as a viable approach to modifying soil heat flux and influencing soil temperature. Mulch cover effectively reduces surface evaporation, preserves soil moisture content, and suppresses weed infestation within the crop field (Prem et al., 2020; Sharma & Bijalwan, 2022). Different mulching materials manipulate moisture levels and enhance overall crop yield. Okra crops, widely distributed across Africa, Asia, Southern Europe, and America, are a culinary resource consumed in various forms, such as boiled greens, blanched, fried, sautéed, and steamed.

Additionally, it is utilised as a nutritional supplement, providing essential vitamins such as C, A, and B complex, as well as minerals like iron and calcium. In some instances, dried okra undergoes processing into soup through a sequence involving slicing, drying, and grinding. The water requirements for okra cultivation in Nigeria exhibit variability influenced by climate, soil type, and cultivation practices (Musa et al., 2017).

This study examines the influence of different mulching materials on the growth parameters and yield of okra production in Minna, situated in the Southern Guinea Savannah region of Nigeria. The impact of mulches extends beyond the soil environment to encompass the plant's surroundings, with effects contingent upon the properties and degree of physical contact between the mulch materials and the soil.

2. Materials and Method

2.1. Study Area

The study area in Minna, the capital city of Niger State, Nigeria, exhibits a tropical wet and dry/savanna climate characterised by a dry season during the low-sun months and the absence of a cold season. The wet season occurs in the high-sun months, featuring an average temperature of 27 degrees Celsius. The annual precipitation is recorded at an average of 1209.7 mm, with a mean yearly relative humidity of 80%. This locale experiences 2672 hours of sunshine annually, and its upland soils, situated under the basement complex formation, are generally deep, weakly to moderately structured, comprising sand to sandy clay with gravelly and concretionary layers (Musa et al., 2017; Musa et al., 2020).

2.2. Experimental Design

This study used a randomised complete block design (RCBD) and replicated it four times on a 100 m^2 plot of 16 plots with 1 m × 1 m units (**Figure 1**) (Tadesse & Kesho, 2023). It involved using various mulching materials such as groundnut shell mulch, black polythene mulch, and white polythene mulch. The experimentation took place at the Federal University of Technology research farm during the rainy season between August and October 2022.

The study involved preparing experimental plots manually using a spade and a significant African hoe, with 60 okra seeds planted on each plot. After planting, 9 plots were mulched, while 3 were not. No standardised planting distance was maintained due to the ethno-scientific nature of the study. Local farmers declined to adopt the central planting method, perceiving it as incompatible with their cultural practices and overly time-intensive. Following the planting phase, the spatial gaps between various treatments were assessed. No artificial or natural fertilisers, nematicides, insecticides, fungicides, or herbicides were administered. To manage pests such as termites and spittlebugs, a conventionally prepared solution derived from the neem tree was employed, aligning with the prevalent approach among traditional farmers who refrain from using insecticides due to their prohibitive costs. One plant from each treatment group was randomly selected for measurement at four distinct dates corresponding to the four-phase stages. Growth and developmental parameters were systematically observed from 1 month after planting (MAP) to 8 months after planting (MAPS).

2.3. Data Collection

The study collected secondary data encompassing climatic and crop parameters and primary data involving soil properties, infiltration rate, soil residual moisture content, and yield and yield components.

2.4. Climatic and Weather Data

The research gathered meteorological information spanning the years 1984 to 2019 from the Minna station of the Nigerian Meteorological Agency (NIMET) in Niger State. Additionally, various weather parameters were obtained from a meteorological station within the designated study area, including temperature, rainfall, wind speed, relative humidity, and duration of sunshine.

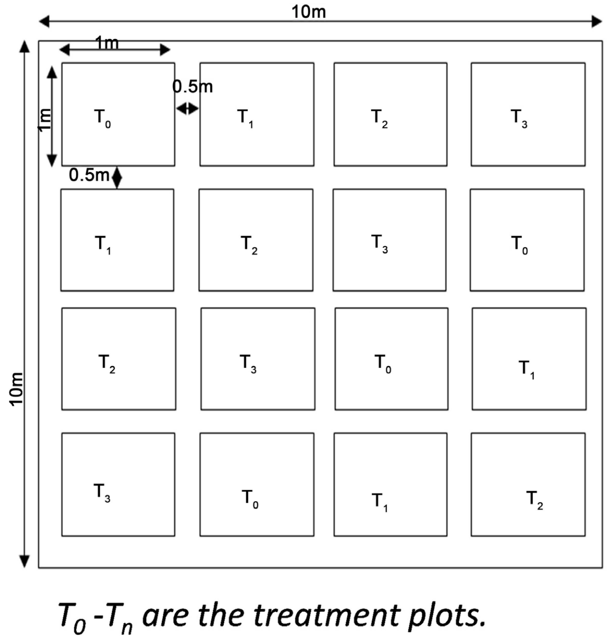

Figure 1. Layout of the experimental plots.

2.5. Soil Moisture Content (SMC)

Soil moisture content (SMC) was assessed by obtaining soil samples from the crop's root zone using an auger at two distinct depths (0 - 30 cm and 30 - 60 cm). Care was taken to position the soil samples between plant rows to mitigate potential damage (Ferreira et al., 2021; Cerdà et al., 2021). After collecting the samples, they were enclosed in a polythene bag to forestall evaporation loss and transported to a laboratory. The initial weight of each sample was documented before the drying procedure (W_1). After that, the samples were subjected to oven-drying at 80˚C ± 2˚C until a constant weight was attained. The final dry soil weight was recorded as W_2. The determination of soil moisture content was carried out utilising the specified formula:

$$\text{Soil Moisture Content} = \frac{W_1 - W_2}{W_2} \quad (1)$$

The symbol W_1 denotes the initial weight of the soil before desiccation, while W_2 represents the weight of the soil post-oven-drying, indicating its dry mass.

2.6. Growth and Yield Components of Okra

The research assessed the developmental aspects of okra over 12 weeks post-planting, tracking variables such as plant height, stem diameter, and leaf area weekly. Harvesting occurred at physiological maturity, with yield data recorded daily using an electronic weighing scale. Subsequently, the fruits underwent sun drying, and the seeds were obtained by splitting the pods. After drying and cleaning, the seeds were weighed and stored in polyethene bags (Odjo et al., 2022). Various yield components were analysed, encompassing parameters like fruit quantity per length, fruit length, fruit dry weight, harvesting duration, total dry output, plant height, fresh fruit weight, marketable and unmarketable fruit weights, overall yield, and water use efficiency.

2.7. Statistical Analysis

The research employed Minitab statistical software to conduct various statistical analyses, such as correlation, chi-square, ANOVA, LSR test, and stepwise regression analysis. Correlation analysis was utilised to assess the connection between climatic variables, growth, and yield, whereas stepwise regression analysis aimed to identify the climatic variables that predicted yield (Liu et al., 2021). ANOVA and chi-square tests were applied to validate the statistical significance of variations among treatments, yield, and water use efficiency.

3. Results and Discussion

3.1. Rainfall Characteristics of the Study Area

Climate significantly impacts various aspects of human life, including agriculture, and comprehending the diverse manifestations of climate change across different geographical areas (Muluneh, 2021) is essential for making well-informed decisions and formulating successful strategies to alleviate and address the consequences of climate change. The rainfall data showed a sinusoidal pattern, with a 38% increase from 1984 to 1994. However, rainfall duration decreased from seven months in 1984 to 1994, as observed in **Figure 2**. The data for 2022, the year crops were planted, relies on the precipitation trends documented in the preceding 35 years. **Figure 2** presents the rain pattern of the study area.

3.2. Soil Properties

3.2.1. Physical Properties

The residual moisture content plays a significant role in influencing the physical characteristics of soil, such as bulk density, porosity, and permeability (Musa et al., 2017). Higher moisture levels increase porosity and permeability, impacting water-holding capacity and air exchange (Zhang et al., 2021). Additionally, the ease with which water and air can traverse through the soil, known as permeability, is also subject to the influence of residual moisture content. In an experimental site, Sandy Clay loam and Clay loam soil textures were identified at 0 - 30 cm and 30 - 60 cm, respectively, featuring average percentages of 44, 23.5, and 32.5 for sand, silt, and clay. This aligns with findings from other studies in Minna, where sandy loam and sandy clay loam were reported as the predominant soil textural classes (Onyutha, 2019). These soil types are deemed suitable for cultivating okra due to their adaptability to various soil conditions.

The study results show that bulk density (**Table 1**) reflects total soil porosity; low values suggest a soil condition characterised by porosity, while high values indicate an unfavourable environment for root growth and diminished water infiltration (Liu et al., 2020). **Table 1** also presents the field capacity and permanent

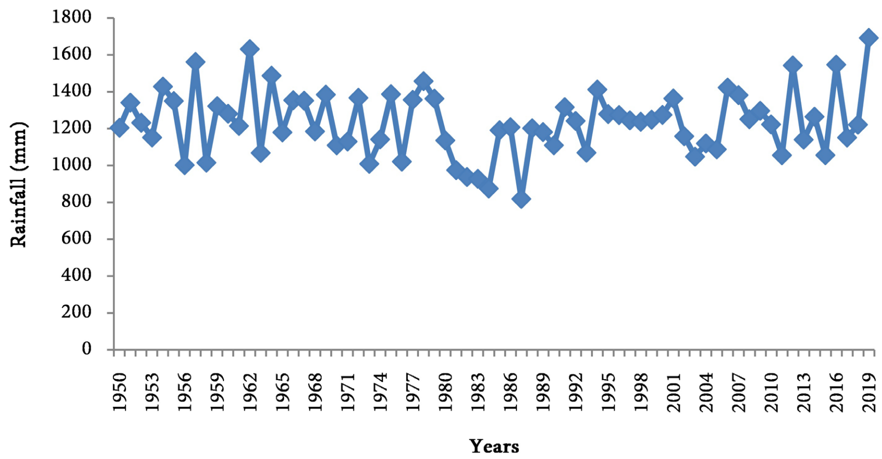

Figure 2. Annual rainfall pattern of Minna between the years 1980 to 2019.

Table 1. Physical characteristics of the soil within the designated study area.

Soil parameters	Soil depth		
	0 - 30 cm	30 - 60 cm	Average
Sand (%)	45	43	44
Silt (%)	21	26	23.5
Clay (%)	34	31	32.5
Soil texture classification	Sandy clay loam	Clay loam	Sandy clay loam
Bulk density (gm/cm^3)	1.47	1.58	1.53
FC (V/V%)	35	41	38
PWP (V/V %)	20	24	22
TAW (mm/m)	130	145	137.5

Note: BD = bulk density; FC = field capacity; PWP = permanent wilting point; TAW = total available water content.

wilting point values exhibit variations between 20% and 24%, with field capacity ranging from 35% to 41% (Torres et al., 2021). The disparity between field capacity and the permanent wilting point is strongly associated with total accessible water (TAW) (Wabela et al., 2023). Applying mulch, organic amendments, and specific irrigation techniques can effectively diminish soil bulk density and enhance overall porosity, drainable pores, and water availability in the soil.

3.2.2. Chemical Properties

The moisture content of soil plays a crucial role in determining its chemical characteristics, affecting nutrient availability and pH levels. Plants, essential for their growth, depend on the soil, and higher moisture content promotes microbial activity and mineralisation, thereby enhancing nutrient accessibility. The soil's pH, another vital property, tends to decrease with increased moisture content, attributed to the leaching of basic cations and the release of organic acids.

At the research site, the soil pH levels slightly increased with depth, ranging from 5.5 to 6.4, falling within the optimal range for okra cultivation (Sedara et al., 2021). Okra thrives in soils with a pH range of 5.5 to 6.5. Additionally, the soil's saturated extract electrical conductivity at depths of 0 - 30 cm and 30 - 60 cm indicated low soil salinity (0.03 and 0.02 ds/m, respectively), signifying no significant adverse impact on crop growth (Singh, 2022).

3.2.3. Biological Properties

The soil's remaining moisture content significantly shapes various biological characteristics, such as microbial activity and plant development. Elevated moisture levels enhance nutrient accessibility and create favourable environments for microbial growth, impacting plant growth and productivity by influencing nutrient cycling and symbiotic relationships (Wang et al., 2020). Also, soil residual moisture influences root growth and water absorption (Melese et al., 2022). The organic matter content in the soil exhibited variability within the range of 1.08 to 1.12, as indicated in **Table 2**, which outlines the chemical and biological properties of the soil in the study area.

3.3. Effect of Mulch on Soil Residual Moisture Conservation at Different Growth Stage

Soil residual moisture is crucial for plant growth and yield, and any deficiency or excess can negatively impact plant growth (Wagg et al., 2021). This study used mulching to conserve soil residual moisture, which was measured for various soil depths and crop growth stages. The capacity of a plant to transform solar energy into economic development relies on the dimensions and effectiveness of its leaf cover. This is affected by various factors, including temperature, solar radiation levels, water and nutrient availability, crop variety, cultivar, and age. Eze et al. (2018) highlight the significance of implementing efficient agricultural management techniques to optimise the absorption and utilisation of the limited remaining moisture supply from rainfall. This approach promotes sustainable soil productivity and enhances crop growth and yield.

Mulching is a widely acknowledged method in agriculture for soil conservation and moisture control. Numerous studies have examined how various mulches affect the preservation of residual moisture in the soil during different growth phases of crops, including okra. During the initial stage of plant growth, seedlings emerge from the soil and are particularly vulnerable to residual moisture stress, leading to hindered growth and diminished yield. The mulch application effectively mitigates residual moisture stress during this stage, alleviating stunted growth and enhancing overall yield.

A study by Eze et al. (2018) investigated the impact of various mulches on soil moisture retention and okra yield. The findings revealed that organic and inorganic mulches significantly increased soil moisture retention and improved yield compared to the control treatment. However, the inorganic mulch proved more effective in conserving soil moisture than the organic mulch.

Table 2. The chemical and biological characteristics of the soil within the designated study area.

Soil parameters	Soil depth		
	0 - 30 cm	30 - 60 cm	Average
pH	6.4	5.5	5.95
ECE (ds/m)	0.03	0.02	0.02
OM (%)	1.08	1.12	1.1

Note: ECE = electrical conductivity; OM = organic matter.

Mandal et al. (2020) characterised the development stage of plant growth as marked by rapid vegetative growth, leaf, and stem development. This study's results illustrate mulching's effectiveness in enhancing soil residual moisture conservation during development. Mulch application influenced the soil's residual moisture content at various depths, with the control plot exhibiting the lowest residual moisture levels (25.27% and 27.15%) as presented in **Table 3**. The black polyethene mulched plot demonstrated the highest residual moisture contents (30.12% and 33.31%).

In research conducted by Onunwa et al. (2023), the impact of various mulch types on soil water utilisation and okra yield was examined. The findings revealed that both mulch varieties notably enhanced soil moisture levels and positively influenced yield compared to the control treatment. Nevertheless, the plastic film mulch demonstrated greater efficacy in preserving soil moisture and improving yield than the straw mulch.

During the intermediate stage of plant development, which signifies the initiation of flowering and fruit formation, studies indicate that the use of mulch significantly enhances the retention of soil residual moisture. A statistical examination of soil residual moisture levels between 0 - 30 cm and 30 - 60 cm during the mid-season stage revealed that mulch substantially impacted soil residual moisture, with a significance level of $P < 0.05$ for both soil depths. The investigation demonstrated that white polythene mulch exhibited a maximum conservation rate of residual moisture, reaching 27.80% at 0 - 30 cm and 30.11% at 30 - 60 cm.

A study by Kumar et al. (2022) evaluated the effect of different mulches on soil moisture conservation and the yield of okra. The findings indicated that both varieties of mulches had a substantial positive impact on retaining soil moisture and enhancing yield compared to the control group. Nevertheless, the inorganic mulch demonstrated greater efficacy in preserving soil moisture and increasing yield when compared to the organic mulch.

3.4. Effect of Mulch on Growth Parameters of Okra

3.4.1. Number of Pods Per Plant

The application of mulch has a notable effect on the mean pod count per plant, wherein plots under controlled conditions exhibit the lowest pod production at 12.25. In contrast, those with white plastic mulch demonstrate the highest pod

Table 3. Effect of mulch application on volumetric residual moisture content (%) at different growth stages and soil depths.

Initial growth stage						
Depth (cm)	**T0**	**T1**	**T2**	**T3**	**CV (%)**	**LSD (0.05%)**
0 - 30	26.28	30.15	31.20	32.15	3.15	2.53
30 - 60	28.31	32.25	33.65	34.48	2.76	2.17
Development stage						
Depth (cm)	**T0**	**T1**	**T2**	**T3**	**CV (%)**	**LSD (0.05%)**
0 - 30	25.27	29.16	30.12	29.80	1.13	1.34
30 - 60	27.15	30.36	30.13	33.31	2.15	2.25
Mid-stage						
Depth (cm)	**T0**	**T1**	**T2**	**T3**	**CV (%)**	**LSD (0.05%)**
0 - 30	24.50	28.41	29.74	28.19	7.14	1.58
30 - 60	26.52	29.15	28.68	30.89	9.34	2.19
Final stage						
Depth (cm)	**T0**	**T1**	**T2**	**T3**	**CV (%)**	**LSD (0.05%)**
0 - 30	21.53	26.18	23.49	22.97	2.57	2.37
30 - 60	24.28	27.48	26.13	26.36	5.28	4.15

yield at 16.65 per plant—improved methods for conserving residual moisture led to a considerable 36% enhancement compared to the control plots. Insufficient residual moisture can contribute to suboptimal fruit setting, attributed to factors like flower shedding and fertilisation failure. The reduction of pods per plant is highest during the flowering stage, as confirmed by Mederski (2019). In a recent study by Kumar et al. (2022), it was discovered that residual moisture stress during the flowering and pod formation stage had a negative impact, leading to a decreased pod count per plant in green gram. Similarly, Rahman et al. (2020) found a noteworthy decline in pods per okra plant when subjected to residual moisture stress during the flowering stage. Exposure to reproductive structure, residual moisture stress, or disturbances in physiological and biochemical processes may create unfavourable conditions for pod formation, reducing the overall pod count per plant.

3.4.2. Pod Length

The plots covered with white plastic exhibited the highest average pod length (11.00 cm), whereas the un-mulched plots showed the lowest average pod length (9.04 cm). No significant variations in pod length were observed between plots with groundnut shell mulch and the control group. The analysis of variance indicated noteworthy differences ($P < 0.01$) in pod length attributed to different mulching types. In general, the conservation of residual moisture in the soil profile, facilitated by plastic mulches, plays a substantial role in plant cell division and fruit cell enlargement. This phenomenon is likely associated with the availability of residual moisture, leading to increased cell expansion through turgor pressure and photosynthesis rate (Wijerathna-Yapa & Pathirana, 2022).

3.4.3. Pod Dry Weight (PWD)

The investigation revealed that the highest individual pod dry weight occurred in a plot covered with white polythene (0.7675 g), while the lowest was observed in a plot without any mulch (0.33 g). The presence of organic mulch (groundnut shells) had a significant impact on pod dry weight (PDW), exhibiting a 66.6% increase compared to control plots (**Table 4**). This observed effect may be attributed to residual soil moisture disrupting physiological and biochemical processes, leading to constraints on carbohydrate metabolism and biochemical alterations in pods. The reduction in acid invert activity potentially decreased the hexoses to sucrose ratio, impeding cell division in ovules and pod walls. Consequently, this weakened the ability to attract photosynthates from source organs, leading to reduced availability of photosynthates in source leaves and diminished distribution of carbohydrates into pods. This impairment may have hindered the developing pods' capacity to utilise incoming sucrose, thereby retarding expansion growth.

3.4.4. Harvesting Period

The harvesting period for pods in un-mulched and black plastic mulch ranges from 7 to 14 days, with a 7-day disparity between control and white plastic conditions noted (**Table 4**). This discrepancy may be attributed to favourable soil residual moisture conditions, promoting increased pod development in well-moistened plots. However, plots experiencing stress or lacking mulch led to pod abortion, resulting in a shortened harvesting period. The use of organic mulch, such as groundnut shells, showed no significant difference compared to un-mulched plots, likely due to consistent residual moisture levels. Noteworthy variations were observed among various mulch applications concerning the duration of pod harvesting, with statistical significance at $P < 0.01$.

3.4.5. Total Dry Matter

The study found a significant difference in total dry weight per plant between different mulch applications. White plastic mulch increased total dry matter by 81.13% compared to control plots (**Table 4**). This could be due to evapotranspiration, reduced transpiration and photosynthesis rates, and reduced biomass accumulation. Organic mulch, exemplified by groundnut shells, had a more pronounced impact on the overall dry matter than plots without mulch. This effect can be attributed to conserving residual moisture in the soil profile. The elevation in plant dry matter, observed in optimal residual soil moisture conditions, is linked to alterations in specific metabolic processes within plant cells induced by water (Gonçalves et al., 2024). An abundance of residual soil moisture diminishes stomatal closure, facilitating the exchange of water, carbon dioxide, and oxygen. This, in turn, enhances the photosynthetic rate, fostering increased vegetative growth in plant height, leaf area, and lateral shoot number. The

Table 4. Effect of mulch on the growth parameters.

Mulch Type	Number of pods per plant (NP)	Pod length (cm)	Pod dry weight (gm)	Harvest period	Total dry matter
Control (T0)	12.25d	9.04c	0.33c	7.00c	6.63c
Groundnut shells (T1)	14.32bc	10.04b	0.55b	9.00b	9.30b
White plastic (T2)	16.65a	11.00a	0.7675a	12.00a	12.00a
Black plastic (T3)	16.03a	10.70b	0.7625a	14.00a	11.30a
LSD (0.05)	1.68	6.06	0.18	3.03	2.38
CV (%)	7.58	0.94	20.7	18.16	16.07

augmented leaf area contributes to heightened light interception and photosynthesis, thereby exhibiting a positive response to enhanced practices in residual moisture conservation.

3.5. Effect of Mulch on Reproductive Growth of Okra

3.5.1. Days of Flowering

The research revealed a notable disparity in the time taken for flowering among various mulch application treatments. Plots covered with white plastic exhibited a prolonged duration of 50% flowering (Table 5), whereas plots lacking mulch displayed the shortest duration (54 days). Control plots experienced flowering six days sooner than those with white plastic mulch. Additionally, plots with groundnut shell mulch significantly impacted the days to flowering (57.37) compared to unmulched plots (Table 5). This phenomenon may be attributed to plants undergoing their life cycle more rapidly under residual moisture stress, ensuring species perpetuation in contrast to those in normal or high soil residual moisture conditions. Plants subjected to residual moisture stress exhibited earlier maturation than those in favourable conditions, suggesting a delay in flowering to allocate more biomass to vegetative growth. The mulch application prolonged the flowering period, likely by harnessing residual moisture in the soil to support vegetative growth.

3.5.2. Days of Physiological Maturity

The study found that mulch application significantly influences the time it takes for okra plants to reach physiological maturity. White plastic mulched okra plants took 71.25 days longer to reach maturity, while unmulched plants took 64.5 days (Table 5). The research additionally identified a 7-day distinction in the growth between plots with white plastic mulch and those without mulch. Nevertheless, plants' maturation with groundnut shells slowed for approximately three days, indicating a notable disparity.

3.5.3. Plant Height

The application of mulch has a noteworthy effect on plant height, as evidenced by the considerable variation observed. Plants in plots devoid of mulch exhibited the shortest height (14.63 cm), while those in plots with white plastic mulch

Table 5. Effects of mulch on reproductive growth of okra.

Mulch type	Days to flowering	Days to physiological maturing	Plant height (cm)
Control (T0)	54.00d	64.50c	14.64d
Groundnut shells (T1)	57.38bc	67.75b	21.00bc
White plastic (T2)	60.00a	71.25a	27.52a
Black plastic (T3)	59.50ab	70.00ab	25.00ab
LSD (0.05)	2.24	3.1	4.22
CV (%)	2.54	2.95	12.83

reached taller heights (27.52 cm), as presented in Table 5. A parallel trend was identified in okra, where plants showed reduced height under conditions of residual moisture stress. Both investigations concluded that residual moisture stress during both vegetative and generative stages led to a decline in plant height, potentially attributable to the conservation of soil residual moisture facilitated by the mulch. A linear relationship between plant height and the availability of soil residual moisture was observed, highlighting the role of mulch in preserving soil residual moisture and influencing plant height.

3.6. Effect of Mulch on Yield Parameter of Okra

3.6.1. Average Fresh Pod Weight Per Plant

The application of mulch has a notable effect on the mean fresh pod weight per plant. The average fresh pod weight in plots covered with transparent polythene is 15.01 g/m^2 (Table 6), whereas in un-mulched plots, it is 11.37 g/m^2. This decrease in soil residual moisture leads to reduced water absorption by roots, affecting leaf area, cell size, and intercellular volume. This results in a reduction of fruit residual moisture accumulation and fruit weight. This is consistent with Feng et al.'s (2021) findings, which suggest pod weight decreases during residual moisture stress. The statistical analysis of variance revealed a significant difference in the weight of fresh pods between plots mulched with groundnut shells and control plots. However, no statistically significant difference was observed between plots mulched with black and transparent polythene, possibly due to the non-availability of residual moisture.

3.6.2. Quality Yield Harvest

The study found that different mulch types significantly impacted marketable okra yields. Transparent polythene mulches yielded the highest marketable product (35.28 tonnes/hectare), while un-mulched plots had the lowest quality yield (24.39 tonnes/hectare) (Table 6). No significant difference was found between transparent and black polythene mulches. The results suggest that mulch helps prevent crop pods from contacting the ground, reducing soil rot and maintaining product cleanliness.

Table 6. The average fresh pod weight, quality harvested yield, poor harvested yield, and overall yield mean value.

Mulch Type	Fresh pod weight (t/ha)	Quality harvested yield (t/ha)	Poor harvested yield (t/ha)	Overall yield (t/ha)
Control (T0)	0.11d	24.39c	4.20a	28.44d
Groundnut shells (T1)	0.13bc	28.82b	3.23bc	33.00bc
White plastic (T2)	0.15a	35.28a	2.16d	37.53a
Black plastic (T3)	0.14ab	33.49a	2.85cd	35.62ab
LSD (0.05)	1.2	293.5	87.57	299.78
CV (%)	5.89	6.39	17.36	5.89

3.6.3. Poor Harvest Yield

Mulching substantially influences the quantity and quality of crop yields, which is relevant to okra cultivation. Research indicates that the least favourable yield was observed in plots without mulch, while the lowest yield was noted in plots treated with transparent polythene. This aligns with a study conducted by Feng et al. (2021) in Zimbabwe, which demonstrated that applying maise stover and cattle manure mulch significantly mitigated poor okra yields compared to control treatments (**Table 6**). Similarly, Kader et al. (2019) in Nigeria reported a noteworthy reduction in poor okra yield when utilising maise stover and dry grass mulch compared to control treatments. The investigation further reveals that mulching enhances soil residual moisture and nutrient retention, improving okra yield and quality. In summary, mulching emerges as a pivotal factor in improving the yield and quality of okra crops.

3.6.4. Total Yield

Various studies have investigated the influence of residual soil moisture on the yield of okra. Wang et al. (2020) discovered that a moderate level of residual soil moisture, approximately 60% of field capacity, proved to be optimal for the growth and yield of okra (**Table 6**). Excessive residual soil moisture, exceeding 80% of field capacity, led to reduced yield due to diminished root respiration and increased susceptibility to diseases. Conversely, insufficient residual soil moisture, falling below 46% of field capacity, reduced yield, attributable to decreased plant growth and nutrient uptake. Distinct differences in total pod yield were observed among various mulch applications. The highest total pod yield, amounting to 37.53 tonnes/hectare, was documented in plots mulched with transparent polythene, followed by black polythene at 35.62 tonnes/hectare. Fine polythene mulch, black polythene mulch, and groundnut shells mulch enhanced total fruit yields by 32%, 25%, and 16%, respectively, compared to treatments without mulch.

Tan et al. (2019) determined that a moderate residual soil moisture content of around 70% of field capacity was optimal for okra growth and yield. Excessive soil residual moisture, surpassing 90% of field capacity, reduced yield due to compromised soil aeration and increased disease incidence. Inadequate soil residual moisture, below 50% of field capacity, reduced yield due to diminished nutrient uptake and plant growth. Similarly, Zhang et al. (2019) established that soil residual moisture content significantly influenced okra yield, with the optimal level identified as 60% of field capacity for achieving the highest yield.

4. Conclusion

The research investigated the influence of mulching on the preservation of residual moisture during okra cultivation. It revealed that inorganic mulch, particularly polythene mulch, exhibited a higher average than organic mulch across all growing seasons except for the late season. Polythene mulch contributed to water conservation at different growth stages, showing varying percentages. While black polythene mulch demonstrated a more outstanding residual moisture content than transparent polythene mulch, this distinction was not statistically significant at any soil depth. Groundnut shells also aided in preserving residual moisture at different growth stages, with no notable difference between the two types. Notably, polythene mulch significantly increased both okra yield and quality yield value when compared to the control group. The study suggests that different materials possess distinct capacities for retaining residual moisture, emphasising the significant role of polythene mulch in reducing evapotranspiration.

In conclusion, mulching effectively improves soil residual moisture retention during various growth stages of crops, including okra. Mulching is crucial in maintaining soil health and productivity by reducing residual moisture stress and promoting optimal fruit quality.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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