



ENHANCING THE PERFORMANCE OF BEETROOT (*Beta vulgaris* L.) AS AFFECTED BY POPULATION DENSITY AND DECOMPOSED MUNICIPAL WASTE IN JOS, PLATEAU STATE, NIGERIA

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ABSTRACT

A field trial was carried out to study how population density and decomposed municipal waste (MW) affect the growth and yield of beetroot (*Beta vulgaris* L.). The experiment was laid out factorially in a Randomised Complete Block Design (RCBD) consisting of three different population densities (50, 33, and 25 plants per square meter) and four application rates of MW (0, 5, 10, and 15 tons per hectare). The result showed highly significant effects from both factors ($P < 0.001$). The findings showed that lowering the population density from 50 to 25 plants per square meter resulted in a significant increase in a number of growth metrics: leaf area increased from 979.71 to 1229.67 cm², leaf count increased from 9.75 to 12.83, leaf area index improved from 2.45 to 6.15, and leaf area duration increased from 26.59 to 78.37 days. Furthermore, economic production increased from 8.37 to 10.27 tons per hectare, root weight per plot increased from 5.02 to 6.17 kg, and root diameter increased from 4.72 to 5.62 cm. With a peak value of 15 tons per hectare (leaf count of 13.00 and economic yield of 10.15 t/ha), the application of MW continuously improved all these parameters. The superiority of MW was highest at the lowest density, according to significant interactions ($P < 0.05$). With the maximum economic production (11.50 tons per hectare), leaf area duration (83.53 days), and root diameter (6.67 cm), a combination of 25 plants per square meter and 15 tons per hectare of MW produced the best results. These results demonstrate that beet growth and yield can be maximized by combining low population density with moderate to high levels of decomposed municipal trash, offering a sustainable method of nutrient management for effective beet production.

Keywords: Beetroot, Population, Density, Municipal, Waste.

INTRODUCTION

Beetroot, *Beta vulgaris* L., is a biennial root crop from the Chenopodiaceae family. It is valued not only for its edible roots and leaves, but for what those parts contain. They are rich in vitamins A and C, key minerals like iron and potassium, and betalains, a group of antioxidant compounds. Together these nutrients offer anti-inflammatory, antihypertensive, and detoxifying benefits, which is why beetroot is increasingly regarded as a functional food with potential to help prevent chronic diseases. In Nigeria, beetroot is still a minor crop compared to the staples, but it has real potential in the highlands. The Jos Plateau is emerging as a particularly suitable zone. With its cool temperate climate, fertile volcanic soils, and elevation of about 1,280 meters above sea level, it already supports Irish potato, which accounts for over 90% of Nigeria's supply, along with maize and other vegetables. Agriculture here is diverse but largely smallholder and rain-fed, providing about 75% of employment and a major share of the state's GDP (Afrimash, 2023)

The Plateau receives 1,260 to 1,400 mm of rainfall annually, mostly from April to October, with temperatures of 15 to 25°C. That combination is ideal for beetroot, which does best in mild, non-tropical conditions and well-drained loamy soils with a pH of 6.0 to 7.5. Soils are predominantly ferruginous tropical types derived from biotite-granites and basalts. They are naturally fertile, but they are also under pressure from nutrient depletion, overgrazing, and erosion, which affects up to 31% of farmland (Theunissen, 2010).

Because beetroot adapts relatively well to these conditions, it offers a strong option for crop diversification, food security, and income in a region where agriculture still operates at only about 20%



of its potential due to infrastructure and climate constraints (Yadav & Garg, 2009). Recent trials in Nigeria, including Minna and Jos and other similar agro-ecologies, have recorded yields up to 32 t ha⁻¹ with good management, using varieties such as 'Detroit Dark Red', 'Action', and 'Ruby Red' [Ibrahim, 2025; Varga et al., 2021]. Planting in the cooler window of October to February improves performance, and organic inputs like poultry manure at 10 t ha⁻¹ have been shown to significantly boost yields (Ibrahim, 2025). Plant population density is a critical factor in beetroot performance. It directly affects growth, yield, and quality. Higher density can improve resource use efficiency through quicker canopy closure and better weed suppression, often raising total yield. But beyond a point, crowding intensifies competition for light, water, and nutrients, leading to smaller roots and lower marketable quality (Ijaz et al., 2023; Sinta, 2021).

Optimum density varies with variety and environment. Some studies (Sinta, 2021; Kikkert et al., 2010) report yields as high as 58.6 tons per hectare at 335,000 plants per hectare, while lower densities of 65,000 to 85,000 plants per hectare favour larger roots in fertile soils. For beetroot generally, 30 to 40 cm between rows and 8 to 10 cm within rows is often recommended. In Nigeria, where beetroot is still new, these figures need to be fine-tuned for local volcanic soils and climate to improve economic returns and reduce problems like bolting in warmer spells. Evidence suggests that densities around 66,666 to 100,000 plants per hectare, combined with adequate nutrition, can maximize root yield, which underscores the need for site-specific trials (Sinta, 2021). Sustainable soil management is especially important on the Jos Plateau, where intensive cultivation is accelerating degradation. Organic amendments such as decomposed municipal waste (DMW) provide an eco-friendly alternative to synthetic fertilizers. They improve soil structure, water retention, nutrient cycling, and microbial diversity, while also diverting waste from landfills (Zaccardelli et al., 2021; Kabiru, 2024). Composted municipal solid waste, including fruit and vegetable residues, yields nutrient-rich material with C/N ratios of 13 to 25, suitable for mineralization and slow release of nitrogen (1.5–2.8%), phosphorus [0.5–1.0%], and potassium (0.8–1.5%) (Theunissen et al., 2010). Almaramah et al. reported that DMW compost can increase vegetable yields by 20–30% and could replace up to 21% of mineral fertilizers in urban agriculture by 2025, while cutting environmental impacts, including greenhouse gas emissions by up to 130% in optimized systems. Frequency of application does influence trace element accumulation, so annual monitoring for heavy metals is essential, but risks remain minimal when composts are properly managed. In beetroot specifically, combining goat manure at 10 t ha⁻¹ with molasses and a half dose of inorganic phosphorus has improved root biomass and nutrient uptake (Petek et al., 2019 Ibrahim, 2024)

Despite its nutritional and economic promise in Jos, where it could complement potato-dominated systems and help meet growing urban food demand, there is still little detailed work on how plant population density interacts with organic fertilizers like DMW. This gap is significant given climate change, soil erosion, and the pressing need for sustainable intensification in Nigeria. This study was therefore designed to evaluate beetroot performance under different plant population densities and varying rates of DMW application on the Jos Plateau.

MATERIALS AND METHODS

Study Area

The experiment was carried out during the 2025 rainy season at the Research Farm of the Federal College of Forestry, Jos, in Jos North Local Government Area, Plateau State, Nigeria (9°52'N, 8°53'E; 1,280 m above sea level). The area has a tropical rainy climate. Annual rainfall averages about 1,260 mm, concentrated between April and October, with temperatures typically ranging from 15 to 25°C.

Soils are ferruginous tropical - well-drained, reddish-brown, and developed from biotite-granites. They are low to medium in fertility, rich in iron and aluminum, with pH between 5.8 and 6.5 (Theunissen, 2010). Pre-planting analysis showed organic carbon at 1.2%, total nitrogen at 0.08%, available phosphorus at 12 mg kg⁻¹, and exchangeable potassium at 0.15 cmol kg⁻¹.



Treatments and Experimental Design

The treatments consisted of three (3) plant population densities (50 plants m⁻² at 20 cm × 10 cm; 33 plants m⁻² at 30 cm × 10 cm; 25 plants m⁻² at 40 cm × 10 cm) and four (4) rates of decomposed Municipal Waste (0 t ha⁻¹; 5 t ha⁻¹; 10 t ha⁻¹; 15 t ha⁻¹). These were factorially combined and arranged in a randomized complete block design (RCBD) with three replications. Decomposed municipal waste (DMW) was sourced from the college composting facility, decomposed for 60 days using bin composting with food/vegetable waste, poultry litter, and cow dung (1:1:1 ratio), achieving a C/N ratio of 13.6 and pH 6.9. Compost nutrient content: N 1.78%, P 0.55 ppm, K 1.005%. The plot size was 3 m × 2 m, with 1 m alleys. Land was ploughed, harrowed, and ridged. DMW was incorporated two weeks before planting. Beetroot seeds ('Detroit Dark Red') were sown directly at 1–2 cm depth in May 2025. Weeding was manual at 3 and 6 weeks after sowing (WAS). No pesticides were applied, as pest pressure was low.

Data Collection

Data were collected from 5 randomly tagged plants on the following parameters:

Leaf Count: Number of leaves per plant was determined by counting from the 5 randomly selected plants from the net plot

Leaf Area (cm²): The leaf area of the sampled plants was taken by measuring the length and Width and later extrapolated as proposed by Gohari and Rouhy (1993) in Ibrahim (2025) using a set of two linear regression equations for estimating the leaf area of beet plants based on leaf length and width. The specific equations are;

For leaves with a length (L) greater than 16 cm;

$$Y = -201.26 + 12.40L + 13.35W \dots\dots\dots (i)$$

For leaves with a length (L) less than 16 cm;

$$Y = 6.47 + 0.84L \times W \dots\dots\dots (ii)$$

Leaf Area Index (LAI): Measures the total leaf surface area per unit ground area. The total leaf area is measured by adding up the individual leaf areas of all leaves in a given plant

$$LAI = \frac{\text{Total Leaf Area of a Plant}}{\text{Ground area occupied by the plant}} \dots\dots\dots (iii)$$

Leaf Area Duration (LAD): It was obtained by adding up the leaf area at different times to see how much total leaf area the plant has over a period. The LAD is expressed in days.

$$LAD = \frac{(LAI_2 + LAI_1)(t_2 - t_1)}{2} \dots\dots\dots (iv)$$

Where;

LAI1 = LAI at the first stage

LAI2 = LAI at the second stage, (t₂ - t₁) = Time interval in days

Root (Bulb) Diameter (cm): Measured at harvest using a Vernier caliper.

Root (Bulb) Weight/Plot (kg): All Beets in a plot were harvested and weighed using a digital weighing balance

Total Yield Per Hectare (kg/ha): Beet yield will be determined by weighing the beet (bulb) in each plot using digital balance and the yield will be computed into kilograms from the individual plots and later extrapolated to tons per hectare.

$$\text{Yield Per Hectare} = \frac{\text{Yield (kg)}}{\text{Plot Size (m}^2\text{)}} \times 10,000 \text{ (m}^2\text{)} \dots\dots\dots (ii)$$

Statistical Analysis

Data collected were subjected to analysis of variance (ANOVA) using a factorial model in RCBD using XLState statistical package. Means were separated using Tukey's Method at p < 0.05.

RESULTS

Effects of Population Density and Decomposed Municipal Waste on Growth Parameters of Beetroot

Table 1 revealed the key impacts of two factors: population density (measured in plants per square meter) and the amount of decomposed municipal waste (in tons per hectare) on four growth



metrics: leaf count, leaf area (in cm²), leaf area index (LAI), and leaf area duration (in days). Findings showed that as population density decreased from 50 to 25 plants/m², all growth parameters improved significantly ($p < 0.000$). The highest leaf count was recorded at 25 plants/m² (12.83), followed by 33 plants/m² (11.83), while the lowest was at 50 plants/m² (9.75). This suggests that lower density gives plants more room to grow leaves by reducing competition for resources. Leaf area followed the same trend, expanding from 979.71 cm² at 50 plants/m² to 1,229.67 cm² at 25 plants/m². The wider spacing clearly favours better canopy development. Leaf Area Index (LAI) more than doubled, from 2.45 at 50 plants/m² to 6.15 at 25 plants/m², indicating greater leaf coverage per unit ground area and potentially higher photosynthetic capacity. Leaf Area Duration also increased sharply, from 26.59 days at 50 plants/m² to 78.37 days at 25 plants/m², showing that leaves remained functional for much longer at lower densities. Lower population density promoted vegetative growth, likely because of reduced intra-plant competition for light, water, and nutrients. The main effects of municipal waste were also clear. Increasing application from 0 to 15 t/ha significantly improved growth parameters ($p < 0.001$) (Table 1).

Leaf count rose from 9.11 at 0 t/ha to 13.00 at 15 t/ha. The intermediate rates of 5 and 10 t/ha did not differ from each other, but both were higher than the control. Similarly, leaf area increased from 1,034.94 cm² at 0 t/ha to about 1,145.55 cm² at 15 t/ha, with 10 and 15 t/ha performing best. This confirms that the waste acts as an organic amendment that improves soil fertility. Also, leaf area index jumps from 3.66 at 0 t/ha to 4.26 at 15 t/ha, with no significant difference among 5, 10, and 15 t/ha. The leaf area duration of the plant from 43.57 days at 0 t/ha to 52.01 days at 15 t/ha, again increasing after 5 t/ha. This showed that decomposed municipal waste enhanced growth, possibly by providing nutrients (e.g., nitrogen, phosphorus) and improving soil structure.

Table 1: Effects of population density and Decomposed Municipal Waste on Growth Parameters of beetroot

Treatment	Leaf Count	Leaf Area (cm ²)	Leaf Area Index	Leaf Area Duration (Days)
Population Density (Plants/m ²)				
50	9.75 ^c	979.71 ^c	2.45 ^c	26.59 ^c
33	11.83 ^b	1090.91 ^b	3.49 ^b	41.25 ^b
25	12.83 ^a	1229.67 ^a	6.15 ^a	78.37 ^a
SE±	0.22	21.08	0.09	1.39
P – Value	<0.000**	<0.000**	<0.000**	<0.000**
Municipal Waste (t/ha)				
0	9.11 ^c	1034.94 ^b	3.66 ^b	43.57 ^b
5	11.55 ^b	1101.55 ^{ab}	4.08 ^a	49.41 ^a
10	12.22 ^b	1118.33 ^a	4.12 ^a	49.98 ^a
15	13.00 ^a	1145.55 ^a	4.26 ^a	52.01 ^a
SE±	0.26	24.35	0.11	1.60
P – Value	<0.000**	<0.001**	<0.000**	<0.000**
Interaction PD * MW				
P – Value	<0.018*	0.369 ^{NS}	0.028*	0.027*
CV (%)	4.79	4.69	5.95	6.97

Means followed by same letter(s) are not significantly different using Tukey's Method at $p < 0.05$

Interaction of Population Density and Decomposed Municipal Waste on Growth Parameters of Beetroot

Significant interaction exists for leaf count ($p < 0.018$), LAI ($p = 0.028$), and leaf area duration ($p = 0.027$), but not for leaf area ($p = 0.369$ NS, non-significant). This means the combined effect of density and waste influences some parameters more than others. The application of 15 t/ha of DMW at



25 plants/m² produced the highest number of leaves (14.66), Leaf area index (6.52), and leaf area duration (83.53 days). Waste improves growth more at lower densities, indicating synergy suggesting that waste provides nutrients that are better utilized when plants have more space. The result (Table 2) indicated that, optimal growth requires balancing density and waste; high density limits waste benefits, while low density maximizes them.

Table 2: Interaction of Population Density and Decomposed Municipal Waste on Growth Parameters of Beetroot

Municipal Waste (t/ha)	Population Density (Plants/m ²)								
	Number of Leaves			Leaf Area Index			Leaf Area Duration (Days)		
	50	33	25	50	33	25	50	33	25
0	8.33 ^g	9.00 ^{fg}	10.00 ^{ef}	2.30 ^c	2.78 ^c	5.89 ^a	24.60 ^c	27.29 ^c	31.30 ^c
5	9.66 ^{efg}	12.00 ^{cd}	13.00 ^{bc}	2.49 ^c	3.59 ^b	6.15 ^a	27.17 ^c	42.57 ^b	74.80 ^a
10	10.33 ^{ef}	12.66 ^{bc}	13.66 ^{ab}	2.50 ^c	3.83 ^b	6.03 ^a	27.29 ^c	45.95 ^b	78.47 ^a
15	10.66 ^{dc}	13.66 ^{ab}	14.66 ^a	2.50 ^c	3.77 ^b	6.52 ^a	27.30 ^c	45.19 ^b	83.53 ^a
SE±	0.45			0.19			2.77		
P – Value	<0.018*			0.028*			0.027*		

Means followed by same letter(s) are not significantly different using Tukey's Method at $p < 0.05$

Effects of Population Density and Decomposed Municipal Waste on Yield Parameters of Beetroot

The main effects of two factors (Table 3) present population density (plants per square meter) and decomposed municipal waste (tons per hectare) on three yield parameters: root diameter (cm), root weight/plot (kg), and economic yield (t/ha). The main effect of population density was significant on root diameter (cm), root weight/plot (kg) and economic yield (t/ha). The result showed that, the highest root diameter was measured at lower density (25 plants/m²) to be 5.62 cm as against 33 plants/m² (4.91 cm) and 50 (4.72 cm) plants/m². This indicates that as density decreases, root diameter increases. Similarly, higher root weight/plot was recorded at lower density (25 plants/m²) as 6.17 kg and the lowest weight recorded at a population density of 50 plants/m² to be 5.02 kg. An economic yield of 10.27 t/ha was highest at 25 plants/m², followed by 9.54 t/ha at 33 plants/m², and the least yield at 50 (8.37 t/ha) plants/m².

The main effect of municipal waste on yield as shown in Table 3 revealed that, higher waste (15 t/ha) produces the largest root diameter (5.61 cm), root weight/plot (6.09 kg), and economic yield (10.15 t/ha) and the lowest 10, 5, and 0 t/ha gave the lowest root diameter, root weight/plot, and economic yield.

Table 3: Effects of Population Density and Decomposed Municipal Waste on Yield Parameters of Beetroot

Treatment	Root Diameter (cm)	Root Weight/Plot (kg)	Economic Yield (t/ha)
Population Density (Plants/m ²)			
50	4.72 ^b	5.02 ^c	8.37 ^c
33	4.91 ^b	5.72 ^b	9.54 ^b
25	5.62 ^a	6.17 ^a	10.27 ^a
SE±	0.09	0.09	0.15
P – Value	0.000**	0.000**	0.000**
Municipal Waste (t/ha)			
0	4.48 ^c	4.78 ^c	7.98 ^c
5	5.06 ^b	5.65 ^b	9.42 ^b
10	5.19 ^b	6.02 ^a	10.04 ^a
15	5.61 ^a	6.09 ^a	10.15 ^a
SE±	0.10	0.10	0.17
P – Value	0.000**	0.000**	0.000**
Interaction			
PD * MW			
P – Value	0.000**	0.002**	0.002**
CV (%)	4.25	3.80	3.82

Means followed by same letter(s) are not significantly different using Tukey's Method at $p < 0.05$

Interaction of Population Density and Decomposed Municipal Waste on Yield Parameters of Beetroot

The result from Table 4 showed that, waste at 15 t/ha (6.67 cm) promotes growth diameter more effectively at low densities (25 plants/m²). Interaction increased weight gains from larger waste (15 t/ha) when plants are spaced-out at low density (25 plants/m²) from 4.53 kg to 6.90 kg. The economic yield of beetroot was found to be at its peak (11.50 t/ha) when 15 t/ha waste was applied to 25 plants/m² plant density

Table 4: Interaction of Population Density and Decomposed Municipal Waste on Yield Parameters of Beetroot

Municipal Waste (t/ha)	Population Density (Plants/m ²)								
	Root Diameter (cm)			Root Weight/Plot (kg)			Economic Yield (t/ha)		
	50	33	25	50	33	25	50	33	25
0	4.26 ^c	4.36 ^{de}	4.80 ^{cde}	4.53 ^f	4.86 ^{ef}	4.97 ^{ef}	7.56 ^f	8.11 ^{ef}	8.27 ^{ef}
5	4.83 ^{cde}	4.96 ^{cd}	5.36 ^{bc}	4.97 ^{ef}	5.86 ^{cd}	6.13 ^{bc}	8.27 ^{ef}	9.77 ^{cd}	10.22 ^{bc}
10	4.90 ^{cde}	5.00 ^{cd}	5.67 ^b	5.20 ^e	6.00 ^{cd}	6.66 ^{ab}	8.66 ^e	10.00 ^{cd}	11.11 ^{ab}
15	4.86 ^{cde}	5.30 ^{bc}	6.67 ^a	5.40 ^{de}	6.16 ^{bc}	6.90 ^a	9.00 ^{de}	10.27 ^{bc}	11.50 ^a
SE±	0.18			0.17			0.29		
P – Value	0.000**			0.002**			0.002**		

Means followed by same letter(s) are not significantly different by Tukey's Method, $p < 0.05$

DISCUSSION

The results showed a clear pattern in how population density and decomposed municipal waste affected beetroot growth and yield. Lower densities, particularly 25 plants/m², consistently supported better vegetative growth. This was evident in higher leaf count (12.83), leaf area (1,229.67 cm²), leaf area index (6.15), and leaf area duration (78.37 days), compared to much lower values at 50 plants/m² (9.75, 979.71 cm², 2.45, and 26.59 days, respectively). With less crowding, competition for light, water, and nutrients is reduced, which allows for stronger canopy development and more efficient photosynthesis.

Yield parameters followed the same trend. Root diameter (5.62 cm), root weight per plot (6.17 kg), and economic yield (10.27 t/ha) all peaked at 25 plants/m². This indicates that sparser planting favours larger, heavier roots even though there are fewer plants per unit area. These findings agree with



earlier work showing that optimal beetroot density depends on cultivar and target root size, but generally shifts toward moderate to low densities for marketable yield. For example, denser stands of around 335,000 plants/ha (about 33.5 plants/m²) have been reported to improve overall yield and uniformity in some systems (Tuyisenge, 2017), while other studies found that higher densities reduced individual root size, with premium-sized roots (0.75–1.625 inches diameter) optimized at about 25 plants/ft², roughly 269 plants/m² depending on row arrangement (Kikkert *et al.*, 2010).

Application of decomposed municipal waste (MW) up to 15 t/ha also significantly improved growth and yield. Leaf count increased from 9.11 at 0 t/ha to 13.00 at 15 t/ha, leaf area from 1,034.94 cm² to 1,145.55 cm², and economic yield from 7.98 t/ha to 10.15 t/ha, though gains levelled off after 10 t/ha. MW appears to act as an effective organic amendment, supplying essential nutrients such as nitrogen and phosphorus while improving soil structure, water retention, and microbial activity. This is particularly valuable in nutrient-depleted soils where it enhances root development and plant vigour. Recent literature supports this: municipal solid waste (MSW) compost at 25% incorporation has been shown to improve proximate composition and nutritional value in vegetables by enriching soil organic matter and essential elements (Ashfaq *et al.*, 2024), and MSW-based composts have increased root diameter and biomass in beetroot, largely due to better phosphorus availability (Belkacemi *et al.*, 2025). In other vegetable trials, MSW compost at 40 t/acre boosted yields of beans and watermelons on sandy or calcareous soils, highlighting its role in correcting low native fertility (Ozores-Hampton, 2012).

Interactions between the two factors were also significant ($p < 0.05$ for most parameters), showing that MW benefits were amplified at lower densities. At 25 plants/m² combined with 15 t/ha MW, leaf area duration reached 83.53 days and economic yield 11.50 t/ha, far above the 27.30 days and 9.00 t/ha recorded at 50 plants/m² with the same waste rate. The synergy suggests that wider spacing allows plants to utilize added nutrients more effectively, with less competition for uptake. Similar interactions have been reported elsewhere. In beetroot, densities of 66,666–100,000 plants/ha (about 6.7–10 plants/m²) combined with 92 kg N/ha gave the highest root yields, with economic analysis favouring lower densities (Tamiru *et al.*, 2017). In sugar beet, higher densities with organic amendments can raise total root yield but may compromise individual root quality if not balanced (Varga *et al.*, 2021). Work on wheat and cotton has also shown that amendments like manure or compost improve root density and length, especially under moderate planting densities, by increasing soil organic carbon and nutrient availability (Zhao *et al.*, 2019). Overall, these interactions highlight the value of integrated management: organic amendments like MW perform best when plantings are less crowded, allowing improvements in soil health to translate directly into crop performance.

CONCLUSION AND RECOMMENDATION

In Jos, beetroot performed best at 50 plants m⁻² combined with 10–15 t ha⁻¹ DMW, reaching up to 12.26 t ha⁻¹. DMW provides an eco-friendly fertilization option that improves productivity in Nigeria's highland systems. The results therefore support sustainable practices that use MW as a low-cost, environmentally sound alternative to inorganic fertilizer, particularly at the urban-agriculture interface where waste recycling is practical. That said, long-term monitoring remains important to check for potential heavy metal accumulation from MSW, as highlighted in previous studies. Future work should look more closely at soil microbial dynamics and varietal responses to further refine these recommendations.

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