EFFECTS OF N, P AND K FERTILIZERS ON EDIBLE AMARANTH *(Amaranthus* spp.) GROWN ON THE RED SOIL OF OKINAWA

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Abstract. Fertilizer regimes were evaluated on edible amaranths to understand fertilizer management on the red soil (pH 5.1) of Okinawa. Effects of fertilizers 0 (Control), N, P, K, N+P (NP), N+K (NK), P+K (PK) and N+P+K (NPK) were evaluated on red leaf amaranth in two experiments. Each of the N, P and K fertilizers was applied at 50 g m^{-2}. In addition, the effects of NPK (N:P:K=1:1:1) fertilizer at 0, 10, 20, 30 and 40 g m^{-2} were evaluated on red stem amaranth and red leaf amaranth. Growth and yield of amaranth cultivated under N, P, K, NK and PK treatments were very poor, but significantly higher with the NPK followed by NP. Growth parameters and yield greatly increased with the NPK fertilizer at 30-40 g m^{-2} for red stem amaranth and 20-30 g m^{-2} for red leaf amaranth. Mineral contents in the amaranths did not clearly differ with the different fertilizers. Mineral contents were higher or same in the amaranths cultivated with the fertilizer NPK at 30-40 g m^{-2}, compared to those under control treatments. The results indicate that combined fertilizer NPK at 30-40 g m^{-2} is effective for higher yield and quality of amaranth in the red soil.
Keywords: *acidic soil, growth characteristics, minerals, nutritive-value, tropical vegetable*

Introduction

Different plant species respond differently to soil nutrient status, and fertilizer rates and combination (Hossain and Ishimine, 2005; Akamine et al., 2007; Chowdhury et al., 2008; Hossain et al., 2011). Balanced fertilizer is effective to sustain soil fertility, and growth, yield and quality of a plant species (Hossain et al., 2004; Akamine et al., 2007; Chowdhury et al., 2008; Shimray et al., 2019). The major nutrients N, P and K individually or together maintain growth, yield and quality of plants (Ivonyi et al., 1997; Nakano and Morita, 2009; Skwaryo-Bednarz et al., 2011; Hossain et al., 2012). Nitrogen, the principal element of chlorophyll, influences photosynthetic efficiency, which contributes to 26-41% of crop yield (Maier et al., 1994; Ivonyi et al., 1997). Potassium regulates activities of minerals and promotes N uptake efficiency of plants. Insufficient K causes shoot yellowing and low resistance to cold and drought in plants (Oya, 1972). Phosphorus enhances absorption of other nutrients and promotes plant growth when applied with other fertilizers (Akamine et al., 2007).

Amaranthus is a promising food crop for its resistance to heat, drought, diseases and pests, as well as high nutritional value (Sreelathakumary and Peter, 1993; Rastogi and Shukla, 2013; Longato et al., 2017; Maurya and Arya, 2018; Soriano-García et al., 2018). Several *Amaranthus* species are popularly cultivated as vegetable and grain in Africa, Bangladesh, Caribbean, China, Greece, India, Nepal and South Pacific Islands (Prakash and Pal, 1991; Stallknecht and Schulz-Schaeffer, 1993; Svirskis, 2003; Dewan et al., 2017). Vegetable amaranth, superior in taste to spinach (*Spinacia oleracea*), possesses higher carotenoids (90-200 mg kg^{-1}), protein (14-30%), carbohydrate

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(5.0 g 100 g^{-1}), fat (0.1 g 100 g^{-1}), calories (43 Kcal 100 g^{-1}) and ascorbic acid (28 mg 100 g^{-1}) (Abbott and Campbell, 1982; Prakash and Pal, 1991; Shittu et al., 2006; Dewan et al., 2017). *Amartanthus* possesses antioxidant, antimalarial and antiviral properties, which prevent cancer, cardiovascular diseases, diabetes, etc. (Dasgupta and De, 2007; Khandaker et al., 2008; Shukla et al., 2010; Adegbola et al., 2020).

Amaranthus grows very fast in tropical and subtropical regions under different agroclimatic and edaphic conditions (Singh and Whitehead, 1996; Dewan et al., 2017). In Okinawa, some amaranth species are found as weed in different soils (Hossain and Ishimine, 2005; Ohshiro et al., 2015). Some edible amaranth lines have been selected as summer vegetables in Okinawa (Ohshiro et al., 2015). Shittu et al. (2006) reported that balanced fertilizer is required to sustain higher yield and nutrients of amaranth in a specific soil.

Soil types and fertilizer regimes were evaluated on growth, yield, and quality of some *Amaranthus* lines in our previous study (Ohshiro et al., 2016). We have also evaluated fertilizer N levels and combined fertilizer NPK on amaranth in three major soil types, gray soil, dark-red soil and red soil of Okinawa. Gray soil was best for higher growth and yield of amaranths, and N fertilizer applied alone increased growth and yield in gray soil but not in dark red soil and red soil. On the other hand, combined fertilizer NPK resulted in the highest growth parameters and yield of amaranths in all soils. Previous studies evaluated fertilizer management strategies for amaranth cultivation on gray soil and dark-red soil (Ohshiro et al., 2016; Akamine et al., 2020). Gray soil covers only 5% of land, whereas dark-red soil covers 35% and red soil covers 60% in Okinawa (Hossain and Ishimine, 2005). In addition, we did not evaluate the effects of separate and combined application of N, P and K on the amaranths in red soil. Therefore, the objectives of this study were to (i) identify the effect of different fertilizer elements and (ii) evaluate rates of combined fertilizer on growth, yield and quality of edible amaranth lines to understand fertilizer management practices in red soil of Okinawa.

Materials and methods

Soil collection

Red soil (Ultisol, Kunigami mahji) was collected from the top 50 cm layer of a field in Nago city, Okinawa. The soil pH was 5.1, and the soil contained 0.06% total N and 0.20% total C. Sodium (Na), K, Ca, Mg, Al, Fe, P and Mn contents in soil were 0.69, 0.93, 14.51, 1.64, 0.04, 0.25, 0.28 and 0.02 mg kg^{-1}, respectively. Coarse sand, fine sand, silt, clay, and apparent density were 16.92%, 20.44%, 26.62%, 30.92%, and 0.92 g cm^{-3}, respectively.

Amaranth lines

Edible red stem amaranth (BB line) and red leaf amaranth (BC line) of *Amaranthus tricolor* selected as higher yield and quality in our previous studies (experiments conducted from April, 2010 to May, 2011) were evaluated in this study (Ohshiro et al., 2015).

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Experiment 1: Effects of N, P and K fertilizers applied alone and in combination on amaranth cultivated during November 5 to December 15, 2014

A glasshouse experiment was conducted at the Subtropical Field Science Center of the University of the Ryukyus, from November 5 to December 15, 2014. The experiment was consisted of eight treatments with five replications (planters). The fertilizer treatments were control (Cont), N, P, K, N plus P (NP), N plus K (NK), P plus K (PK) and N plus P plus K (NPK). Each of the N, P and K fertilizers at 50 g m^{-2} (5.0 g per planter) was mixed with 13 kg of air dried soil per planter (size 65E; 0.1 m^2) prior to the seed sowing according to the treatment design. Seed of red leaf amaranth was sown on the soil surface and covered with 0.5 cm soil layer. The planters were placed randomly, and the plants were thinned to the 8 healthiest stands per planter at 2- to 3-leaf stage. Water was applied as required (considering soil moisture checked by squeezing the soil sample firmly in hand to form an irregularly shaped "ball", plant size and growth stage, daily weather condition, etc.) every day for proper seedling emergence and plant growth. All the windows were kept open to maintain outdoor conditions (light, temperature, humidity) in the glasshouse during the experiment, except typhoon and rainy days.

Experiment 2: Effects of N, P and K fertilizers applied alone and in combination on amaranth cultivated during February 19 to April 4, 2015

Experiment 1 was repeated to reconfirm the effects of the fertilizers on the amaranth in the same glasshouse from February 19 to April 19, 2015. The experiment was consisted of eight treatments with five replications (planters). The same amaranth line, planter, treatments, fertilizer rates, seed sowing and management practices applied in the experiment 1 were taken in this experiment.

Experiment 3: Effects of NPK fertilizer rates on amaranth cultivated during June 20 to July 24, 2014

This experiment was conducted in the same glasshouse from June 20 to July 24, 2014. Each experiment was consisted of five treatments with four replications (planters). The fertilizer treatments of 0 g m^{-2} (Control, 0 g $planter^{-1}$), 10 g m^{-2} (1 g $planter^{-1}$), 20 g m^{-2} (2 g $planter^{-1}$), 30 g m^{-2} (3 g $planter^{-1}$) and 40 g m^{-2} (4 g $planter^{-1}$) were taken. The fertilizers of N ($CO(NH_2)_2$), P_2O_5 ($CaH_4(PO_4)_2H_2O$) and K_2O (KCl) were applied at the ratio of N:P:K=1:1:1. The fertilizers were mixed with 13 kg air dried soil per planter (size 65E) prior to the seed sowing according to the treatments. Seeds of red stem amaranth (BB line) and red leaf amaranth (BC line) were sown on the soil surface and covered with 0.5 cm soil layer. The planters were placed randomly, and the plants were thinned to the 10 healthiest stands per planter at 2- to 3-leaf stage. Water was applied as required every day for proper seedling emergence and plant growth.

Data collection

In the experiment 1, five plants were harvested at 40-day after seed sowing (DAS) from each planter, and plant height, stem diameter, leaf number, largest leaf area, total leaf area, and fresh and dry weights of leaf, stem and shoot (leaf+stem is called yield) were determined. In the experiment 2, plant height and leaf number were measured 6 times at a five-day interval strating from 23 DAS, and five plants were harvested from

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each planter at 44 DAS and similar data parameters were measured. In the experiment 3, five plants were harvested from each planter at 35 DAS, and similar data parameters were measured. Stem diameter was measured at 5 cm from the soil surface.

Determination of leaf area, dry weight, mineral, nitrogen, carbon, soil pH and nutrients

Leaf area was measured with an automatic area meter (AAM-8, Hayashi Denkoh Co. Ltd.). Various parts of amaranth plants were dried at 60 ℃ for 48 h for chemical analysis, and at 80 ℃ for dry weight measurement using forced convection oven (DRLF23WA, Advantec). Soil samples were dried at room temperature of 25-28 ℃ for 5 days. The plant parts and soil were ground finely for chemical analysis. Mineral contents of soil and nutrients of amaranth were determined with Inductively Coupled Plasma Spectrometer (ICPS-8100, Shimadzu Co. Ltd.). Total C and N were determined with Gas Chromatograph (Soil GS-8A, Shimadzu Co. Ltd., NC-220F Juka analysis center) and Sumigraph (NC-90A, Shimadzu Co. Ltd.). Soil pH was determined with TOA pH meter (HM-20S, Toa Electronic Ltd.).

Statistical analysis

Average data for each replication was calculated, and then mean and standard deviation (SD) of the replications were determined using analysis of variance. Fishers protected least significant difference (LSD) test at the 5 % level was used to compare treatment means. The amaranth lines were analysed separately.

Results

Effects of fertilizer N, P and K applied alone and in combination on growth and yield of amaranth line BC

Effects of fertilizer N, P and K applied alone and in combination on growth, plant height and leaf number of amaranth line BC cultivated from November 5 to December 15, 2014 are shown in the *Figs. 1 and 2*. The plants with the fertilizer N and NK grew for some days but did not survive finally. Growth of the plants with the fertilizer K, P and PK was very poor, and many of plants died. The growth of amaranth was best with the fertilizer NPK followed by NP.

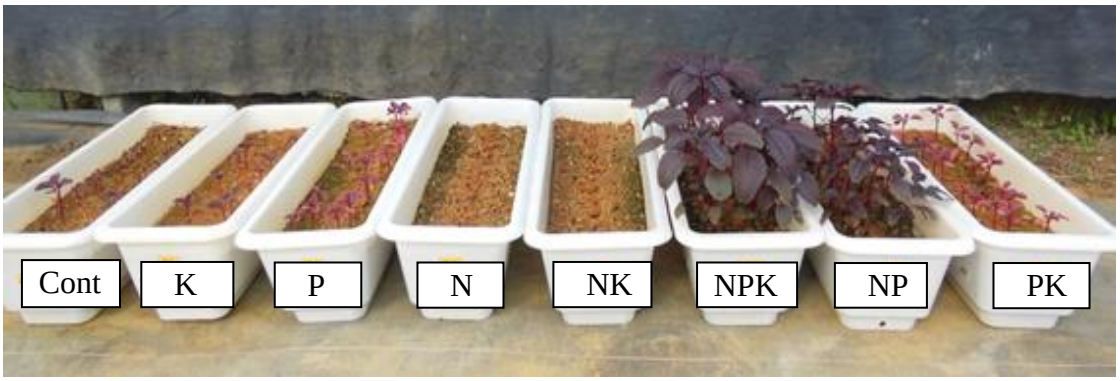

Figure 1. *Effects of fertilizer N, P and K applied alone or in combination on growth of amaranth line BC cultivated from November 5 to December 15, 2014*

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Plant height was the highest with the combined fertilizer of NPK, which was 3.6 times higher than that with the control treatment (*Fig. 2*). The fertilizer N and NK showed adverse effect on plant height. The other fertilizer treatments resulted in increased plant height. The fertilizer NP resulted in the second highest plant height. Plant height with the NPK was about two times higher than the plant with NP (*Fig. 2*).

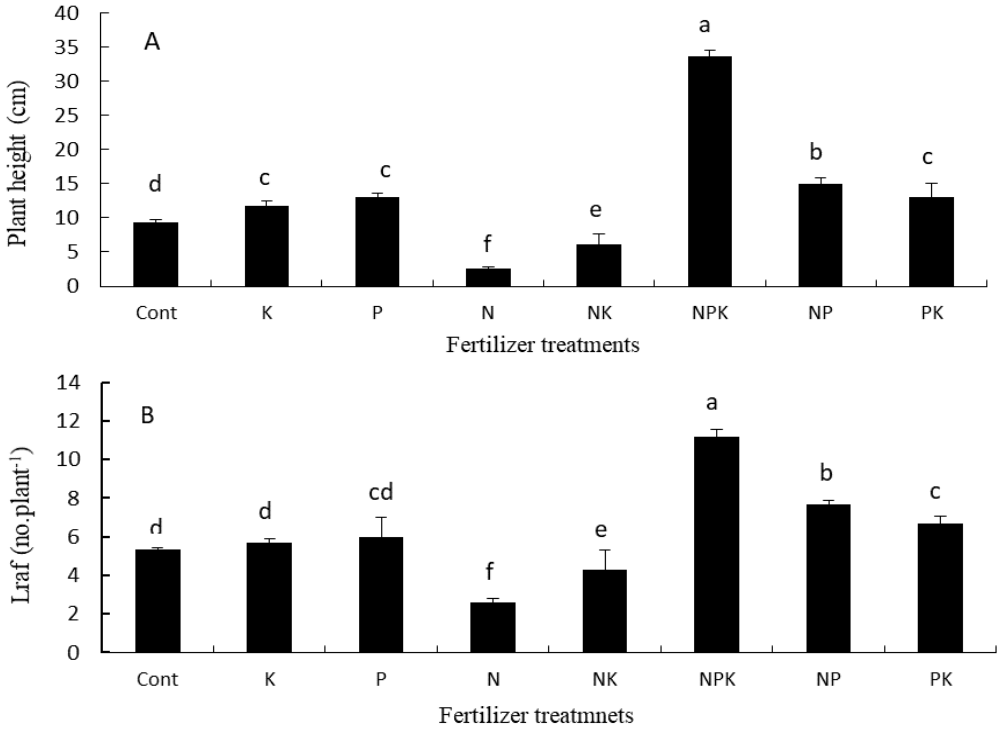

Figure 2. *Effects of fertilizer N, P and K applied alone or in combination on plant height (A) and leaf number (B) of amaranth line BC cultivated from November to December, 2014. Bars with the same letter are not significantly different at the 5% level, as determined by LSD test. Error bars represent standard deviation of the data*

The plant with the fertilizer NPK had highest leaf number (11) followed by the fertilizer NP (8) (*Fig. 2*). The fertilizer K and P applied alone did not result increased leaves per plant. The plant cultivated with the fertilizer N and NK resulted in the decreased number of leaves as compared with the control plant.

Data were not recorded for the fertilizers N and NK due to very poor plant growth. Stem diameter, largest leaf area, total leaf area, fresh leaf and dry leaf of amaranth were increased with the fertilizers NPK and NP (*Table 1*). Fresh and dry weight of stem and shoot (yield) were highest with the fertilizers NPK followed by NP. The fertilizers K, P and PK did not increase the growth parameters and yield of the amaranth. All the growth parameters and yield were highest with the fertilizer NPK followed by NP.

Plant height and leaf number of amaranth BC line cultivated from February 19 to April 4, 2015 under different fertilizers are shown in the *Fig. 3*. Plant height and leaf number (*Fig. 3*) were highest with the fertilizer NPK followed by NP. The leaf number was 11, 9 and 6 with the fertilizer NPK, NP and NK, respectively. The other fertilizer treatments did not show positive effect on plant height. The fertilizers P and PK showed somewhat positive effect on leaf number.

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Table 1. *Effects of fertilizer N, P and K applied alone or in combination on growth parameters and yield of amaranth cultivated from November to December, 2014*

Fertilizer treatment	Stem diameter (mm)	Largest leaf area (cm^2)	Total leaf area (cm^2)	Fresh leaf weight (g /plant)	Dry leaf weight (g /plant)	Fresh stem weight (g /plant)	Dry stem weight (g /plant)	Fresh shoot weight (g /plant)	Dry shoot weight (g /plant)
Cont	1.698c	2.325c	6.535c	1.456c	0.120c	0.602c	0.066c	2.058c	0.186c
K	1.750c	1.993c	6.675c	1.496c	0.210c	0.734c	0.048c	2.230c	0.258c
P	2.025c	2.743c	7.873c	1.887c	0.287c	1.065b	0.085c	2.952c	0.372c
N	-	-	-	-	-	-	-	-	-
NK	-	-	-	-	-	-	-	-	-
NPK	6.593a	26.760a	130.238a	15.561a	1.775a	17.566a	0.907a	33.127a	2.682a
NP	3.330b	11.250b	45.983b	4.998b	0.685b	2.659b	0.240b	7.657b	0.925b
PK	2.393c	5.486c	13.515c	1.660c	0.229c	1.689b	0.211b	3.349bc	0.440c

Data with the same letter within each column for each applied fertilizer are not significantly different at the 5% level, as determined by LSD test. - data not recorded due to poor growth

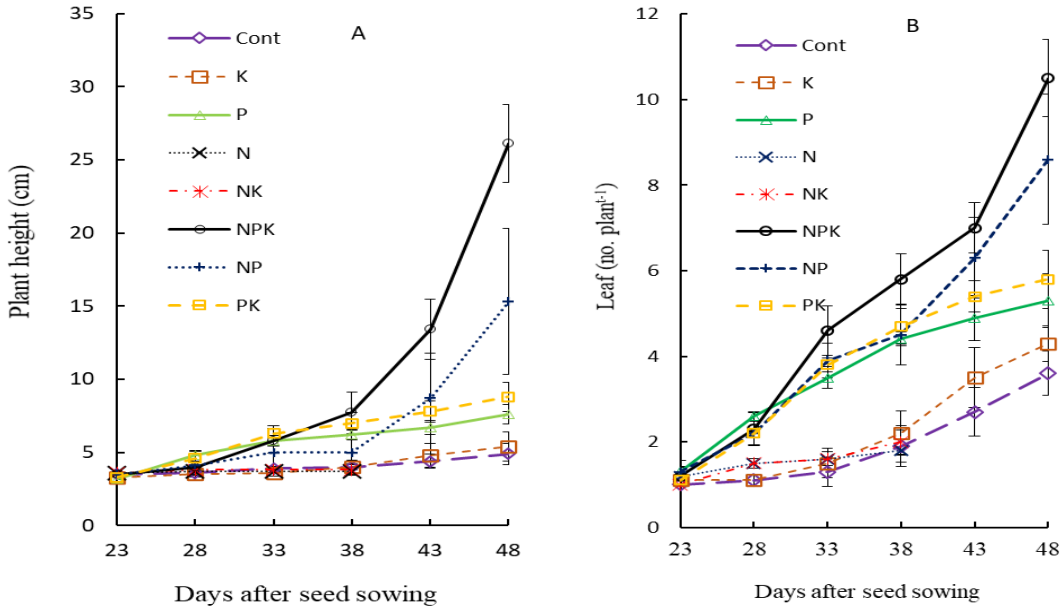

Figure 3. *Effects of fertilizer N, P and K applied alone or in combination on plant height and leaf number of amaranth line BC cultivated from February to April, 2015. Error bars represent standard deviation of the data*

Growth parameters and yield of amaranth line BC were not measured due to very poor growth (*Table 2*). Stem diameter and largest leaf area were highest with the fertilizer NPK followed by NP (*Table 2*). Total leaf area, fresh leaf and dry leaf increased with only NPK. Fresh and dry weights of stem and shoot were highest with the fertilizer NPK followed by NP (*Table 2*). Most of the growth parameters and yield (shoot) were highest with the fertilizer NPK followed by NP (*Table 2*).

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Table 2. *Effects of fertilizer N, P and K applied alone or in combination on growth parameters and shoot (yield) of amaranth cultivated from February to April, 2015*

Fertilizer treatment	Stem diameter (mm)	Largest leaf area (cm^2)	Total leaf area (cm^2)	Fresh leaf weight (g /plant)	Dry leaf weight (g /plant)	Fresh stem weight (g /plant)	Dry stem weight (g /plant)	Fresh shoot weight (g /plant)	Dry shoot weight (g /plant)
Cont	1.880c	6.807b	19.350b	1.456b	0.233b	0.602c	0.066c	2.058b	0.299c
K	1.946c	3.973c	13.680b	1.496b	0.210c	0.734c	0.058c	2.230b	0.268c
P	2.120b	6.073b	17.893b	1.887b	0.287b	1.065b	0.148b	2.952b	0.436b
N	-	-	-	-	-	-	-	-	-
NK	-	-	-	-	-	-	-	-	-
NPK	6.748a	34.893a	147.510a	15.561a	1.773a	17.566a	0.907a	33.127a	2.682a
NP	2.705b	7.518b	32.610b	3.066b	0.403b	1.689b	0.211b	4.755b	0.615b
PK	2.331b	4.711c	8.953c	0.413c	0.201c	0.202d	0.120b	0.615c	0.321c

Data with the same letter within each column for each applied fertilizer are not significantly different at the 5% level, as determined by LSD test. - data not recorded due to poor growth

Effects of NPK fertilizer rates on growth and yield of amaranth BB and BC lines

Growth of amaranth BB and BC lines cultivated in red soil is shown in the *Fig. 4*. The growth of amaranth BB line was better with the increasing fertilizer rates. However, the growth was similarly higher with the fertilizers 30 and 40 g m^{-2}. The growth of amaranth BC line increased with the increasing fertilizer rates up to 30 g m^{-2}, and the growth was found to be lower with the fertilizer 40 g m^{-2} than with the 30 g m^{-2}. The plant grown without fertilizer was very poor in both the amaranth lines.

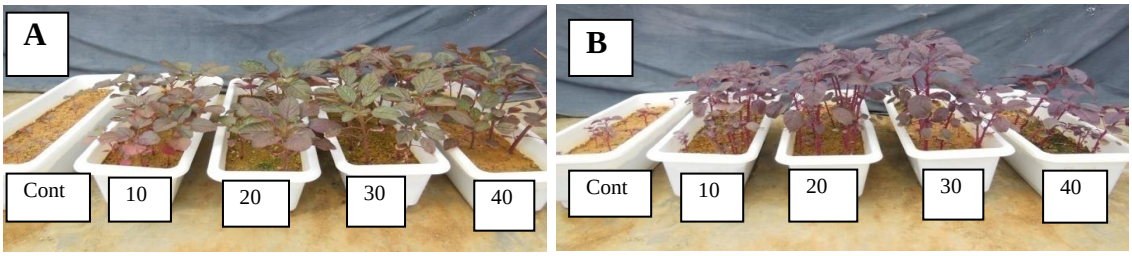

Figure 4. *Effects of combined fertilizer NPK rates on growth of amaranth lines BB (A) and BC (B) cultivated from June to July, 2014 in red soil. Cont (0 g), 10 (10 g m^{-2}), 20 (20 g m^{-2}), 30 (30 g m^{-2}), 40 (40 g m^{-2})*

Plants height of the amaranth BB line increased similarly with all the fertilizer rates, however the plant height was highest with the 40 g m^{-2} followed by 30 g m^{-2} (*Fig. 5*). On the other hand, plants height of the amaranth line BC increased with all the fertilizer rates, and the plant height was similarly highest with the 30 and 40 g m^{-2} (*Fig. 5*).

The leaf number of BB line increased with all the fertilizer rates, which was similarly highest with the fertilizer rate of 30 and 40 g m^{-2} (*Fig. 6*). The BC line obtained similarly higher leaf number with all the fertilizer rates, however the leaf number was found to be highest with the fertilizer 20 and 30 g m^{-2} (*Fig. 6*).

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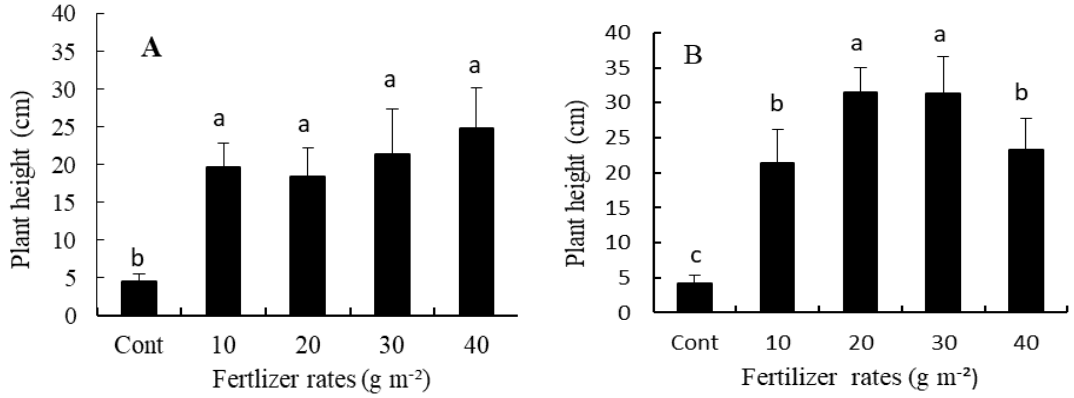

Figure 5. *Effects of combined fertilizer NPK rates on plant height of amaranth lines BB (A) and BC (B) cultivated from June to July, 2014. Bars with the same letter are not significantly different at the 5% level, as determined by LSD test. Error bars represent standard deviation of the data*

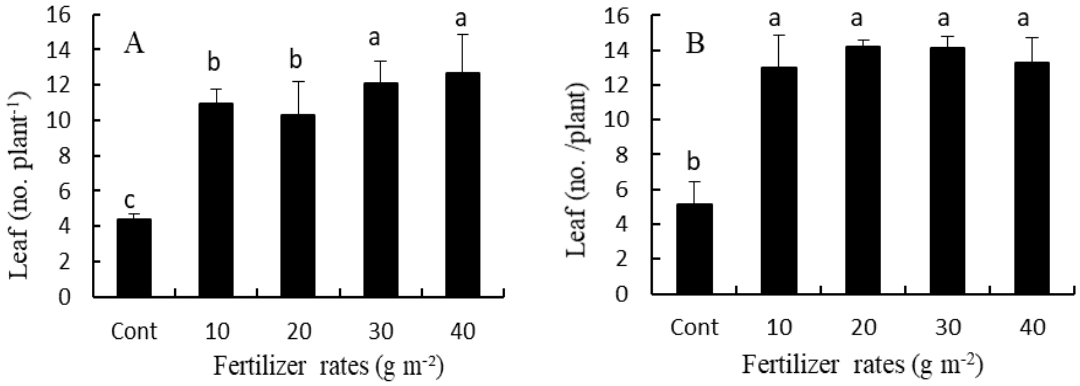

Figure 6. *Effects of combined fertilizer NPK rates on leaf number of amaranth lines BB (A) and BC (B) cultivated from June to July, 2014. Bars with the same letter are not significantly different at the 5% level, as determined by LSD test. Error bars represent standard deviation of the data*

Stem diameter of amaranth BB line was similarly higher with the fertilizer rate of 20-40 g m^{-2} (*Table 3*). Largest leaf and total leaf area were similarly highest with the 30-40 g m^{-2}. Fresh and dry weight of leaf and stem was similarly higher with the fertilizer rate of 20-40 g m^{-2}. Fresh and dry shoot weight was highest with the 40 g m^{-2} followed by 30 g m^{-2} (*Table 3*).

Amaranth BC line had increased growth parameters and yield (shoot) with all the fertilizer rates (*Table 3*), and the growth parameters and yield were similarly higher with the fertilizer rates of 20-30 g m^{-2}. The growth parameters and yield were found to be decreased with the fertilizer of 40 g m^{-2} (*Table 3*).

Effects of fertilizer N, P and K applied alone and in combination on minerals, N and C content of amaranths

The Na content increased with the fertilizer P and NP and decreased with the NPK and PK (*Table 2*). The K content increased with all the fertilizer treatments except NP,

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which was highest with the fertilizer NPK followed by P. The Ca content increased with the fertilizer K but decreased with the fertilizer NPK and NP. The content of Mg was not influenced with the fertilizers. The P content increased with the fertilizer NPK but decreased with the P and NP. The N content was highest with the fertilizer NPK followed by NP, and C content was lower with all the fertilizers (*Table 4*). Data was not recorded for the fertilizer treatments of N and NK due to very poor plant growth.

Table 3. *Effects of combined fertilizer NPK rates on plant growth parameter and yield (shoot) of amaranth lines BB and BC cultivated in red soil from June to July, 2014*

Fertilizer rates	**Stem diameter**	**Largest leaf area**	**Total leaf area**	**Fresh leaf weight**	**Dry leaf weight**	**Fresh stem weight**	**Dry stem weight**	**Fresh shoot weight**	**Dry shoot weight**
Lines (g m^{-2})	(mm)	($cm^2 leaf^{-1}$)	($cm^2 plant^{-1}$)	($cm^2 plant^{-1}$)	($cm^2 plant^{-1}$)	($cm^2 plant^{-1}$)	($cm^2 plant^{-1}$)	($cm^2 plant^{-1}$)	($cm^2 plant^{-1}$)
BB Cont	1.28c	2.08c	5.61d	0.15c	0.03c	0.16c	0.01c	0.31e	0.04d
BB10	4.16b	22.69b	101.60c	4.62b	0.61b	2.30b	0.21b	6.92d	0.82c
BB20	5.40ab	22.56b	131.39b	5.51ab	0.78ab	3.39ab	0.35a	8.90c	1.13b
BB30	5.61ab	24.37ab	138.75ab	6.73a	0.84a	3.55ab	0.38a	10.28b	1.22ab
BB40	6.01a	26.70a	153.19a	7.58a	0.97a	4.54a	0.41a	12.12a	1.38a
BC Cont	1.57c	1.71d	7.54d	0.25d	0.14c	0.13c	0.05c	0.38c	0.19c
BC10	4.88b	16.76c	75.74c	2.96c	0.41b	3.48b	0.30b	6.44bc	0.72b
BC20	7.06a	27.75a	121.82ab	6.55a	0.58a	9.22a	0.50a	15.77a	1.07a
BC30	6.69ab	27.56a	134.95a	6.25a	0.57a	9.51a	0.47a	15.76a	1.04a
BC40	5.85b	24.44b	105.91b	4.72b	0.39b	5.36b	0.23b	10.08b	0.62b

Data with the same letter within each column for each applied fertilizer are not significantly different at the 5% level, as determined by LSD test

Table 4. *Effects of fertilizer N, P and K applied alone or in combination on mineral, total nitrogen and total carbon content of amaranth cultivated from November to December, 2014*

Fertilizer Treatment	**Na** (mg g^{-2})	**K** (mg g^{-2})	**Ca** (mg g^{-2})	**Mg** (mg g^{-2})	**Fe** (mg g^{-2})	**P** (mg g^{-2})	**TN** (%)	**TC** (%)
Cont	6.1bc	61.6d	29.0b	20.5a	0.70ab	14.3b	2.43b	39.27a
K	6.9b	74.3c	46.6a	23.9a	1.01a	15.2b	2.49b	37.88c
P	10.4a	95.6b	27.7b	25.5a	0.53b	10.9c	1.64c	37.85c
N	–	–	–	–	–	–	–	–
NK	–	–	–	–	–	–	–	–
NPK	4.5c	118.2a	13.7d	11.5b	0.69ab	29.5a	6.49a	38.69b
NP	10.6a	43.8e	18.1cd	19.1a	0.48b	3.9e	3.87ab	37.87c
PK	4.3c	76.3c	25.6bc	19.1a	0.22c	6.7d	1.73c	37.22d

Data with the same letter within each column for each applied fertilizer are not significantly different at the 5% level, as determined by LSD test. - data not recorded due to poor growth

Effects of fertilizer NPK rates on mineral, N and C content of amaranths

In the amaranth BB line, Na and Ca content increased with the fertilizer rate of 10-20 g m^{-2} and 10 g m^{-2}, respectively (*Table 5*). The content of K and Mg was similarly higher with the 20-40 g m^{-2} and 10-30 g m^{-2}, respectively. The content of Al,

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Fe and P increased with all the fertilizer rates., and N and C contents were highest with the 20 g m^{-2}. In the BC line, the content of Na, K, Fe and P increased with all the fertilizer rates, and Ca, Mg and Al increased with the fertilizer at 10-30 g m^{-2}, 20-40 g m^{-2} and 40 g m^{-2}, respectively (*Table 5*). The K, Mg and P contents were highest with the 30 g m^{-2} followed by 40 g m^{-2}, and Ca was highest with the 20 g m^{-2} followed by 30 g m^{-2}. The Al content was highest with the 40 g m^{-2} followed by 30 g m^{-2} and Fe was highest with the 10 g m^{-2} followed by 20 g m^{-2}. The N content was highest with the 40 g m^{-2} followed by 30 g m^{-2} and C content was highest with the 10 g m^{-2} followed by 20 g m^{-2}.

Table. 5. *Effects of combined fertilizer NPK rates on mineral, nitrogen and carbon content of amaranth lines BB and BC cultivated in red soil from June to July, 2014*

Line	Fertilizer rates (gm^{-2})	Na (mg g^{-2})	K (mg g^{-2})	Ca (mg g^{-2})	Mg (mg g^{-2})	Al (mg g^{-2})	Fe (mg g^{-2})	P (mg g^{-2})	TN (%)	TC (%)
BB	Cont	6.73b	80.16c	52.48b	35.93b	0.45c	0.79c	22.63d	–	–
	10	7.63ab	112.00b	70.53a	44.36a	0.53b	0.83b	31.23c	2.75d	36.99b
	20	8.30a	135.66a	56.02b	44.25a	0.56a	0.81bc	30.53c	3.78a	37.21a
	30	6.83b	142.83a	55.73b	41.65a	0.57a	0.91a	44.00b	3.40b	36.93b
	40	6.86b	151.66a	55.60b	36.06b	0.58a	0.92a	49.26a	3.06c	37.00b
BC	Cont	6.23c	73.03d	36.40c	36.36bc	0.51b	0.68b	13.63d	–	–
	10	8.86b	117.66c	43.70b	32.53c	0.53b	0.90a	22.13c	2.23d	38.03a
	20	10.90a	144.33b	53.43a	38.16b	0.54ab	0.82a	23.03c	2.98c	37.40a
	30	10.93a	188.66a	48.53ab	44.93a	0.56ab	0.74b	31.60a	3.99b	37.07a
	40	9.56ab	175.66a	37.40c	44.10a	0.60a	0.72b	28.06b	5.07a	35.73b

Data with the same letter within each column for each applied fertilizer are not significantly different at the % level, as determined by LSD test. - data not recorded due to insufficient sample

Discussion

The growth of amaranth was best with the fertilizer NPK followed by NP, and plant growth was very poor with the fertilizer N, P, K, NK and PK and many of the plants died (*Figs. 1, 2 and 3*). The fertilizer N and NK showed adverse effect on plant height and leaf. All the growth parameters and yield (shoot) of amaranth were highest with the fertilizer NPK followed by NP (*Table 1*). The fertilizer N and NK showed adverse effect on all the growth parameters and yield of the amaranth, which indicate that P level is not available and N is not effective without P in the red soil. The fertilizers K, P and PK did not increase the growth parameters and yield, which indicates that amaranth plant cannot grow without combined fertilizers NP or NPK in the red soil. Similarly, several studies reported that shoot and root growth is reduced by P deficiency, N fertilizer contributes to 26-41% of crop yield, and P and K promote absorption of other nutrients and plant growth (Oya, 1972; Maier et al., 1994; Ivonyi et al., 1997; Sarker et al., 2002; Akamine et al., 2007).

Plants height of the BB line increased with all the fertilizer rates, however the fertilizer rates did not differ from each other, but they differed from the control. Plant height of the BC line did not increase with all the fertilizer rates, while it seems that a plateau was reached at 20-30 g m^{-2} rates, then the height decreased (*Fig. 5*). Similarly, the leaf number of the BC line increased only compared to control, therefore

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determining the highest value at a certain fertilizer rate is not relevant (*Fig. 6*). The stem diameter and leaf area of BB line were similarly highest with the 30-40 g m^{-2} (*Table 4*). Weight of leaf and stem was similarly higher with fertilizer rates of 20-40 g m^{-2}. Fresh and dry shoot weight was highest with the 40 g m^{-2} followed by 30 g m^{-2}. All the growth parameters and yield of amaranth BC line were similarly higher with the fertilizer rates of 20-30 g m^{-2} and found to be decreased with the 40 g m^{-2}. Similarly, Hossain et al. (2004) reported that too much fertilizer has a negative impact on *Panicum repens*. The amaranth BB line obtained 29% higher shoot (yield) biomass which required higher rate of fertilizer NPK, compared to line BC (the value was calculated from the best data of each amaranth line, *Table 3*). Similarly, *Panicum repens* required increasing rate of fertilizer with the increasing shoot biomass (Hossain et al., 2004).

The Na content was lower but K content was highest with the fertilizer NPK (*Table 2*). The Ca content increased with the fertilizer K but decreased with the NPK and NP. The content of Mg was not influenced with the fertilizers. The P and N content in amaranth increased with the fertilizer NPK. The results indicate that a specific fertilizer does not show the same trend in the accumulation of all the minerals and N; some minerals increased but other minerals decreased with a fertilizer element. Similar results were reported in several plants (Hossain et al., 2011; Gruber et al., 2013). It is difficult to clarify the fertilizer effects on the mineral accumulation in amaranth plants cultivated on red soil, which supported the results reported by Akamine et al. (2020).

The content of Na and Ca in amaranth BB increased with the fertilizer rate of 10-20 g m^{-2} and 10 g m^{-2}, respectively (*Table 5*). The content of K, Mg, Al and Fe was similarly increased with the fertilizer at 20-40 g m^{-2}, 10-30 g m^{-2}, 20-40 g m^{-2} and 30-40 g m^{-2}, respectively. The content of N was higher with the 20 g m^{-2}. The Na content of amaranth BC line was similarly higher with the 20-40 g m^{-2}. The K content was highest with the 30 g m^{-2} followed by 40 g m^{-2}, and Ca was highest with the 20 g m^{-2} followed by 30 g m^{-2}. The Mg and P content was highest with the 30 g m^{-2} followed by 40 g m^{-2}, Al was highest with the 40 g m^{-2} followed by 30 g m^{-2}, and Fe was highest with the 10 g m^{-2} followed by 20 g m^{-2}. The N content was highest with the 40 g m^{-2} followed by 30 g m^{-2}. These results indicate that mineral accumulation influenced by fertilizer rates differ with the amaranth lines, and a certain level of fertilizer NPK may be required to accumulate a particular mineral, which is similar to the results in other study (Akamine et al., 2020). In addition, it is thought that positive or negative interactions occur among the minerals and N existed in the soil and supplied fertilizers, which influence differently in accumulation of mineral and N in the amaranth plants. However, the major minerals were increased with the fertilizer rates of 20-40 g m^{-2} in both the amaranth lines.

Conclusion

The plant cultivated with the fertilizer N, P, K, NK and PK was very poor in growth, and N and NK showed adverse effect. All the growth parameters and yield of amaranth were highest with the fertilizer NPK followed by NP. Growth parameters and yield were significantly higher with the fertilizer 30-40 g m^{-2} for the BB line, and with the 20-30 g m^{-2} for the BC line. The fertilizer NPK resulted higher content of K, P and N, and lower content of Na and Ca in the amaranths. The content of Na and Ca was not influenced by the fertilizer NPK rates, whereas the content of K, Fe and Mg was higher with the fertilizer 30-40 g m^{-2} in the amaranth BB line. The content of Na, K, Ca, Mg, P

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and N was higher with the fertilizer 30 g m^{-2} in the BC line. The results indicate that mineral accumulation differed with the fertilizer rates and amaranth lines, however major minerals increased with the fertilizer NPK rates of 20-40 g m^{-2}. The results indicate that P level was not available, N was not effective without P, amaranth plant could not grow without combined fertilizers NP or NPK, and mineral contents in the amaranths did not differ clearly with the individual or combined fertilizers in the red soil. Above results suggest that fertilizer NPK at 30-40 g m^{-2} is effective for higher yield and quality of amaranth in the red soil of Okinawa. However, it was not possible to evaluate clear effects of fertilizer N, P and K on yield and quality of amaranth in this soil. Therefore, more detailed experiments should be conducted considering the physical and chemical properties of the red soil to clarify the actual effects of individual and combined fertilizers of N, P and K on yield and mineral content of different amaranth cultivars.

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Conflicts of interests. The authors declare no conflict of interests.

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