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Effect of variety and soil fertility management on performance of grain amaranth in different agro-ecological zones in Uganda

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Abstract

Grain amaranth (*Amaranthus* spp.) is becoming an important crop in Uganda because of its nutritional value and potential grain yield. Since grain amaranth is a new crop, optimising its production requires adapted genotypes including optimum crop management practices. In this study, on-farm experiments were conducted in three agro-ecological zones represented by Kamuli, Nakasongola, and Apac districts; and one on-station experiment at Makerere University Agricultural Research Institute, Kabanyolo (MUARIK, Wakiso), to compare performance of grain amaranth varieties (*Amaranthus hypochondriacus* [cream] and *Amaranthus cruentus* [golden]) and determine influence of fertiliser application rate of (a) Urea at 0, 50, 100, 150 and 200 kg N/ha, (b) a composite fertiliser regime of urea and farmyard manure at 0:6, 25:6, 50:3, 75:1.5 and 100:0 kg N to tonnes of FYM/ha; on grain amaranth performance. Experiments were laid out as a randomised complete block design with a split-plot arrangement and replicated three times, for three seasons. Results from the single nitrogen fertiliser trial indicate that plant height, inflorescence height and grain yield of both varieties across all locations increased as more nitrogen was applied and maximum yield was achieved at fertiliser rate of 150kg N/ha. Results from the composite fertiliser trial show that maximum plant height, inflorescence height and grain yield were registered at a composite rate of 50KgN + 3 tonnes of FYM or 75kgN + 1.5 tonnes of FYM/ha for both varieties across study sites. Overall, grain amaranth performed better at MUARIK-Wakiso followed by Kamuli, Nakasongola and Apac. Also, cream variety performed better than golden variety in all locations regardless of fertiliser application rate.

Key words: *Amaranthus* spp., composite fertiliser, farmyard manure, fertiliser rate, grain yield, inorganic fertiliser, urea

Introduction

Grain amaranth (*Amaranthus* spp.) is a nutritious, short-maturing, and high-yielding crop able to survive harsh environmental conditions (Gupta and Thimba, 1992; Myers, 1996), making it a potential crop for alleviation of nutrition and food insecurity in marginal areas of Uganda. Grain amaranth has a high nutritional value due to its high protein, vitamins, minerals and essential amino acid content (Muyonga *et al*., 2008, Bressani, 2018). In Uganda, two varieties of grain amaranth identified as cream (*Amaranthus hypochondriacus*) and golden (*Amaranthus cruentus*) are being grown (Muyonga *et al*., 2008). Grain amaranth was introduced in Kamuli district in 2005 through a research partnership of Iowa State University's Center for Sustainable Rural Livelihoods (CSRL), Volunteer Efforts for Development Concerns (VEDCO), and Makerere University. Grain amaranth is becoming an important crop in Uganda, with cultivation area potentially increasing due to its nutritional qualities and potential grain yields. However, its yields are relatively low (<1200 kg/ha) compared to the potential yield of 2,500 kg/ha as its production is constrained by lack of information on agronomic practices to maximise grain production (Muyonga *et al*., 2008).

Grain yields reported in literature exhibit a large degree of variability depending on factors such as environmental (soil fertility and soil moisture), varietal genetic variation, planting density, and planting time (Putnam *et al*., 1993; Graham, 2010; Bisikwa *et al*., 2014; Love and Nyankanga, 2018). A study by Bisikwa *et al*. (2014) showed that grain amaranth can grow reasonably well in different agroecological zones of Uganda so long as optimum agronomic conditions are in place. Soil fertility needs for grain amaranth production varies significantly depending on rainfall amounts and distribution (Mposi, 1999). To grow this vegetable efficiently, it is important to know the effect of fertilisation on its yield because nitrogen is the most limiting factor under most environments (Elbehri *et al*., 1993; Pospisil *et al*., 2006). A study by Olofintoye *et al*. (2015) revealed that grain amaranth gave optimum grain yield with the application of NPK at 100 kg N/ha inorganic fertiliser and there were significant varietal differences across soil amendment treatments. Though NPK fertiliser application enhanced grain amaranth productivity, this study also indicated that use of organic fertilisers hold a great potential as an alternative, where the use of inorganic fertiliser pose environmental and expense issues.

In sub Saharan Africa (SSA), only 25% of grain amaranth farmers use either inorganic or organic fertiliser, even then, at less than the recommended rates (Nyankanga *et al*., 2012); and the remaining majority are resource limited and cannot afford inorganic fertilisers (Alemu and Bayu, 2005). Therefore, farmyard manure available at the farm level could be used. However, the use of organic manures alone may not meet crop nutrient demand because of the limited available quantities, low nutrient content and high labour demand for processing and application (Zafari and Kianmehr, 2012). Moreover, the decomposition and the mineralisation of manure is fairly slow. Hence to enhance the quality and effectiveness of organic manures, many researchers have recommended a fertiliser augmented soil enhancing strategy which involves the combined use of manures and inorganic fertilisers. This approach combines the short-term benefits of inorganic fertilisers with the long-term values of organic manures (Alemu and Bayu, 2005; Alemi *et al*., 2010). Love and Nyankanga (2018) recommended that use of organic and inorganic fertiliser combination is useful in grain amaranth production, as it ensures continuous supply of nutrients to the plant resulting in sustainable crop production. According to their study, the application of CAN at the rate of 83.25 kg/ha in combination with cow dung manure at the rate of 6.8 t/ha significantly increased yield of grain amaranth. A study in Nigeria by Sanni (2016) indicated that use of cow dung and compost improved *Amaranthus hybridus* performance and improved soil physiochemical properties.

Grain amaranth is a new crop in Uganda and optimising its production requires adapted genotypes grown at optimum crop management practices including soil fertility management. This study was therefore undertaken to determine appropriate levels of nitrogen fertiliser and a composite of inorganic plus an organic fertiliser for enhanced grain amaranth production in different agro-ecological zones in Uganda.

Materials and methods

Study area description

On-farm experiments were conducted in the districts of Kamuli, Nakasongola and Apac, representing three different agro-ecological zones in Uganda (Kyoga Plains, Lake Victoria Crescent, and North Western Savannah Grasslands, respectively). An on-station experiment was conducted at Makerere University Agricultural Research Institute Kabanyolo (MUARIK), in Wakiso district. Kamuli district is located in Eastern Uganda at 00°56’N 33°05’E/01°20’N/33°20’E and at an elevation of 1,100m above sea level with annual average temperature of 22^{o}C and mean annual rainfall of 1,350mm. During the experimental period, 1327mm annual rainfall was received in 2011 and 489mm during the months of September-December, 2010 and mean temperature was 23.2°C. The area was characterised by clay loam soils with acidic pH (5.4), deficient of soil organic matter less than 3%, but with desirable levels of total nitrogen (0.18%), high phosphorus (10.19%) and low potassium (0.38 Cmol/kg) (Table 1). Nakasongola district is in Central Uganda located at 01°18' N 32°30'E/1.3°N 32.5°E and an elevation of 1,160m above sea level with an average annual temperature of 27°C and annual average rainfall of 1000mm. During the experimental period, 1289mm annual rainfall was received in 2011 and 387mm during the months of September-December, 2010 and mean temperature was 23.7°C. It is characterised by the following soil properties: low total nitrogen (0.16%), low phosphorus (8.35%), high potassium (0.50 Cmol/kg), deficient of soil organic matter (2.7%) and moderately acidic pH (5.94) (Table 1). Soil texture is predominantly sandy loams, implying that they are characterised with high infiltration. Apac district is located in Northern Uganda at 01°59'N 32°34'E/1.98°N 32.53°E and an elevation of 700m above sea level, with mean annual temperature of 28°C and annual average rainfall of 950mm. During the experimental period, 1008mm annual rainfall was received in 2011 and 389mm during the months of September-December, 2010 with mean temperature of 23.7°C. Soils in Apac are sandy loams with acidic pH (5.3) and low in soil organic matter (2.7%), deficient of total nitrogen (0.17%), implying that they are characterised with high infiltration (Table 1). Wakiso district is located at 0° 09' 60.00" N /32° 29' 59.99" E at an attitude of 1134m above sea level. The rainfall in Wakiso is bi-modal with two wet seasons running from March-May and September-November with mean annual rainfall of 1320mm. Minimum temperature of the district is 11°C while the maximum is 33.3°C. During the experimental period, 1147mm annual rainfall was received in 2011 and 549mm during the months of September-December, 2010 and mean temperature was 22.3°C. Soil properties were: adequate total nitrogen (0.20%), high phosphorus (13.41%), high potassium (0.60 Cmol/kg), high organic matter (3.25%) and acidic pH (5.17) which are favorable for normal growth of most crops (Table 1). Soils were predominantly clay loams.

Experimental design and layout

Experiments were conducted for a period of three growing seasons starting from September 2010 to December 2011 (i.e. second growing season of 2010, first and second growing seasons of 2011). In these experiments, two grain amaranth varieties (*Amaranthus hypochondriacus* L. [cream variety] and *Amaranthus cruentus* L. [golden variety]), the most commonly grown in Uganda were used. Two experiments were laid out in a randomised complete block design with a split-plot arrangement and replicated three times each season. Main plots consisted of two grain amaranth varieties, while subplots comprised fertilisers of different rates randomly assigned.

Table 1. Soil nutrient levels across study locations

Location/district	pH	OM	N	P	K	Na	Ca	Mg	%Sand	%Clay	%Silt
		— — — % — — —			— — Cmoles/kg — — — —						
MUARIK/Wakiso	5.17	3.25	0.20	13.41	0.60	0.09	5.00	1.76	57.69	28.56	13.75
Kamuli	5.59	2.91	0.18	21.32	0.34	0.09	5.43	2.01	53.88	33.13	13.00
Apac	5.33	2.69	0.17	10.19	0.38	0.08	4.36	1.72	62.75	20.42	16.84
Nakasongola	5.94	2.70	0.16	8.35	0.50	0.09	5.93	1.49	62.25	23.83	13.92
Critical levels	**5.50**	**3.00**	**0.20**	**10.00**	**0.40**	**1.00**	**0.88**	**0.44**			

The sub-plots measurements were 3m x 2m, each consisting of 3 rows of grain amaranth, spaced at 60cm apart with 1m distance between the main plots while the sub-plots were separated by 0.8m. In each location, 2 experimental sites were setup for three consecutive seasons.

In the first trial, nitrogen fertiliser in form of urea (46% N) was applied at rates of 0 (control), 50, 100, 150 and 200 kg N/ha equivalent to 0g, 65.3g, 130.5g, 195.7g and 260g per plot of $6m^2$, respectively. Prior soil analysis results (Table 1) showed that total soil nitrogen and organic carbon are at low concentration, <0.2% and 3.0%, respectively, thus enhancing soil fertility through application of required fertiliser rates would be the one way of improving soil nutrients to increase crop yields. Urea was used because it has the highest nitrogen concentration and the crop is known to respond better to nitrogen than to potassium and phosphorus. Fertiliser was split into two equal proportion with 50% applied at planting while the other half applied prior to flowering.

In the second trial, composite fertiliser rate of inorganic fertiliser (urea) and organic fertiliser [farmyard manure (FYM)], were studied at five (5) levels in the ratios of 0:6, 25:6, 50:3, 75:1.5 and 100:0 kg of urea + tonnes of FYM per hectare, respectively. These converted into combination rates of 0g + 3.6kg, 130.4g + 0kg, 97.3g +900g, 65.3g +1.8kg and 32.7g +3.6kg of urea and FYM applied in the plots of $6m^2$, representing the above ratios. While urea was applied at planting, FYM was applied three weeks before planting to enable it undergo mineralisation to release nutrients to plants.

All plots in both trials were thinned at the spacing of 60cm x 30cm, three weeks after planting to obtain the plant density of 60,000 plants/ha.

Data collection

Study parameters included plant height, inflorescence height and grain yield. Plant height and inflorescence height were taken from any six randomly selected plants per plot. Plant height was taken from ground level to the top of each flower head using a tape measure. Mean inflorescence height was determined by measuring the top flower heads of the six randomly selected plants using a tape measure. To determine grain yield, mature inflorescence heads per plot/treatment were separately hand harvested, threshed and dried to moisture content of 12-13% and then weighed for yield analysis. Threshing and winnowing using local protocols was done by farmers to remove any dirt and immature seeds to obtain clean seeds and their mean weights determined using electronic weighing scale model SF-400, Nops.

Data analysis
Data were subjected to Analysis of Variance (ANOVA) using GenStat version 14 (GenStat, 2012), to compare parameters means of plant height, inflorescence height and grain yields for different locations and various treatments. The means were separated by using Fisher's Protected LSD test at 5% level of significance. Regression analysis was done to determine optimum fertiliser application rates.

Results

Results of the inorganic fertiliser (Urea) rates trial

Effect of nitrogen fertiliser on plant and inflorescence heights
Location, variety, nitrogen level, and their three-way interaction significantly affected plant height (Table 2a). Plant height significantly increased with the application of nitrogen fertiliser from 0 (control) to 150kg N/ha for both varieties in most of the on-farm sites (Table 2b), which had low soil nitrogen (<0.2%) as shown in Table 1. On-station trials at MUARIK (Wakiso), a site which had adequate soil N (0.2%), the tallest plants were recorded at fertiliser rate of 100kg N/ha for both varieties cream (193.9cm) and golden (186.5cm) but reduced or remained the same beyond that rate (Table 2b). Cream variety plants were taller than golden variety plants across locations and treatments. Similarly, inflorescence height was significantly influenced by location, variety, nitrogen level; the two-way interactions of location$_*$variety, and location$_*$nitrogen level, but not the three-way interaction (Table 2a). Inflorescence height increased across locations as more nitrogen was applied from 0 to 150kg N/ha for both varieties, with maximum inflorescence height obtained at 150kg N/ha in Kamuli, where cream variety topped at 53.38cm and the golden variety at 59.88cm (Table 2c). Generally, golden variety had taller inflorescences than cream variety across locations and treatments.

Effect of nitrogen fertiliser on grain yield
Location, variety and nitrogen level significantly influenced grain yield as sole factors (Table 2a). Grain yield of both varieties increased as more nitrogen was applied from 0 (control) to 150kg N/ha, then declined from150 to 200kg (Table 2d). The highest grain yield was recorded on-station in Wakiso followed by Kamuli, Nakasongola and Apac, regardless of nitrogen rate applied. The cream variety (*Amaranthus hypochondriacus*) yielded higher than golden variety (*Amaranthus cruentus*) in all locations under the different nitrogen levels (Table, 2d).

Through regression analysis, grain yield showed a quadratic response to inorganic fertiliser application (Fig. 1). Since there was no significant interaction between location, nitrogen level, and variety for grain yield (Table 2a), data was pooled across locations.

Table 2a. Mean squares of the combined analysis of variance for effect of nitrogen fertiliser on grain amaranth growth and yield parameters

Source of variation	D.f.	Plant height (cm)	Inflorescence height (cm)	Grain yield (kg/ha)
Replicate stratum	2	1813.4	254.74	44924
Location	3	170675.6***	10377.46***	3795353***
Nitrogen level	4	132209.5***	18701.65***	14789949***
Variety	1	93686.2***	11058.93***	7111500***
Location x nitrogen level	12	5369.2***	419.09***	130486 NS
Location x variety	3	13719.7***	462.68**	165915 NS
Nitrogen level x variety	4	6322***	171.54 NS	111365 NS
Location x nitrogen level x variety	12	2529.7***	100.59 NS	186796 NS
Residual	1728	642.6	99.72	120716

* Significant at P<0.05; ** Significant at P<0.01; *** Significant at P<0.001; NS not significant at P<0.05

Table 2b. Effect of nitrogen fertiliser on grain amaranth plant height (cm)

Location	Variety	Fertiliser level					
		0 kg N/ha	50 kg N/ha	100 kg N/ha	150 kg N/ha	200 kg N/ha	Mean
Apac	Cream	94.2	115.2	126.1	148.3	145.4	125.84
	Golden	97.9	106.0	124.0	134.5	122.4	116.96
	Mean	96.05	110.6	125.05	141.4	133.9	121.4
Nakasongola	Cream	98.0	105.3	128.1	139.1	120.1	118.12
	Golden	91.2	106.5	113.5	118.4	114.0	108.72
	Mean	94	105.9	120.8	128.75	117.05	113.42
Kamuli	Cream	122.3	142.4	182.9	187.1	185.7	164.08
	Golden	117.6	126.0	138.6	146.5	154.1	136.56
	Mean	119.95	134.2	160.75	166.8	169.9	150.32
Wakiso	Cream	112.9	137.5	193.9	170.7	172.5	157.5
	Golden	100.6	141.2	186.5	186.8	173.7	157.76
	Mean	106.75	139.35	190.2	178.75	173.1	157.63

Table 2c. Effect of nitrogen fertilizer on grain amaranth inflorescence height (cm)

Location	Variety	Fertiliser level					
		0 kg N/ha	50 kg N/ha	100 kg N/ha	150 kg N/ha	200 kg N/ha	Mean
Apac	Cream	27.42	35.47	39.33	49.12	44.16	39.1
	Golden	35.46	38.93	47.99	55.24	51.79	45.9
	Mean	31.44	37.2	43.66	52.18	47.975	42.5
Nakasongola	Cream	32.87	35.99	39.54	42.71	37.83	37.79
	Golden	32.09	34.19	42.66	48.4	42.29	39.93
	Mean	32.48	35.09	41.1	45.56	40.06	38.86
Kamuli	Cream	36.06	40.41	50.03	53.38	54.1	46.80
	Golden	40.07	46.21	56.17	59.88	58.73	52.21
	Mean	38.07	43.31	53.1	56.63	56.42	49.51
Wakiso	Cream	34.32	42.44	49.35	45.75	48.02	43.98
	Golden	39.34	44.73	49.44	54.82	52.60	48.19
	Mean	36.83	43.59	49.40	50.29	50.31	46.09

Grain yield followed quadratic regression equations; $y = -0.04557x^2 + 13.4x + 1019$ ($R^2 = 0.9546$) and $y = -0.0384x^2 + 12.28x + 787.79$ ($R^2 = 0.9716$) for cream variety and golden variety, respectively. Response to inorganic fertiliser application showed maximum grain yield of 2,037 kg/ha for cream variety and 1,791 kg/ha for golden variety. Maximum grain yield was achieved at an optimum inorganic fertiliser application rate of 150kg N/ha (Fig. 1).

Results of the composite fertiliser rates trial

Effect of a composite of farmyard manure and urea on plant and inflorescence heights

Location, variety, combination level, and their three-way interaction significantly affected plant height (Table 3a). A composite of urea and farmyard manure (FYM) significantly affected plant height across all locations (Table 3b). The maximum plant height was registered at a composite rate of 75kg N + 1.5 tonnes of FYM per hectare for both varieties for all locations. Similar to the single nitrogen trial, cream variety was taller than golden variety across all treatment combinations and locations.

Table 2d. Effect of nitrogen fertilizer on amaranth grain yield (kg/ha)

Location	Variety	Fertiliser level					
		0 kg N/ha	50 kg N/ha	100 kg N/ha	150 kg N/ha	200 kg N/ha	Mean
Apac	Cream	745	1156	1591	1910	1732	1426.8
	Golden	604	1028	1674	1719	1697	1344.4
	Mean	674.5	1092	1632.5	1814.5	1714.5	1385.6
Nakasongola	Cream	1078	1273	1638	1856	1787	1526.4
	Golden	729	1060	1403	1737	1541	1294
	Mean	903.5	1166.5	1520.5	1796.5	1664	1410.2
Kamuli	Cream	1276	1652	2040	2105	2071	1828.8
	Golden	1035	1410	1745	1847	1764	1560.2
	Mean	1155.5	1531	1892.5	1976	1917.5	1694.5
Wakiso	Cream	1202	1666	2641	2276	1765	1910
	Golden	964	1277	1883	1861	1651	1527.2
	Mean	1083	1471.5	2262	2068.5	1708	1718.6

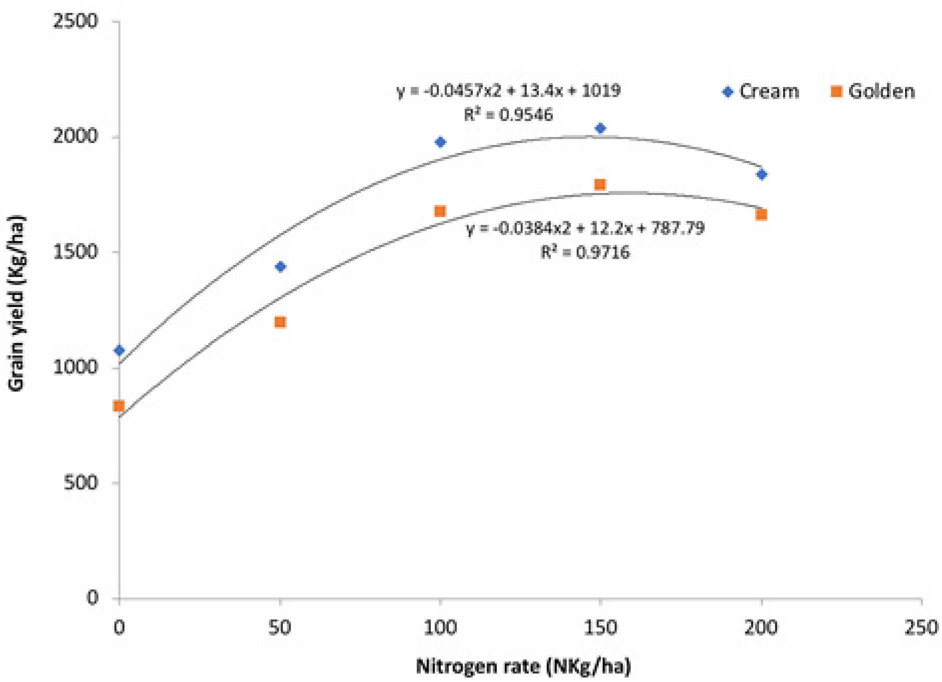

Figure 1. Regression analysis of inorganic fertilizer on grain yield across locations.

Table 3a. Mean squares of the combined analysis of variance for effect of composite of urea and farmyard manure on grain amaranth growth and yield parameters

Source of variation	D.f.	Plant height (cm)	Inflorescence height (cm)	Grain yield (kg/ha)
Replicate stratum	2	596.6	996.3	2841
Combination level	4	15268.4***	1619.3***	6281402***
Location	3	130893.5***	22692.3***	3024798***
Variety	1	94618.5***	11811.7***	4083537***
Combination level x location	12	1238.1**	96.5^{NS}	122790^{NS}
Combination level x variety	4	2994***	426.8^{NS}	67405^{NS}
Location x variety	3	9253.3***	3527.1***	191619^{NS}
Combination level x location x variety	12	1420.2**	455.2^{NS}	64149^{NS}
Residual	1431	625.6	357.7	84405

* Significant at P<0.05; ** Significant at P<0.01; *** Significant at P<0.001; NS, not significant at P<0.05

Table 3b. Effect of a composite of urea and FYM on grain amaranth plant height (cm)

Location	Variety	Combination level					
		0 kgN + 6T FYM	25 kgN + 6T FYM	50 kgN + 3T FYM	75 kgN + 1.5T FYM	100 kgN + No FYM	Mean
Apac	Cream	119.29	113.0	120.8	127.6	120.4	120.22
	Golden	105.35	106.2	108.8	121.6	117.83	111.96
	Mean	112.32	109.6	114.8	124.6	119.12	116.09
Nakasongola	Cream	137.12	124.1	133.2	151.9	123.8	134.02
	Golden	120.41	119.9	121.2	144.9	117.59	124.8
	Mean	128.77	122	127.2	148.4	120.70	129.41
Kamuli	Cream	164.27	148.1	164.9	180.2	165.5	164.59
	Golden	147.04	143.0	137.8	143.3	135.22	141.27
	Mean	155.66	145.55	151.35	161.75	150.36	152.93
Wakiso	Cream	171.90	149.2	173.0	192.0	166.9	170.6
	Golden	144.63	140.9	141.0	138.7	140.94	141.23
	Mean	158.27	145.05	157	165.35	153.92	155.92

Generally, plant height was in the order of Wakiso, Kamuli, Nakasongola and Apac. Wakiso (MUARIK) site had the tallest plants at 172cm while Apac had the shortest plants at 127.6cm for cream variety.

Similar to plant height, inflorescence height increased at increasing levels of urea in the combination and this was observed for both varieties (Table 3c). Maximum inflorescence height was obtained at a composite level of 75 kg N + 1.5 tonnes of FYM per hectare for both varieties across locations. However, unlike in the case of plant height, golden variety had longer inflorescences than cream variety. Tallest inflorescences were recorded in Wakiso and Kamuli districts, while shorter inflorescences were produced in Nakasongola and Apac districts (Table 3c).

Table 3c. Effect of a composite of urea and FYM on grain amaranth inflorescence height (cm)

Location	Variety	Combination level					
		0 kgN + 6T FYM	25 kgN + 6T FYM	50 kgN + 3T FYM	75 kgN + 1.5T FYM	100 kgN + No FYM	Mean
Apac	Cream	39.08	37.58	38.52	40.59	38.99	38.95
	Golden	45.6	41.99	41.24	47.28	44.49	44.1
	Mean	42.34	39.79	39.88	43.94	41.74	41.53
Nakasongola	Cream	43.17	30.48	35.83	39.34	32.98	36.36
	Golden	47.3	46.81	43.77	54.69	56.31	49.78
	Mean	45.24	38.65	39.8	47.02	44.65	43.07
Kamuli	Cream	49.02	50.76	53.04	56.09	47.16	51.21
	Golden	55.24	56.2	54.99	59.02	52.94	55.68
	Mean	52.13	53.48	54.02	57.56	50.05	53.45
Wakiso	Cream	56.13	50.32	54.76	61.24	58.46	56.18
	Golden	54.81	56.02	57.36	58.22	56.51	56.58
	Mean	55.47	53.17	56.06	59.73	57.49	56.38

Effect of a composite of farmyard manure and urea on grain yield

Location, variety and nitrogen level significantly influenced grain yield as sole factors but there was no significant interaction among the factors (Table 3a). Grain yield increased as the inorganic fertiliser in the combination increased; with the maximum yield recorded at composite level of 75kg N and 1.5 tonnes of FYM/ha for all locations (Table 3d). Increase in yield with the application of a composite of urea and FYM was in the order Wakiso (MUARIK)>Kamuli>Nakasongola>Apac. Similar to the single inorganic fertiliser trial, cream variety yielded higher than golden variety regardless of combination level. At the optimum composite application rate of 75kg N and 1.5 tonnes of FYM per hectare, cream variety yield was 2731, 2284, 1946 and 1785 kg/ha for Wakiso, Kamuli, Nakasongola and Apac, respectively, while golden variety yield was 2423, 1912, 1692 and 1548 kg/ha for Wakiso, Kamuli, Nakasongola and Apac, respectively. Combinations of FYM and urea at different levels performed better that the highest level of the single components (0 kgN + 6T FYM, and 100 kgN + No FYM) (Table 3d, Fig. 2).

Table 3d. Effect of a composite of urea and FYM on amaranth grain yield (kg/ha)

Location	Variety	Combination level					
		0 kgN + 6T FYM	25 kgN + 6T FYM	50 kgN + 3T FYM	75 kgN + 1.5T FYM	100 kgN + No FYM	Mean
Apac	Cream	1021	1414	1530	1785	1251	1426.8
	Golden	1043	1370	1411	1548	1244	1323.2
	Mean	1032	1392	1470.5	1666.5	1247.5	1375
Nakasongola	Cream	1224	1283	1571	1946	1251	1455
	Golden	1140	1207	1419	1692	1158	1323.2
	Mean	1182	1245	1495	1819	1204.5	1389.1
Kamuli	Cream	1360	1734	1863	2284	1531	1754.4
	Golden	1141	1265	1517	1912	1234	1413.8
	Mean	1250.5	1499.5	1690	2098	1382.5	1584.1
Wakiso	Cream	1738	1520	1867	2731	1903	1951.8
	Golden	1410	1336	1563	2423	1467	1639.8
	Mean	1574	1428	1715	2577	1685	1795.8

Grain yield showed a quadratic response to the composite of inorganic fertiliser (urea) and organic manure (FYM) application across locations (Fig. 2); similar to the single inorganic fertiliser trend. For combined results across locations, grain yield followed regression equations, $y = -72.411x^2 + 490.34x + 878.55$ ($R^2 = 0.8794$) for cream variety and $y = -60.071x^2 + 400.43x + 807.75$ ($R^2 = 0.8511$) for golden variety. Combinations of FYM and urea at different levels, notably 50 kgN + 3T

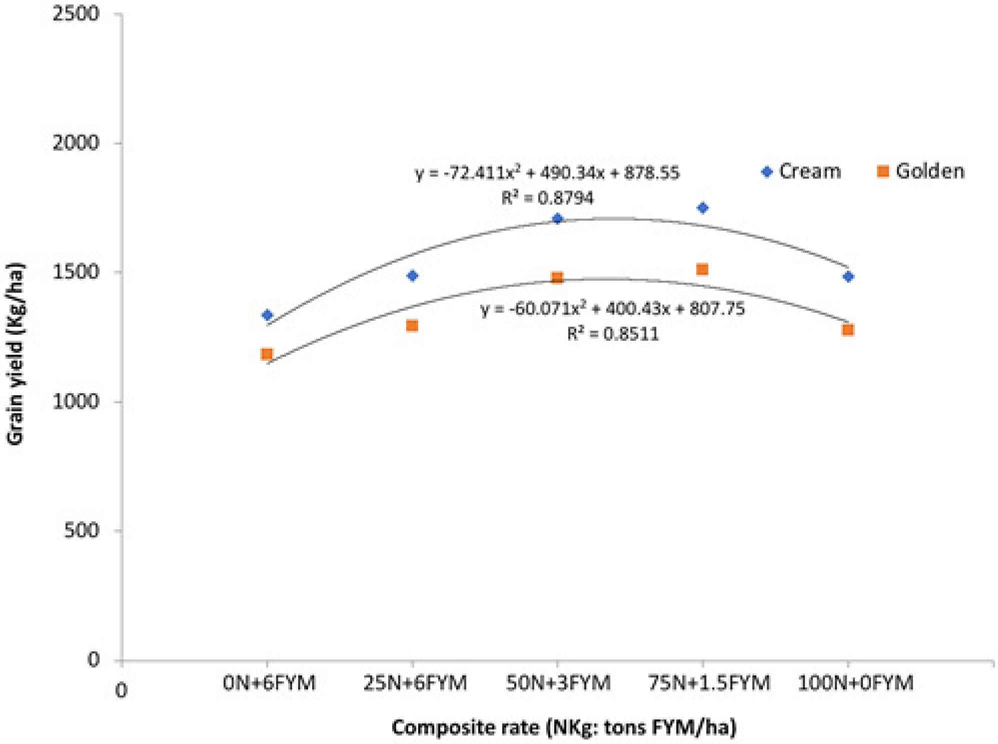

Figure 2. Regression analysis of a composite of inorganic fertiliser and farmyard manure on grain yield across locations.

FYM, 75 kgN + 1.5T FYM, performed far better that the highest level of the single components (0 kgN + 6T FYM, and 100 kgN + No FYM) (Fig. 2).

Discussion

As grain amaranth is relatively a new crop in Uganda, optimising its production requires adapted genotypes and appropriate soil fertility management strategies. Its nutritional attributes coupled with its adaptation to a wide range of environmental conditions make it a very promising crop. Plant height, inflorescence height and grain yield were significantly affected by the application of nitrogen fertiliser in form of urea and they were all at their maximum at an optimum rate of 150kg N/ha across all locations. On-station trials at MUARIK recorded the tallest plants due to high soil nitrogen levels compared to on-farm sites, which had low soil nitrogen levels as reflected in soil analysis data. Nitrogen as reported in other studies, is known to affect grain amaranth performance and in this study nitrogen was below critical level on the on-farm sites of Apac, Kamuli and Nakasongola but adequate on-station at MUARIK in Wakiso. This concurs with the reports of Olaniyi (2007), Graham (2010), and

Nyankanga *et al*. (2012), who conducted similar studies on nitrogen. Plant height varied across amaranth varieties and locations and their interactions were significant with respect to nitrogen levels suggesting that it may be heritable but also influenced by the environment (Elbehri *et al.*1993; Myers, 1998). Other studies also reported high genetic variability and phenotypic plasticity for grain amaranth, which was also location dependent (Kulakow and Hauptli, 1994).

The study showed that the yield potential for grain amaranth is in the order of Wakiso (MUARIK), Kamuli, Nakasongola and Apac districts. Generally, on-station grain yield at MUARIK was higher than that for on-farm trials. Differences in grain amaranth performance in different locations could be linked to differences in soil moisture content, which affects the availability and uptake of nutrients. Nutrients may be available but must be in the soluble form before being absorbed by plants. Areas with high moisture content as reflected by annual rainfall received during plant growth cycle registered better crop performance. For example, Wakiso received an annual rainfall of 1147mm and Kamuli received 1327mm, which could have enhanced nutrient absorption and utilisation by grain amaranth leading to improved grain yields in these locations compared to Apac and Nakasongola, which had relatively less rainfall. Disparity of yields between on-station and on-farm trials have been widely reported (Bressani et al., 1987; Elbehri et al., 1993; van Bruggen, 1995; Myers, 1998; Olaniyi, 2007; Graham, 2010; and Nyankanga *et al*., 2012).

An increase in grain yield as fertiliser application rates increased could have been due to enhanced leaf area index as more nitrogen was applied, thus leading to higher assimilates production (Mengel and Kirkby, 2001). According to Elbehri *et al.* (1993), nitrogen is the most limiting nutrient in crop cultivation in the tropics and yet it is needed by plants in larger amounts than other nutrients. Also, nitrogen is required by plants for synthesis of amino acids, protein and nucleic acids and its deficiency results in stunted growth hence reduced crop production (Mengel and Kirkby, 2001). The negative regression coefficients for the inorganic nitrogen fertiliser levels, predict a decline in grain yield with nitrogen application beyond optimal rate of 150kg N/ha across locations. These findings are also in agreement with earlier studies by (Myers, 1998; Olaniyi *et al*., 2008; Olofintoye *et al*., 2015) that reported increase in grain yield with increase in fertiliser rates applied up to an optimum with a decline beyond that optimum rate. Studies by Olofintoye *et al*. (2015) revealed that grain amaranth gave optimum grain yield responses with the application of soil amendment at 100kg N/ha inorganic fertiliser but grain yield was variety-dependent across soil amendment treatments.

The study showed that grain amaranth growth and grain yield for both varieties was significantly affected by the composite fertiliser application rate across locations.

Plant height, inflorescence height and grain yield for both varieties reached a maximum at a composite rate of 75kg N+1.5 tonnes of FYM/ha for all locations; with the 50 kgN/ha+3 tonnes FYM/ha not far behind. Giving farmers an option with respect to what is most available. Introducing relatively lower rates FYM to the moderate nitrogen levels was superior in grain yield compared to higher rates (≥100 kgN/ha) of the sole nitrogen fertiliser. This could have been due to the beneficial effects of FYM on soil fertility and structure (Mario *et al*., 1989; Ayeni *et al.,* 2009). Similar studies conducted in Kenya by Nyankanga *et al.* (2012) and Love and Nyankanga (2018) reported that use of organic and inorganic fertiliser composite ensures continuous supply of nutrients to plants resulting in sustainable crop production. In their study, an application of CAN at 83.25 kg/ha in combination with cow dung manure at 6.8 t/ha significantly increased grain amaranth performance. Other studies conducted in Nigeria by Kolawole *et al*. (2009), Okutu *et al*. (2011), Sanni (2016) and Barau *et al*. (2018) indicated that inclusion of organic manures additionally improved soil physiochemical properties. Adding nitrogen to FYM ensures immediate and continuous supply of nutrients as opposed to sole organic manures, which initially cause immobilisation of available N in the soil thus limiting amount of nitrogen available to plants at that time (Akanbi and Togun, 2002; Apaza *et al*., 2002; and Ainika *et al.*, 2011), Therefore, a combination of 75 kg N/ha and 1.5 tonnes of FYM with in form of urea might have supplied the microbes with sufficient nitrogen needed for the breakdown of the FYM to release nutrients and buffer soil conditions. The results show the complementary role played of combining organic and inorganic fertilisers in the release of nutrients overtime. Also according to Baggie *et al*. (2004), combined application of organic fertilisers and inorganic fertilisers improves utilisation of nitrogen in crop cultivation due to synergistic effects. Organic fertilisers are known to mineralise slowly and thus provide nutrients gradually while inorganic fertilisers are readily available for crop growth. Organic manure also increases the availability of phosphorus that is already present in the soil through the reduction of phosphorus fixation by iron and aluminum oxides (Baggie *et al*., 2004), besides supplying macronutrients and micronutrients to the soil. Mengel and Kirkby (2001) reported that use of FYM has other advantages including improvement of soil bio-physical properties thereby activating soil microbial activities attributed to higher organic matter levels in the soil.

Conclusion

Plant height, inflorescence height and grain yield varied with level of inorganic nitrogen (urea) applied, and the maximum yield was achieved at an optimum application rate of 150kg N/ha for both varieties and all locations. The amount of inorganic nitrogen applied can be reduced by including appreciably low levels of farm yard manure with a boost in grain yield. A composite rate of 50 kgN/ha + 3 tonnes of FYM/ha or 75kg kgN/ha + 1.5 tonnes of FYM/ha for both varieties in all the locations is optimal to increase grain yields. *A. hypochondriacus* was higher yielding than *A. cruentus* across locations.

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References

Ainika, J.N., Bindawa, M.A. and Abdulhameed, U.Y. 2011. Response of grain Amaranth (*Amaranthus cruentus* L) to nitrogen and farmyard manure rates in Northern Guinea and Sudan Savanna Ecological Zones of Nigeria. *World J of Engineering and Pure and Applied Sci.* 1(2):46 ISSN 2249-0582.

Akanbi, W.B. and Togun, A.O. 2002. The influence of maize–stover compost and nitrogen fertiliser on growth, yield and nutrient uptake of amaranth. *Scientia Horticulturae* 93(1): 1-8.

Alemi, H., Kianmehr, M.H. and Borghaee, A.M. 2010. Effect of pellet processing of fertiliser on slow-release nitrogen in soil. *Asian J. Plant Sci.* 9(2):74-80.

Alemu, G. and Bayu, W. 2005 Effects of farm yard manure and combined N and P fertiliser on sorghum and soil characteristics in northern Ethiopia. *J. Sustain Agric.* 26(2).

Apaza-Gutierrez, V., Romero-Saravia, A., Guillen-Portal, F.R. and Baltensperger, D.D. 2002. Response of grain amaranth production to density and fertilization in Tarija, Bolivia. In: Janick J., Whipkey A. (eds.): Trends in New Crops and New Uses. ASHS Press, Alexandria. pp. 107–109.

Ayeni, L.S., Omole,T.O., Adeleye, E.O. and Ojeniyi, S.O. 2009. Comparative effect of poultry manure and N.P.K on the performance of tomato in derived savanna transition zone of southwest Nigeria. *American Eurasian Journal of Sustainable Agriculture* 3(4):850-853.

Baggie, I., Rowel .D., Robinson.J.S. and Warren,G.P. 2004. Decomposition and phosphorus release from organic residues as affected by residue quality and added inorganic phosphorus. *Agroforestry Systems* 63(2) DOI: 10.1007/BF01846824

Barau, B., Olufajo, O.O., Umar, F.G., Ibrahim, A.A. , S.S. Jibia., James D., Yusif U., Maiwada A.A. and Wakili A. 2018. Growth and yield of vegetable Amaranth as affected by poultry manure and seedling age at transplanting. *Universal Journal of Agricultural Research* 6(4): 127-132, 2018 http://www.hrpub.org DOI: 10.13189/ujar.2018.060402

Bisikwa, J., Walukano, W., Ugen, M. A., Muyinda, A. M. and Muyonga, J. H. 2014. Effect of plant density and cropping pattern on grain amaranth [*Amaranthus* sp.] performance in selected agroecological zones in Uganda. *African Journal of Applied Agricultural Sciences and Technologies* 1(2): 115-130

Bressani, R., Gonzalez, J.M., Elias, L.G. and Melgar, M. 1987. Effect of fertiliser application on yield, protein and fat content, and protein quality of raw and cooked grain of three amaranth species. *Plant Foods for Human Nutrition* 37: 59-67.

Bressani, R. 2018. Composition and nutritional properties of amaranth. In Paredes-Lopez (Ed) Amaranth biology, chemistry, and technology. Boca Raton: CRC Press. 2018. pp. 185-205.

Elbehri, A., Putnam, D.H. and Schmitt, M. 1993. Nitrogen fertiliser and cultivar effects on yield and nitrogen-use efficiency in grain amaranth. *Agronomy Journal* 85: 120-128. https://doi.org/10.2134/agronj1993.00021962008500010023x

Graham, Michael William, 2010. Grain amaranth production and effects of soil amendments in Uganda. *Graduate Theses and Dissertations*. 11462. https://lib.dr.iastate.edu/etd/11462

Gupta, V.K. and Thimba, D. 1992. Grain amaranth: A promising crop for marginal areas of Kenya. *Food Reviews International* 8(1): 51-69.

Kolawole, E., Law-Ogbomo and Ajayi, S.O. 2009. Growth and yield performance of *Amaranthus cruentus* influenced by planting density and poultry manure application. *Not. Bot. Hort. Agrobot. Cluj* 37 (1):195-199. Print ISSN 0255-965X; Electronic ISSN 1842-4309

Kulakow, P.A. and Hauptli, H. 1994. Genetic characterization of grain amaranth. In: O. Paredes-López (Ed.) Amaranth: Biology, Chemistry, and Technology, pp. 9–22.

Love, J.H. and. Nyankanga, R.O 2018. Response of growth and grain yield of Amaranth (*A. hypochondriacus*) to combined manure and inorganic fertiliser pellets and non-pellets. *International Journal of Plant & Soil Science* 24(3): 1-10, 2018; Article no.IJPSS.43110 ISSN: 2320-7035

Mengel, K. and Kirkby, E. A. 2001. Principles of plant nutrition. Ann Bot. 2004 Apr; 93(4): 479-480.doi: 10.1093/aob/mch063. 5th edn. Kluwer Academic Publishers.

Mposi, M.S. 1999. Vegetable amaranth improvement for South Africa. Australian New Crops Newsletter, Issue No 11, January 1999.

Muyonga, J.H., Nabakabya, D., Nakimbugwe, D. N. and Masinde, D. 2008. Efforts to promote amaranth production and consumption in Uganda to fight malnutrition. In: Using food science and technology to improve nutrition and promote national development, Kampala, Uganda

Myers, R.L. 1996. Amaranth: New crop opportunity. p. 207-220. In: J. Janick (ed.), *Progress in New Crops*.ASHS Press, Alexandria, VA.

Myers R. L. 1998. Nitrogen Fertiliser Effect on Grain Amaranth. *Agronomy Journal* 90:597-602.http://dx.doi.org/10.2134/agronj1998.00021962009000050005x

Nyankanga, R.O., Richard, N. Onwonga, Francis, S. Wekesa, Dorothy Nakimbugwe, Dorothy Masinde and Johnny Mugisha 2012. Effect of inorganic and organic fertilisers on the performance and profitability of grain Amaranth (*Amaranthus caudatus* L.) in Western Kenya. *Journal of Agricultural Science* 4(1). doi:10.5539/jas.v4n1p223

Olaniyi, J.O. 2007. Evaluation of yield and quality performance of grain Amaranth varieties in the Southern Nigeria. *Research Journal of Agronomy* 1(2):42-45.

Olaniyi, J.O., Adelasoye, K.A. and Jegede, C.O. 2008. Influence of nitrogen fertiliser on the growth, yield and quality of grain Amaranth varieties. *World Journal of Agricultural Sciences* 4 (4): 506-513. ISSN 1817-3047 © IDOSI Publications, 2008

Olofintoye, J. A.T., Abayomi, Y.A. and Olugbemi, O. 2015. Yield responses of grain amaranth (*Amaranthus cruentus* L.) varieties to varying planting density and soil amendment. *African Journal of Agricultural Research* 10(21):2218-2225. ISSN 1991-637X

Okutu, P.C., Abdullahi, M.A., Oyidiya, I.J. and Owolabi Jacob Olatunde, O.J. 2011. Response of grain amaranth (*Amaranthus cruentus*) to method and rate of cattle kraal manure application at Kawada and Samaru in Nigeria. J*ournal of Agricultural Sciences* 56(3):173-186. DOI: 10.2298/JAS1103173O

Pospisil, A., Pospisil, M., Varga B. and Svecnjak, Z. 2006. Grain yield and protein concentration of two amaranth species (*Amaranthus* spp.) as influenced by the nitrogen fertilization. *European Journal of Agronomy* 25(3):250-253 DOI: 10.1016/j.eja.2006.06.001

Putnam, D.H., Elberhri, A.E. and Schmitt, M. 1993. Nitrogen fertiliser and cultivar effects on yield and nitrogen use efficiency of grain Amaranth. *Agronomy Journal* https://doi.org/10.2134/agronj1993.00021962008500010023x. Scientific Journal Series no. 19525

Sanni, K.O 2016. Effect of compost, cow dung and NPK 15-15-15 fertiliser on growth and yield performance of Amaranth (*Amaranthus hybridus*). A research Article. *International Journal of Advances in Scientific Research* ISSN: 2395-3616 (Online) Journal DOI: 10.7439/ijasr

Van Bruggen, A.H.C. 1995. Plant disease severity in high-input compared to reduced-input and organic farming systems. *Plant Disease* 79(10): 976-984.

Zafari, A. and Kianmehr, MH. 2012. Livestock manure management and pelleting. *Agric Eng Int: CIGR J.* 14(3):78-84.