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Okra (*Abelmoschus esculentus* L. Moench) performance as affected by inorganic fertilizer under weed stress conditions

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Abstract

Okra is economically and nutritionally valued in the tropics. Sustaining yield is challenging due to declines in soil fertility and labor constraints in weed management. Fertilizers promote crop resilience to field pests, but information on okra's resilience to weed pressure remains limited. This study examined the influence of NPK fertilizer on okra's tolerance to weed infestation. In 2022 and 2023, a 2×4 factorial experiment evaluated weedy (uncontrolled weed growth) and weed-controlled (Weeded) conditions, alongside four levels of NPK 20-10-10 fertilizer (0, 30, 60, and 90 kg N/ha) in a randomized complete block design with three replicates. The results revealed that fruit weight ranged from 15814.30 (weeded with 0 kg N/ha) to 45994.07 kg/ha (weeded with 60 kg N/ha) in 2022. In 2023, weeding with 60 kg N/ha NPK treatment produced the highest yield. Weeding improved okra survival (77.08%) in 2022 compared to weedy plots (60.88%). Interactions revealed that weedy conditions with 60 kg N/ha had the highest weed cover (73.33% in 2022, 66.67% in 2023), while weeded conditions with 30 kg N/ha had the lowest (38.33% in 2022, 33.33% in 2023). Conclusively, effective weed control combined with 60 kg N/ha NPK optimizes okra growth and survival, while minimizing weed pressure.

Keywords: Crop survival rates, Inorganic fertilizer, Okra resilience, Okra yield, Sustainable production, Weed interference.

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Contents

Contribution of this paper to the literature

Okra cultivation in low-fertility, weed-prone soils is a challenge to increase production. This study clarifies the interaction between inorganic fertilizer and weed stress on okra growth and yield. It quantifies nutrient–weed competition, identifies optimal fertilizer rates, and provides evidence-based recommendations to enhance productivity and sustainability in resource-limited okra production systems.

1. Introduction

Vegetables are a vital source of nutrients essential for maintaining good health [1]. Globally, they represent a significant component of diets, and their production is expanding, partly driven by population growth [2]. For numerous smallholder farmers, vegetable cultivation, alongside arable crops, serves as a primary source of income [3]. Okra (Abelmoschus esculentus L. Moench) stands out as an important fruit and vegetable crop. Its fruits are rich in iodine and calcium, which contribute substantially to human dietary energy (4550 Kcal/kg). Okra fruits account for a significant portion of fresh vegetable exports, excluding potatoes, onions, and garlic [4]. It also provides crucial vitamins, calcium, potassium, and other micronutrients often lacking in the diets of individuals in developing nations [1]. Okra is widely cultivated in tropical regions and holds the position of the most important vegetable crop in Nigeria [5]. For many farmers across Africa, okra farming is a key source of their livelihoods. However, sustaining consistent crop yields faces considerable challenges due to rapid soil fertility decline and a scarcity of field labor, as pests such as weeds have limited the expansion of cultivated land and threaten food security among rural farmers.

A major constraint to maintaining crop yields in the tropics is inherent soil infertility. These soils are reportedly low in organic matter and available nutrients, leading to a decline in productivity within a short time of intensive use [6]. This reduction in soil fertility contributes to stagnant or even decreasing crop yields, raising concerns about the long-term viability of current agricultural productivity to ensure food security for the growing global population [7]. Enhancing soil fertility through fertilizer application has become a critical factor in enabling global food production [8]. Fertilizers are essential inputs in crop production, improving both the quantity and quality of yields. Supplying plants with the necessary nutrients through fertilizer application can also enhance their resistance to pests and diseases [9]. Research by Bala, et al. [10] and Rajareddy, et al. [11] indicates that balanced levels of phosphorus (P) and potassium (K) directly contribute to plant tolerance against pests through mechanical, biochemical, and physical mechanisms. Bala, et al. [10] have noted favorable responses to pest infestation through fertilizer application, and Rajareddy, et al. [11] reported the positive impact of plant nutrition on resilience to pests. However, the effect of applied fertilizer on the occurrence and impact of pests like weeds in crop fields can vary depending on the fertilizer type and application method [9]. Organic manure serves as a reservoir of essential plant nutrients, including nitrogen (N), phosphorus (P), potassium (K), and micronutrients, while also helping to prevent nutrient leaching. Purwanto and Alam [6] observed a decline in soil organic matter content due to poor management and intensive soil manipulation. Nevertheless, organic manures release nutrients slowly, potentially limiting the immediate resilience crops need against pests, including weeds. Rajareddy, et al. [11] found that improved plant nutrition positively influenced crop tolerance to insect pests. In contrast, Ibironke and Akinrinola [12] reported that poultry manure did not enhance the tolerance of garden eggplants to weed infestation. The inability of organic fertilizers to support crop tolerance to pests, such as weeds, could be attributed to the slow release of nutrients that cannot foster crop resilience.

Inorganic fertilizers are primary sources of N, P, and K, and the adequate supply of these nutrients is linked to spontaneous and high photosynthetic activity, vigorous vegetative growth, and improved resistance to pests and diseases [13]. Production limitations in Nigerian okra farming have been attributed to low input supply and inadequate management practices (mainly removal of weeds), which often result in low green fruit yields [14]. Even when high-yielding varieties are cultivated, insufficient soil nutrient status to promote crop growth, combined with a lack of labor for weed control, remains a major constraint to okra production by the small-scale farmers. Consequently, yields of only 2 to 3 tons per hectare of green fruits have been reported. The land preparation and fertilizer placement methods employed also influence the crop's response to fertilizer application and its susceptibility to pests like weeds [15].

Weed interference and competition with crops represent a significant challenge affecting both the yield and quality of agricultural produce [16]. Effective weed control in okra is crucial for the first nine weeks after planting [17]. The cumulative effects of weeds can lead to substantial crop losses through competition for resources, allelopathy, acting as alternative hosts for pests and pathogens, and contamination of harvested products. Comparing fruit yield in plots with uncontrolled weeds to those with plastic mulch, Shittu, et al. [18] documented a substantial loss in *Arachis hypogea*. Uncontrolled weed growth has been reported to cause yield reductions in maize [19], okra [20], and cowpea [21]. Field studies suggest that the critical period for weed control in a crop is influenced by factors such as season, soil conditions, weed species and density, location, and management practices [22].

All plants, including crops and weeds, have similar basic nutrient requirements, and their responses to nutrient availability can differ [16]. Providing nutrients for crops generally also makes them susceptible to weed interference [12]. As with other crops, weeds negatively impact okra plants by competing for nutrients, light, and water [23]. They also exacerbate water management issues, harbor pests and diseases, and reduce labor efficiency [24]. Some farmers in tropical regions recognize the need for weed control but face significant labor limitations, often resulting in delayed intervention until weeds have extensively covered their crops [22]. The use of herbicides carries considerable health and environmental risks [25]. Furthermore, the land preparation method used can influence a crop's susceptibility to pests like weeds. Tillage during land preparation for okra cultivation aims to delay weed interference during the early growth stages when the crop's ability to compete for resources is limited. Ibironke and Akinrinola [12] observed yield reductions in garden eggplants despite tillage and poultry manure application. However, compared to the understanding of inorganic fertilizers' impact on crop tolerance to other field pests in okra production, information regarding their effect on tolerance to weed interference is limited.

Therefore, this research aims to investigate how weed infestation and NPK fertilizer application influence okra growth, yield, and survival rate under weed stress.

2. Materials and Methods

2.1. Experimental Site

The experiment was conducted during the 2022 and 2023 cropping seasons at the Research Field (longitude 3°45´E and latitude 7°27´N) of the Department of Agronomy, University of Ibadan, Nigeria. The area lies within the ecosystem of Nigeria, with annual rainfall ranging from 1250-1500 mm [26]. According to Weather Atlas [27] the average annual maximum temperature ranges from 28°C (August, coolest) to 35°C, while the minimum ranges from 21.9°C (January) to 24.8°C (March). The land was arable land that was not cultivated in the last two seasons, but had elephant grass as the dominant vegetation, with a sparse population of Cynodon grass. The crop cultivated before the two-season fallow was cocoyam. Figure 1 illustrates the rainfall and average minimum and maximum temperature patterns at the study site in 2022 and 2023.

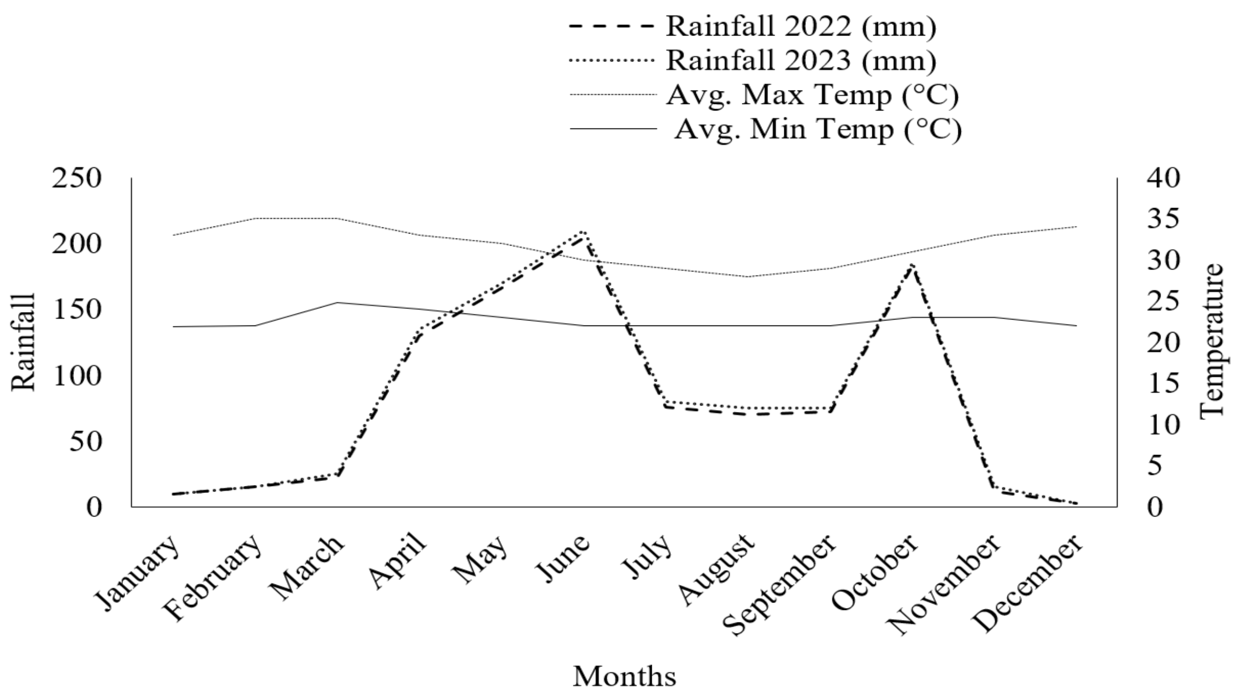

Figure 1. Monthly rainfall and temperature for Ibadan, Nigeria, in 2022 and 2023.

Source: Weather Atlas [27].

The soil chemical and physical properties used in the 2022 and 2023 studies indicated that the pH level of the 2022 soil was close to the critical level, whereas the pH level in 2023 was lower (Table 1). The soil organic carbon and total N levels were lower than the critical levels in both years, indicating that the two soils were not adequate in terms of fertility status to support optimal okra growth, as recommended by Brandenberger, et al. [28]. The 2023 soil was comparably lower in fertility status than in 2022.

Table 1. Soil chemical and physical parameters before the experiment.

Parameters	2022	2023	Critical level
Soil chemical properties			
pH (H_2O)	6.93	6.48	6.9
Organic C (g/kg)	1.80	1.27	1.86
Total N (g/kg)	23	19	52
Available P (mg/kg)	17.93	120	51
Available K (mg/kg)	70.0	66.3	0.078
Ca	2.88	1.19	0.043
Mg	1.07	1.10	
Na	1.35	0.83	
Physical properties (g/kg)			
Sand	810	840	
Silt	120	100	
Clay	70	60	
Textural class (USDA)	Sandy loam	Sandy loam	

Source: Brandenberger, et al. [28].

2.2. Experimental Design and Treatment

The experiment was a 2×4 factorial experiment with two weeding options [Weedy (W1) and Weeded (W2)] and four fertilizer levels [0 (F0), 30 (F1), 60 (F2), and 90 (F3) kg N/ha of NPK 20-10-10 fertilizer] were evaluated in a randomized complete block design with three replicates.

2.3. Sources of Experimental Materials

Seeds of the okra variety (LD88) sown were obtained from the National Horticultural Research Institute in Ibadan, Nigeria. The NPK fertilizer (20:10:10) was collected from the Department of Crop and Horticultural Sciences, University of Ibadan, Ibadan, Nigeria.

2.4. Cultural Practices

Land clearing and bed making were done manually; the bed size was 3 m × 1.5 m. The seeds were sown at three seeds per hole and thinned to two plants per hole at a spacing of 0.5 m × 0.5 m (40000 plants/ha). Sowing of the seeds was done in August 2022 and April during the following growing season 2023. Fertilizer application was carried out two weeks after planting in both crops. The plant population was 20 plants per plot. The fertilizer treatments were applied two weeks after planting using the ring method at 0, 30, 60, and 90 kg N/ha according to respective treatments. Weeding was done manually for all the plots two weeks after planting, before fertilizer application was imposed as a treatment, due to weed occurrence resulting from the delay in seed sowing. This was followed by subsequent weeding, which was done at 4-week intervals for the weedy plots, and the weeds were left undisturbed for the weedy plots. Matured okra fruits were harvested at 4 weeks after planting and at 3-day intervals afterwards.

2.5. Data Collection

The growth and yield data collected at 10 weeks after planting include plant height, stem girth, and leaf area, while the number of plants per plot was extrapolated to per hectare. The fresh fruit and the weight of dry plant biomass are estimated per hectare. Weed cover score (%) on the scale of 0-100 was visually estimated per plot, while the number of missing plants was counted per plot and determined on a percentage basis.

2.6. Statistical Analysis

Data were subjected to analysis of variance (ANOVA) using SAS software, version 9.0. Statistical significance is determined using Duncan's Multiple Range Test at a probability level of $P<0.05$. The level of relationships among the yield and yield components was determined using the Pearson correlation coefficient.

3. Results and Discussion

3.1. Effect of Weed Infestation and Fertilizer Application on the Growth of Okra

The heights of plants under the Weeded and weedy plots were similar at 10 weeks after planting during the 2022 and 2023 cropping seasons (Table 2). The weedy conditions resulted in slightly taller plants than the weedy ones, but the difference was not significant during the two seasons of plantings. This suggests that weed control had a minimal effect on the height of okra plants, possibly due to varietal factors influencing growth. The variety (LD88) is noted for its tallness among other cultivated varieties [29]. As such, competing for light under weedy conditions should not be a threat. The competition for space between the plant and weeds to intercept light did not cause preferential diversion of assimilate toward height increase. According to Mwendwa, et al. [30] the increase in height helps to elevate leaves to access sunlight in dense stands with weeds. The response to interference could be expressed in other growth parameters.

The variations in plant heights as influenced by NPK fertilizer applications were significant during the first cropping season, with the fertilizer-treated plants having significantly taller plants than the control. In 2023, however, fertilizer effects were less consistent, with heights ranging from 78.11 cm (60 kg N/ha) to 94.40 cm (90 kg N/ha), and no significant difference was observed. This indicates that nitrogen fertilizer application generally promotes taller plants by encouraging cell mitosis and expansion through the increase in the synthesis of cytokinin and auxin in the plant Romera, et al. [31]. Ibrahim, et al. [4] reported that the improvement in soil nutrients enhances photo-assimilate processes, thus increasing cell mitosis at the apical meristem, leading to taller plants than plants with limited nutrients. This increase in height would further encourage interception of light compared to those plants growing under nutrient-limited conditions.

The observed result for weed infestation × fertilizer interactions on plant height indicated significant variation among the treatments. In 2022, the combination of weedy conditions with 90 kg N/ha produced the tallest plants (149.95 cm), and was significantly taller than weedy conditions with 0 kg N/ha (79.68 cm). Weeded conditions with 60 kg N/ha also resulted in tall plants (146.63 cm). These interactions suggest that weedy control combined with no fertilizer application suffers from weed competition, while fertilizer under weedy and Weeded conditions encouraged taller plants. The adequacy in soil nutrition encouraged the plants to compete favorably with the weeds for light interception by supporting the increase in apical cell division with nutrients. This finding is substantiated by the increase in height with the addition of fertilizer under the weedy and weeded conditions. This study affirms Ibrahim, et al. [4] that improvement in okra nutrition promotes height increase. However, while the height of plants under the weedy treatments increased till 90 kg N/ha due to the presence of weeds, there was a reduction in the heights of plants under the weeded treatment after 60 kg N/ha, indicating that there is a limit to promoting height by applying fertilizer. However, at lower nutrient levels, including control, the level of activities of the hormones responsible for height increase was limited due to nutrient deficiency [31]. The deficiency in nutrients could be the result of competition from weeds.

The leaf area observed for the plants under the weedy condition was significantly lower than that of the weeded plot during the 2022 and 2023 cropping seasons (Table 2). This suggests that weed competition reduces leaf expansion, likely due to competition for light, water, or nutrients Lyu, et al. [32]. Little, et al. [33] also reported that competition with weeds limits leaf expansion. The differences in leaf area indicated that the plants under the weedy condition were allocating more assimilates for meristematic cell division, and the avoidance of shade at the expense of leaf area expansion. Fertilizer effects on leaf area were significant in both years. The increase in fertilizer application increased the leaf areas observed, with the highest values observed at 60 and 90 kg N/ha of NPK during the first and second cropping, respectively. The lowest leaf areas during both cropping seasons were observed in the control treatments. In 2022, fertilizer application at 60 kg N/ha of NPK produced the largest leaf area (2849.88 cm^2) that was significantly higher than the control (1602.80 cm^2) or 30 and 90 kg N/ha. In 2023, the 90 kg N/ha (1268.87 cm^2) and 60 kg N/ha (1218.69 cm^2) had significantly larger leaves than the control (772.61 cm^2). This result indicates that higher nitrogen levels enhance leaf development, though excessive fertilizer application may not always yield proportional benefits, as revealed at 90 kg N/ha in 2022. A similar result was reported, that the supply of N, P, and K improves chlorophyll content, protein synthesis, and carbohydrate accumulation in plants, which leads to an increase in leaf size [15].

Table 2. Effect of weed infestation and fertilizer application on the height and leaf area of okra plants.

Treatments	Plant height (cm)		Leaf area (cm²)	
	2022 cropping	2023 cropping	2022 cropping	2023 cropping
Weed infestation				
Weedy	118.04	85.02	1683.10b	786.41b
Weeded	118.85	87.30	2349.11a	1295.08a
SE	5.45	4.31	204.66	125.66
Fertilizer (kg N/ha)				
0	82.88b	81.13	1602.80b	772.61c
30	122.75a	91.00	2000.68b	902.81bc
60	135.13a	78.11	2849.88a	1218.69ab
90	133.02a	94.40	1611.05b	1268.87a
SE	7.71	6.10	289.44	177.72
Interactions				
Weedy × 0	79.68d	96.12a	1429.67c	694.97c
Weedy × 30	118.90ab	84.37a-c	1239.40c	609.18c
Weedy × 60	123.63ab	60.47c	2365.95a-c	864.18a-c
Weedy × 90	149.95a	99.12a	1697.38bc	977.30a-c
Weeded × 0	86.08cd	66.15bc	1775.93bc	850.25bc
Weeded × 30	126.60ab	97.63a	2761.97ab	1196.43a-c
Weeded × 60	146.63ab	95.75a	3333.82a	1573.20a
Weeded × 90	116.08bc	89.68ab	1524.72c	1560.43a
SE	10.91	8.62	409.33	251.33

Note: Mean values followed by a similar letter(s) are not significantly different at $P < 0.05$, according to Duncan's Multiple Range Test.

The interactions of weed interference × fertilizer application had a significant influence on the leaf area observed during the two cropping seasons. During the first and second cropping, the observed leaf area ranged from 1239.40 (Weedy × 30 kg N/ha) to 3333.82 (Weeded × 60 kg N/ha) and 609.18 (Weedy × 30 kg N/ha) to 1573.20 (Weeded × 60 kg N/ha), respectively. However, the weedy × 60 kg N/ha treatments during the two cropping seasons were not significantly different from the highest values observed in the plants under the Weeded × 60 kg N/ha treatments. These interactions suggest that weed control combined with moderate to high fertilizer application optimizes leaf development, which is critical for light interception for photosynthesis and overall plant vigor [30]. According to the study by Shah, et al. [34] leaf area is influenced by light intensity, nutrient levels, and water availability, which interact with genetic traits, thus promoting hormonal synthesis and enzymatic activities. Despite fertilizer applications, the values observed for leaf areas under weed-stressed conditions were not comparable with the weed treatments.

3.2. Effect of Weed Infestation and Fertilizer Application on the Dry Biomass and Fruit Weight of Okra

The dry biomass and fruit weight of okra under varying weed and fertilizer treatments varied as indicated in Table 3. In 2022, dry biomass (kg/ha) was slightly higher in Weeded conditions (5534.99) compared to weedy (5420.92), but the difference was not significant. In 2023, weedy plants had higher dry biomass (3355.74 kg/ha) than weedy ones (2943.52 kg/ha), though the difference was not significant. This indicates that weed control enhances biomass accumulation, but its impact is less pronounced than expected, possibly due to limited soil nutrient status. The improvement in plant biomass accumulation resulting from the weeded plot compared to the weedy condition was also reported by Shah and Wu [35]. This was due to the absence of competition for resources with weeds, allowing the crop adequate access to below and above-ground resources, thus leading to increased assimilate accumulation [16].

Fertilizer effects on dry biomass varied among treatments during the two cropping seasons. In 2022, higher fertilizer levels (60 and 90 kg N/ha) resulted in significantly lower dry biomass (5304.80 and 4592.60 kg/ha, respectively) compared to the control (6378.50 kg/ha), suggesting possible nutrient imbalances or toxicity at high nitrogen levels.

In 2023, dry biomass ranged from 3048.89 g/plant (0 kg N/ha) to 3249.63 kg/ha (90 kg N/ha), with no significant difference observed among the treatments. Reduced shoot biomass in crops under low soil nutrient conditions was also reported by Korav, et al. [23]. The lower soil nutrient status or higher levels, causing nutrient imbalance, leading to reduced dry biomass, was reported to be due to constrained metabolic activity [31].

Interactions between weed interference and fertilizer application showed that in 2022, weedy conditions with 0 kg N/ha produced the highest dry biomass (6840.00 kg/ha), while weedy conditions with 90 kg N/ha had the lowest (3462.96 kg/ha). This might be attributed to stress resulting from intense competition due to fertilizer application that promoted weed growth or hormonal imbalances leading to a reduction in photosynthetic efficiency, thus, lower biomass accumulation [16]. According to Makinde, et al. [36], the variety of okra (LD88) has a canopy structure that suppresses weeds; thus, at lower nutrient status, the plant was able to cope with weeds. However, increasing the soil nutrients promoted weed interference, causing more detrimental effects to the crop, leading to biomass reduction.

This assertion is supported by Burke, et al. [37] and Ibironke and Akinrinola [12] that improving soil nutrient conditions reduces maize and garden egg resilience to weed interference. However, 90 kg N/ha had similar dry biomass accumulation compared to the highest response observed during the two cropping seasons.

Table 3. Influence of weed infestation and fertilizer application on the dry biomass and fruit weight of okra.

Treatments	Dry biomass (kg/ha)		Fruit weight (kg/ha)	
	2022 cropping	2023 cropping	2022 cropping	2023 cropping
Weed infestation				
Weedy	5420.92	2943.52	28043.81b	16054.69
Weeded	5534.99	3355.74	31860.98a	17068.30
SE	227.33	164.01	1158.64	1029.96
Fertilizer (kg N/ha)				
0	6378.50a	3048.89	22949.37c	16372.00
30	5635.90ab	3177.41	34298.89b	15107.49
60	5304.80bc	3122.59	39499.85a	16386.56
90	4592.60c	3249.63	23061.48c	18379.93
SE	80.36	231.96	1638.56	1456.59
Inter				
Weedy × 0	6840.00a	2469.63b	30084.44c	13563.26bc
Weedy × 30	4425.93cd	3301.48ab	29720.89c	18177.04ab
Weedy × 60	4695.56b-d	2618.52b	33005.63bc	10351.78c
Weedy × 90	5722.22a-c	3384.45ab	19364.29d	22126.67a
Weeded × 0	5917.03ab	3628.15a	15814.30d	19180.74ab
Weeded × 30	6845.93a	3053.33ab	38876.89b	12037.93c
Weeded × 60	5914.07ab	3626.67a	45994.07a	22421.33a
Weeded × 90	3462.96d	3114.81ab	26758.67c	14633.19bc
SE	30.10	328.04	2317.28	2059.93

Note: Mean values with similar letter(s) are not significantly different at $P < 0.05$, according to Duncan's Multiple Range Test.

Fruit weight showed significant differences among the treatments in 2022 (Table 3). Weedy conditions resulted in significantly lower fruit weight compared to weeded conditions. In 2023, fruit weight (kg/ha) was slightly higher (6.31%) in weeded conditions than in weedy conditions, but the difference was not significant. This result, where weedy conditions produced lesser fruit compared to the Weeded plot, is similar to Mhlanga, et al. [19], Yadav, et al. [21] and Patel, et al. [20] reports on maize, cowpea, and okra, respectively. Although the variation in the extent of yield reduction between the two years could be due to the intensity of competition for resources with okra, depending on specific weed species or densities [22, 38].

In 2022, the 60 kg N/ha produced the highest fruit weight (39499.85 kg/ha), while in 2023, 90 kg N/ha yielded the highest (18379.93 kg/ha), though differences were not significant in both years. A similar result was also reported by Makinde, et al. [36] that fertilizer increases enhance okra yield. The lower fertilizer levels limit photosynthetic efficiency and resource allocation to reproductive structures, reducing photosynthate supply and hormonal stimulation (cytokinin and auxin), leading to lower fruit yields due to decreased flower retention and pod development [15]. This variability suggests that optimal fertilizer levels depend on soil fertility and seasonal conditions, as reported by Rao, et al. [39] and Purwanto and Alam [6].

For the effect of weed interference × fertilizer interactions on fruit weight, weeding with 60 kg N/ha yielded the highest (45994.07 kg/ha), while weeding with 0 kg N/ha was the lowest (15814.30 kg/ha). In 2023, weeding with 0 kg N/ha and weeding with 90 kg N/ha produced higher dry biomass and fruit weight, respectively. These findings highlight the complex interplay between weed management and fertilizer application, where certain combinations may unexpectedly reduce or enhance yield components. According to Makinde, et al. [36] the LD88 okra variety has the potential to suppress weeds at the appropriate spacing. However, under improved soil conditions, which also aid weed growth, the interaction of okra with weeds is more intense, further limiting okra performance in the weed-crop competition [15, 16, 33]. However, this study revealed that under weed-stressed conditions, 60 and 90 kg N/ha in 2022 and 2023, respectively, were effective in enhancing comparatively high yields with the Weeded condition.

3.3. Effect of Weed Infestation and Fertilizer Application on Weed Cover Score and Survival of Okra Plants

Weed cover (as a percentage of ground cover) and okra survival rates varied significantly between the weedy and weeded conditions during the two cropping seasons (Table 4). In 2022, weedy plots had significantly higher weed cover (61.66%) than weeded plots (49.58%). The same trend was observed, with significantly lower weed cover observed in the weedy plot compared to the weed-free plot during the 2023 growing season. This indicates that weeding minimizes weed infestation, thus limiting competition for available resources with the cultivated crop. A similar observation was made by Makinde, et al. [36] that the canopy structure of the LD88 okra variety suppresses weeds.

Fertilizer effects were significantly different among treatments for weed cover scores. In 2022, 60 kg N/ha resulted in the highest weed cover (64.17%), significantly more than 30 kg N/ha (42.50%). In 2023, 60 kg N/ha again had significantly high weed cover (57.50%), while the other treatments had lower and similar values. This suggests that moderate to high nitrogen levels may promote weed growth, complicating weed management. The findings in this study negate Adigun, et al. [40] report that increasing N application results in a lower weed cover score due to improvement in crop growth.

The interaction results showed that weedy conditions had relatively higher weed cover scores, with 60 kg N/ha having the highest weed cover in both years (73.33% in 2022, 66.67% in 2023), while weedy conditions with 30 kg N/ha had the lowest (38.33% in 2022, 33.33% in 2023). In these results, an increase in fertilizer application further increased the weed cover score. Variation in weed cover score in plants treated with different fertilizer levels under weedy and Weeded conditions arises from nutrient availability influencing weed growth and competitiveness, where higher fertilizer levels enhance weed vigor through increased photosynthetic rates and hormonal activity (e.g., cytokinin and auxins), leading to higher weed cover in weedy conditions [13, 40, 41]. In weedy conditions, regular weed removal minimizes weed cover regardless of fertilizer levels, while in weedy conditions, lower fertilizer levels limit nutrient availability, reducing weed growth and cover due to constrained metabolic activity. This observation corroborates the result for biomass accumulation reduction with increasing fertilizer application.

Table 4. Influence of weed infestation and fertilizer application on the weed cover score and missing stands of okra.

Treatments	Weed cover score (%)		Missing stands (%)	
	2022 cropping	2023 cropping	2022 cropping	2023 cropping
Weed infestation				
Weedy	61.66a	50.83a	39.12	49.37a
Weeded	49.58b	40.42b	22.92	30.62b
SE	1.16	1.29	0.38	1.15
Fertilizer (kg N/ha)				
0	57.50b	40.83b	37.96a	52.50a
30	42.50c	40.83b	19.91b	27.92c
60	64.17a	57.50a	31.02a	37.92b
90	58.33b	43.33b	35.19a	41.67b
SE	1.64	1.82	0.86	1.63
Inter				
Weedy × 0	48.33cd	41.67bc	44.44ab	66.67a
Weedy × 30	45.00e	48.33b	23.15bc	30.83cd
Weedy × 60	73.33a	66.67a	50.93a	55.83b
Weedy × 90	58.33b	46.67bc	37.96b	44.17c
Weeded × 0	50.00c	40.00cd	31.48c	38.33c
Weeded × 30	38.33e	33.33d	16.67cd	25.00de
Weeded × 60	48.33de	48.33b	11.11d	20.00e
Weeded × 90	43.33e	40.00cd	32.41bc	39.17c
SE	2.32	2.58	1.98	2.30

Note: Mean values with similar letter(s) are not significantly different at $P < 0.05$, according to Duncan's Multiple Range Test.

Weeded conditions also improved survival rates, with 77.08% in 2022 compared to 60.88% in weedy plots, and in 2023 (Table 4). Weeded plots had significantly lower stand loss (30.62%) than weedy ones (49.37%). These results confirm that weed control reduces competition and enhances plant survival, critical for maintaining crop stands [38].

Survival rates varied significantly among the fertilizer treatments, with 30 kg N/ha yielding the highest survival in 2022 (80.09%) and the lowest stand loss in 2023 (27.92%), indicating that moderate fertilizer application may optimize plant health without excessively boosting weeds. The report by Adigun, et al. [40] corroborated this finding that an increase in nitrogen fertilizer reduced weed cover.

Survival varied significantly and was highest in Weeded plots with 60 kg N/ha (88.89% in 2022) and lowest stand loss in Weeded plots with 60 kg N/ha (20.00% in 2023). These findings emphasize that combining weed control with moderate fertilizer application minimizes weed pressure and maximizes plant survival. The intense competition for nutrients, light, and water, especially at lower fertilizer levels, weakens plants, thus increasing their susceptibility to environmental stress due to reduced metabolic support and impaired defence mechanisms, resulting in stand loss [30, 32, 40].

3.4. Correlations Between Yield Components and Weed Factors

Pearson correlation coefficients between the yield and yield component (Fruit weight and dry shoot biomass), weed cover score, and stand loss, for 2022 and 2023, are presented in Table 5. In 2022, fruit weight was strongly correlated with dry shoot biomass, indicating that vigorous vegetative growth supports higher yields. Stand loss was negatively correlated with fruit weight and dry shoot biomass, showing that plant mortality significantly reduces yield potential. Weed intensity had a weak correlation with fruit weight or dry biomass, suggesting a limited direct impact on yield.

Table 5. The relationships between the yield components, weed intensity, and stand loss in okra production during two cropping seasons.

Parameters	Fruits weight	Dry shoot biomass	Weed cover (%)
2022 cropping			
Dry shoot biomass	0.78**		
Weed cover	0.01	0.06	
Stand loss	-0.89**	-0.74**	0.13
2023 cropping			
Dry shoot biomass	0.74**		
Weed cover	0.12	0.20	
Stand loss	0.15	0.37**	0.21

Note: * and ** represent significant correlations at $p<0.05$ and $p>0.01$, respectively.

In 2023, fruit weight was significantly correlated with dry shoot biomass as observed in 2022, substantiating the link between plant vigor and yield (Table 5). Weed cover score also had a weak positive correlation with fruit weight and dry shoot biomass, reaffirming that plant survival primarily affects vegetative growth and yield. However, stand loss was strongly correlated with dry shoot biomass (0.37**), suggesting that plant survival primarily affects vegetative growth in this season. The relationship could be attributed to lesser competition for space, giving room for maximum interception of light for photosynthesis, leading to biomass accumulation. The effect was an increase in average yield per plant, but a lower yield per hectare.

4. Conclusion

The data collectively highlight the complex interactions between weed management, nitrogen fertilizer application, and okra performance. Weed control consistently improved leaf area, survival rates, and reduced weed cover, but its impact on plant height, biomass, and fruit weight varied by season. Fertilizer application, particularly at 30–60 kg N/ha, enhanced plant height and leaf area, but high levels (90 kg N/ha) reduced biomass or yield, possibly due to nutrient imbalances or increased weed competition. The correlation analysis underscores that stand loss is a critical factor reducing yield potential, while weed intensity has a limited direct impact on fruit weight but influences vegetative growth. These findings suggest that effective weed control combined with moderate fertilizer application at 60 kg N/ha optimizes okra growth and survival while minimizing weed pressure.

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