

Full Length Research Paper

Effect of organic and inorganic fertilization on the growth and yield of two *Amaranthus* accessions

Mpaballeng Ramangoele^{1,2*}, Simphiwe Mhlontlo¹, Tembakazi Silwana¹, Retief Celliers² and Bongani Kubheka^{1,3}

¹Dohne Agricultural Development Institute, Private Bag x 15, Stutterheim, 4930, Eastern Cape, South Africa.

²Department of Agriculture, Faculty of Science, Nelson Mandela University, Port Elizabeth, 6001, Eastern Cape, South Africa.

³Department of Plant Pathology, School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, Pietermaritzburg 3209, KwaZulu-Natal, South Africa.

Received 8 May, 2024; Accepted 19 July, 2024

The production of Indigenous leafy vegetables such as *Amaranthus* could address malnutrition and food insecurity experienced globally by providing the necessary nutrients needed in a balanced diet. However, escalating prices of chemical fertilizers make them unaffordable to small-holder farmers and this aggravates more threat to food security. This is because an adequate nutrient supply through fertilization is essential to achieve better growth of these vegetables. Based on this, a study aiming to evaluate the effects of organic and inorganic fertilizers on the growth and yield of two *Amaranthus* accessions (*Amaranthus hypochondriacus* L. and *Amaranthus retroflexus*) was established. The study consists of eight treatments, *A. hypochondriacus* L. + control (T1), cattle manure (T2), goat manure (T3), NPK (T4), and *A. retroflexus* + control (T5), cattle manure (T6), goat manure (T7), and NPK (T8). The experiment was laid out in a Completely Randomized Design (CRD) with four replications. Goat manure application increased the growth, fresh and dry shoot biomass yield of both *A. retroflexus* L. and *A. hypochondriacus* L. Goat manure application resulted in considerable results in growth and yield parameters and thus serves as a good alternative to small-scale farmers who may not be able to purchase inorganic fertilizer.

Key words: *Amaranthus* accessions, biomass yield, fertilization, goat manure, growth.

INTRODUCTION

Food insecurity and malnutrition have increased from about 804 million in 2016 to at least 820 million by 2019 globally leaving more than 2 billion people under

starvation (Imathiu, 2021). In Africa, feeding a fast-growing population remains a challenge that is further fueled by factors such as climate change. On the other

*Corresponding author. E-mail: mpaballeng.ramangoele@gmail.com.

side, high demand for food poses more challenges to This situation challenges the targeted achievement of 'zero hunger', the UN's Sustainable Development Goal (SDG) number two target by 2030. To achieve this, the production of food crops especially those with high nutritional value, for example, indigenous leafy vegetables, could address malnutrition and food insecurity in a more balanced manner (Asghari et al., 2015). Food security is said to have been achieved when people have access to adequate, nutritious, and safe food that can meet their dietary requirements (Islam et al., 2022). Adoption of indigenous leafy vegetables (ILVs) is one of the best ways of promoting food security by reducing overreliance on staple food crops (Asghari et al., 2015).

Indigenous vegetables are plants whose leaves, fruits, and roots are traditionally used as vegetables and are widely consumed in both urban and rural areas, especially during famines and natural disasters (Ama et al., 2022). The ILVs contain micronutrients, vitamins and minerals and this suggests that these vegetables could offer solutions to combating 'hidden hunger'. There is a large number of indigenous vegetables across the globe, hence it is important to identify a few of them based on their nutritional value, ease of cultivation, drought tolerance, pest and disease resistance (Aworh, 2018).

Some of the most popularly cultivated and consumed ILVs in the African context include cowpea (*Vigna unguiculata*), jute mallow (*Corchorus carinata*), leafy amaranth (*Amaranthus* species), pumpkin (*Cucurbita moschata*), African nightshade (*Solanum scabrum*), African kale (*Brassica carinata*), slender leaf (*Crotalaria brevidens*) and spider plant (*Cleome gynandra*) among others (Imathiu, 2021). ILVs grow well in harsh and marginal environments that are unsuitable for staple food crops (Conti et al., 2019) hence consideration of their cultivation could be ideal. Mabhaudhi et al. (2017) identified thirteen indigenous vegetables that were a priority for the farmers in South Africa. A wide variety of ILV is consumed in the globe especially in the sub-Saharan Africa and many parts of Asia (Baldermann et al. 2016). Most ILVs are produced within a very short time after the first rains, and are usually harvested three to four weeks after emergence (Shayanowako et al., 2021). *Amaranthus* species are among the ILVs that are commonly found growing in the wild in South Africa (Maseko et al., 2017) that offer high nutritional value. Indigenous vegetables, though underutilized, offer economic advantages due to their uniqueness and suitability to the environments in which they are grown including their low input requirements (Mabhaudhi et al., 2016).

Amaranthus spp. belong to the Caryophyllales order, Amaranthaceae family, Amaranthoideae subfamily, and *Amaranthus* genus (Mlakar et al., 2009). The *Amaranthus* genus includes around 60 species of which 40 are native to the Americas and the rest to Africa, Asia,

and Europe, with 17 species with edible leaves and 3 grain amaranths (The genus *Amaranthus* has been cultivated as a leafy vegetable crop worldwide since ancient times (Zhigila et al., 2014).

Though *Amaranthus* is a low-management crop that can grow in poor soils, improved yields can be realized through fertilization (Dlamini et al., 2020). Poor soil fertility is one of the limiting factors to crop production as soils found in the Eastern Cape are deficient in macronutrients such as N and P whilst S, Mn, Zn, Cu, and B are readily available. The continuous cultivation of the soil without sufficient nutrient replenishment is one of the major causes of the low nutrient status of the soil (Bvenura and Afolayan, 2014).

In addition, Law-Ogbomo and Osaigbovo (2017) noted that the low fertility status of the soil could arise from various environmental factors such as erosion, desertification, and intensive cultivation. Alternative use of accessible and sustainable fertilizers such as organic fertilizers could curb challenges related to decreased soil fertility while also improving health problems for consumers and environmental hazards. Fertilizers are applied to leafy vegetables to ensure a continuous supply of nutrients. Organic and inorganic fertilizers are the major sources of improving soil fertility. Most farmers tend to use inorganic fertilizer due to its quick action on crops (Law-Ogbomo and Osaigbovo, 2017).

However, chemical fertilizer application has been linked to some negative effects on soil health and the environment (Sharada and Sujathamma, 2018).

The continuous use of synthetic fertilizers alone without the application of organic manures can result in the deterioration of soil health in terms of chemical, physical, and biological characteristics leading to a decline in crop yields (Ayinla et al., 2018). Additionally, over-dependence on synthetic fertilizers by farmers becomes an economic constraint due to the escalating costs of inorganic fertilizers. Organic fertilizers are therefore a good option as they are affordable, eco-friendly, improve soil structure and microbial mass as well as provide nutrients through mineralization (Bvenura and Afolayan, 2014; Ayinla et al., 2018). *Amaranthus* requires soil with high organic matter and adequate nutrient reserve for optimum yields hence this can sustain soil fertility and productivity (Mabhaudhi et al., 2016).

One of the ways to improve soil fertility is by maintaining its organic matter. Perhaps this can be achieved through the use of organic fertilizer. The high content of organic matter in organic fertilizers makes them steadily release their embedded soil nutrients and enhance soil quality (Adesoji, 2015). Other organic practices reported, include sheep manure application on *Amaranthus* accession (Mhlontlo et al., 2007), goat manure fertilization on *C. gynandra* and *Amaranthus hybridus* (Seeiso and Materechera, 2014), cow manure amendment on *Beta vulgaris* (Dlamini et al., 2020) and

Table 1. Mean minimum and maximum weekly temperatures recorded within the greenhouse in summer (December 2018-January 2019) and autumn (April-May 2019).

Week	Summer		Autumn	
	Mean Min T°C	Mean Max T°C	Mean Min T°C	Mean Max T°C
Week 1	16.2	30.4	14.5	29.5
Week 2	12.9	31.5	10.2	27.5
Week 3	15.9	30.9	12.6	25.5
Week 4	15.9	31.3	13.6	27.5
Week 5	16.2	30.2	13.6	26.9
Week 6	17.9	29.1	12.1	26.5

Table 2. Monthly rainfall, temperature and humidity distribution at DADI, Stutterheim during the growing season (2018-2019).

Month	Rainfall (mm)	Temperature (°C)		Humidity (%)	
		Mean Min	Mean Max	Mean Min	Mean Max
December	33.2	13.72	30.01	30.91	91.74
January	93.6	13.28	28.08	37.24	92.86
February	100.9	14.06	26.54	47.65	93.37
March	88.3	14.05	26.15	47.61	93.74
April	114.2	11.11	23.51	44.59	92.91
May	15.8	9.56	23.67	34.55	87.99
Mean	74.3	12.6	26.3	40.4	92.10

Source: ARC, Soil, Climate and Weather services.

Table 3. Physical and chemical properties of soil used in the experiment.

Property	Unit value
Sand (%)	69
Clay (%)	18
Silt (%)	13
Textural class	Sandy loam
Soil pH (KCl)	3.92
Organic carbon (%)	0.28
Phosphorus (mg/L)	14
K (mg/L)	68
Ca (mg/L)	277
Mg (mg/L)	54

District, Eastern Cape Province. Cattle and goat manures used in the study were collected from Mlungisi Township (Stutterheim) under Amathole District, Eastern Cape. NPK fertilizer {2:3:4(30) + 0.5% Zn} was sourced from a well-established agricultural supplier known as Kei Seeds based in the City of East London, Buffalo City Metropolitan Municipality, Eastern Cape.

Experimental procedure

Thirty-two 5 kg pots placed on steel tables were thoroughly cleaned

and disinfected with Spore-Kill (Didecyldimethylammonium chloride). The soil collected from the Döhne Agricultural Development Institute (DADI) agro-blocks was sieved and used as the medium in the pot experiment. Both soil and manures were analyzed to determine their nutrient composition at DADI Analytical Laboratory before the application and the results are shown in Tables 3 and 4 respectively. The soils and manures were thoroughly mixed in the pots which had holes at the bottom to allow drainage of excess water. Based on soil analysis results, NPK fertilizer, dolomitic lime cattle and goat manures were applied in 5 kg of soil at the recommended rates of 2.22, 4.44, 432 and 486 g,

Table 4. Chemical properties of organic fertilizers used in the experiment.

Manure	N%	P%	Ca%	Mg%	K%	Zn (mg/kg)	Fe (mg/kg)	Na (mg/kg)	Cu (mg/kg)	Mn (mg/kg)
Goat	0.7	0.08	3.79	0.82	3.61	468	17203	4902	9	949
Cattle	0.1	0.09	0.88	0.68	1.39	108	6805	186	161	440

respectively which were equivalent to 1, 2, 219 and 194 t.ha⁻¹.

Soil, manure, and dolomitic lime were incorporated and kept for one month prior to transplanting of seedlings whereas NPK fertilizer {2:3:4(30) + 0.5% Zn} was applied at transplanting. Lime was only applied in NPK and control treatments.

The seeds were collected in June 2018, sun-dried for one week, threshed, winnowed, and kept in an airtight bottle container at room temperature for five months. Seed viability testing was done 21 days prior to the experiment. The seeds were first sown in the nursery using seedling trays filled with growing media known as hygrotech and watered twice daily. Proper nursery management practices were carried out to obtain healthy and uniform seedlings. After four weeks in the nursery, four seedlings of two *Amaranthus* accessions were randomly picked and transplanted in pots of their respective treatments. Seedlings were watered twice daily using a watering can to ensure effective and maximum growth until harvesting six weeks after transplanting. Data collection for plant height, stem girth, and the number of leaves was recorded weekly starting from one week to six weeks after transplanting (WAT). Harvesting was done 6WAT when plants were at the vegetative stage. The fresh and dry mass of the harvested plant shoots were measured.

Experimental design

The experiment was arranged in a Completely Randomised Design (CRD) with four replications and eight treatments. It comprised of two *Amaranthus* accessions: *A. retroflexus* and *A. hypochondriacus* L. and four fertilization regimes namely: no fertilizer (absolute control), cattle manure, goat manure and NPK fertilization (positive control). The treatment combinations were then arranged as follows: *A. hypochondriacus* L. + control (T1), *A. hypochondriacus* L. + cattle manure (T2), *A. hypochondriacus* L. + goat manure (T3), *A. hypochondriacus* L. + NPK (T4), *A. retroflexus* + control (T5), *A. retroflexus* + cattle manure (T6), *A. retroflexus* + goat manure (T7), and *A. retroflexus* + NPK (T8).

Data analysis

Analysis of variance was done using Genstat® 14th edition for statistical analysis and the least significance difference (LSD) at a 5% significant level was used to separate the means.

RESULTS AND DISCUSSION

The results of the analysis of the soil used for this experiment are shown in Table 3. The texture class of the soil is sandy loam in which sand was highest (69%), followed by clay (18%) and silt was lowest (13%). This indicates that the water-holding capacity of the soil is good. The soil pH of 3.92 (KCI) suggests that the soil was

too acidic. The essential elements such as organic carbon, phosphorus potassium, and magnesium were low which shows the low fertility status of the soil which concurred with the work by Basak et al. (2022). Table 4 shows that goat manure had higher nutrient concentrations than cattle manure except phosphorus and copper which were higher in cattle manure than in goat manure.

Interactive effect of fertilization and accession on plant height of *A. hypochondriacus* L. and *A. retroflexus* grown in summer and autumn

The interaction between fertilization and accession was not significant throughout the growing period in summer (Table 5). However, T3 produced the tallest plants (78.8 cm) which was insignificantly different from T7 whilst T1 gave the shortest plants (46.6 cm). The interactive effect between fertilization and accession in autumn significantly influenced ($p < 0.05$) the plant height at 1 to 3 WAT. As shown in Table 5 T8 exhibited the tallest plants (53.3 cm) in 6 WAT while the shortest (37.7 cm) was observed from T1. *A. retroflexus* fertilized with NPK fertilizer in autumn was superior to those fertilized with goat manure, cattle manure, and control plants. This could be probably due to the nitrogen which is in ample amounts in inorganic fertilizer as it encourages vegetative growth. Nitrogen plays a role in plant cell division and cell elongation; therefore, nitrogen fertilizer has the prosperity to improve plant height (Mazumder et al., 2019). Nutrients provided by inorganic fertilizers are easily soluble in soil solutions and hence available to plants almost immediately (Anisuzzaman et al., 2021). In addition, this could be probably due to the release of nutrients that encourage vigorous plant development through effective photosynthesis (Sanni, 2016). A similar increase in plant height of *A. cruentus* due to inorganic fertilization was observed by Akinbile et al. (2016) and Charachimwe et al. (2018). These results are also consistent with the findings by Ukamaka (2023) who reported an increased plant height of *A. cruentus* fertilized with NPK fertilizer. The inferior response from plants treated with goat and cattle manures could be attributable to the fact that these manures generally contain low quantities of plant nutrients which are usually released slowly. The control plants produced the lowest

Table 5. Effect of interaction between fertilization and accession on plant height (cm) of *A. hypochondriacus* L. and *A. retroflexus* grown in summer and autumn.

Treatment	Summer						Autumn					
	Weeks after transplanting (WAT)						Weeks after transplanting (WAT)					
	1	2	3	4	5	6	1	2	3	4	5	6
T1	10.09 ^c	16.92 ^c	25.34 ^c	33.76 ^e	41.71 ^c	46.64 ^d	5.54 ^e	6.86 ^e	10.51 ^f	17.24 ^e	25.72 ^e	37.69 ^d
T2	13.96 ^{ab}	22.30 ^a	36.06 ^b	42.89 ^d	58.16 ^b	69.54 ^b	5.89 ^{de}	8.08 ^{cd}	13.79 ^d	25.26 ^d	34.09 ^{cd}	42.88 ^{cd}
T3	12.22 ^{abc}	23.52 ^a	38.37 ^a	50.13 ^b	67.67 ^a	78.79 ^a	6.86 ^{cd}	8.46 ^c	15.37 ^{bc}	27.75 ^c	37.47 ^{bc}	45.42 ^{bc}
T4	12.63 ^{abc}	24.07 ^a	39.20 ^a	46.53 ^c	54.65 ^b	61.35 ^c	7.58 ^{bc}	10.21 ^b	16.81 ^b	33.43 ^b	43.86 ^a	50.10 ^{ab}
T5	10.63 ^c	15.52 ^c	24.57 ^c	33.83 ^e	41.99 ^c	46.84 ^d	6.16 ^{de}	7.78 ^d	12.33 ^e	18.82 ^e	29.31 ^{de}	39.21 ^d
T6	14.14 ^a	22.30 ^a	37.51 ^{ab}	43.29 ^d	56.22 ^b	64.15 ^c	6.69 ^{cd}	8.22 ^{cd}	14.35 ^{cd}	24.82 ^d	36.05 ^{bc}	43.13 ^{cd}
T7	10.59 ^c	23.52 ^a	35.99 ^b	53.96 ^a	65.86 ^a	78.76 ^a	8.45 ^b	10.28 ^b	15.96 ^b	29.55 ^c	40.05 ^{ab}	46.86 ^{bc}
T8	10.95 ^{bc}	24.07 ^a	39.23 ^a	47.49 ^{bc}	56.76 ^b	61.74 ^c	10.40 ^a	12.19 ^a	21.41 ^a	37.61 ^a	45.13 ^a	53.27 ^a
LSD (0.05)	2.80	2.09	1.95	2.70	3.67	4.34	0.96	0.50	1.42	2.36	5.46	5.35
CV (%)	16.0	6.8	3.8	4.2	4.5	4.6	9.0	3.8	6.4	6.0	10.2	8.1
F-value	0.76	2.33	2.89	1.21	1.19	1.79	4.75	12.57	4.41	2.77	0.14	0.22
p-Value	0.532	0.103	0.059	0.330	0.337	0.180	0.011	0.001	0.015	0.067	0.934	0.883

The mean values within each column followed by a different letter, differ significantly ($p < 0.05$). T1 = *A. hypochondriacus* L. + control, T2 = *A. hypochondriacus* L. + cattle manure, T3 = *A. hypochondriacus* L. + goat manure, T4 = *A. hypochondriacus* L. + NPK, T5 = *A. retroflexus* + control, T6 = *A. retroflexus* + cattle manure, T7 = *A. retroflexus* + goat manure, and T8 = *A. retroflexus* + NPK.

height mainly due to the intrinsic fertility status of the experimental soil as exhibited by the soil chemical analysis to be low (Table 3). Kahu et al. (2019) reported a similar effect for control on *Amaranthus caudatus* and *Amaranthus cruentus*. Plant height is an essential factor in determining plant growth. According to Saeed (2001), an optimum plant height is claimed to be positively related to plant productivity.

Interaction between fertilization and accession on stem girth of *A. hypochondriacus* L. and *A. retroflexus* grown in summer and autumn

The summer results (Table 6) showed that the interaction between accessions and fertilization significantly ($p < 0.05$) influenced the stem girth at 6WAT. T7 resulted in plants with thicker significant stems (1.30 cm) whilst the smallest were obtained from the unfertilized control treatments (T1 and T5). These findings concurred with Ama et al. (2022) who reported an increase in the stem girth of *A. cruentus* following the application of cow dung. The interaction between accessions and fertilizer treatment in autumn was highly significant ($p < 0.001$) at 4 and 5WAT as shown in Table 6. The thickest stem girth was attained from T3 (1.05 cm) at 6WAT whilst the thinnest was observed from T1 (0.54 cm). Different plant species respond differently to soil nutrient status, fertilizer rates, and combination (Hossain et al., 2011). The superior vegetative growth observed in summer compared to autumn could be due to the day length effect, hence in

summer days are long enough and temperatures were optimal for *Amaranthus* growth hence in autumn the growth decreased with short day length and low temperatures. *Amaranthus* favors temperatures between 21 and 30°C, and most species flower when day-length is shorter than 12 h (Mhlontlo et al., 2007).

Interactive effect between fertilization and accession on the number of leaves of *A. hypochondriacus* L. and *A. retroflexus* grown in summer and autumn

Table 7 shows that in both seasons the effect of fertilization on the number of leaves was significantly different ($p < 0.05$) at 6 WAT. In summer, T3 yielded plants with the highest number of leaves (28) compared to other treatments. Plants fertilized with cattle manure compared well with the NPK fertilized plants. The better growth performance from goat manure fertilized plants could probably be due to the higher uptake of inherent nutrients in the goat manure as compared to cattle manure. Goat manure used in this study was superior to cattle manure owing to its higher quality in terms of nutrient content. The significant growth improvement observed in *Amaranthus* fertilized with goat manure could be attributable to the fact that organic manure improves the physical, chemical, and biological properties of the soil (Okoli and Nweke, 2015). Organic fertilizers not only avail nutrients to plants but also create conducive conditions corresponding to the plant by improving water-holding capacity, improving aeration, and making it easier for root

Table 6. Interactive effect of fertilization and accession on stem girth (cm) of *A. hypochondriacus* L. and *A. retroflexus* grown in summer and autumn.

Treatment	Summer						Autumn					
	Weeks after transplanting (WAT)						Weeks after transplanting (WAT)					
	1	2	3	4	5	6	1	2	3	4	5	6
T1	0.26 ^a	0.48 ^c	0.62 ^b	33.76 ^c	0.76 ^d	0.84 ^e	0.17 ^c	0.28 ^f	0.36 ^e	0.37 ^e	0.39 ^e	0.54 ^d
T2	0.34 ^a	0.58 ^{ab}	0.78 ^a	42.89 ^d	0.94 ^b	0.99 ^d	0.23 ^b	0.35 ^{bc}	0.54 ^{abc}	0.55 ^{cd}	0.56 ^{cd}	0.2b ^c
T3	0.33 ^a	0.55 ^{abc}	0.80 ^a	50.13 ^b	1.08 ^a	1.21 ^b	0.23 ^b	0.36 ^{ab}	0.55 ^a	0.81 ^a	0.83 ^a	1.05 ^a
T4	0.30 ^a	0.55 ^{abc}	0.77 ^a	46.53 ^c	0.96 ^b	0.97 ^d	0.19 ^c	0.34 ^{bc}	0.49 ^c	0.67 ^b	0.69 ^b	0.74 ^{bc}
T5	0.28 ^a	0.51 ^{bc}	0.65 ^b	33.83 ^e	0.77 ^d	0.80 ^e	0.18 ^c	0.29 ^{ef}	0.44 ^d	0.52 ^d	0.54 ^d	0.60 ^{cd}
T6	0.34 ^a	0.60 ^a	0.76 ^a	43.29 ^d	0.94 ^b	1.04 ^c	0.22 ^b	0.33 ^{cd}	0.54 ^{ab}	0.56 ^{cd}	0.57 ^{cd}	0.72 ^{bc}
T7	0.28 ^a	0.56 ^{ab}	0.77 ^a	53.36 ^a	1.05 ^a	1.30 ^a	0.27 ^a	0.37 ^a	0.55 ^a	0.58 ^c	0.59 ^c	0.82 ^b
T8	0.30 ^a	0.57 ^{ab}	0.77 ^a	47.49 ^{bc}	0.87 ^c	0.96 ^d	0.23 ^b	0.31 ^{de}	0.50 ^{bc}	0.65 ^b	0.68 ^b	0.75 ^{bc}
LSD (0.05)	0.073	0.074	0.038	0.054	0.054	0.048	0.023	0.024	0.041	0.045	0.045	0.145
CV (%)	16.4	9.2	3.5	4.2	3.9	3.2	7.4	5.0	5.6	5.3	5.13	13.3
F-Value	0.85	0.08	2.53	3.55	2.99	6.65	4.89	4.12	3.43	51.03	55.57	3.48
p-Value	0.484	0.972	0.085	0.032	0.053	0.002	0.010	0.019	0.036	0.001	0.001	0.034

The mean values within each column followed by a different letter, differ significantly ($p < 0.05$). T1 = *A. hypochondriacus* L. + control, T2 = *A. hypochondriacus* L. + cattle manure, T3 = *A. hypochondriacus* L. + goat manure, T4 = *A. hypochondriacus* L. + NPK, T5 = *A. retroflexus* + control, T6 = *A. retroflexus* + cattle manure, T7 = *A. retroflexus* + goat manure, and T8 = *A. retroflexus* + NPK.

Table 7. Effect of interaction between fertilization and accession on the number of leaves of *A. hypochondriacus* L. and *A. retroflexus* grown in summer and autumn.

Treatment	Summer						Autumn					
	Weeks after transplanting (WAT)						Weeks after transplanting (WAT)					
	1	2	3	4	5	6	1	2	3	4	5	6
T1	10.18 ^{ab}	11.79 ^c	14.00 ^{bc}	16.21 ^c	18.36 ^c	21.10 ^d	8.03 ^b	8.82 ^e	9.93 ^d	11.31 ^d	12.17 ^d	13.55 ^d
T2	10.16 ^{ab}	14.04 ^{ab}	16.05 ^a	20.30 ^{ab}	21.64 ^{ab}	23.21 ^c	9.59 ^a	10.85 ^{bc}	13.16 ^{bc}	14.16 ^c	15.14 ^b	15.55 ^c
T3	9.79 ^b	13.08 ^b	16.33 ^a	21.64 ^a	22.70 ^a	27.75 ^a	9.65 ^a	12.08 ^b	14.88 ^a	15.70 ^a	17.01 ^a	18.21 ^b
T4	10.94 ^{ab}	13.31 ^{ab}	15.18 ^{ab}	19.71 ^{ab}	20.30 ^b	22.69 ^c	9.63 ^a	10.48 ^c	13.76 ^{abc}	14.26 ^c	15.27 ^b	18.55 ^b
T5	10.68 ^{ab}	11.76 ^c	13.50 ^c	15.50 ^c	18.11 ^c	21.24 ^d	8.15 ^b	9.03 ^{de}	10.78 ^d	11.93 ^d	13.80 ^c	14.56 ^{cd}
T6	10.16 ^{ab}	14.45 ^a	16.56 ^a	20.10 ^{ab}	21.38 ^{ab}	23.36 ^c	9.41 ^a	11.31 ^{bc}	14.29 ^{ab}	15.23 ^{ab}	16.44 ^a	17.94 ^b
T7	9.80 ^b	13.85 ^{ab}	15.40 ^a	21.14 ^{ab}	21.83 ^{ab}	24.65 ^b	9.71 ^a	13.38 ^a	14.50 ^a	15.92 ^a	17.10 ^a	18.24 ^b
T8	10.19 ^{ab}	13.50 ^{ab}	15.45 ^a	19.16 ^b	21.66 ^{ab}	22.24 ^{cd}	9.00 ^a	10.16 ^{cd}	12.88 ^c	14.46 ^{bc}	15.44 ^b	21.17 ^a
LSD (0.05)	1.3	1.1	1.3	1.9	1.5	1.3	0.8	1.2	1.2	0.8	0.9	1.2
CV (%)	8.3	5.9	5.7	6.6	4.9	3.7	6.3	7.8	6.2	4.0	3.9	4.6
F-value	1.64	0.39	1.18	0.06	1.79	6.42	0.70	1.29	2.87	1.05	3.51	4.68
p-Value	0.211	0.763	0.342	0.981	0.180	0.003	0.565	0.305	0.061	0.391	0.033	0.012

The mean values within each column followed by a different letter, differ significantly ($p < 0.05$). T1 = *A. hypochondriacus* L. + control, T2 = *A. hypochondriacus* L. + cattle manure, T3 = *A. hypochondriacus* L. + goat manure, T4 = *A. hypochondriacus* L. + NPK, T5 = *A. retroflexus* + control, T6 = *A. retroflexus* + cattle manure, T7 = *A. retroflexus* + goat manure, and T8 = *A. retroflexus* + NPK.

penetration (da Silva, 2019). Improved growth and yield of tomatoes were observed due to goat manure application as reported by (Ojeniyi et al., 2007). Similarly, Seeiso and Materechera (2014) reported an increase in growth and yield parameters of *A. hybridus* and *C. gynandra* due to organic fertilization. The leaves are the

primary photosynthetic organ of a plant; therefore, changes in leaf number might affect the overall performance of *Amaranthus* (Miah et al., 2013). Manures are a source of almost all the necessary nutrients required for plant growth including N, P, and K, thus enriching the soil with organic matter, maintaining soil

Table 8. The interactive effect between fertilization and accession (*A. hypochondriacus* L. and *A. retroflexus*) on fresh biomass yield (g plant⁻¹) in summer.

Treatment	Leave	Stem	Shoot
	g plant ⁻¹		
T1	19.21 ^d	30.89 ^d	50.09 ^e
T2	24.66 ^c	44.12 ^c	67.28 ^c
T3	38.14 ^b	85.08 ^b	123.25 ^b
T4	21.56 ^{cd}	31.95 ^d	53.63 ^{de}
T5	19.56 ^d	31.58 ^d	51.13 ^e
T6	22.68 ^{cd}	37.67 ^d	60.35 ^{cd}
T7	44.12 ^a	93.15 ^a	137.27 ^a
T8	21.57 ^{cd}	33.73 ^d	55.30 ^{de}
LSD (0.05)	3.38	6.15	8.50
CV (%)	8.7	8.6	7.7
F-Value	4.43	4.04	4.48
p-Value	0.015	0.020	0.014

The mean values within each column followed by a different letter, differ significantly ($p < 0.05$). T1 = *A. hypochondriacus* L. + control, T2 = *A. hypochondriacus* L. + cattle manure, T3 = *A. hypochondriacus* L. + goat manure, T4 = *A. hypochondriacus* L. + NPK, T5 = *A. retroflexus* + control, T6 = *A. retroflexus* + cattle manure, T7 = *A. retroflexus* + goat manure, and T8 = *A. retroflexus* + NPK.

fertility, and increasing yield (Kahu et al., 2019). However, in autumn the highest significant number of leaves (21) was produced from T8 whilst the least was obtained from T1. *A. retroflexus* fertilized with NPK outperformed those fertilized with goat manure, cattle manure, and control plants. This could be due to the release of nutrients that encourage robust plant growth through effective photosynthesis. The considerable variation in the growth response of *A. hypochondriacus* L. and *A. retroflexus* to fertilization in this study could be attributable to genetic differences in their ability to use fertilizers (Hossain et al., 2011).

Interactive effect between fertilizer application and accession in fresh biomass yield of *A. hypochondriacus* L. and *A. retroflexus* grown in summer

A significant effect ($p < 0.05$) between fertilization and accession on the fresh leaf, stem, and shoot biomass yield was observed (Table 8). The highest fresh leaf biomass (44.12 g plant⁻¹), fresh stem biomass (93.15 g plant⁻¹), and fresh shoot biomass (137.27 g plant⁻¹) yield were observed from T7. The lowest shoot biomass was attained from T1 (50.09 g plant⁻¹). A remarkable increase in fresh biomass yield obtained from *A. retroflexus* fertilized with goat manure might be due to the application of organic manure as fertilizers, which provided growth-regulating substances and improved the physical, chemical, and microbial properties of the soil

(Anisuzzaman et al., 2021). These findings concurred with Seeiso and Materechera (2014) who observed an increase in fresh leaf biomass on *C. gynandra* and *A. hybridus* due to goat manure fertilization. The lowest yield was observed from the control treatments. The increase in growth and yield parameters of the fertilized plants over the control confirms the importance of fertilization.

Effect of fertilization on dry biomass yield of *Amaranthus* accessions in summer and autumn

In both seasons, goat manure fertilization resulted in a highly significant effect ($p < 0.001$) on dry biomass yield (Figure 2a and b). Goat manure fertilization exhibited a superior effect on the leaf, stem, and shoot dry biomass in both summer and autumn. In summer (Figure 2a), the highest leaf dry biomass yield recorded 8.24 g plant⁻¹ whilst in autumn it recorded 1.73g plant⁻¹ (Figure 2b) yet CM and NPK compared well with the unfertilized control. Dry stem and dry shoot biomass yield follow the same trend. Yields obtained from CM and NPK fertilized plants differed insignificantly. The unfertilized control gave the lowest yield in both seasons. *Amaranthus* accessions assessed were more highly responsive to organic fertilization than inorganic fertilization. A substantial increase in dry biomass yield observed from goat manure-fertilized plants both in summer and autumn was attributable to the effect of organic fertilizers in encouraging growth and, as a result, maximizing yields. Organic fertilizers are important for increasing biomass in

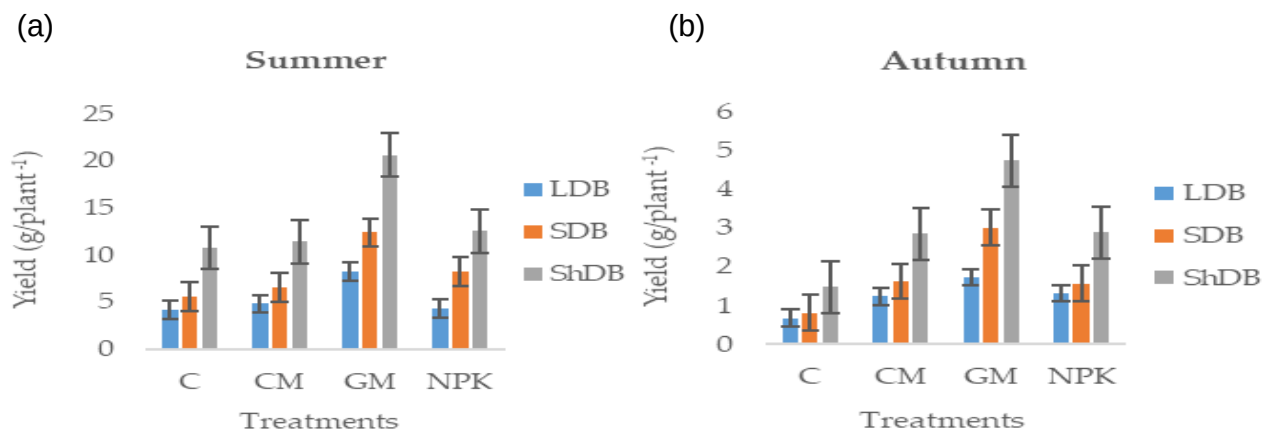


Figure 2. Fertilization effect on dry biomass yield of *Amaranthus* accessions in summer (a) and autumn (b). LDB = Leaf Dry Biomass, SDB = Stem Dry Biomass, ShDB = Shoot Dry Biomass, C= Control, CM = Cattle manure, GM = Goat manure, NPK = Chemical fertilizer.

vegetables due to their ability to fix some of the physical, chemical, and biological properties of the soil to enable the absorption of nutrient elements to become more optimal (Seeiso and Materechera, 2014; Okoli and Nweke, 2015).

Organic fertilizers gradually release nutrients into the soil, which is responsible for the enhancement of water-holding capacity, pH, and organic matter of soil, which in turn improves the yield (Suge et al., 2011). Also, an increased yield of okra due to organic fertilization was reported (Abdulmalik et al., 2015). In contradiction, Onyango et al. (2012) reported the lowest yield obtained from plants treated with manure compared to those treated with mineral fertilizer.

Conclusions

Based on the findings of the study, it may be concluded that organic fertilizers in the form of goat manure have the potential to increase the growth and yield parameters of *Amaranthus*. It was discovered that *A. hypochondriacus* L. fertilized with goat manure resulted in a significant response in plant height, leaf number, and dry biomass than the other treatments in summer. These findings justify the use of organic fertilizer over chemical fertilizer owing to improved vegetative growth and development. Goat manure application produced substantial results in terms of growth and development and thus serves as a good alternative to small-scale farmers who may not be able to purchase inorganic fertilizer. The study showed that *A. hypochondriacus* L. outperformed *A. retroflexus* in most of the growth and yield parameters in both seasons. It is therefore recommended that *A. hypochondriacus* L. be grown and fertilized with goat manure as this increases the growth and yield of *Amaranthus* while also maintaining

and improving soil health.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

- Abdulmalik SY, Isah MK, Bello OB, Ahmood J (2015). Effects of time of application and rates of poultry manure on the performance of okra (*Abelmoschus esculentus* L.) in southern guinea savanna ecology of Nigeria. *Journal of Organic Agriculture and Environment* 3:84-94.
- Adesoji AG (2015). Potentials and Challenges of Inorganic and Organic Fertilizers in Nutrient Management. *Fertilizer Technology I Synthesis*. Studium Press LLC, Houston, TX, USA. pp. 77-100.
- Akinbile CO, Adefolaju S, Ajibade FO (2016). Effect of organic and inorganic fertilizer on the growth and yield of *amaranthus curenthus* in Akure, Ondo State, Nigeria. In *Proceedings of the 37th Annual Conference and Annual General Meeting—Minna*.
- Ama S, Padi F, Serwaa G, Nyame B, Appiah F, Adu F (2022). Effects of Three Different Rates of Application of Cattle Dung on the Growth and Quality of Two Traditional Leafy Vegetables (*Amaranthus Cruentus* and *Corchorus Olitorius*). *Journal of Food Technology* 9(4):176-193.
- Anisuzzaman M, Rafii MY, Jaafar NM, Izan Ramlee S, Ikbal MF, Haque MA (2021). Effect of organic and inorganic fertilizer on the growth and yield components of traditional and improved rice (*Oryza sativa* L.) genotypes in Malaysia. *Agronomy* 11(9):1830.
- Asghari G, Palizban A, Bakhshaei B (2015). Quantitative analysis of the nutritional components in leaves and seeds of the Persian Moringa peregrina (Forssk.) Fiori. *Pharmacognosy Research* 7(3):242.
- Aworh OC (2018). From lesser-known to super vegetables: the growing profile of African traditional leafy vegetables in promoting food security and wellness. *Journal of the Science of Food and Agriculture* 98(10):3609-3613.
- Ayinla A, Alagbe IA, Olayinka BU, Lawal AR, Aboyeji OO, Etejere EO (2018). Effects of organic, inorganic and organo-mineral fertilizer on the growth, yield and nutrient composition of *Corchorus Olitorius* (L.). *Ceylon Journal of Science* 47(1):13-19.
- Baldermann S, Blagojević L, Frede K, Klopsch R, Neugart S, Neumann

- A, Ngwene B, Norkewit J, Schröter D, Schröter A, Schweigert FJ (2016). Are neglected plants the food for the future? *Critical Reviews in Plant Sciences* 35(2):106-119.
- Basak BB, Sarkar B, Saha A, Sarkar A, Mandal S, Biswas JK, Wang H, Bolan NS (2022). Revamping highly weathered soils in the tropics with biochar application: What we know and what is needed. *Sci. Total Environ* 822:153461.
- Bvenura C, Afolayan AJ (2014). Growth and physiological response of *Solanum nigrum* L. to organic and/or inorganic fertilisers. *Journal of Applied Botany and Food Quality* 8:87.
- Charachimwe R, Tembo L, Mhungu S (2018). Response of pig weed *Amaranthus cruentus* to organic and inorganic fertilizers. *International Journal of Agronomy and Agricultural Research* 13(1):1-10.
- Conti MV, Campanaro A, Coccetti P, De Giuseppe R, Galimberti A, Labra M, Cena H (2019). Potential role of neglected and underutilized plant species in improving women's empowerment and nutrition in areas of sub-Saharan Africa. *Nutrition reviews* 77(11):817-28.
- da Silva AP, Nabais CN, Gomes DC (2019). The influence of the type and dose of manure toward growth and development of plants pakcoy mustard (*Brassica chinensis* L.). *International Journal of Development Research* 9(01):25222-25228.
- Dlamini SN, Masarirambi MT, Wahome PK, Oseni TO (2020). The Effects of organic fertilizers on the growth and yield of *Amaranthus (Amaranthus hybridus* L.) grown in a lath house. *Asian Journal of Advances in Agricultural Research* 12(1):1-10.
- Dumani A, Silwana TT, Mpambani B, Celliers RP, Mbangcolo MM (2021). Effect of bioslurry effluent on growth, biological yield and nutritional content of Swiss chard (*Beta vulgaris* L.). *Journal of Agricultural Extension and Rural Development* 13(3):173-181.
- Hossain MA, Araki H, Takahashi T (2011). Poor grain filling induced by waterlogging is similar to that in abnormal early ripening in wheat in Western Japan. *Field Crops Research* 123(2):100-108.
- Imathiu S (2021). Neglected and underutilized cultivated crops with respect to indigenous African leafy vegetables for food and nutrition security. *Journal of Food Security* 9(3):115-125.
- Islam Z, Kokash DM, Babar MS, Uday U, Hasan MM, Rackimuthu S, Essar MY, Nemat A (2022). Food security, conflict, and COVID-19: perspective from Afghanistan. *The American journal of tropical medicine and hygiene* 106(1):21.
- Kahu JC, Umeh CC, Achadu AE (2019). Effects of Different Types of Organic Fertilizers on Growth Performance of *Amaranthus caudatus* (Samaru Local Variety) and *Amaranthus cruentus* (NH84/452). *Asian Journal of Advances in Agricultural Research* 9(2):1-2.
- Law-ogbomo KE, Osaigbovo A (2017). Growth and yield performance of jute mallow (*Corchorus olitorius* L.) in response to nitrogen levels of poultry manure in an ultisols environment. *Journal of Organic Agriculture and Environment* 5(2).
- Mabhaudhi T, Chimonyo VG, Chibarabada TP, Modi AT (2017). Developing a roadmap for improving neglected and underutilized crops: A case study of South Africa. *Frontiers in plant science* 8:300777.
- Mabhaudhi T, O'Reilly P, Walker S, Mwale S (2016). Opportunities for underutilised crops in southern Africa's post-2015 development agenda. *Sustainability* 8(4):302.
- Masarirambi MT, Sibandze N, Wahome PK, Oseni TO (2012). Effects of kraal manure application rates on growth and yield of wild okra (*Corchorus olitorius* L.) in a sub-tropical environment. *Asian Journal of Agricultural Science* 4(1):89-95.
- Maseko I, Mabhaudhi T, Tesfay S, Araya HT, Fezzehazion M, Plooy CP (2017). African leafy vegetables: A review of status, production and utilization in South Africa. *Sustainability* 10(1):16.
- Mazumder NI, Sultana T, Paul PC, Noor MM (2019). Influence of NPK fertilizer and spacing on growth parameters of onion (*Allium cepa* L. Var. BARI piaz-1). *Research in Agriculture, Livestock and Fisheries* 6(1):19-25.
- Mhlontlo S, Muchaonyerwa P, Mkeni PN (2007). Effects of sheep kraal manure on growth, dry matter yield and leaf nutrient composition of a local amaranthus accession in the central region of the Eastern Cape Province, South Africa. *Water Sa* 33(3).
- Miah MY, Roy PK, Islam MS, Fazal KI (2013). Stem amaranth yield in response to organic manuring. *Journal of Environmental Science and Natural Resources* 6(2):19-23.
- Mrakar SG, Turinek M, Joko M, Bavec M, Bavec F (2009). Nutrition value and use of grain amaranth: potential future application in bread making. *Agricultura* 6(4):43-53.
- Nemat A (2022). Food security, conflict, and COVID-19: perspective from Afghanistan. *The American journal of tropical medicine and hygiene* 106(1):21.
- Ogbomo L, Osaigbovo AU (2017). Influence of plant population and cattle manure application on productivity and profitability of early maturing maize (*Zea mays* L.) in humid ultisol. *Journal of Organic Agriculture and Environment* 5(1):15-22.
- Ojeniyi SO, Awodun MA, Odedina SA (2007). Effect of animal manure amended spent grain and cocoa husk on nutrient status, growth and yield of tomato. *Middle-East Journal of Scientific Research* 2(1):33-6.
- Okoli PS, Nweke IA (2015). Effects of different rates of poultry manure on growth and yield of *Amaranthus (Amaranthus, cruentus)*. *Journal of Agriculture and Veterinary Science* 8:73-76.
- Onyango CM, Harbison J, Imungi JK, Shibairo SS, van Kooten O (2012). Influence of organic and mineral fertilization on germination, leaf nitrogen, nitrate accumulation and yield of vegetable amaranth. *Journal of plant nutrition* 35(3):342-365.
- Saeed IM, Abbasi R, Kazim M (2001). Response of maize (*Zea mays*) to nitrogen and phosphorus fertilization under agro-climatic conditions of Rawalokol, Azad Jammu and Kaslim and Kashmir. *Pakistan Journal of Biological Sciences* 4:949-952.
- Sanni KO (2016). Effect of compost, cow dung and NPK 15-15-15 fertilizer on growth and yield performance of *Amaranth (Amaranthus hybridus)*. *International Journal of Advances in Scientific Research* 2(3):76-82.
- Seeiso MT, Materechera SA (2014). Biomass yields and crude protein content of two African indigenous leafy vegetables in response to kraal manure application and leaf cutting management. *African Journal of Agricultural Resources* 9(3):397-406.
- Sharada P, Sujathamma P (2018). Effect of organic and inorganic fertilizers on the quantitative and qualitative parameters of rice (*Oriza sativa* L.). *Current Agriculture Research Journal* 6(2):166.
- Shayanowako AI, Morrissey O, Tanzi A, Muchuweti M, Mendiando GM, Mayes S, Modi AT, Mabhaudhi T (2021). African leafy vegetables for improved human nutrition and food system resilience in Southern Africa: A scoping review. *Sustainability* 13(5):2896.
- Suge JK, Omunyan ME, Omami EN (2011). Effect of organic and inorganic sources of fertilizer on growth, yield and fruit quality of eggplant (*Solanum Melongena* L.). *Archives of Applied Science Research* 3(6):470-479.
- Ukamaka EU (2023). Effects of planting method and different nutrient sources on the yield, growth and quality of *Amaranthus* species in Northern Guinea Savanna Zone of Nigeria. *Russian Journal of Agricultural and Socio-Economic Science* 9(141).
- Zhigila DA, Yuguda UA, Akawu JJ, Oladele FA (2014). Palynomorphs and floral bloom as taxonomic characters in some species of the genus *Amaranthus* I(Amaranthaceae). *Bayero Journal of Pure and Applied Sciences* 7(2):164-168.