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# Sensitivity of rainfed okra (*Abelmoschus esculentus* L. Moench) to mulch material and plant spacing in drought-prone tropical soils

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## ABSTRACT

Mulch regulates soil hydrothermal regime while suppressing weed growth, effects of which may depend on mulch material and/or similar to that of closed crop canopy. Combined use of organic or inorganic material as surface mulch and appropriate plant spacing may produce synergistic agronomic effects in water-stressed environments. This study evaluated the sensitivity of rainfed okra to mulch-spacing variants in droughty derived-savannah soils. With dry-grass mulch (DGM) and sawdust mulch (SDM) representing organic mulch material and black polythene (BPM) as inorganic/plastic, treatments were factorial combinations of surface-applied DGM, SDM and BPM with close (60 cm × 30 cm), intermediate (60 cm × 45 cm) and wide (60 cm × 60 cm) spacings. Crop growth/performance and fruit yield data were collected. Mulch material affected okra growth (with overall better results in BPM than SDM), but not flowering/fruiting and fruit yield. For plant spacing, sum of weights of pods and fruit yield were higher in close than intermediate and wide spacings, with fruit yields as 2.42, 1.21 and 0.76 t $ha^{-1}$, respectively. Mulch-spacing interaction effects showed that BPM with close spacing gave the highest values for stem girth 8 weeks after sowing (SDM treatments gave the lowest), sum of weights of pods and fruit yield (2.93 t $ha^{-1}$). Fruit yield, however, depended not on stem girth but on certain okra yield attributes. The BPM or, where not feasible, either of DGM and SDM, could be effectively combined with close spacing to improve okra productivity in droughty soils of the derived savannah.

**Keywords:** water-stressed environments; surface mulching; black polythene mulch; close spacing; plant density; okra fruit yield.

## 1. Introduction

Okra (*Abelmoschus esculentus* L. Moench) is native to Africa and is one of the most important vegetable crops in tropical/ subtropical and warm temperate climates in different countries cutting across Africa, Asia, Southern Europe and America (Islam, 2019). The green seed pods constitute the edible part of this plant which are consumed as cooked vegetable, mostly fresh but sometimes sun-dried (Liu et al., 2021). Okra seeds fail to germinate at soil temperatures below 17 °C, just as the seedlings are susceptible to low night temperatures (Thamburaj & Singh, 2018). The crop thrives well under a higher temperature range

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of 21 - 30 °C and maximally at 35 °C (Abd El-Kader et al., 2010; Adekiya et al., 2017), and in almost all soils from sandy to clayey texture and within a soil pH range of 5.8 – 8.0. Maintenance of adequate warmth in the root zone is thus critical for okra production in the tropics.

Okra is mainly grown under rainfed conditions in sub-Saharan African agro-ecologies where erratic rainfall often leads to either moderate to severe droughts (Ayub et al., 2020), or excessive soil wetness that lowers soil temperature. One adverse agronomic effect of soil droughtiness in water-stressed environments is impaired plant nutrition, not only because it leads to high soil temperatures which can deter microbial activities and nutrients release, but also because soil solution is needed for nutrients uptake and transport. Moisture deficit shortens the vegetative/ generative stage and decreases growth, biomass accumulation and yield in okra (Wojtyla et al., 2020; Iqbal et al., 2021). Abiotic stress that constrains okra production thus bothers on warmth (heat) inadequacy and drought incidence (Mkhabela et al., 2021).

In the past, arable crop farmers relied on viable practices based on sound ecological principles such as extended fallowing and crop rotation to increase soil fertility and productivity (Obalum et al., 2012a; Franke et al., 2018; Onah et al., 2021). Fallowing is, however, increasingly becoming out-fashioned. The soil resources of the humid tropics are not only dominantly sandy but also inherently low in soil organic matter (SOM), a situation that is often linked to inadequate proportion of clay to foster clay-SOM aggregation and to the associated excessive leaching (Obalum et al., 2012b; Oguike et al., 2023). With this situation, the ever-viable crop rotation alone may not always give rise to sufficient build-up of SOM in these soils; other soil-agronomic management practices that can promote SOM accretion in them have, over the years, been a subject of research. These practices include mulching which could help to cope with the soil-related agro-environmental constraints in rainfed agriculture. Mulch provides coverage to the soil surface to conserve heat, minimize moisture losses, control weed population and enhance crop yields (Obalum et al., 2011; Kader et al., 2019).

Besides soil temperature regulation, moisture conservation and weed control, mulching improves SOM status (where organic materials are used) and soil structure to minimize surface compaction, leading to reduced runoff/erosion and associated nutrient losses and, ultimately, to increased water use efficiency (Obalum et al., 2011). The role of mulch in reducing soil erosion in crop fields is particularly important because the losses of both macro- and micronutrients to runoff and eroded sediments have been threatening agricultural sustainability (Obalum et al., 2012a; Borrelli et al., 2015; Rodrigo-Comino et al., 2016). Many biodegradable organic and non-biodegradable inorganic (plastic) materials can be used as surface mulch. Its effectiveness varies according to the material and its colour and thickness as well as by the prevailing environmental conditions, the species of crop grown, and its production technology including plant spacing. This is owing to their varying abilities to influence soil 'physical' and nutrient-related fertility and hence regulate the hydrothermal regimes of the soil and that of the crop's microclimate.

The choice of appropriate plant spacing that gives optimum plant density is crucial for increased agronomic productivity. Such a density may depend on crop, its cultivar and cropping system as well as on climatic and soil conditions. Research has shown the benefits of optimum plant density in crop production (Binalfew et al., 2016; Adubasim et al., 2017; Obalum et al., 2017), and that plant spacing and hence density is particularly a critical agronomic factor in okra production (Kumar et al., 2016). Adequate space ensures less competition among plant stands for space, sunlight, nutrients and moisture for increased growth and yield (Carciochi et al., 2019).

Surface mulching reduces evaporation from the soil, soil moisture conservation benefit of which can be pronounced in the derived savannah (Mbagwu, 1991a,b; Ezenne et al., 2019), and which could also be achieved with appropriate plant spacings that give crop canopy allowing minimal light penetration at a later crop growth stage. Both mulching and maintenance of optimal plant density are among soil and agronomic management practices towards achieving sustainable agriculture in tropical fragile agroecosystems (Igwe & Obalum, 2023).

Combined use of mulch and a compatible plant spacing may produce synergistic effects in the soil to which okra may be sensitive. However, because of the varying abilities of mulch materials to regulate soil hydrothermal regime, such effects may vary widely. There is paucity of data on the most appropriate combination of mulch material (organic and plastic/polythene) with plant spacing to enhance okra production in the coarse-textured and hence droughty soils of the derived savannah. Therefore, the objective of this study was to evaluate the sensitivity of rainfed okra to mulch material and plant spacing in this environmental setting.

## 2. Methodology

### 2.1 Description of study area

The experiment was conducted at the University of Nigeria Teaching & Research Farm (06°52´N, 07°24 ´E; 447 m asl) at Nsukka, southeastern Nigeria. The climate is humid tropical; mean annual rainfall of 1600 mm that is bimodal rainfall distributed with peaks in July and October, evapotranspiration of 1560 mm, minimum and maximum temperatures of 21 and 31 °C, respectively, and relative humidity in the range of 69-79%. The soil, derived from false-bedded sandstone and/or colluvium from weathered upper coal measures, belongs to the order Ultisols. It is characterized by rich content of Fe oxide (and hence reddish brown colour) and dominance of low-activity clay, and is in the textural class of sandy clay loam (Table 1).

Owing to the coarse texture and the low-SOM status of the soils, they are often subject to excessive leaching. This affects the key soluble macronutrients including N and P which are in addition subject to volatilization and fixation, respectively, while also rendering them acid. The vegetation is typically derived savannah agroecology (dominated by grassland).

**Table 1**
Physico-chemical properties of the experimental site

| Soil property | Value |
|---|---|
| Textural class | Sandy loam |
| pH-$H_2O$ | 5.50 |
| Organic Carbon | 1.40 mg $kg^{-1}$ |
| Total Nitrogen | 0.27 mg $kg^{-1}$ |
| Available Phosphorous | 5.35 mg $kg^{-1}$ |
| Exchangeable Potassium | 0.10 mg $kg^{-1}$ |
| Exchangeable Calcium | 0.65 mg $kg^{-1}$ |
| Exchangeable Magnesium | 0.61 mg $kg^{-1}$ |
| Exchangeable Sodium | 0.05 mg $kg^{-1}$ |
| Total Exchangeable Bases | 1.40 mg $kg^{-1}$ |
| Hydrogen | 2.41 mg $kg^{-1}$ |
| Aluminum | 0.12 mg $kg^{-1}$ |
| Exchangeable Acidity | 2.53 mg $kg^{-1}$ |
| Effective Cation Exchange Capacity | 3.93 cmol $kg^{-1}$ |
| Cation Exchange Capacity | 12.18 cmol $kg^{-1}$ |
| Base Saturation | 37.85% |

### 2.2 Experimentation

The experiment was carried out between May and July 2016. Treatments were three mulch materials namely dry grasses (comprising mostly *Panicum maximum*), sawdust chips and black polythene sheet, each of which was applied as surface mulch and used to grow okra at three plant spacings. Specifically, dry-grass mulch (DGM), sawdust mulch (SDM) and black polythene mulch (BPM) were each used to grow okra at a constant intra-row spacing of 60 cm while inter-row spacing was varied to be 30, 45 and 60 cm termed close, intermediate and wide spacings, respectively (Table 2). There were thus nine treatments coded BPM-30, BPM-45, BPM-60, DGM-30, DGM-45, DGM-60, SDM-30, SDM-45 and SDM-60. These treatments were laid out in a 3 × 3 factorial arrangements replicated three times in a randomized complete block design (RCBD). Plant densities of 55,555, 37,037 and 27,777 plants were obtained with the close, intermediate and wide spacings, respectively.

The experimental field was cleared, thoroughly ploughed and harrowed using a tractor. To further bring the soil to a fine tilth, seedbeds were manually prepared using an African hoe before the execution of the layout of the experimental field. The required land area of 27 m × 8 m (216 $m^2$) was delineated, split into blocks and subdivided into nine treatment plots per block to give 27 in all, each measuring 2 m × 2 m (4 $m^2$). A 1-m pathway was maintained between blocks and a distance of 0.5 m between treatment plots in a block.

Basal application of poultry manure at the rate of 10 t $ha^{-1}$ was done; the manure was incorporated uniformly into the top-(0 - 20 cm) soil three days before mulching. The DGM at the rate of 15 t $ha^{-1}$, SDM laid to a thickness of 3 cm corresponding to an application rate of 60 t $ha^{-1}$, and BPM (2.02 x 2.02 m) were applied on the surface of the treatment plots two days before sowing okra seeds. The variety of okra used was Clemson spineless. Seeds were sown three per hole after drilling to shallow depths of about 2 - 3 cm. Planting holes were drilled at pre-marked points according to plant spacings. Seedlings were later thinned down to one per stand two weeks after emergence.

**Table 2**
Combination of the factors resulting to treatments for the survey

| Surface mulch material | Inter-row plant spacing (cm) | | |
|---|---|---|---|
| | Close | Intermediate | Wide |
| Dry-grass mulch (DGM) | 60 cm × 30 cm | 60 cm × 45 cm | 60 cm × 60 cm |
| Sawdust mulch (SDM) | 60 cm × 30 cm | 60 cm × 45 cm | 60 cm × 60 cm |
| Black polythene mulch (BPM) | 60 cm × 30 cm | 60 cm × 45 cm | 60 cm × 60 cm |

For the BPM plots, the polythene sheets were laid loose and held in place to avoid wrinkling by field operations and wind.

The treatment plots were supplemented with NPK 15:15:15 fertilizer at the rate of 80 g per plot (corresponding to 200 kg ha$^{-1}$) by side placement. It was applied by half-split dosing (Umezinwa et al., 2020) at 2 and 6 weeks after sowing (WAS). Weeding was manually done at 4, 6 and 8 WAS with an African hoe and also by hand picking on the DGM and SDM plots, while few weeds that sprouted from the marked open holes on the BPM plots were removed by hand picking. Harvesting of fruit pods was started at the maturity of the okra plants from 8 WAS and continued at three-day intervals till end of the field experiment.

## 2.3 Data collection and analysis

Agronomic data were collected on four randomly selected and tagged middle-row plants per plot. The same data were also collected from the remaining plants in the plot.

### *2.3.1 Vegetative growth characteristics*

Observations on okra vegetative growth were done at 4, 6 and 8 WAS. Data collected were plant height, stem girth, and numbers of branches and leaves. Okra plant height was measured using measuring tape stretching from the soil surface to the terminal end of the plant.

Stem girth was measured using micro-meter screw gauge. The stem girth was taken 5 cm from the plant base above the soil level. Number of branches was counted per sampled plant. Also, number of leaves per plant was counted, excluding dried and senescing leaves.

### *2.3.2 Reproductive/flowering, fruiting and yield*

At the flowering stage, numbers of days to flower bud initiation, flower formation (anthesis) and fruit pod formation were recorded. For fruit pod formation, for example, it was the number of days it took the plant to bear fruits. At okra harvest, weight of fresh fruits per plant, number of fruit pods per plant, and length and diameter of the pods were recorded. The fruit length was measured from the base to tip excluding the stalk of the fruits. The fresh fruit weight per plant was denoted fruit yield and, after extrapolation, reported in t ha$^{-1}$.

### *2.3.3 Data analysis*

Data were subjected to two-way analysis of variance by the procedure appropriate for RCBD experiments using the software GenStat Release 10.3 Discovery Edition. Differences were deemed significant at the 5% probability level ($p$ < 0.05), and the means separated using the Fisher's Least Significant Difference ($LSD_{0.05}$). Pearson's multiple correlation analysis was performed on the measured agronomic traits using SPSS 17.0 software, to determine the crop growth and performance (flowering and fruiting) traits that influenced the fruit yield of okra.

## 3. Results and discussion

## 3.1 Main effects of surface mulch material on vegetative growth of okra

Table 3 shows that surface mulch material influenced okra growth parameters markedly.

**Table 3**
Main effects of surface mulch material on vegetative growth traits of okra (*Abelmoschus esculentus*)

| Surface mulch material | Plant height (cm) | Stem girth (cm) | Number of branches | Number of leaves |
|---|---|---|---|---|
| | | | 4 WAS | |
| Dry-grass mulch (DGM) | 28.64 | 4.31 | 1.22 | 5.61 |
| Sawdust mulch (SDM) | 23.14 | 4.00 | 1.03 | 7.06 |
| Black polythene mulch (BPM) | 30.56 | 5.28 | 1.17 | 8.94 |
| $LSD_{(0.05)}$ | 7.95 | 1.41 | 0.14 | 1.97 |
| F-Test | NS | NS | NS | * |
| | | | 6 WAS | |
| Dry-grass mulch (DGM) | 46.56 | 7.53 | 1.33 | 17.31 |
| Sawdust mulch (SDM) | 37.67 | 5.94 | 1.14 | 13.89 |
| Black polythene mulch (BPM) | 42.56 | 8.14 | 1.42 | 18.33 |
| $LSD_{(0.05)}$ | 8.24 | 1.54 | 0.20 | 3.25 |
| F-Test | NS | * | * | * |
| | | | 8 WAS | |
| Dry-grass mulch (DGM) | 64.33 | 10.42 | 2.06 | 22.58 |
| Sawdust mulch (SDM) | 59.14 | 7.69 | 1.42 | 17.61 |
| Black polythene mulch (BPM) | 62.58 | 11.78 | 1.97 | 23.56 |
| $LSD_{(0.05)}$ | 6.75 | 0.99 | 0.35 | 2.82 |
| F-Test | NS | * | * | * |

WAS - weeks after sowing; LSD - Least Significant Difference; NS - Not significant; *significant.

The BPM gave overall better results than the SDM but not DGM in terms of stem girth and numbers of leaves and branches per plant. It could be that these three mulch materials varied in their ability to reduce erosion, evaporation, surface temperature, wind impact and weed infestation (Döring et al., 2005; Bucki & Siwek, 2019; Niziolomski et al., 2020). The SDM-treated plots had the lowest values of the vegetative growth parameters including plant height, stem girth, number of branches, and number of leaves. At 4 WAS, okra plants had more leaves due to BPM and SDM than to DGM. At 6 WAS, these plants showed were wider stems and more branches and leaves under BPM compared with SDM. At 8 WAS, they showed wider stems and more leaves under BPM compared with SDM, while also taller with more branches under BPM and DGM than SDM. Increased soil moisture retention close to the roots can minimize leaching and evaporation losses leading to floral development of okra (Sharma & Patel, 2011; Bake et al., 2017), and this can cause overall increases in above-soil growth of crops (Kader et al., 2019). The present effect of mulch was such that DGM and BPM behaved as mulch unlike the rather less effective SDM.

### 3.2 Main effects of surface mulch material on performance and yield of okra

There were no differences in number of days to flower bud initiation (mean, 26.33 days), flower formation (mean, 44 days) and fruit pod formation (mean, 46 days) under the various mulch materials. Similar no effects of mulch material occurred for okra yield attributes including average diameter of pods (2.58 - 2.73 cm), average length of pods (10.98 - 11.54 cm), sum of weights of pods for sampled (55.81 - 66.24 g) and for all plants in a plot (120.20 - 155.40 g), average weight of pods for sampled (22.13 - 24.89 g) and for all plants in a plot (18.80 - 22.45 g), total number of pods (3.89 - 4.74) as well as okra fruit yield (1.33 - 166 t/ha). The results for fruit yield suggest that soil hydraulic and hydrothermal properties did not vary under these three different mulch materials (Adekiya et al., 2017). However, BPM-treated plots tended to produce higher values of all these yield attributes of okra compared with SDM- and DGM-treated plots. Similar to this tendency, Iderawumi & Yusuf (2019) reported increased yield parameters of okra from polythene-mulched, frequently weeded plots.

### 3.3 Main effects of plant spacing on vegetative growth and fruiting of okra

Plant spacing had no effects ($p > 0.05$) on plant height, stem girth and numbers of branches and leaves at 4, 6 and 8 WAS. However, close spacing (60 cm × 30 cm) consistently tended to produce the tallest plants with widest stem compared with intermediate (60 cm × 45 cm) and wide spacings (60 cm × 60 cm). For instance, close, intermediate and wide spacings showed okra plants that were 61.28, 60.69 and 59.14 cm tall with stem girth of 10.56, 9.67 and 9.67 cm, respectively at 8 WAS, when wide spacing tended to show more branches and leaves compared with the others. Similar to these results, Ekwu & Nwokwu (2012) and Maurya et al. (2013) reported taller plants with fewer branches in close spacing. Widening the plant spacing was reported to lead to shortened internodal spaces in cotton (Alfaqeih et al., 2002; Ali et al., 2007), but to also promote profuse branching due to less intra-specific competition (Rafi et al., 2015). Therefore, the present observation may be due to reduced competition among the okra plants in the wide spacing. Also, there were no differences ($p > 0.05$) among the three plant spacings in okra flowering/fruiting traits including number of days to flower bud initiation (mean, 26 days), flower formation (mean, 46 days) and fruit pod formation (mean, 44 days).

### 3.4 Main effects of plant spacing on yield attributes and fruit yield of okra

Table 4 shows the influence of plant spacing on yield attributes and fruit yield of okra.

**Table 4**
Main effects of plant spacing on diameter of pods, length of pods, weight, number of pods per plant and fruit yield parameters of okra

| Plant Spacing | ADP (cm) | ALP (cm) | SWP (g) | $SWP_{all}$ (g) | AWP (g) | $AWP_{all}$ (g) | TNP | Yield (t ha$^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| 60 cm × 30 cm | 2.67 | 11.84 | 67.95 | 169.48 | 26.04 | 23.08 | 5.00 | 2.42 |
| 60 cm × 45 cm | 2.68 | 11.30 | 50.94 | 118.69 | 23.21 | 19.19 | 4.41 | 1.21 |
| 60 cm × 60 cm | 2.60 | 10.54 | 60.51 | 112.79 | 22.54 | 18.76 | 3.83 | 0.76 |
| $LSD_{(0.05)}$ | 0.13 | 1.18 | 15.60 | 36.56 | 4.23 | 4.13 | 1.55 | 0.67 |
| F-Test | NS | NS | NS | * | NS | NS | NS | * |

ADP: Average diameter of pods; ALP: Average length of pods.
SWP: Sum of weights of pods (based on only sampled plants in a plot).
$SWP_{all}$: Sum of weights of pods (including both sampled and other plants in a plot).
AWP: Average weight of pods (based on only sampled plants in a plot).
$AWP_{all}$: Average weight of pods (including both sampled and other plants in a plot).
TNP: Total number of pods per plant; LSD - Least Significant Difference; NS - Not significant; *significant.

There were differences ($p < 0.05$) in sum of weights of pods for all plants in a plot and in fruit yield, with higher values in close spacing than intermediate and wide spacings. Average length and diameter of pods, average weights of pods and total number of pods, though not significantly affected, all tended to decrease as plant spacing widened. The higher values of number of pods associated with close spacing may have contributed to its fruit yield benefit, and the ensuing high plant density cannot be said to have diminished the physical quality of the okra pods. Overall, plant spacing had no significant effects on the growth and performance (reproductive/ flowering) of okra but affected its sum of weights of pods and fruit yield. These results partially contrast with the widely believed agronomic concept that plant density affects light absorption, moisture availability and wind movement, which influence all of plant height, architecture, crop maturity and crop production (Khan et al., 2019; Fahad et al., 2021).

### 3.5 Interaction effects of mulch material and plant spacing on some okra agronomic traits

Treatment generally did not affect ($p > 0.05$) okra vegetative growth traits. However, DGM with wide and intermediate plant spacings (DGM-60 and DGM-45, respectively) tended to show the tallest plants at 4, 6 and 8 WAS when compared with the rest. This could be attributed to the fact that low plant density encourages plant growth due to limited competition for available resources (such as light, moisture and nutrients), and to more favourable humidity and minimal weed infestation (Stephenson et al., 2011; Zhanbota et al., 2022).

The only growth trait that differed ($p < 0.05$) due to the interaction effects of mulch material and plant spacing was stem girth, and this occurred only at 8 WAS, showing highest values in BPM-30 and lowest values in SDM treatments (Table 5). There were also differences ($p < 0.05$) in number of days to fruit pod formation (Table 5) and fruit yield (Table 6).

**Table 5**
Interaction effects of surface mulch material and plant spacing treatments on stem girth and reproductive/fruiting traits of okra

| Mulch Material | Plant Spacing | Stem girth (cm) | | | Number of Days to | | |
|---|---|---|---|---|---|---|---|
| | | 4 | 6 | 8 | Flower Bud Initiation | Flower Formation (Anthesis) | Fruit Pod Formation |
| | | weeks after sowing | | | | | |
| Dry-grass mulch (DGM) | 60 cm × 30 cm | 3.50 | 7.33 | 10.33 | 27 | 44 | 47 |
| | 60 cm × 45 cm | 4.75 | 7.25 | 10.50 | 26 | 44 | 46 |
| | 60 cm × 60 cm | 4.67 | 8.00 | 10.42 | 26 | 44 | 46 |
| Sawdust mulch (SDM) | 60 cm × 30 cm | 4.75 | 6.08 | 7.67 | 26 | 44 | 46 |
| | 60 cm × 45 cm | 4.00 | 6.08 | 7.83 | 27 | 44 | 46 |
| | 60 cm × 60 cm | 3.25 | 5.67 | 7.58 | 27 | 44 | 47 |
| Black poly-thene mulch (BPM) | 60 cm × 30 cm | 5.75 | 9.42 | 13.67 | 26 | 44 | 46 |
| | 60 cm × 45 cm | 4.67 | 7.33 | 10.67 | 26 | 44 | 46 |
| | 60 cm × 60 cm | 5.42 | 7.67 | 11.00 | 26 | 44 | 46 |
| SEM (±) | | 1.15 | 1.26 | 0.812 | 0.4 | 0.3 | 0.4 |
| $LSD_{(0.05)}$ | | 2.45 | 2.67 | 1.72 | 0.9 | 0.6 | 0.8 |
| F-Test | | NS | NS | * | NS | NS | * |

SEM - Standard errors of differences of means; LSD - Least significant difference; NS - Not significant; *significant.

**Table 6**
Interaction effects of surface mulch material and plant spacing treatments on diameter of pods, length of pods, weight, number of pods per plant and fruit yield parameters of okra

| Mulch material | Plant Spacing | ADP (cm) | ALP (cm) | AWP (g) | $AWP_{all}$ (g) | SWP (g) | $SWP_{all}$ (g) | TNP | Yield (t $ha^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| Dry-grass mulch (DGM) | 60 cm × 30 cm | 2.59 | 10.88 | 25.94 | 19.15 | 55.50 | 120.83 | 4.08 | 2.01 |
| | 60 cm × 45 cm | 2.68 | 11.61 | 25.47 | 20.80 | 49.00 | 123.42 | 4.25 | 1.30 |
| | 60 cm × 60 cm | 2.65 | 10.46 | 23.26 | 19.38 | 62.94 | 116.28 | 3.33 | 0.66 |
| Sawdust mulch (SDM) | 60 cm × 30 cm | 2.66 | 12.27 | 23.46 | 20.73 | 62.25 | 159.17 | 5.33 | 2.31 |
| | 60 cm × 45 cm | 2.63 | 10.60 | 20.88 | 17.48 | 50.92 | 107.08 | 4.67 | 1.14 |
| | 60 cm × 60 cm | 2.44 | 10.59 | 22.05 | 18.21 | 58.89 | 109.89 | 3.83 | 0.74 |
| Black poly-thene mulch (BPM) | 60 cm × 30 cm | 2.75 | 12.37 | 28.70 | 29.37 | 86.11 | 228.44 | 5.58 | 2.93 |
| | 60 cm × 45 cm | 2.73 | 11.69 | 23.29 | 19.28 | 52.92 | 125.58 | 4.31 | 1.18 |
| | 60 cm × 60 cm | 2.71 | 10.57 | 22.31 | 18.70 | 59.69 | 112.19 | 4.33 | 0.88 |
| SEM (±) | | 0.11 | 0.962 | 3.457 | 3.372 | 12.75 | 29.87 | 1.27 | 0.55 |
| $LSD_{(0.05)}$ | | 0.23 | 2.040 | 7.329 | 7.148 | 27.02 | 63.33 | 2.69 | 1.16 |
| F-Test | | NS | NS | * | * | * | * | NS | * |

ADP: Average diameter of pods; ALP: Average length of pods.
SWP: Sum of weights of pods (based on only sampled plants in a plot).
$SWP_{all}$: Sum of weights of pods (including both sampled and other plants in a plot).
AWP: Average weight of pods (based on only sampled plants in a plot); $AWP_{all}$: Average weight of pods (including both sampled and other plants in a plot); TNP: Total number of pods per plant; LSD - Least Significant Difference; NS - Not significant; *significant.

Though numbers of days to flower bud initiation and flower formation were not affected, treatment increased weights of pods and fruit yield owing to nutrients translocation into the fruits. This conforms to the reports of Baraiya et al. (2017), Adekiya et al. (2017) and Obalum et al. (2017).

Drought stress affects okra growth and productivity, disrupting physiological functions and the photosynthetic rate, resulting in yield losses (Chaturvedi et al., 2019), sometimes ranging between 30% and 100%, primarily when the stress occurs during the flowering and pod-filling stages (Mkhabela et al., 2021). Prolonged drought causes leaf senescence in okra as a result of limited soil moisture and nutrients to sustain its growth (Iderawumi, 2020). In the present investigation, treatments DGM-30, SDM-30 and BPM-30 generally outyielded DGM-45, SDM-45 and BPM-45 and more evidently DGM-60, SDM-60 and BPM-60 (Table 6). The highest fruit yields due to close intra-row spacing of 30 cm which ranged from 2.01 to 2.93 t $ha^{-1}$ are quite high when related to the values (0.60 - 0.69 t $ha^{-1}$) recently reported for the same variety of okra grown with heavy application rates of poultry-droppings manure in the same environment (Onah et al., 2023), a juxtaposition pointing at the importance of favourable hydrothermal regime due to surface mulch in drought-prone tropical soils.

However, the close intra-row spacing of 30 cm rather than any of the three mulch materials was responsible for the present drought-proof effect of treatment. For the BPM, increase in soil temperature and the required warmth was the case because of black colour's sensitivity to high temperatures and ability to absorb heat. The fact that there were no contrasting plastic/polythene mulch colours here would explain the apparent similarity in soil hydrothermal properties and hence the microclimate that prevailed around the crop (Mbagwu et al., 1991a; Filipović et al., 2016; Zhu et al., 2022). This situation plausibly caused the differences in okra fruiting and fruit yield to be driven by plant spacing. Notably, however, the highest weights of pods and the highest fruit yields (mean, 2.93 t $ha^{-1}$) were recorded in BPM-30 plots.

### 3.6 Relationships between vegetative/yield attributes and okra fruit yield

Table 7 shows the relationship between the vegetative/yield attributes and fruit yield of okra. Average diameter of pod and sum weight of pod had positive correlations ($p < 0.05$) with fruit yield. Also, average length of pods, sum weight of pods for all plants in a plot, average weight of pods, average weight of pods for all plants in a plot, and total number of pods per plant all had positive correlations ($p < 0.01$) with fruit yield. Therefore, yield attributes rather than vegetative growth attributes of okra influenced its fruit yield in this study. In an experiment conducted in South Africa to characterize okra accessions from Africa, Asia, South America, North America and Europe that varied in drought tolerance, Mkhabela et al. (2022) reported that both vegetative growth and yield attributes of okra influenced its pod yield under drought-stressed and non-stressed growing conditions.

**Table 7**
Linear correlation matrix between vegetative growth and yield attributes with the fruit pods yield in tons per hectare in okra assessment under study

| | ADP | ALP | SWP | $SWP_{all}$ | AWP | $AWP_{all}$ | TNP | PLH | STG | NOL | NOB | FBI | FFA | FPF | Yield |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ADP | - | | | | | | | | | | | | | | |
| ALP | 0.607** | - | | | | | | | | | | | | | |
| SWP | 0.316 | 0.423* | - | | | | | | | | | | | | |
| $SWP_{all}$ | 0.340 | 0.605** | 0.718** | - | | | | | | | | | | | |
| AWP | 0.605** | 0.720** | 0.678** | 0.685** | - | | | | | | | | | | |
| $AWP_{all}$ | 0.406* | 0.669** | 0.622** | 0.907** | 0.742** | - | | | | | | | | | |
| TNP | 0.100 | 0.395* | 0.068 | 0.413* | 0.157 | 0.361* | - | | | | | | | | |
| PLH | 0.228 | 0.188 | 0.174 | 0.481** | 0.400* | 0.564** | 0.181 | - | | | | | | | |
| STG | 0.304 | 0.196 | 0.409* | 0.560** | 0.438* | 0.561** | 0.124 | 0.840** | - | | | | | | |
| NOL | 0.217 | 0.103 | 0.099 | 0.191 | 0.249 | 0.221 | 0.012 | 0.733** | 0.770** | - | | | | | |
| NOB | -0.028 | -0.093 | 0.125 | 0.208 | 0.141 | 0.179 | 0.125 | 0.675** | 0.729** | 0.774** | - | | | | |
| FBI | -0.249 | -0.324 | -0.258 | -0.233 | -0.290 | -0.284 | -0.445** | -0.349* | -0.439* | -0.507** | -0.464** | - | | | |
| FFA | -0.174 | 0.06 | 0.026 | -0.068 | 0.035 | -0.041 | -0.056 | 0.055 | -0.036 | 0.164 | -0.071 | -0.075 | - | | |
| FF | -0.500** | -0.236 | -0.05 | -0.006 | -0.184 | -0.034 | 0.182 | 0.155 | 0.061 | 0.147 | 0.097 | -0.117 | 0.582** | - | |
| Yield | 0.353* | 0.686** | 0.398* | 0.759** | 0.618** | 0.698** | 0.720** | 0.324 | 0.337 | 0.077 | 0.098 | -0.315 | 0.011 | 0.068 | - |

ADP: Average diameter of pods; ALP: Average length of pods; AWP: Average weight of pods (based on only sampled plants in a plot). $AWP_{all}$: Average weight of pods (including both sampled and other plants in a plot); SWP: Sum of weight of pods (based on only sampled plants in a plot); $SWP_{all}$: Sum of weight of pods (including both sampled and other plants in a plot); TNP: Total number of pods per plant; PLH: Plant height; STG: Stem girth; NOL: Number of leaves; NOB: Number of branches; FBI: Flower bud initiation; FFA: Flower formation (Anthesis); FPF: Fruit pod formation.

## 4. Conclusions

This study demonstrates that mulch material could affect okra vegetative growth, but generally may have no effects on okra flowering, fruiting and yield. Black polythene mulch, compared to mulch materials of organic origin (dry grasses and sawdust), may be a more effective mulch material for increasing the vegetative growth of okra. Also, plant spacing influenced the more important agronomic trait of fruit yield, with higher values in close spacing (60 cm × 30 cm) than intermediate (60 cm × 45 cm) and wide (60 cm × 60 cm) spacings both of which were similar.

None of the three mulch materials evaluated could be adjudged the most effective with a given plant spacing as regards increasing the yield of rainfed okra in the study area. However, our data support using black polythene mulch and adopting a close plant spacing as an effective technique for enhancing okra productivity and yield in droughty soils of the derived savannah zone. Where the use of black polythene mulch is not feasible, either of the two organic mulches (dry grasses and sawdust) could serve as its close alternative which still must be combined with a close plant spacing in okra production in this agro-ecological zone. This soil and agronomic management practice is expected to apply to other 'water-stressed' tropical agro-ecologies, which are those with climatic and soil characteristics similar to the derived savannah.

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**Authors' Contributions**

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**Ethical Implications**

This article has no ethical implications.

**Conflict of Interest**

The authors declare no conflicts of interest in this study.

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