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Effects of basal fertilizer type and application rates on growth and yield of grain amaranth in Kwekwe, Zimbabwe

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ABSTRACT

This research examines the effects of basal fertilizer type and application rates on the growth and yield of grain amaranth in Kwekwe, Zimbabwe. Grain amaranth is a neglected crop of tremendous nutritional and agronomic qualities. However, knowledge on basal fertilizer rates and types to use in grain amaranth production is limited in Zimbabwe; therefore, this experiment was carried out to investigate this limitation at Midlands State University (MSU), Kwekwe farm, from December 2022 to April 2023 using a 3x5 factorial design, consisting of 3 basal fertilizer types and 5 application rates. The basal fertilizer types were compound C (6:24:20), compound D (7:14:7) and compound L (6:15:12). The application rates were 0 (control), 90 kg/ha, 180 kg/ha, 270 kg/ha, and 360 kg/ha. Data was collected on plant height, stem girth, Leaf Area Index (LAI), biomass yield, grain yield from the main head (panicle weight), grain yield produced by side suckers, 1000 seed weight, and overall grain yield. There was no significant difference ($p>0.05$) in amaranth biomass, plant height, and stem girth due to the effects of basal fertilizer type. Compound C at a rate 360 kg/ha, produced the highest grain yield of 2.671 tons /ha, while the 0 kg/ha control produced the lowest grain yield of 0.659 t/ha. Treatment interaction effects were significant only for total grain yield, grain yield of the main panicle, suckers, and 1000 seed weight. Compound C produced the highest results on most parameters, significantly outperforming compounds D and L. However, at higher rates of basal fertilizer application, all 3 compound fertilizers turned out to be equally good. In conclusion, we recommended that, for efficient production of grain amaranth, compound C should be used at 270 kg/ha.

Contribution/Originality: This research is very original and contributes tremendously to the generation of new knowledge around grain amaranth basal fertilizer management aspects of application rates and type, which falls in an area that has not been previously researched and published on extensively in Zimbabwe.

1. INTRODUCTION

Grain amaranth (Amaranthus spp.) is a nutritious, early-maturing, high-yielding, and drought-tolerant crop that is able to survive harsh climatic conditions (Bisikwa, Walukano, Ugen, Muyinda, and Muyonga, 2020). Grain amaranth can be grown several times a year, and it tolerates drought, heat stress, high soil acidity, and salinity, and it is a low-input crop that easily adapts to a wide range of agro-ecological zones (Chaudhary et al., 2024). Grain amaranth is adapted to marginal lands, has high genetic diversity and phenotypic plasticity, and has tolerance to high temperatures, drought, and nutrient-poor soils, qualities that render it a valuable crop that can be cultivated under adverse conditions (Gomes, Mesquita, Nunes, & Innecco, 2024). The ability to survive harsh environmental conditions makes grain amaranth a crop that can potentially be produced effectively by resource-poor farmers resident in marginal areas of Zimbabwe. Grain amaranth is a high-nutritional-value crop that contains high protein, vitamins, minerals, and essential amino acid content. The exact nutritional characteristics of this species include the high protein content (15-18%), as well as the lysine and calcium, with averages of 5.2g and 0.37 g 100 g-1 of dry matter, respectively (Bressani, 2018). Pseudo-cereals such as quinoa, amaranth, and buckwheat are underexploited plants that are gluten-free, high in protein and other vital nutritional components, and have been known to offer beneficial health-promoting characteristics for millennia (Sattar et al., 2024).

Therefore, grain amaranth has a lot of potential in the alleviation of nutrition and food insecurity in Zimbabwe's poverty-stricken arid regions, due to its ease of production, good nutritional qualities, and fairly high grain-yielding potential. Havugimana, Nsengumuremyi, Kiseleva, and Umukwiye (2023) said that, due to their potential economic value, pseudo-cereals are now a subject of great interest among stakeholders and farmers, but unfortunately, they remain underutilized due to a lack of coherent strategies for their evaluation. Grain amaranth is a climate-smart crop whose cultivation area is potentially set to increase with the increasing awareness of the value of leafy vegetables in construction of balanced diets, particularly in areas where animal protein sources will be deficient (Adebayo & Adebayo, 2014). Currently, the few farmers in Zimbabwe's Midlands Province that have adopted grain amaranth production are experiencing relatively low yields, partly due to an unknown fertilizer management regime. Most grain amaranth farmers that are producing relatively low yields of (<1000 kg/ha) compared to amaranth potential yield range that stretches from 1500 kg/ha to 7200 kg/ha were reported by Mukuwapasi, Mavengahama, and Gerrano (2024). Failure by African farmers to achieve potential yield of grain amaranth is partly attributed to lack of information on proper agronomic practices that would maximize yields, which include fertilizer management, (Abdullahi, Haruna, Ibrahim, and Lawal (2019).

Grain amaranth is a pseudo cereal in that it exhibits characteristics that are in between cereals and broadleaved plants, and again it is a plant that produces grains but is not a grass (Gomes et al., 2024). Grain amaranth does not have a high nitrogen requirement like maize but responds well to appropriate soil amendment (Olofintoye, Abayomi, & Olugbemi, 2015). Recommendations on basal fertilizer type and application rates are not available owing to no experiments having been conducted before in Zimbabwe to answer this question. Therefore, farmers use the basal fertilizer that will be available to them, be it compound D, compound C, or compound L, at arbitrary rates. According to Tyrus and Lykhochvor (2022) one of the main reasons for incomplete realization of the genetic potential of amaranth's yielding capacity is the insufficient study of its fertilizer system's features for specific soil and climatic conditions. Therefore, to optimally produce grain amaranth, it is important to know the effect of different basal fertilizer types and rates on grain amaranth productivity. Grain yield of amaranth increased with an increase in organic soil amendments even though the values were significantly lower than the values obtained with the application of 100 kg N ha-1 inorganic fertilizer (Olofintoye et al., 2015). Optimum grain yield came with the application of nitrogen at 100 kg/ha of inorganic fertilizer, and there were significant varietal differences across different nitrogen treatments. Although grain amaranth can be produced under limited inorganic fertilizer application by resource-poor smallholder farmers, studies by Bisikwa et al. (2020) revealed grain amaranth productivity can be enhanced by the use of both organic and inorganic fertilizers, with organic fertilizers standing out as a great alternative to synthetic fertilizers in circumstances where synthetic fertilizers will be expensive or where they pose environmental issues.

In most regions of Zimbabwe, farmers produce cotton, maize, and vegetables in their cropping systems. Therefore, they will have access to all the 3 major basal fertilizer types available on the Zimbabwean market. The sources of the fertilizers are either government donations, supply by private contracting companies, or purchases, from commercial agro-dealer shops using their private funds. For cotton production, usually cotton contracting companies will supply farmers with compound L (5:18:10); to produce maize, the staple crop for food security, the same farmer will receive compound D (7:14:7) from government, to produce vegetable crops, the farmer will usually purchase compound C (vegetable fertilizer) (6:24:20) from agro-shops. In cases like this, when all the major basal fertilizers would be readily available to the farmers, farmers face a dilemma with regard to which basal fertilizer to choose and which application rate to use for their grain amaranth crop, because none of the three basal fertilizers and their application rates has been tested and recommended for grain amaranth before. It was therefore imperative to carry out this study and determine the appropriate type and application rate of basal fertilizer that is best suitable for grain amaranth production in the dry ecological zones of Zimbabwe.

2. MATERIALS AND METHODS

This field trial was done in Zimbabwe, at Midlands State University, Kwekwe Campus, in December 2022 to April 2023 cropping season. The site featured loamy soils, exhibiting the following soil parameters. Table 1 presents the status of major parameters that have a bearing on overall soil fertility at the research site.

Table 1. Soil status at the research site.

Parameter	Level measured	Status
Organic carbon	(0.37%)	Low
Available N	(48 kg/ha)	Low
Available P	(22.7kg/ha)	Low
Available K	(19 kg/ha)	Low
pH	(5.7)	Acidic

The experiment was conducted in a 3x5 factorial structure in completely randomized block design (CRBD) with 3 replications. The treatments consisted of 3 compound fertilizers, which were Compound C with an NPK ratio of (6:24:20), Compound D with an NPK ratio of (7:14:7), and Compound L, with an NPK ratio of (5:18:10). The second factor was fertilizer application rates and had the following 5 levels: 0 kg/ha (control), 90 kg/ha, 180 kg/ha, 270 kg/ha and 360 kg/ha. A Kenyan grain amaranth variety (KAM 01) was imported and used as the test variety. Plots that measured 4m in length by 2m and were prepared to a fine tilth. Inter-row spacing was set at 60 cm, and 5 rows were fitted into each and every plot. To ensure uniformity in sowing, seeds were mixed with fine sand (Bashyal et al., 2022). For data collection, the three middlemost rows are used as the net plot, with the border rows being discarded. Planting was done by direct seeding into rows on the 18th of December 2022 using a seeding rate of 8.3 kg ha-1 as used by Casini and Biancofiore (2020) using a rate of 5 kg seed per hectare. Thinning was done manually by hand, 3 weeks after planting at a spacing of 60 cm x 30 cm, to obtain a plant density of about 60,000 plants/ha, Bisikwa et al. (2020). The weeds were managed by spraying a combination of Metolachlor 1.5 Litres/ha and Atrazine 5 Litres/ha pre-emergent herbicides. The weeds that later emerged were removed by hand pulling as the experiment progressed. Grain amaranth harvesting was done on 15 April 2023.

2.1. Data Collection

Data on plant height, stem girth, leaf area index, biomass yield, sucker grain yield, head/panicle grain yield, 1000 seed weight, and total grain yield was collected and recorded by the researchers.

2.1.1. Plant Height

Plant height was evaluated by selecting 6 plants randomly in the 6 innermost lines per plot (that constituted the net plot), and the height measurement was taken from ground level to the top of each panicle head using a tape measure (Bisikwa et al., 2020). Measurements were done at 90 days after planting when further plant height increase would be insignificant, with the crop having entered the grain filling and maturation stage.

2.1.1.1. Stem Girth

Grain amaranth stem thickness was evaluated by measuring six randomly selected plants chosen from the 3 net plot lines by measuring their respective stem diameter using a digital veneer caliper at 90 days after planting. At this point, further increases in stem girth were expected to be no longer taking place as the plants were at the grain filling and maturation stage. Measurements were taken roughly 7 cm from the ground at points where the stem will usually be most thick.

2.1.2. Leaf Area Index (LAI)

Leaf-area index (LAI) per plot was measured using LICOR-BIOSCIENCES (a USA-based manufacturer of crop physiology equipment) 2200 canopy analyzer.

2.1.3. Head/Panicle Yield

All the heads were harvested and processed separately from the suckers, and the resultant grain yield was measured using a digital scale and recorded separately.

2.1.4. Sucker Yield

All the suckers were stripped down and processed separately from the main head flower. The yield of the suckers alone was weighed on the digital scale and noted down.

2.1.5. Total Biomass Yield

All the plants that constituted the net plot (approximately 42) were cut at ground level using a sharp machete and heaped together and left to dry in the open for 5 days. They were then tied together with tying wire and pliers before being weighed on an appropriate scale, and the total yield was recorded separately.

2.1.6. 1000 Seed Weight

According to Deivasigamani and Swaminathan (2018) 1000 grain weight is a seed quality since it gives an indication of seed quality in terms of seed dampness, insect infestation, seed maturation, and effectiveness of grain filling. They mentioned that if grain can be prevented from filling effectively in the field due to a killing frost, hail, drought, nutrient deficiencies, and insect damage, it can lead to poor test weight values. 1000 seeds were carefully counted manually by hand, using a toothpick, since the seed size of grain amaranth is very small. The mass of the 1000 seed sample was then measured using an Adams analytical balance. Readability: 0.0001g; and max. capacity: 210g.

2.1.7. Total Grain Yield

Total grain yield was determined by adding head/panicle yield and sucker yield described above for the various treatments. Average yield in ton/ha was obtained by simple proportion of the net plot area to the actual area of a hectare.

2.2. Statistical Data Analysis

Analysis of Variance (ANOVA) was done using GenStat 18.1, VNSi. VNSi. International Ltd is a leading UK-based company that specializes in the provision of data analysis software and consultancy in plant, animal, aquaculture, and forestry breeding domains.

Means were subsequently separated using the least significant difference (LSD) at a 5% significance level.

3. RESULTS AND DISCUSSION

3.1. Effects of Different Basal Fertilizer Application Rates on Grain Amaranth Height

Grain amaranth plant height results indicated that there was no significant interaction between basal fertilizer type and application rate ($p>0.05$). It was only the fertilizer application rates that were significantly affecting plant height ($p<0.05$). Plant height responded positively to all the basal fertilizers at all application levels. The treatment that did not receive any application of basal fertilizer produced the shortest plants that were at 1.41 cm. Grain amaranth height was increasing in almost a linear pattern from 0 kg to 180 kg across all basal fertilizer types. However, at the higher basal fertilizer application rates of 270 kg/ha and 360 kg/ha, the increase in height was not taking a simple linear form. It turned out that height value of 270 kg/ha was not significantly different from the height level of 180 kg/ha. However, the highest application rate of 360 kg/ha, was significantly different from the 180 kg/ha application rate but not significantly different from 270 kg/ha. In other words, a 360 kg application rate produced the tallest plants that measured 2.06 m, while the 270 kg per hectare application rate produced plants that were 1.99 m tall, and these two values were statistically equal. 180 kg/ha produced an average height of 1.9 m, which was statistically equal to 2.01 m of 270 kg/ha but statistically smaller than 2.06 m of 360 kg/ha.

Figure 1 presents the effects of basal fertilizer application rate on grain amaranth height.

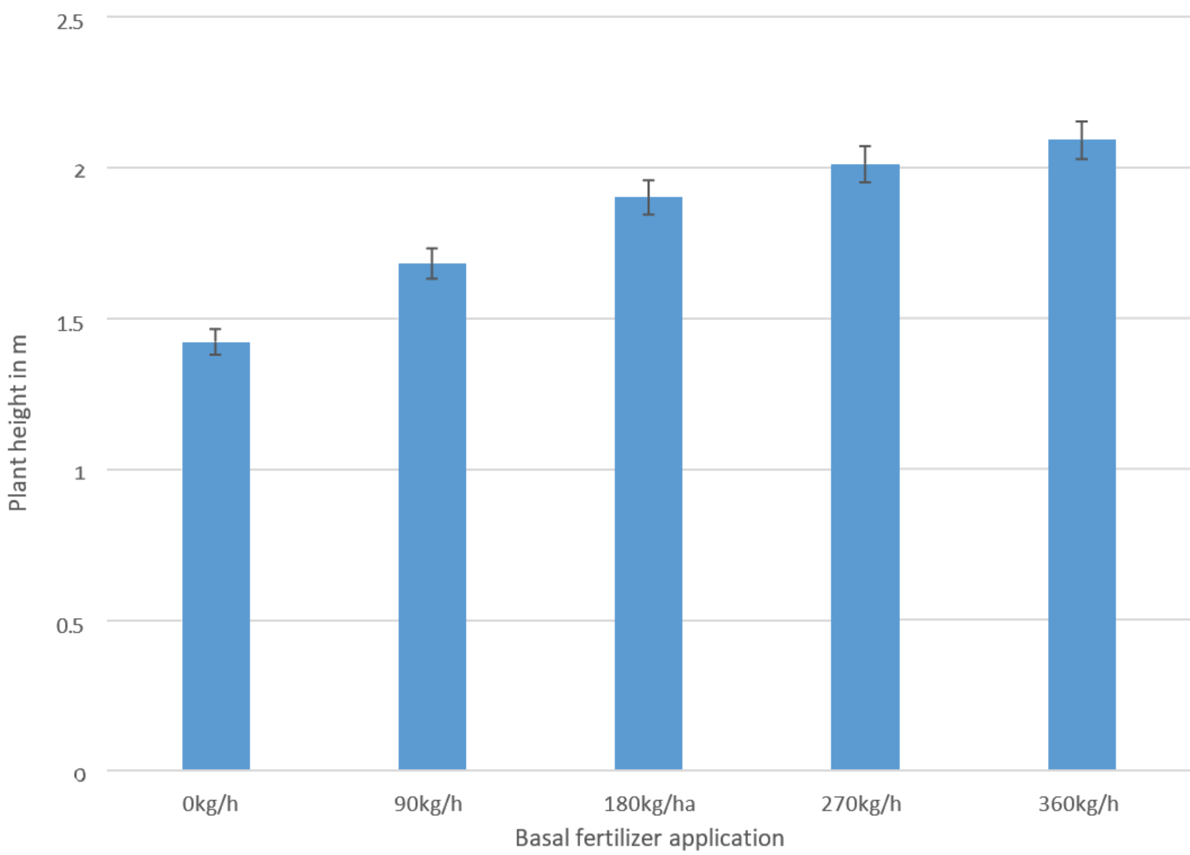

Figure 1. Depicts the effect of basal fertilizer application rate on grain amaranth height in meters (m).

3.2. Plant Height-Discussion

The positive effect of basal fertilizer rates on grain amaranth height indicated that the addition of fertilizer to the soil made nutrients available to the plant. This result is in conformity with the findings of Waizah and Onwu (2024) who attributed the positive effect on amaranth height they noticed in their trial to the release of the balanced nutrients contained in the organic fertilizer. The available macronutrients were absorbed by the plant and were in turn channeled by the plant towards vegetative growth. The same trend was also found by Adebayo and Adebayo (2014) who indicated that the highest plant height obtained in their grain amaranth trial was probably due to favorable nutrient mineralization of their fertilizer or the organic matter in the compost. The production of the shortest plants, which measured 86.4 cm on the control treatment that did not receive a basal fertilizer application, also agrees with what was reported by Adebayo and Adebayo (2014) who said that 'the control plots produced the shortest plants as they had to rely on the native soil fertility, which, from the result of chemical analysis, was deficient in nutrients.' Generally, the availability of macronutrients does promote robust plant vegetative growth that exhibits itself in more plant height, stem thickness, and tillering. However, since grain amaranth is a non-tillering crop, it converts the available nutrients into gains in height and stem thickness. In this study, the application of all types of the three basal fertilizers and any increase in their rates resulted in an increase in plant height. These findings support the results of Shehu, Bello, Haruna, and Abdullahi (2019) who noted that amaranth requires soils with high organic content and adequate mineral nutrients for rapid aerial growth. This increase in plant height due to an increase in basal fertilizer rates is most likely to have been brought about by the release of the balanced macronutrients contained in the basal fertilizers used in this study.

3.3. Stem Girth

The results indicate that the type of basal fertilizer did not significantly affect the stem girth. It was the basal fertilizer rate that had a significant effect on stem girth. Interaction between basal fertilizer type and rates was also not significant for this study. The highest average stem girth of 4.1 cm was obtained at a 360 kg/ha basal fertilizer application rate, whilst the least average stem girth of 2.63 cm was obtained at the no-application treatment. The average stem diameter of the least fertilizer application rate of 90 kg/ha was 3.12 cm, and when compared to 2.63 cm that was obtained at the no fertilizer treatment, this represents a 19% gain in stem diameter by amaranth. However, the 180 kg application rate gave an average of 3.76 cm, which represents a 43% gain in stem diameter when compared to the 2.63 cm that was produced at the control treatment that did not receive any basal fertilizer. The 270 kg/ha application rate gave a 54% gain in stem diameter as compared to the control. Stem diameter for the 360 kg/ha application rate of 4.2 cm when compared to the 4.04 cm, which was obtained at the 270 kg/ha application rate, translated to an insignificant gain in stem diameter between the two treatments.

Table 2 presents effects of basal fertilizer rates on amaranth stem diameter.

Table 2. presents effects of basal fertilizers rates on amaranth stem diameter.

Basal fertilizer rate of application	Grain amaranth stem diameter
No application (Negative control)	2.63[a]
90kg/ha	3.12[b]
180kg/ha	3.76[c]
270kg/ha	4.04[d]
360kg/ha	4.2[d]
Statistical values of interest	
Mean	3.53
Least significant difference (LSD)	0.23
Co-efficient of variation (CV)	4.2

Note: The superscripts letters a, b, c and d above represent comparisons of Amaranth biomass yield, means with different superscripts letters are considered significantly different.ly different from one another.

3.4. Amaranth Stem Girth- Discussion

The positive correlation between increase in stem thickness and increase in basal fertilizer rate applied that was observed is in agreement with the findings of Akinwumi, Adetula, Olofintoye, and Olabode (2011) who reported an increase in stem girth of grain amaranth with an increase in organic fertilizer application rates. They reasoned that this was due to nitrogen availability from the added amendments and stated that adequate nitrogen enables plants to grow at their optimum potential. These findings indicate that although grain amaranth can tolerate soil with fewer nutrients, adding synthetic fertilizers to enhance the availability of macronutrients will increase yields. Gomes et al.

(2024) also reported that when grain amaranth plants are cultivated at 40 and 30 cm plant spacing, they achieve greater stem diameter. They reasoned that at that spacing the plants were less packed and were therefore in less competition for nutrients with other plants; hence they got enough nutrients that made them support thicker stems.

3.5. Results -Leaf Area Index

The results also showed that basal fertilizer types and the interaction between basal fertilizer types and application rates had no significant effect on Leaf Area Index (LAI). It was only the basal fertilizer rate that produced a significant effect on Leaf Area Index. Leaf Area Index was increasing with every increase in application rates from 0-360 kg/ha. The highest Leaf Area Index of 3.051 was obtained at a 360 kg/ha application rate, while the least Leaf Area Index of 1.49 cm was obtained at the no-application treatment. Of interest was the fact that, at a 270 kg/ha application rate, an average LAI of 2.94 was produced, which was statistically equal to 3.051 that was produced under 360 kg/ha application rate mentioned above. The least fertilizer application rate of 90 kg/ha produced an LAI of 2.12 cm, which was statistically higher than the 1.49 that was obtained at no application but was also statistically lower than the 2.67 that was obtained at 180kg/ha fertilizer application rate.

Figure 2 presents the effect of different basal fertilizer application rates on amaranth Leaf Area Index (LAI).

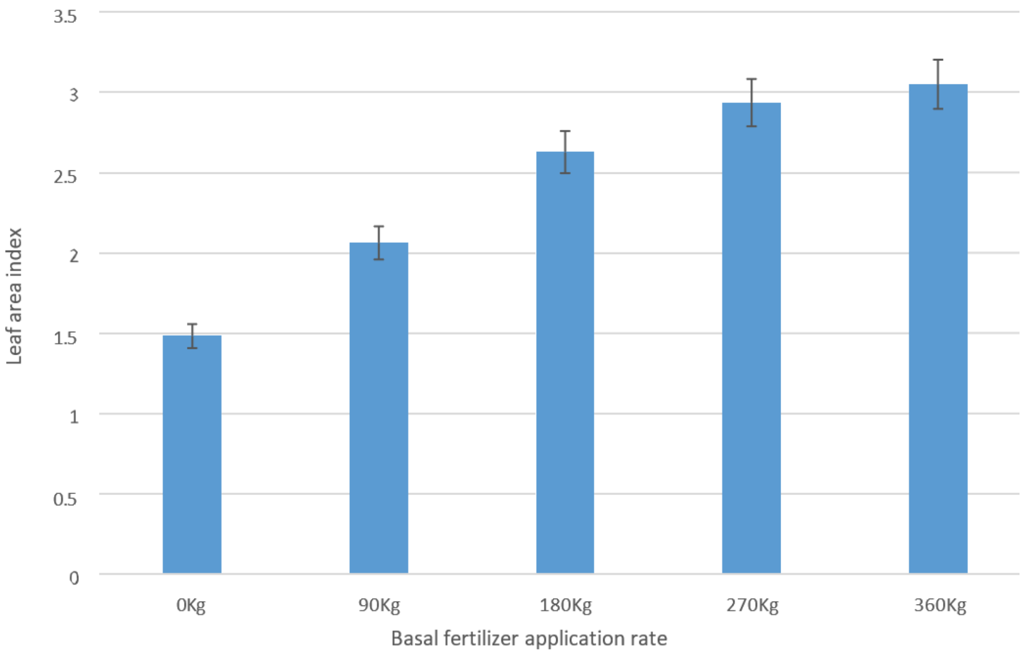

Figure 2. Depicts the effect of different basal fertilizers types and their rates on of grain amaranth LAI.

3.6. Leaf Area Index–Discussion

These findings are in agreement with the findings of Abdullahi et al. (2019) who observed a serious increase in the number of leaves with increased rates of poultry manure of up to 15 t ha^{-1} and reasoned that this rapid leaf area expansion of amaranths at treatments that had received more organic manure was an indication that grain amaranth is a crop that responds very well to the availability of nutrients to its root zone. The amaranth treatments that did not receive any basal fertilizer and that received the least rate of 90 kg/ha did not show any signs of rapid increase in leaf area index. However, at a higher rate of basal fertilizer application, a rapid increase in plant leaf area was obtained. This result showed that the macronutrients of nitrogen, phosphorous, and potassium (NPK) in the basal fertilizers that were used in this study were released and were made available to the plant such that upon their absorption, optimum growth was achieved and was proved through the production of more and larger leaves (Sanni, 2016). The control treatment, which did not receive fertilizer, produced the least Leaf Area Index of 1.34. This study agrees Waizah and Onwu (2024) who reported that fertilizers have a strong role in promoting the growth of leafy plants like amaranth through production of numerous and huge leaves that contain more chlorophyll content. The production of a higher leaf area index due to the addition of higher basal fertilizer rates is a positive agronomic thing that is expected to have a significant impact on the overall performance of the plant because the abundant leaves produced will serve as photosynthetic engine of the plant that will manufacture lots of assimilate that will be partitioned to the economic product of grain. Waizah and Onwu (2024) also showed that macronutrient availability tends to create lush or soft growth in amaranth, resulting in larger leaves and darker green plants.

3.7. Effects of Basal Fertilizer Application Rates on Grain Amaranth Biomass

The basal fertilizer type and application rate main effects significantly ($p \leq 0.01$) improved the biomass of grain amaranth in this trial, with interaction effects being not statistically significant. The biomass of the amaranth was higher than at a 360 kg application rate across all basal fertilizer types, taking an absolute value of 11.1tons/ha. The control treatment, which did not receive any basal fertilizer application, produced the lowest biomass yield of 3.47 tons/ha. The relationship between the application rates of treatments with regard to biomass yield was 360>270>180>90>0. However, the percentage gain in biomass yield varied depending on the application rate. At low-level application rates of 90 and 180 kg/ha gain in biomass yield was steep, while at 270 and 360 kg/ha the rate of gain in biomass yield, although being significant, was now slowing down. The trend was 0-90 (87% gain), 90-180 (36% gain), 180-270 (18% gain), 270- 360 (6.5% gain). In general, the highest basal fertilizer application rate gave an average biomass yield of 11.1 tons, which was a 320% increase as compared to the control treatment that did not receive a basal fertilizer application.

3.8. Effect of Basal Fertilizer Type on Amaranth Biomass

With regard to basal fertilizer type, it was observed that basal fertilizer type main effects were significantly affecting biomass yield of grain amaranth. Compound C produced the highest biomass yield of 9.31 tons/ha against 9.13 tons /ha for compound L and 8.96 tons/ha for Compound D, which was the lowest. 9.31 tons/ha of Compound C was statistically equal to 9.14 tons /ha of Compound L. However, 9.31 ton/ha of Compound C was statistically higher than 8.96 that was produced under Compound D basal fertilizer type. Interestingly, the 8.96 tons/ha produced under Compound D was also not significantly different from the 9.14 of compound L. Figure 3 depicts effects of basal fertilizer application rates on grain amaranth biomass yield in kg./ha.

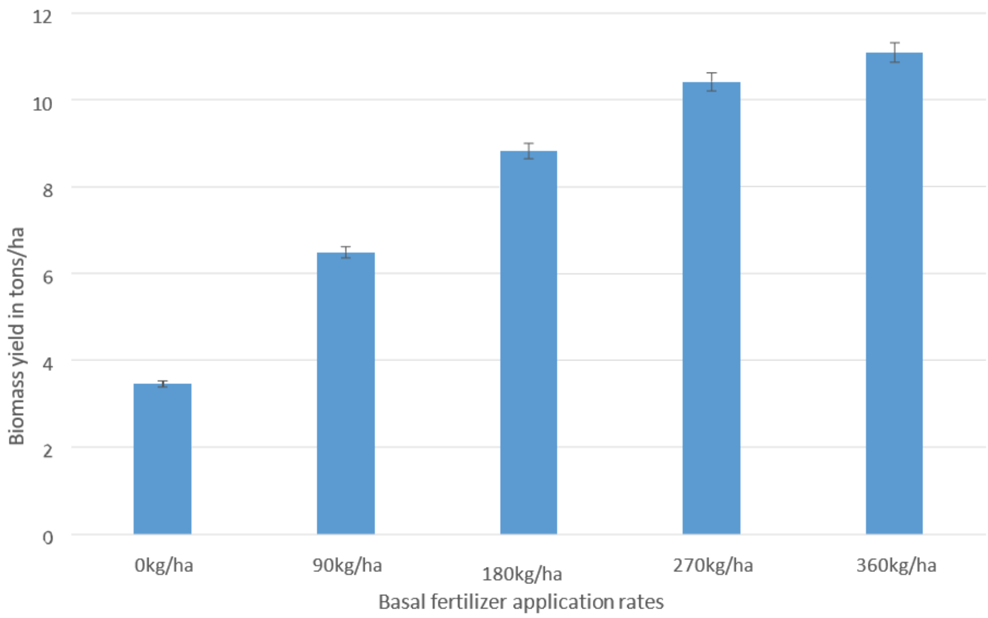

Figure 3. Depicts effects of basal fertilizer application rates on grain amaranth biomass yield.

Table 3 presents the Effect basal fertilizer types of amaranth biomass.

Table 3. Effect basal fertilizer type of amaranth biomass.

Basal fertilizer type	Grain amaranth biomass
Compound C	9.31[ab]
Compound L	9.14[bc]
Compound D	8.96[c]
Statistical values of interest	
Grand mean	9.153
LSD	0.192
CV	4.9

Note: The superscripts letters a, b and c above represent comparisons of Amaranth biomass yield, means with different superscripts letters are considered significantly different from one another.

3.9. Biomass Discussion

Although amaranth is considered a resilient crop that can tolerate abiotic stress factors of drought and poor soil fertility, this study proved that when given a sufficient supply of all the major macronutrients, amaranth exhibits a fantastic positive response. These results agree with Adebayo and Adebayo (2014) who pointed out that the increase in the number of leaves under amended and NPK fertilizer application treatments reconfirms the role of fertilizer in promoting vegetative growth in leafy vegetables like amaranth. Therefore, it means that when supplied with adequate macronutrients, amaranth will yield optimum biomass yield. Proper management of basal fertilizers turned out to be a growing strategy in terms of increasing the growth (plant height, stem diameter, plant canopy, grain yield) and biomass yield of Amaranth species. In conformity with the results of this study, Sanni (2016) found out that the application of organic fertilizers probably increased nitrogen in the soil, which positively affected leaf fresh weight and quality of the leaves because nitrogen stimulates plant vegetative growth and increases leaf area. The amaranth grown under higher rates of basal fertilizers produced plants with better height, stem diameter, and LAI, which are vegetative growth parameters that result in more biomass production. Application of basal fertilizers at higher quantities was able to supply the macro elements in sufficient quantities for ready uptake by the plants, thus prompting vigorous vegetative growth. These results agree with Abdullahi et al. (2019) who, upon observing a significant increase in the number of leaves with increased rates of poultry manure of up to 15 tons/ha, discussed that changes in the number of leaves are bound to affect the overall performance of amaranths, as the leaves serve as the photosynthetic organ of the plant, which will translate to more biomass yield at the end of the growth period.

3.10. Results- 1000 Seed Weight

It was observed that the thousand seed weight of grain amaranth was significantly affected by the interaction of basal fertilizer type and application rate ($p<0.05$). From Table 4 it is clear that grain amaranth seeds that were the heaviest weighed 1.096 g per 1000 seeds and were recorded from the treatment that was heavily fertilized by compound D at 360 kg/ha. However, there were no significant differences in the results that were obtained at the 270 kg application rate across all basal fertilizer types. The lowest 1000 seed weight of 0.628 g was found for the control treatment that did not receive any basal fertilizer. Grain amaranth 1000 seed weight increased readily with an increase in basal fertilizer application rates from 0 to 270 kg/ha irrespective of basal fertilizer type. However, the increase in 1000 seed weight beyond the 270 kg application rate did not produce significant gains for compound C and L. The interaction can be simply described as follows. Compound C at lower application levels (90 Kg/ha) was outperforming compound L, and compound L was also outperforming compound D. At 180kg/ha, compound L was now the best, followed by compound C, and the least was compound D. At 270 kg/ha all the basal fertilizers gave statistically equal values for grain amaranth 1000 seed weight. Lastly, at the highest application rate of 360 kg/ha, compound D was now the best, followed by L, and lastly compound C was the least. However, the values for compound L and C were not statistically different at a 360 kg/ha application rate. Also of interest to note is that the 1000 seed weight values of grain amaranth for compound C and L at 360 kg/ha application rates were statistically equal to those found at the 270 kg/ha application rate.

Table 4. Presents effects of basal fertilizer type and application rate on Amaranth 1000 seed/grain test weight in g.

Application rates					
Basal fertilizer type	**0 kg/ha**	**90kg/ha**	**180kg/ha**	**270kg/ha**	**360kg/ha**
Compound C	0.631^{a}	0.831^{d}	0.9077^{e}	1.0397^{g}	1.0173^{g}
Compound D	0.6297^{a}	0.7060^{b}	0.8503^{d}	1.0163^{g}	1.0960^{h}
Compound L	0.628^{a}	0.7697^{c}	0.9617^{f}	1.0110^{g}	1.0183^{g}
Grand mean	0.8718				
Sig.	<0.001				
LSD	0.049g				
CV	4.2				

Note: The superscripts letters, a, b, c, d e, f, and g above represent comparisons of Amaranth Sucker grain yield. Means with different superscripts letters are significantly different from one another.

3.11. 1000 Seed Weight-Discussion

These results agree with what was found by Patel, Pankhaniya, Bartwal, and Katara (2022) who reported significantly higher values of growth and yield attributes, viz., stem girth, spike length, number of lateral spikelets per spike, test weight, and dry matter accumulation per plant under a combination of organic and inorganic sources of plant nutrients. Under conditions of adequate supply of nutrients, at the right time, from organic and inorganic sources, optimum dry matter partitioning from the source to sink (seed) during reproductive stage of plant is enhanced, and the resultant effect will be better grain filling that produces seeds with higher test weight. Also, Gimplinger, Dobos, Schonlechner, and Kaul (2007) reported closely related findings and said that delayed sowing of grain amaranth and poor soil fertility result in a decrease in the weight of 1000 seeds. The fact that non-fertilized treatment and the one fertilized at the lowest rate of 90 kg/ha produced less value of 1000 seed weight could be attributed to the fact that a poorly fertilized crop could not support good leaves that could act as a robust photosynthetic engine of the plant that manufactures enough assimilates that could be subsequently partitioned to the grain to enhance its inherent weight.

3.12. Sucker Grain Yield Dynamics

There was significant interaction of basal fertilizer type and application rate ($p<0.05$) on sucker grain yield. A statistically significant higher sucker grain yield of 0.964 kg was obtained from the treatment that was heavily fertilized by compound C at 360 kg/ha. Results for 270 kg/ha compound C, 270 kg/ha compound D, 270 kg/ha compound L, 360 kg/ha compound D, and 360 kg/ha compound L were not statistically different. The lowest sucker grain weight, 0.398 g, was found from the control treatment that did not receive any basal fertilizer. Grain yields from the suckers/ side spikelets of the grain amaranth crop increased readily with an increase in basal fertilizer application rates from 0 to 270 kg/ha irrespective of basal fertilizer type. However, the increase in grain yield from the suckers beyond 270 kg application rate was only significant for compound C and not significant gains for compounds D and L. The interaction can be simply described as follows. Compound D was producing lower grain yields from suckers as compared to compounds C and L at a 90 kg/ha application rate. However, increase in sucker yields was positive for all the application rates for compound C, while for compounds L and C, at the higher application rates of 360 kg/ha and 270 kg/ha, sucker grain yield remained equal. At 180 kg/ha application rate, sucker grain yield of Compound C was equal to that of Compound L but higher than that of Compound D. However, the yield for compound D and compound L was statistically equal.

Table 5 presents effects of basal fertilizer type and application rate on total grain yield of amaranth in tons/ha.

Table 5. Effect of crop basal fertilizer type and application rate on total grain yield of Amaranth in tons/ha.

Basal fertilizer application rates					
Basal fertilizer type	**0 kg/ha**	**90kg/ha**	**180kg/ha**	**270kg/ha**	**360kg/ha**
Compound C	0.258[a]	0.590[b]	0.795[d]	0.891[f]	0.964[g]
Compound D	0.280[a]	0.517[c]	0.737[e]	0.911[f]	0.897[f]
Compound L	0.245[a]	0.576[b]	0.781[de]	0.887[f]	0.907[f]
Grand mean	1.907				
Sig.	<0.05				
LSD	0.051				
CV	6.7				

Note: The superscripts letters, a, b, c, d e, f, g and h above represent comparisons of Amaranth Sucker grain yield. Means with different superscripts letters are significantly different from one another.

3.13. Head/Panicle Grain Yield

Head grain weight of amaranth exhibited significant interaction of basal fertilizer type and application rate ($p<0.05$). In Table 6, it is clear that the highest grain weight from the head/panicle of 1.707 tons/ha was obtained from the treatment that was heavily fertilized by compound at C 360 kg/ha. However, this result was not significantly different from what was obtained at 270 kg/ha compound C, 270 kg/ha compound D, 270 kg/ha compound L, 360 kg/ha compound D, and 360 kg/ha compound L application rates. However, this highest yield value of 1.707 tons/ha was significantly higher than what was being obtained at the other application rates that are less than 270 kg/ha regardless of basal fertilizer type. The lowest head grain weight, 0.398 tons/ha, was found from the control treatment that did not receive any basal fertilizer. Grain yields from the main head/panicle of amaranth grain crop increased readily with an increase in basal fertilizer application rates from 0 to 270 kg/ha irrespective of basal fertilizer type. However, the increases in grain yield from the panicle beyond 270 kg application rate were no longer only significant. At a 90 kg fertilizer application rate, compounds C and L were statistically equal but significantly more than compound D. At a 180 kg application rate, compound C was higher than compound D but equal to compound L; however, this time compound L was also equal to compound D.

Table 6 presents the effects of basal fertilizer type and application rate on head grain yield of amaranth in tons/ha.

Table 6. Effect of crop basal fertilizer type and application rate on head grain yield of amaranth in tons/ha.

Basal fertilizer application rates					
Basal fertilizer type	**0 kg/ha**	**90kg/ha**	**180kg/ha**	**270kg/ha**	**360kg/ha**
Compound C	0.412[a]	1.007[b]	1.338[d]	1.703[f]	1.707[f]
Compound D	0.393[a]	0.975[c]	1.304[e]	1.670[f]	1.704[f]
Compound L	0.388[a]	1.002[b]	1.460[de]	1.702[f]	1.702[f]
Grand mean	1.907				
Sig.	<0.05				
LSD	0.0251				
CV	6.7				

Note: The superscripts letters, a, b, c, d e, f, g and h above represent comparisons of amaranth head grain yield. Means with different superscripts letters are significantly different from one another.

3.14. Results

Total Grain Yield

Total grain yield was taken as the sum of sucker grain yield and head grain yield. Significant interaction between basal fertilizer type and rate on grain yield was observed ($p<0.05$), as shown in Table 5. Amaranth grain yield increased as more basal fertilizer was applied from 0 (control) to 360 kg kg/ha for compound D. However, for compound C and L, the increase in amaranth grain yield was no longer significant beyond 270 kg/ha; that is to say, at the 360 kg/ha application rate, diminishing returns on grain yield were observed. The highest grain yield of 2.671 tons/ha was recorded when compound D was applied at a rate of 360 kg/ha. Compound C and L at 360 kg/ha produced 2.607 tons/ha and 2.601 tons/ha, respectively, and these values for compound C and compound L are at par statistically but are, however, significantly lower than the 2.714 kg/ha that was produced under compound D at 360 kg/ha. At the 270 kg application rate, (2.594 tons/ha) were produced by compound C, whilst Compound D and L produced 2.581 tons/ha and 2.589 tons/ha, respectively, and all these values were statistically equal. However, at a 180 kg/ha application rate, compound L produced 2.241 ton/ha against 2.133 tons/ha and 2.041tons/ha that were produced by compound C and compound D, respectively. At the least application rate of 90 kg/ha compound D produced the least grain yield as compared to its sister compound fertilizers of compound, C and L. Compound D produced 1.327 tons/ha, while compound C produced 1.597 tons/ha, and compound L produced 1.578 tons/ha. The grain yield values of compound C (1.597 tons/ha.) and compound L (1.578 tons/ha) were statistically equal, but were all significantly higher than those of compound D (1.327 tons/ha). At the control treatment that did not receive any basal fertilizer application, the least yields of the study of 0.657 tons/ha were obtained. In summary, it can be stated that at the lower rate of 90 kg per ha, compound C and compound L were at par but significantly above compound D. At 180 kg/ha application rate, compound L was the best, outperforming both compound C and compound D. AT 270 kg/ha and 360 kg/ha Compound D and L were at par, while compound C was superior to them all.

Table 7 presents effect of crop basal fertilizer type and application rate on total grain yield of amaranth in tons/ha.

Table 7. Effect of crop basal fertilizer type and application rate on total grain yield of Amaranth in tons/ha.

Basal fertilizer application rate					
Basal fertilizer type	**0 kg/ha**	**90kg/ha**	**180kg/ha**	**270kg/ha**	**360kg/ha**
Compound C	0.67[a]	1.597[b]	2.133[d]	2.694[h]	2.671[g]
Compound D	0.673[a]	1.492[c]	2.041[e]	2.581[f]	2.601[f]
Compound L	0.633[a]	1.578[b]	2.241[de]	2.589[f]	2.609[f]
Grand mean	1.907				
Significance level	<0.05				
Least significant difference	0.0785				
Co-efficient of variation	6.7				

Note: The superscripts letters, a, b, c, d e, f, g and h above represent comparisons of amaranth total grain yield and means with different superscripts letters are considered significantly different from one another.

3.15. Grain Yield-Discussion

The fact that amaranth grain yield levels tend to increase with an increase in fertilizer rates is in close agreement with the findings of Gitonga, Njoka, and Mushimiyimana (2018) who reported that amaranth grain performs better when intercropped with legumes than when it is grown as a sole crop with no addition of artificial fertilizers. They argued that legumes will fix nitrogen and make it available for the intercropped amaranth. From this study, it can be deduced that the addition of basal fertilizers made soil nutrients in the form of nitrogen, phosphorous, and potassium available to the grain amaranth plants, resulting in robust canopies that could support higher yields. The highest basal fertilizer rates of 360 kg/ha Compound D resulted in a significant increase in grain yield of up to 2744 kg/ha, which is within the range of Adediran, Bodunde, Salau, Shobo, and Owolabi (2019) who obtained the highest grain yield of (5357.50 kg/ha) with accession 641049 and the least grain yield of (1071.90 kg/ha) with accession 576454, and argued that grain yield in amaranth is a complex quantitative trait, considerably affected by environment, with contributions from genetic make-up. The results further support the findings of Bisikwa et al. (2020) and Salman, Sukanya, Kalyana, Murthy, and Chikkaramappa (2019) who also observed, 'an increased in grain yield as fertilizer application rates increased, and reasoned that this could have been due to enhanced leaf area index as more nitrogen was applied, thus leading to higher assimilates production' and have variously reported a linear response of grain amaranth grain yield to N fertilization. The increase in grain yield of amaranth as basal fertilizer application rates were increased is likely to be as a result of a steady supply of adequate macronutrients to the plant, with the supplied macronutrients producing a direct effect on growth performance of the crop. This positive response of grain amaranth yield to basal fertilizer application was also comparable to the findings of Abdullahi et al. (2019) upon observing a significant increase in the number of leaves with increased rates of poultry manure of up to 15 tons/ ha, and discussed that changes in the number of leaves are bound to affect the overall performance of amaranth as the leaves serve as the photosynthetic organ of the plant, hence more grain yield. The better performance of C (6:15:12) of 1.597 tons/ha at a lower rate of application of 90 kg/ha, which was significantly higher than the results of compound D and L is direct proof of the nutritional composition superiority of compound L (5:18:10) over compound C (6:15:12) and compound D (7:17:7).

4. CONCLUSION

This experiment showed that grain amaranth is a crop that readily responds to all types of compound fertilizers. While compound C fertilizer at 270 kg/ha gave the best performances in all the Amaranthus caudatus growth parameters, and therefore, it is recommendable for use in grain amaranth production in Zimbabwe, the other compound fertilizers of compound D and compound L that were tested were also good and can be adopted in the event of shortages of compound C at the market. While 270kg/ha application rate turned out to be the best application rate across all the basal fertilizer types, 180kg/ha application rate also gave fairly high yields and can be adopted under conditions that call for reduced use of synthetic fertilizers. 360kg/ha application rate produced diminishing returns, and due to higher fertilizer costs associated with this rate, it is not advisable to use this rate in grain amaranth because it supplies more nutrients than what the crop can effectively use.

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Institutional Review Board Statement: The Ethical Committee of the Midlands State University, Zimbabwe has granted approval for this study on 4 August 2021 (Ref. No. ECO197-01R).
Transparency: The authors declare that the manuscript is honest, truthful and transparent, that no important aspects of the study have been omitted and that all deviations from the planned study have been made clear. This study followed all rules of writing ethics.
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