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Effect of Soil Amendment on the Growth and Yield of Grain Amaranth in Southwest Nigeria

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ABSTRACT

Grain amaranth is an important leaf and seed vegetable crop in Nigeria. There is scanty information on its nutrient requirements for optimum yield and quality. A nutrient trial was conducted at the National Horticultural Research Institute Ibadan, Nigeria to evaluate the performance of grain amaranth with poultry manure and inorganic fertilizers applied alone or in combination. The experiment was laid out in a randomized complete block design with three replications. Grain amaranth seeds were spot planted and later thinned down to one plant per stand. Cured poultry manure and NPK (15:15:15) were used as organic and inorganic fertilizer, respectively. Treatments imposed were 10 t/ha organic fertilizer only (F_1), 80 kg/ha NPK (15:15:15) inorganic fertilizer only (F_2), 5 t/ha organic fertilizer + 40 kg/ha NPK (15:15:15) inorganic fertilizer (F_3) and control (no NPK or organic fertilizer) F_0. Data collection commenced 6 weeks after planting at two weeks interval. Result indicated that organic and inorganic applied solely showed significant influence on the growth and yield of amaranth. Organic fertilizer was the best in terms of plant height and stem girth, while the inorganic fertilizer and their combination have the highest value in number of leaves and leaf area respectively. Yield was significantly ($P < 0.05$) influenced by different fertilizer treatments. Highest yield (0.66t/ha) was obtained in inorganic fertilizer.

Keywords: cured poulry manure, inorganic fertilizer, leaf vegetable, nutrient

Abbreviations: DMRT, Duncan's multiple range test; **WAP**, weeks after planting; **HCL**, hydrochloric acid; **HNO_3**, trioxonitrate (V) acid

INTRODUCTION

Amaranthus cruentus L. is commonly called African spinach and green vegetable. It is a cheap source of protein and vitamin (Pospišil *et al.* 2006). Vegetables and fruits are the regular and reliable sources of nutrients and vitamins, especially vitamin A and C, which are readily available to most rural household (Ojeniyi and Adejobi 2002). *A. cruentus* is extensively cultivated in Southwest of Nigeria to alleviate the suffering of malnourished and starving people especially children (Omidiji *et al.* 1986; Olaniyi 2007). It is also cultivated in Northern Nigeria (Ayuba *et al.* 2001). *A. cruentus* is useful both as leafy vegetable and as grain (Bressani 1988; Kauffman 1992; Akingbala *et al.* 1994). Both the leaves and seeds contain protein of high quality (Pospišil *et al.* 2006). It has a protein content of 16% (Olufolaji and Tayo 1980). Protein levels in some wild amaranth species have been reported at about 30% (Wesche-Ebeling *et al.* 2001). Amaranth grain contains 6 to 10% oil, which is found mostly within the germ. It is predominantly unsaturated oil (76%) and is high in linoleic acid, which is necessary for human nutrition and commercial purpose (Gonor *et al.* 2006; Olaniyi *et al.* 2008).

A. cruentus has been proposed as an inexpensive native crop that could be cultivated by indigenous farmers due to easy harvest, production of good quality seeds and large amounts of protein and essential amino acids, such as lysine (De Macvean and Poll 1997; Juan *et al*. 2007).

Amaranthus species are reported to have a 30% higher protein value than cereals, such as *Oryza sativa*, *Triticum aestivum*, *Avena sativa*, and *Secale cereale* (De Macvean and Poll 1997). The grains are popped, and mixed with honey for human consumption. *A. cruentus* is also a useful crop for livestock, especially ruminants (Stordahl *et al.* 1999; Sleugh *et al.* 2001). However, fertilizer requirement is among the factors constraining its production. Temperature and soil fertility have also been known to contribute to plant growth (Anegbeh and Akomeah 2005).

Research on its response to organic and inorganic fertilizer applied alone or in combination as its affect it growth and flowering in southwest remain poorly documented. As Kauffman (1992) pointed out, the potential of amaranth availability and accessibility of the vegetable to people would reduce hunger, poverty and human suffering. Grain amaranth is a new crop that is attracting interest worldwide. If this crop will continue to increase appropriate agronomic practices for high yield and quality have to be developed. This study is therefore conducted to evaluate the performance of *A. cruentus* supplied with organic and inorganic fertilizer applied alone or in combination with ultimate aim of improving productivity and this would go a long way towards enhancing the livelihoods of Nigerians.

MATERIALS AND METHODS

This study was conducted at National Horticultural Research Institute, Ibadan (7° 30' N, 3° 54' E; in an altitude of 234 m above sea level), Oyo State. The experimental site, Ibadan is located in the savannah rain-forest agro-ecological zone. The average mean minimum and maximum temperatures were 22.8 and 31.9°C, respectively. Grain amaranth seed were planted directly drilled on prepared plot of size 3 m × 2 m. Three weeks after emergence, plants were thinned to one stand/hole using a spacing of 0.5 m × 0.5 m. The experimental design was laid out in randomized complete block with three replications. Fertilizer was applied 5 weeks after planting (WAP). The treatments imposed were:

i) Control (F_0)
ii) 10 t/ha/stand organic fertilizer only (F_1).
iii) 80 kg/ha/stand (NPK 15:15:15) inorganic fertilizer only (F_2).
iv) 5 t/ha/stand organic fertilizer + 40 kg/ha/stand inorganic fertilizer (F_3).

NPK (15:15:15) fertilizer and cured poultry manure serves as

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Table 1 Climatic conditions prevailing in the experimental field, during the experiment (2009).

Month	Total rainfall (mm)	Ambient temperature (°C) Minimum	Ambient temperature (°C) Maximum	Relative humidity (%)	Rain days
January	65.6	22	33	87	2
February	31.6	24	35	88	4
March	145.3	24	34	89	7
April	238.2	23	33	89	10
May	198.9	23	32	88	9
June	183.1	23	31	88	13
July	158.9	23	30	91	17
August	44.0	23	28	90	15
September	193.7	21	30	90	9
October	182.8	23	30	89	13
November	52.1	22	32	87	5
December	0.0	23	35	89	0
Total	1494.2	274	383	1065	104

Computed from NIHORT, Meteorological station weather data for Ibadan

sources of inorganic and organic fertilizer respectively. Climatic condition prevailing during the experimental period were Registered (**Table 1**). Plants were treated once against insect and fungi with Cymbush (Cypermetrin) produce in India (Baselt 2008). Grain yield were sampled per plot. Parameters considered included: plant height (cm), stem girth, number of leaves and leaves area were collected at two weeks intervals. Data were subjected to statistical analysis of variance (ANOVA) using general linear model procedure of the Statistical Analysis System (SAS Institute 2003), means were separated using the Least Significant different (LSD) at $P < 0.05$.

Soil and manure analysis

In order to elaborate fertilization plans, soil and manure were analyzed. The Alfisol soil sample was collected at 10-15 cm depth at five different places all over the experimental plot, mixed and analyzed for texture and chemical characteristics. Soils were air-dried and ground to pass through a 2-mm sieve. Soil pH in water was determined in a 1: 2.5 (w/v) soil: water suspension. Organic C was determined by chromic digestion and spectrophotometric analysis (Heanes 1984). Total N was determined from a wet acid digest (Buondonno *et al*. 1995) and analyzed by colometric analysis (Anderson and Ingram 1993). Exchangeable Ca, Mg, K and Na were extracted using ammonium acetate solution and determined by atomic absorption spectrophotometry (Black 1965). Available P was extracted by the Bray-1 procedure and analyzed using the molybdate blue procedure described by Murphy and Riley (Murphy and Riley 1962).

Poultry manure was collected from a local farmer and analyzed for chemical characteristics as follows: cations (Ca, Mg and K) were determined by dry ashing in a muffle furnace at 500°C, diluted using aqua regia (acid mix of HCI/HNO_3) and analyzed using an atomic absorption spectrophotometer. Phosphorus was extracted by dry ashing and analyzed by colorimetry (Murphy and Riley 1962). Data are reported as a percentage of dry matter. Total N was determined from a wet acid digest (Buondonno *et al*. 1995) by colorimetric analysis (Anderson and Ingram 1993).

Evaluation of plant growth, development and yield

The stem girth (10 cm above the soil surface) and plant height (from the soil up to the apex) were measured and the number of leaves was counted from 6-12 weeks after planting at every 2 weeks interval. Grain amaranth seeds were harvested at orange to purple stage for yield determination and yield was estimated in t/ha.

RESULTS AND DISCUSSION

The results regarding the physical and chemical soil analysis at the time of cultivation (**Table 2**) show that the soil was loamy sand in nature, with pH of 5.25, a level suitable for many tropical crops. The organic carbon of 0.67% and total nitrogen of 0.26% were low. The available P (2.52 cmol/kg) was very low. The exchangeable bases (K of 0.23 cmol/kg, Ca of 1.14 cmol/kg, Mg of 0.79 cmol/kg and Na of 0.12 cmol/kg) were low. The extractable Zn (71.54 ppm) and Mn (109.31 ppm) were high.

Poultry manure is slightly acidic and low in macronutrient with very low contents of cations. The ratio [C:N] = 4:1 reveals normal N content and a good capacity for mineralization (**Table 2**).

There were significant treatment effects on the vegetative growth of grain amaranth (**Tables 3-6**). Six weeks after transplanting, amaranth plants that received organic fertilizer (poultry manure) were significantly taller than plants from other treatments tested. The shortest plants were control plants (i.e., no fertilizer treatments). This same trend occurred throughout the period of data collection until 12 weeks after transplanting (**Table 3**). This same trend occurred for the stem girth. An increase in the stem girth was observed with an increase in organic fertilizer rates. The most efficient treatment producing significantly higher girth was with plants that received organic fertilizer only (**Table 4**). The response of amaranth plants in terms of number of leaves followed different trend whereby the highest values were recorded for plants that received inorganic fertilizer (**Table 5**). This result suggests that nutrient availability, especially N, determines plant vegetative development (Adebayo *et al.* 2009). The consistently poor performance of non-fertilized plants and those planted with low N amendment revealed that when nutrients are available in adequate amounts, plants tend to grow at their optimum potential. The non-fertilized plots contained only 0.23 cmol/kg of K^+ and 2.52 cmol/kg of P. These nutrients deficient were probably the first limiting factor of plant growth and productivity in control treatment. Phosphorus availability in the soil is very low and this is one of the main constraints for crop production (Otani and Ae 1997; Tonfack *et al*. 2008). Moreover, phosphorus supplied by fertilization may not be fully available depending on the nature of the fertilizer. Mineralization of organic matter occur at a slow rate while also improving the soil physical, chemical and biological properties while that of inorganic matter is faster. Grichs (1990) observed that, apart from the role of organic manure as a store house for plant nutrients, it is a major contributor to the cation exchange capacity and acts as a buffering agent against pH fluctuation. Organic fertilizer plays a key role in sustaining the desirable soil physical, chemical and

Table 2 Physicochemical characteristics of composite soil (0-15 cm) at the experimental site before planting and after the addition of poultry manure.

Before planting

Organic matter (%)	Organic C (%)	Total N (%)	pH H_2O	Available P (cmol/kg)	Exchangeable Ca (cmol/kg)	Exchangeable Mg (cmol/kg)	Exchangeable K (cmol/kg)	Exchangeable Na (cmol/kg)	Extractable Zn (ppm)	Extractable Mn (ppm)	Sand (%)	Silt (%)	Clay (%)
1.04	0.67	0.26	5.25	2.52	1.14	0.79	0.23	0.12	71.54	109.31	82.35	8.62	5.15

Poultry manure

Organic C (%)	Total N (%)	Total P (%)	pH H_2O	pH KCI	Ca^{2+} (%)	K^+ (%)	Mg^{2+} (%)	Na^+ (%)	Mn^{3+} (%)	Fe^{2+} (%)	Zn^{2+} (%)	Cu^{2+} (%)
11.58	2.80	0.66	5.9	5.6	0.009	0.004	0.005	0.019	0.069	0.11	0.029	0.006

Table 3 Effect of organic and inorganic fertilizer on plant height (cm) of grain amaranth.

Fertilizer rate	Weeks after planting (WAP)			
kg/ha	**6**	**8**	**10**	**12**
F_0	25.47 b	49.64 b	100.27 a	123.50 b
F_1	30.67 a	64.82 a	101.47 a	147.75 a
F_2	29.20 ab	62.12 a	105.87 a	144.92 a
F_3	30.00 a	61.92 a	99.20 a	135.75 ab

Values followed by the same letter under each treatment in the same column are not significantly different at $P < 0.05$ (DMRT). F_0: Control, F_1 : Organic fertilizer, F_2: Inorganic fertilizer, F_3 : Organic + Inorganic fertilizer

Table 4 Effect of organic and inorganic fertilizer on the stem girth (cm) of grain amaranth.

Fertilizer rate	Weeks after planting (WAP)			
kg/ha	**6**	**8**	**10**	**12**
F_0	0.68 a	1.39 b	1.90 a	5.52 a
F_1	0.82 b	1.84 a	2.13 a	7.60 a
F_2	0.79 b	1.62 a b	1.98 a	6.89 a
F_3	0.79 b	1.75 a b	1.92 a	7.12 a

Values followed by the same letter under each treatment in the same column are not significantly different at $P < 0.05$ (DMRT). F_0: Control, F_1 : Organic fertilizer, F_2: Inorganic fertilizer, F_3 : Organic + Inorganic fertilizer

Table 5 Effect of organic and inorganic fertilizer on the number of leaves of grain amaranth.

Fertilizer rate	Weeks after planting (WAP)			
kg/ha	**6**	**8**	**10**	**12**
F_0	12.87 b	22.76 a	26.33 b	36.58 a
F_1	14.27 a	26.38 a	28.33 ab	57.83 a
F_2	14.60 a	26.32 a	30.73 a	58.33 a
F_3	13.33 ab	25.22 a	28.33 ab	47.08 a

Values followed by the same letter under each treatment in the same column are not significantly different at $P < 0.05$ (DMRT). F_0: Control, F_1 : Organic fertilizer, F_2: Inorganic fertilizer, F_3 : Organic + Inorganic fertilizer

Table 6 Effect of organic and inorganic fertilizer on the leaf area (cm) of grain amaranth.

Fertilizer rate	Weeks after planting (WAP)			
kg/ha	**6**	**8**	**10**	**12**
F_0	70.60 a	115.25 b	152.20 b	93.73 b
F_1	80.08 a	158.08 ab	208.25 a	152.87 a
F_2	79.70 a	179.23 a	170.43 ab	158.00 a
F_3	88.87 a	195.53 a	169.05 ab	161.84 a

Values followed by the same letter under each treatment in the same column are not significantly different at $P < 0.05$ (DMRT). F_0: Control, F_1 : Organic fertilizer, F_2: Inorganic fertilizer, F_3 : Organic + Inorganic fertilizer

Table 7 Grain yield, percentage dry matter of grain amaranth plant and percentage dry matter of weed.

Fertilizer rate (kg/ha)	Grain yield (t/ha)	% Dry matter of whole plant	% Dry matter of weed
F_0	0.38 b	20.11 b	27.60 a
F_1	0.58 ab	23.99 ab	24.49 a
F_2	0.66 a	28.76 a	21.47 a
F_3	0.61 ab	25.63 ab	22.85 a

Values followed by the same letter under each treatment in the same column are not significantly different at $P < 0.05$ (DMRT). F_0: Control, F_1 : Organic fertilizer, F_2: Inorganic fertilizer, F_3 : Organic + Inorganic fertilizer

biological conditions for satisfactory growth and development of crops.

Grain amaranth yield differed significantly among treatments (**Table 7**). The highest yield value of 0.66 t/ha was obtained in plant treated with inorganic fertilizer, while combined fertilizer resulted in 0.61 t/ha, organic fertilizer resulted in 0.58 t/ha and control in 0.38 t/ha. Evaluation of grain yield and percentage dry matter of grain amaranth plant revealed significant difference among the treatments with inorganic fertilizer having highest grain yield and plant dry matter. In this experiment, higher grain yield were obtained when inorganic fertilizer (NPK 15:15:15) was used at 80 kg/ha as compared with 90 kg/ha recommended by other authors (Myers 1994, 1998; Elberhri *et al*. 1994). Safia *et al*. (2001) reported that the addition of chemical fertilizer caused higher sweet pepper yield. This might be attributed to the improved phosphorus concentration that is higher with balanced mineral fertilizer. The lower value recorded in organic matter treatment when compared with inorganic treatment is attributed to lower percentage of organic phosphorus in the poultry manure applied which inhibit the integration of pool of the soil steady organic matter (Bodet *et al.* 2001) and organic colloids invariably prevent soluble phosphates from linking with soluble Fe and Al in acidic soils. Fulvic acids of poultry manure have significant carboxyl and hydroxyl phenolic contents that form cation complexes to a greater level and therefore increases P availability to the plants.

Our study shows that it would be possible to increase *A. cruentus* in South-western Nigeria by improving the fertilization strategy. In particular, the use of balanced poultry manure proved to be very satisfactory for the nutritional needs of the culture. This beneficial effect of poultry manure has been proven by other authors (Oikeh and Asiegbu 1993; Zhang *et al.* 1988; Cavero *et al.* 1997). In a general way, the use of organic matter in the systems of culture should be promoted. It allows keeping soil fertility, while improving soil structure and availability of mineral elements (Unger 2001; Wasswa *et al*. 2003; Micheni *et al*. 2004). In fact, the increase in soil organic matter to optimum levels is a key aspect of any organic production system (Gaskell *et al.* 2000). The locally produced poultry manure is available in good quantity and for all social groups and it seems to be economically more profitable than more expensive mineral manure.

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REFERENCES

Adebayo AG, Akintoye HA, Aina OO, Olatunji MT, Shokalu AO (2009) Assessment of organic amendments on growth and flower yield of sunflower (*Helianthus annus*). In: *Proceedings of the Horticultural Society of Nigeria*, 11-16 October 2009, Kano State, Nigeria, pp 292-298

Akingbala JO, Adeyemi JA, Sangodoyin SO, Oke OL (1994) Evaluation of *Amaranth* grains for Ogi manufacture. *Plant Foods for Human Nutrition* **46 (1)**, 19-26

Anegbeh PO, Akomeah PA (2005) Flooding effect on yield of an indigenous vegetable (*Amaranthus cruentus* L.) in the Niger Delta region of Nigeria. *Global Journal of Agricultural Sciences* **4 (1)**, 41-44

Anderson JM, Ingram JSI (1993) *Tropical Soil Biology and Fertility: A Handbook of Methods* (2nd Edn), CABI, Wallingford, Oxfordshire, UK, 221 pp

Ayuba SA, Attah ES, Ali EAT (2001) Growth response of *Amaranthus* (*Amaranthus cruenthus* L.) to application of urea and organic manure under irrigation. In: Ojeniyi SO, Esu IE, Amalu UC, Akamigbo FNR, Ibanga JI, Raji BA (Eds) *Proceedings of 27th Annual Conference of Soil Science Society of Nigeria*, 5-9 November 2002, University of Calabar, Port Harcourt, pp 226-228

Baselt R (2008) *Disposition of Toxic Drugs and Chemical in Man* (8th Edn), Biomedical Publication, Foster City, CA, pp 389-391

Black CA (1965) *Methods of Soil Analysis. Agronomy* (No 9 Part 2), America Society of Agronomy, Madison, Wisconsin, USA, pp 1372-1376

Bodet JM, Hacala S, Aubert C, Texier C (2001) Fertilizer avec les engrais de ferme. Édition Commune Institut de l'Elevage, ITAV-ITCF-ITP, Paris, France, 104 pp

Bressani R (1988) The protein of grain amaranth. *Food and Nutrition Bulletin* **5 (1)**, 19-38

Buondonno A, Rashad AA, Coppola E (1995) Comparing tests for soil fertility ll. The hydrogen peroxide/sulphuric acid treatment as an alternative to the copper/selenium catalyzed digestion process for routine determination of soil nitrogen-Kjeldahl. *Communications in Soil Science Plant Analysis* **26**, 1607-1619

De MacVean X, Pöll Y (1997) Ethnobotany. In: Vozzo JA (Ed) *Tropical Tree Seed Manual*, USDA Forest Service, pp 1-30

Elberhri A, Putnam DH, Schmitt M (1993) Nitrogen fertilizer and cultivars effect on yield and nitrogen-use efficiency of grain amaranth. *Agronomy Journal* **85**, 5-8

Gonor KV, Popozheva AV, Derbeneva SA, Mal'tsev Glu, Trushina EN,

Mustafina OK (2006) The influence of a diet with including amaranth oil on antioxidant and immune status in patients with ischemic heart disease and hyperlipoproteidemia. *Vapor Pitman* **75 (6)**, 30-33 (in Russian)

Grichs DI (1990) Biological and organic aspects of plant nutrition in relation to needed research tropical soils. Seminar on tropical soils International Institute of Tropical Agriculture, Ibadan, Nigeria

Heanes DL (1984) Determination of organic C in soil by an improved chromic acid digestion and spectrophotometric procedure. *Communications in Soil Science Plant Analysis* **15**, 1191-1213

Kauffman CS (1992) Realizing the potential of grain amaranth. *Food Reviews International* **8**, 5-21

Micheni AN, Kihanda F, Irungu J (2004) Soil organic matter (SOM). The basis for improved crop production in Arid and semi-arid climates of Eastern Kenya. In: Bationo A (Ed) *Managing Nutrient Cycles to Sustain Soil Fertility in Sub-Saharan Africa*, TSBF Institute of CIAT, pp 239-248

Murph J, Riley JP (1962) A modified single solution method for determination of phosphate in natural waters. *Analytica et Chimica Acta* **27**, 31-36

Myers RL (1994) Regional amaranth variety test. *Legacy* **7**, 5-8

Ojeniyi SO, Adejobi KB (2002) Effect of ash and goat dung manure on leaf nutrient composition, growth and yield of *Amaranthus*. *Nigerian Agricultural Journal* **33**, 46-57

Olaniyi JO (2007) Evaluation of yield and quality performance of grain amaranth varieties in South western Nigeria. *Research Journal of Agronomy* **1 (2)**, 42-45

Olaniyi JO, Adelasoye KA, Jegede CO (2008) Influence of nitrogen fertilizer on the growth, yield and quality of grain amaranth varieties. *World Journal of Agricultural Sciences* **4 (4)**, 506-513

Olufolaji AO, Tayo TO (1980) Growth development and mineral contents of three cultivars of *Amaranthus cruentus* L. *Horticultural Science* **13 (2)**, 181-190

Omidiji MO, Oyedokun JB, Akinlosotu TA, Oputa CO (1986) Vegetable production in traditional farming systems of South Western Nigeria. *Rural Development in Nigeria* **2**, 111-119

Otani T, Ae N (1997) The status of inorganic and organic phosphorus in some soils in relation to plant availability. *Soil Science Plant Nutrition* **43 (2)**, 419-429

Pospišil A, Pospišil M, Varga B, Svečnjak 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

Safia M, Abdala AM, Shaheen AM (2001) The productivity of sweet pepper (*Capsicum annum* L.) plant cultivated under plastic houses as effected by some organic manures as well as chemical fertilizer. *Egyptian Journal of Applied Sciences* **16 (1)**, 18-27

SAS Institute (2003) Statistical Analytical Systems SAS/STAT user's guide version 8, SAS Institute Inc., Cary, NC

Sleugh BB, Moore KJ, Brunmer EC, Knapp AO, Russel J, Gibson L (2001) Forage nutritive value of various *Amaranthus species* at different harvest dates. *Crop Science* **41 (2)**, 466-472

Stordahl JC, Sheaffer CC, Dicostanzo A (1999) Variety and maturity affect *Amaranthus* forage yield and quality. *Journal of Production Agriculture* **12**, 249-253

Tonfack LB, Bernadac A, Youmbi E, Mbouapouognigni VP, Ngueguim M, Akoa A (2009) Impact of organic and inorganic fertilizers on tomato vigor, yield and fruit composition under tropical andosol soil conditions. *Fruits* **64**, 167-177

Unger WP (2001) Paper pellets as a mulch for dry land grain sorghum production. *Agronomy Journal* **93**, 349-357

Wasswa BN, Mugendi DN, Vanlauwe B, Nandwa S, Kung'u J (2003) Organic crop residue effects on soil physical and chemical properties in Kenya. In: *Proceedings of the 21st SSSEA Conference*, December 1-5, Kiambu district, Kenya, pp 180-189

Wesche-Ebeling P, Maiti R, García-Díaz G, González DI, Sosa-Alvarado F (1995) Contribution to the botany and nutritional value of some wild *Amaranthus* species (*Amaranthaceae*) of Nuevo Lean, Mexico. *Economic Botany* **49 (4)**, 423-430