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Full Length Research Paper

Responses of yield on grain amaranth (*Amaranthus cruentus* L.) varieties to varying planting density and soil amendment

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Field experiments were conducted at the Experimental Farm of the National Horticultural Research Institute (NIHORT), Ibadan, Nigeria (7° 30' N, 3° 50' E), at altitude 168 m above the sea level, during the 2010 and 2011 cropping seasons, to assess the yield responses of two grain amaranth varieties (TE81/28 and CEN 18/97) to planting densities (100,000, 60,000 and 40,000 plants ha^{-1}) and soil amendments (0, 25, 50, 75 and 100 kg N ha^{-1} organic fertilizer and 100 kg N ha $^{-1}$ inorganic fertilizer). The experiment, designed as 2 x 3 x 6 factorial and fitted to randomized complete block design (RCBD) was laid out in split-split-plots and replicated three times. Measurements were taken on yield components (dry matter, biological yield, unthreshed seed weight and harvest index) and grain yield. All data were analyzed using the analysis of variance (ANOVA) with the split-split-plots model and significant means separated by the least significant difference at five percent probability level ($LSD_{0.05}$). The results revealed that grain amaranth gave optimum grain yield responses when grown at a planting density of 60,000 plants ha^{-1} and with the application of soil amendment at 100 kg N ha^{-1} inorganic fertilizer, while the grain yield was significantly ($p < 0.01$) higher with the CEN18/97 amaranth variety than in the TE81/28 across soil amendment and planting density treatments in both years of assessment. However, significant second order interaction effects of variety x planting density x soil amendment observed in the study revealed that grain yield was best with variety TE81/28 planted at 60,000 plants/ha density with the application of 100 kg N/ha of inorganic soil amendment. In conclusion, results of this study revealed that the application of inorganic fertilizer was the best soil amendment treatment for the grain amaranth production. Nevertheless, the results suggested that the use of organic fertilizer at the rate higher than 100 kg N ha^{-1} holds a great potential as an alternative, where the use of inorganic fertilizer has an issue, especially for environmental and health reasons.

Key words: Grain amaranth (*Amaranthus cruentus* L), responses to, organic and inorganic fertilizers, planting density.

INTRODUCTION

Like many other vegetables, grain amaranth (*Amaranthus cruentus* L.), is a widely cultivated plant which produces grain as well as leaves for human and animal utilization. It is a pseudo-cereal crop with high protein content that has great potential for sustainable food security among the poor population of Nigeria. Grain amaranth has served as a staple to the Aztecs who had also incorporated it into their religious ceremonies. Amaranth, generally, has been cultivated as leafy vegetable crop by early civilization, and it is still essentially being utilized as such world-wide (NRC, 2006; O'Brien and Price, 2008). In the cultivation of grain amaranth, the recommended planting density varies considerably worldwide, depending on a number of factors such as the environment, the production system and the variety involved (Weber et al., 1990; O'Brien and Price, 2008).

This fact is further corroborated by the work of Henderson et al. (2000) who observed a significant environment × population effect on the grain yield of grain amaranth, suggesting that different planting density should be adopted in different environments. Although high planting density of grain amaranth may result in high yield, O'Brien and Price (2008) have pointed out that low planting density results in larger heads and vice versa. Thus there appears to be an optimum where the yield is not affected by planting density.

Despite the huge nutritional benefits of grain amaranth, there is a dearth of information with regards to its requirements for optimum productivity, especially in this part of the world where amaranth is grown mainly for its leaves by resource-poor farmers who have little knowledge on the potential benefits of the grain types.

According to O'Brien and Price (2008), grain amaranth does not have a high nitrogen requirement like maize, but responds well to appropriate soil amendment. In order to obtain good yield, soil amendment then becomes necessary if the crop is to be grown in the tropics where the maintenance of soil fertility and productivity over long periods with inorganic fertilizer have resulted in increased soil degradation and nutrient imbalance, leading to deleterious effects on crop growth, quality, ecosystem and soil health (Avery, 1995).

This study was carried out to evaluate the effects of organic and inorganic soil amendments on the grain yield and other yield components, in view of its enormous benefits and potential role in improving the nutritional quality of man, especially those of the teeming rural populace in Nigeria. The study was also aimed at determining the appropriate planting density that will result in optimum grain yield in two grain amaranth varieties under the environmental condition of this study area.

MATERIALS AND METHODS

The experiment was conducted at the Experimental Farm of the National Horticultural Research Institute (NIHORT), Ibadan, Nigeria (7° 30' N, 3° 50' E), located at an altitude of 168 m above sea level, during the 2010 and 2011 cropping seasons. The experiment was designed as a 2 × 3 × 6 factorial, laid out in split-split-plots arrangement, and replicated three times. Grain amaranth varieties (TE81/28 and CEN18/97) were allotted to the main plots, planting density (100,000, 60,000 and 40,000 plants ha^{-1}) to the sub-plots and soil amendments (0, 25, 50, 75 and 100 kg N ha^{-1} organic fertilizer and 100 kg N ha^{-1} inorganic fertilizer) to the sub-sub-plots. Pretreatment soil physico-chemical analyses of the experimental site for the periods of the study were carried out, and the rainfall distribution and mean temperature data of the area were obtained.

The field was ploughed twice and harrowed thrice to give a well pulverized flat surface. The field was then divided into thirty six raised beds per replicate with each plot measuring 2 m × 2 m, separated by alleyways of 1 m between plots. Seeds were sown directly on the 5th and 7th July in 2010 and 2011 respectively and later thinned to obtain the required densities. The application of the organic and inorganic fertilizer was done two weeks after sowing. Weed control was achieved by the pre-emergent application of Pendimethalin (500EC) at the rate of 2.5 kg ha^{-1} immediately after planting. This was later supplemented by manual weeding at 6 and10 weeks after sowing, and occasional hand-pulling throughout the period of the experiments. Insect pests were controlled using Karate® 2.5CE (Lambda-cyhalothrin) at the rate of 25 gL^{-1} of water at 4, 8 and 12 weeks after sowing.

Dry matter samples were obtained at 6 weeks after sowing from randomly four selected plants from the inner rows per plot. The samples were oven-dried at 80°C and then used for estimating the dry matter yield per plot. At maturity, two randomly selected plants from the inner rows were uprooted and weighed, and the average weight recorded as the biological yield per plot. Heads of the plants used for estimating biological yield were sundried for about five days, weighed and the average weight recorded as the unthreshed seed weight per plant which was then used to estimate the unthreshed seed weight per plot. Dried heads were threshed and the grains obtained were sundried for about three days. The weight of the grains were recorded and used to estimate the grain weight per plot, which was later converted to grain yield per hectare. Harvest Index (HI) was obtained by using the expression:

$$HI = GY\ (BY) - 1 \times 100$$

Where GY is the grain yield and BY is the biological yield at harvest.

All data obtained were subjected to analysis of variance (ANOVA) using Genstat Discovery 4 statistical package (Genstat, 2011) and means separated using the least significant difference, at 5% probability level.

RESULTS AND DISCUSSION

The agro-meteorological data for the two years of the experiment revealed that there was adequate rainfall which was well distributed throughout the growing period in both years (Figure 1a and b). Maximum temperature decreased progressively from May to its lowest values in August and then increased thereafter. The result of the pre-sowing soil analysis indicated that soil of the experimental site was loamy sand in texture with low level of organic carbon (Table 1). The soil was also shown to be low in major macro nutrients such as nitrogen, phosphorus and potassium. This was a proof that the soil is suitable for soil amendment experiment.

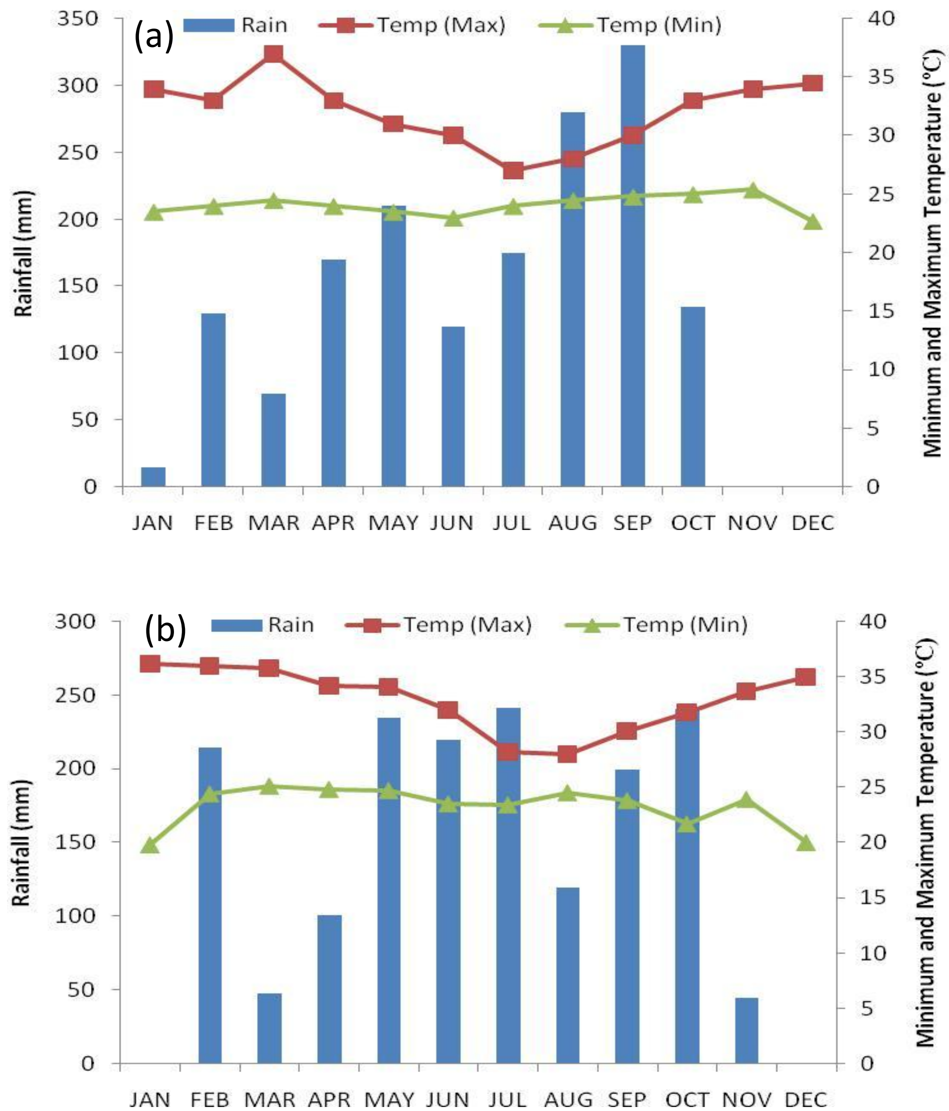

Figure 1. Rainfall distribution and the maximum and minimum temperature of the experimental in 2010 (a) and 2011 (b) cropping seasons.

The soil pH was 5.5, indicating a slightly acidic soil suitable for grain amaranth production (Putnam et al.,1989).

The results of the analyses of variance (Table 2a and b) for the yield parameters indicated that the effects of variety, density and fertilizer application on the DM and BY of grain amaranth were highly significant (<0.01) in 2010. This situation is only true for DM in 2011. While the various order of interaction were significant for DM in both years of the experiment, only variety × planting density interaction was significant for BY in 2010, and none in the year 2011. In the year 2010, both harvest index and grain yield were significantly affected by planting density and fertilizer application. This situation was however, only repeated in grain yield in 2011; harvest index was only significantly affected by fertilizer application. In 2010, all the orders of interaction showed significant effects on the grain yield. This was not the case in 2011 where only the highest interaction order (Variety × Density × Fertilizer) and Density × Fertilizer were significant for grain yield. Variety × Density interaction was also significant for harvest index in the year 2010. The effects of soil amendment and variety were highly significant ($p<0.01$) for the unthreshed seed weight, while there were no significant effects due to planting density in both 2010 and 2011. These effects were also qualified by interaction effects except variety × density in 2010 and variety × density × fertilizer in 2011.

The results of this study revealed that the yield components examined increased significantly with increased application rate of the organic soil amendment, and the highest values were obtained with the application

Table 1. Pre-planting soil physical and chemical characteristics of the experimental site at 0 – 30 cm depth in 2010.

Soil properties	Value
Sand (g/kg)	812
Silt (g/kg)	98
Clay (g/kg)	90
Textural Class	Loamy Sand
pH(H_2O)	5.5
Exchangeable Ca (cmol/g)	0.68
Exchangeable Mg (cmol/kg)	0.26
Exchangeable Na (cmol/kg)	0.11
Exchangeable K (cmol/kg)	0.13
ECEC (cmol/kg)	1.47
% Base Saturation (mg/kg)	59.3
% OC (organic carbon)	0.35
Total N (g/kg)	1.2
Available P (mg/kg)	9.13
Exchangeable Cu (mg/kg)	1.51
Exchangeable Zn (mg/kg)	1.76
Exchangeable Fe (mg/kg)	5.35
Exchangeable Mn (mg/kg)	10.02

Table 2a. ANOVA table showing mean squares from the analysis of variance for dry matter (DM), harvest index (HI), biological yield (BY) weight of unthreshed seed (USW) and grain yield (GY) of grain amaranth in 2010.

Source of variation	DF	DM	HI	BY	USW	GY
Variety (Var)	1	472.75***	67.64ns	6.44***	5200833***	745944ns
Error (a)	2	4.00	11.11	1.52	35625	110716
Density (Den)	2	3297.27***	10.15**	1.93***	81927ns	27991664***
Var x Den	2	228.14***	11.93***	2.07***	512552ns	499640*
Error (b)	8	0.0001	1.78	1.05	141181	108528
Fertilizer (Fer)	5	27021.36***	120.82***	4.44***	98544583***	23447880***
Var x Fert	5	106.48***	2.20ns	7.05ns	234208**	1017469***
Den x Fert	10	949.18***	2.85ns	8.81ns	537927***	426131***
Var x Den x Fer	10	117.72***	1.35ns	8.94ns	482052***	334170***
Error (c)	60	1.33	3.82	1.94	82806	109971

*, ** and *** denote effects significant at 5, 1 and 0.1 percent probability level, respectively ns denotes effects no significant

of 100 kg N ha^{-1} of inorganic fertilizer in both years of the experiment (Table 3a and b). The effects of soil amendments on the dry matter yield as recorded in this study were in accordance with the findings of Nyankanga et al. (2012) who, in a similar study, obtained the highest dry matter in grain amaranth in Western Kenya with the application 100 kg N ha^{-1} inorganic fertilizer. Gupta et al. (1996) and a host of others who have also reported significant increase in plant dry matter accumulation per plant with corresponding increase in the fertility level up to a certain level (Kushwaha, 2001; Kalmani et al., 2002; Olaniyi and Ajibola, 2008). Ejieji and Adeniran (2010) have, however, contrarily reported that N fertilizer application had no significant effect on the dry matter yield of grain amaranth.

The results of this study also showed positive relationship between fertilizer application and the harvest index of grain amaranth. This result is contrary to an earlier report of Gunda et al. (2005) who recorded no significant differences in the harvest index with the application of N at different rates from 0 up to 120 kg N ha^{-1}, and Ejieji and Adeniran (2010) who similarly reported that N fertilizer application had no significant effects on the harvest index of grain amaranth.

Table 2b. ANOVA table showing mean squares from the analysis of variance for dry matter (DM), harvest index (HI), biological yield (BY) weight of unthreshed seed (USW) and grain yield (GY) of grain amaranth in 2011.

Source of variation	DF	DM	HI	BY	USW	GY
Variety (Var)	1	151.70***	0.47ns	3.38ns	303.34***	213689ns
Error (a)	2	0.12	0.35	1.08	0.93	132753
Density (Den)	2	2137.04***	0.01ns	2.28ns	113.12ns	1646652***
Var x Den	2	1041.37***	3.52ns	2.90ns	70.95***	478870ns
Error (b)	8	1.33	2.09	8.70	2.26	118367
Fertilizer (Fer)	5	55317.04***	239.24***	4.16**	5978.79***	29179241***
Var x Fert	5	832.24***	2.57ns	1.72ns	23.45***	150196ns
Den x Fert	10	1358.70***	0.95ns	8.53ns	14.40***	588067***
Var x Den x Fer	10	433.30***	2.96ns	1.61ns	15.47ns	1016561***
Error (c)	60	4.99	3.00	1.56	1.17	104518

*, ** and *** denote effects significant at 5, 1 and 0.1 percent probability level, respectively ns denotes effects no significant

Table 3a. Effects of variety, planting density and soil amendments on the dry matter (DM), harvest index (HI), biological yield (BY) weight of unthreshed seed (USW) and grain yield (GY) of grain amaranth in 2010.

Treatment	DM (g plant^{-1})	HI	BY (kg ha^{-1})	USW (kg ha^{-1})	GY (kg ha^{-1})
Variety					
TE81/28	152.11	9.11	13952	4254	3030
CEN18/97	147.93	10.69	12407	4693	3196
SED	0.22	0.64	150.1	36.3	64.0
LSD (0.05)	0.45	ns	323.1	156.3	ns
Planting Density (plants ha^{-1})					
100,000	139.11	10.51	12350	4435	2799
60,000	153.94	9.67	13456	4527	3330
40,000	157.01	9.53	13733	4458	3211
SED	0.272	0.31	241.0	88.6	77.6
LSD (0.05)	0.58	0.73	ns	Ns	160.6
Soil amendment (kg N ha^{-1})					
0 (Organic)	101.00	6.76	6335	2058	1818
25 (Organic)	118.96	7.91	9511	2608	2216
50 (Organic)	138.98	9.06	11711	3321	2765
75 (Organic)	157.57	10.33	14732	4425	3080
100 (Organic)	176.48	11.37	16988	6292	3855
100 (Inorganic)	207.11	13.99	19801	8138	4946
SED	0.31	0.65	464.0	95.9	110.0
LSD (0.05)	0.67	1.30	928.3	191.9	221.1

SED = standard error of difference, LSD = least significant figure, ns = not significant.

Biological yield, the total above ground plant components including leaves and stem, contributes significantly to the economic yield, and is known to be affected by various environmental and genetic factors. In accordance with the results of this study, Olofintoye et al. (2011) had earlier reported significant variations in biological yield due to planting density, even though their results revealed that high planting density produced higher biological yield. Although planting density did not show significant effect on the biological yield in this study in both years, the values increased with decrease in planting density (Table 3a and b).

Table 3b. Effects of variety, planting density and soil amendments on the dry matter (DM), harvest index (HI), biological yield (BY) weight of unthreshed seed (USW) and grain yield (GY) of grain amaranth in 2011.

Treatment	DM (g plant^{-1})	HI	BY (kg ha^{-1})	USW (kg ha^{-1})	GY (kg ha^{-1})
		Variety			
TE81/28	347.04	8.50	29272	8689	3712
CEN18/97	344.67	8.37	29335	10195	3801
SED	0.45	0.35	62.8	132.9	63.0
LSD (0.05)	0.91	ns	ns	Ns	Ns
		Planting Density (plants ha^{-1})			
100,000	337.33	8.45	28738	9750	3536
60,000	352.31	8.45	29483	10082	3963
40,000	347.89	8.42	29691	9994	3770
SED	0.25	0.31	56.4	237.6	92.8
LSD (0.05)	0.52	ns	ns	Ns	187.5
		Soil amendment (kg N ha^{-1})			
0 (Organic)	257.17	3.59	22867	5958	2194
25 (Organic)	318.33	5.17	25600	7635	2830
50 (Organic)	337.94	7.94	28213	8810	3295
75 (Organic)	361.17	9.50	30825	10761	3841
100 (Organic)	384.00	11.00	32778	12247	4695
100 (Inorganic)	416.50	14.00	35540	14221	5681
SED	0.99	0.67	85.6	312.8	107.8
LSD (0.05)	2.19	1.49	190.7	697.0	215.8

SED = standard error of difference, LSD = least significant figure, ns = not significant

Grain yield has been affected by various production and environmental factors on the field. In the present study, increased soil amendments resulted in significant increase in grain yield. The application of 100 kg N ha^{-1} of inorganic soil amendments produced the highest grain yield. The results support the findings of Elbheri et al. (1993), Myers (1998), and Bruce and Philip (2008) who have variously reported a linear response of grain amaranth grain yield to N fertilization. The increase in grain yield as fertilizer application rates increased is a direct result of the effects of the fertilizer on growth performance of the crop. This responsiveness of grain amaranth yield to nitrogen fertilization was also comparable to the findings of other researchers such as Myers (1996) and Bruce and Philipe (2008). Apaza-Gutierrez et al. (2002) had also reported that grain amaranth yield revealed a linear response to chemical and organic fertilizers. Nyankanga et al. (2012) reported that the rate of increase in grain amaranth yield rose steadily as the rates of organic and inorganic N was raised from 0 to 100 kg N ha^{-1}. On the contrary, Law-Ogbomo and Ajayi (2009) reported that increase in organic soil amendment decreased the grain yield of grain amaranth.

The 60,000 plants ha^{-1} planting density produced the highest grain yield values in both years (Table 3a and b). These results are at variance with the findings of Henderson et al. (2000) who suggested that the plasticity of grain amaranth morphology may limit its response to row spacing. Aufhammer et al. (1995); Myers (1996) and Gimplinger et al. (2007) similarly did not observe significant yield responses to row spacing. A Missouri study that compared different row spacing at Thomas Jefferson Agricultural Institute found that the widest row spacing (lowest planting density) produced the highest grain yield. It was suggested that amaranth plants seem to compete excessively with each other when planted at high planting density (narrower spacing), leading to shorter, less vigorous plants and smaller grain yield. The result of this study was however, contrary to the findings of Malligawad and Patil (2001) who reported that grain yield increased with an increase in planting density in grain amaranth. It would be noted that the grain yield obtained in the second year across the soil amendment levels were greater than the ones obtained in the first year of the study. This is probably because the average monthly rainfall around the period of active growth of the crop was higher in the second year than what was obtained in the first year (Figure 1).

The interactive effects Table 4 revealed that at fertilizer

Table 4. Interactive effects of planting density, variety and soil amendments on dry matter production and grain yield of grain amaranth in 2010 and 2011 cropping seasons.

Planting density ('000 plants ha)	Dry Matter (g plant $^{-1}$)				Grain Yield (kg ha^{-1})			
	2010		2011		2010		2011	
	TE81/28	CEN 18/97	TE81/28	CEN 18/97	TE81/28	CEN 18/97	TE81/28	CEN 18/97
0 Kg N ha^{-1}								
100	100.00	100.00	265.00	260.00	2101	1700	2225	2200
60	92.00	100.00	271.00	268.00	1938	1938	2428	2125
40	110.00	104.00	279.00	200.00	1344	1604	2080	2105
25 kg N ha^{-1} (organic)								
100	113.67	110.00	316.00	325.00	2167	2227	2915	2917
60	116.33	114.67	318.00	316.00	2371	2505	2620	3005
40	130.12	129.00	315.00	320.00	1579	2450	2572	2952
50 kg N ha^{-1} (organic)								
100	142.33	124.00	332.00	339.00	2911	2936	3145	3176
60	143.23	139.00	335.00	336.00	2506	3205	3422	3592
40	142.30	143.00	348.00	338.00	2221	2810	3072	3365
75 kg N ha^{-1} (organic)								
100	154.00	144.33	354.00	359.00	3057	3376	4062	3483
60	160.10	150.00	360.00	360.00	2833	3433	3953	4030
40	169.00	168.00	368.00	366.00	2662	3116	3665	3852
100 kg N ha^{-1} (organic)								
100	170.00	152.33	365.00	370.00	3602	4684	5065	5097
60	190.24	165.00	382.00	398.00	3978	3557	4480	4885
40	185.33	196.00	390.00	399.00	3308	3998	4065	4580
100 kg N ha^{-1} (inorganic)								
100	180.33	178.33	379.00	384.00	5177	4590	4541	6415
60	237.67	239.00	438.00	446.00	6406	5010	7405	5607
40	201.33	206.00	432.00	420.00	3308	4111	5095	5025
SED	0.91		1.74		270.6		266.8	
LSD$_{(0.05)}$	1.82		3.50		539.9		532.0	

SED = standard error of difference, LSD = least significant figure.

rate of 0 kg N ha^{-1}, the variety TE 81/28 produced significantly higher dry matter values at the rate of 40,000 plants ha^{-1} than CEN 18/97 in both years. But in terms of grain yield, CEN 18/97 surpassed TE 81/28 at the same planting density and fertilizer level in both years. Although no specific trend was noted at higher fertilizer levels in the dry matter yield, it would be noted that variety CEN 18/97 had higher grain yield at all the levels of organic fertilization and most of the planting densities in both years. The best grain yield values of 6,406 kg ha^{-1} (2010) and 7,405 kg ha^{-1} (2011) were however, obtained from variety TE 81/28 at 100 kg N ha^{-1} inorganic fertilizer application and population rate of 60,000 plants ha^{-1}. The better grain yield obtained in the second year, especially with the application of inorganic fertilizer, could also be attributed to the better rainfall pattern during the active growing period of the crop. Also, the highest grain yield values of 4,684 kg ha^{-1} (2010) and 5,097 kg ha $^{-1}$ (2011) was obtained in the variety TE 81/28 with organic fertilizer applied t 100 kg N ha^{-1} and at 100,000 plants ha^{-1}. It should be noted that the highest grain yield obtained for this variety (TE 81/28) was in plants that received 100 kg ha^{-1} inorganic fertilizer at 100,000 plants ha^{-1}.

Conclusion

The results of this study revealed that grain yield increased with 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. Thus, the application of inorganic soil amendment (NPK fertilizer) was observed to be the best for grain amaranth productivity. Nevertheless, where the use of the inorganic fertilizer is an issue, especially for environmental and health reasons, the results suggested that the use of organic fertilizer possibly at the rate higher than the 100 kg N ha^{-1} holds a great potential as an alternative to the inorganic fertilizer. Planting at 60,000 plants ha^{-1} was found to be most appropriate, and CEN 18/97 amaranth variety appeared to be more promising.

Conflict of Interest

The authors have not declared any conflict of interest.

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