Response of Anchote (*Coccinia Abyssinica*) to Organic and Inorganic Fertilizers Rates and Plant Population Density in Western Oromia, Ethiopia

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Abstract: A comparative study of organic and inorganic fertilizer, and intra-row and inter-row spacing experiments were conducted at Bako Agricultural Research Center for three consecutive years (2002-2004) to determine optimum nutrient supply and plant population, respectively, for anchote production. The experiments were laid out in a randomized complete block design with three replications. The fertilizer study consisted of four nitrogen levels: 0, 46, 92 and 138 kg N ha^{-1} and three phosphorous levels: 0, 20 and 40 kg P ha^{-1} in a factorial arrangement along with farmyard manure (FYM) at rates of 5, 8 and 10 t ha^{-1}. The spacing study was conducted using three intra-rows: 10, 20 and 30 cm and four inter rows: 40, 60, 80 and 100 cm. Analysis of variance showed highly significant difference among N rates with respect to root length and root yield. Similarly, P and FYM supply resulted in highly significant difference in root yield. Apparently, application of 5 and 8 t ha^{-1} FYM resulted in an improved root yield of 44% and 63% over control, respectively. The supply of FYM was found to be superior over inorganic fertilizer supply perhaps due to its merits in improving soil structure, organic matter and enhancement of nutrient uptake. Intra-row spacing affected root yield highly and significantly while inter row spacing affected root yield and average root weight per plant. The reduction of intra-row spacing from 30 cm to 10 cm resulted in increase of total tuberous root yield by 137%. Reduction of inter row spacing from 100 cm to 40 cm resulted in high total tuberous root yield by 37.4%. From the present findings, therefore, 5-8 t ha^{-1} FYM or 46/20 kg ha^{-1} N/P and 40-60 cm inter row and 10 cm intra-row spacing are recommended for high yield of anchote production and enhancement of soil structure and its nutrient contents for the western sub-humid zones of Oromia, Ethiopia.

Keywords: Anchote; Farm Yard Manure; Inorganic Fertilizer; Root Yield; Spacing

1. Introduction

Root and tuber crops have been the main components of the traditional foods of the southern, southwestern and western parts of Ethiopia, particularly in densely populated areas (PGRC/E, 1988). Various native and exotic root and tuber crops are cultivated in these densely populated areas. Of the native root and tuber crops to Ethiopia, which are believed to have enormous genetic diversity, as they are indigenous and have been cultivated by farmers for a long time are anchote (*Coccinia abyssinica*), kote hare (*Dioscorea bulbifera*), enset (*Ensete ventricosum* C.), Oromo dinchi (*Coleus edulis*) and yam (*Dioscorea abyssinica* and *Dioscorea schimperiona*).

Anchote belongs to the family Cucurbitaceae, which are fruit bearing plants. However, anchote is the only root-bearing crop in the genus Coccinia and family Cucurbitaceae. Anchote is one of the indigenous root and tuber crops, which has been grown over a wide range of environments (1300-2800 meter above sea level.), with sporadic distribution. It is commonly produced by botanical seed. Basically anchote produces one root per plant. Its stem is a vine like cucurbit with tendrils and usually requires staking for seed production. The vine of anchote can grow on average up to 2 m heights. Anchote produces many branched stems just at the base of the plant. It also produces large above ground biomass, which may grow at the expense of tuberous root growth and deserves some agronomic management studies.

Anchote is a good source of protein, carbohydrate, calcium and iron (Amare, 1973). Except for some preliminary work undertaken at Bako Agricultural Research Center, no planned and coherent research has been conducted on anchote. On the other hand, anchote farmers, especially women, have been carrying out anchote husbandry from time immemorial.

In western Oromia zones, anchote is produced on several hectares of land with an average yield varying from 10–15 t ha^{-1} (Abdissa, 2000). Farmers usually grow local varieties of anchote under sub-optimal management practices like method of planting (broadcasting), weeding (varies from farmer to farmer), blanket fertilizer levels, mainly from organic sources such as crop residue, farm yard manure, household garbage, etc. It is significant to note that inappropriate agronomic packages may be some of the factors limiting crop productivity, quality and nutritive value of anchote. Of which, lack of recommended optimum organic and inorganic fertilizer rates and spacing were found to overweigh the other problems in the case of anchote.

Fertilizer studies conducted on different crop species over different locations in Ethiopia in general and in the

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western parts in particular entails that most of the soils of Ethiopia are deficient in P and N and are unable to support high crop productivity (Gemechu *et al.,* 1991; Tadesse and Tolessa, 1998). On the other hand, it was observed that anchote responds strongly to soil fertility, particularly to wood ash, burnt crop residues and household garbage, and produces large sized and quality roots of good shape (Abera, 1995; Girma, 1997). Further, like other root and tuber crops, anchote is a short cycle crop which bulks high yield in a relatively shorter period of time, and hence requires high fertilizer supply.

In the traditional anchote production system, farmers on average use about 15-20 cm spacing in broadcasting for anchote production. This spacing is apparently not optimum to provide sufficient soils for root coverage and to undertake some agronomic management practices. Spacing is of primary importance in greatly influencing root yield by affecting root size categories and quality. The manipulation of row spacing, plant populations, and the overall spatial arrangement of crop plants in a field has been the subject of considerable discussion among farmers and agronomists for many years.

Therefore, understanding the shortages of information pertaining to anchote production and management system, agronomic studies (fertilizer and spacing) were initiated with the objectives to understand anchote response to different fertilizer sources, determine optimum fertilizer rates and spacing for high yield and quality anchote production.

2. Materials and Methods

The studies were conducted at Bako Agricultural Research Center, western Oromia, Ethiopia. Bako Agricultural Research Center is situated at an altitude of 1650 m asl. The area receives total annual rainfall of 1213 mm (30 years average) with the rainfall season extending from April to October with the highest peak received in June and August. The mean minimum, optimum and maximum temperatures (30 years average) are 13 ^{O}C, 21 ^{O}C and 34 ^{O}C, respectively. The experiments were laid out in a randomized complete block design with three replications.

The study was undertaken on reddish brown Nitisols, which is acidic with a pH of 4.83 (Table 1). The fertilizer level bases for this study have been potato and sweet potato fertilizer studies so far made at Bako. The fertilizer study consisted of four N levels: 0, 46, 92 and 138 kg N ha^{-1}, in the form of urea, and three P levels: 0, 20 and 40 kg P ha^{-1}, in the form of triple super phosphate, in a factorial arrangement along with organic fertilizer at the rate of 5, 8 and 10 t ha^{-1} FYM. The FYM was well decomposed before use.

Seed of local anchote variety was sown on June 14th, 17th, and 9th in 2002, 2003 and 2004, respectively. Local anchote variety is herbaceous prostrating and climbing type which can produce up to 2 m long vine depending on the management and moisture supply of the area. It is ready for harvesting after 4 to 5 months after planting. The size of the plot was 8 m^2. The spacing used was 80 cm between rows and 20 cm between plants. Half the quantity of N was applied in band on the row and incorporated into the soil at the time of planting while the remaining N was side-dressed 5 cm around the root zone at one and a half months after planting. The entire quantity of P was applied at the time of planting in band on the row and incorporated in to the soil.

The spacing study involved three intra-row spacings: 10, 20 and 30 cm and four inter row spacings: 40, 60, 80 and 100 cm. Seed of local anchote variety was sown on June 21st, 17th and 8th in 2002, 2003 and 2004, respectively, on various plot size according to factorial arrangement of spacing. Blanket recommendation of fertilizer for root and tuber crops, 40 kg P ha^{-1} in the form of DAP and 66 kg N ha^{-1} in the form of urea was applied on every plot. The entire quantity of DAP and half of the total urea required were applied at the time of planting in band on the row and incorporated into the soil while the remaining urea was side-dressed 5 cm around the root zone at one and half months after planting.

2.1. Soil Sampling and Analysis

Soil samples were collected from a depth of 0–30 cm from different places of the experimental site before planting to form one composite sample to determine some soil physico-chemical properties (Table 1).

The collected soil samples were air-dried and ground to pass through a 2 mm pore size sieve for analysis. Particle size distribution was determined by Bouyoucos Hydrometer Method (Day, 1965). The soil pH at 1:2.5 soil-water ratio was measured using a digital pH meter (Page, 1982).

Table 1. Physico-chemical characteristics of the soil of experimental site in 2004

pH	EC	Sand (%)	Silt (%)	Clay (%)	CEC	BS	TN (%)	OC (%)	Phosphorus (ppm)		AvK (meq/100g)
									AvP	TP	
4.83	0.08	14.7	28.0	57.3	29.5	54.84	0.21	3.68	0.54	706.03	1.88

EC= electric conductivity, CEC= cation exchange capacity, BS = base saturation, TN = total nitrogen, OC = organic carbon, AvP = available phosphorous, TP = total phosphorous, AvK = available potassium and ppm= parts per million.

The organic matter content of the soil was determined by Walkley and Black method (Dewis and Freitas, 1970). Total nitrogen was estimated by micro-Kjeldahl method (Dewis and Freitas, 1970), available K by flame photometry (Anon, 1984) and soil cation exchange capacity (CEC) and basic exchangeable cations (Ca, Mg, K and Na) were determined by ammonium acetate method (Chapman, 1965). The available and total soil P were estimated following THE standard procedure (Olsen and Dean, 1965). Percentage base saturation was calculated by dividing total exchangeable base by CEC of the soil and multiplied by 100.

Data collected included total root yield, root diameter, root length and root weight per plant. Root diameter (cm) was measured by caliper at mid point of the root length at harvesting time. Root length indicates the measurement of root from tip to tip in cm by using measuring tape or ruler at harvesting. Root yield in this report indicates fresh root yield as soon as harvested. Roots were evaluated for root disease and found immune from any diseases. Data were analyzed by GENSTAT software program (Version 7) as factorial combinations and also as single factor. When a significant treatment effect was found, the test of least significance difference (LSD, P at 0.05 and 0.01) was used to separate means. After separate each year data was analyzed and normality of error variance was validated, over years data were pooled together.

3. Results and Discussion

3.1. Inorganic Fertilizer Response

The years combined analysis of variance showed highly significant difference ($p < 0.01$) among nitrogen levels with respect to root length and yield, whereas root diameter and average root weight per plant were found to be non-significant (Table 2). The increment of nitrogen supply from 0 to 46 kg ha^{-1} resulted in an increase of 20% root yield and then afterwards declined (Table 2). The increase in root yield was found to be low when compared with root yields of potato and sweet potato on the same soil implying that anchote can perform on poor marginal soils or it is less N nutrient demanding root crop. Basically in any root and tuber crops, yield increase is attributed to the increase in nutrient supply probably resulted from promoting yield components and prolonging the vegetative growth. Hence, the contribution of anchote yield components towards root yield increase cannot be underestimated (Table 2). Similar findings were reported on sweet potato at Bako by Girma *et al.* (2003).

Table 2. Influence of different rates of nitrogen fertilizer on tuberous root yield and yield components of anchote at Bako during 2002 to 2004 cropping seasons.

Nitrogen (kg ha^{-1})	RY (t ha^{-1})	RD (cm)	RL (cm)	FRW per plant (kg)
0	9.88	7.142	13.274	0.383
46	11.81	7.711	14.289	0.426
92	11.73	7.422	13.304	0.416
138	10.23	7.451	13.622	0.383
CV	19.07	13.24	10.62	13.83
LSD	1.72*	n.s.	0.786*	n.s.

*RY = Root yield; RD = Root diameter; RL = Root Length; FRW = Fresh root weight per plant; n.s = Non-significant at 5% probability level; * = Significant at 5% and 1% probability level, respectively.*

Similarly, phosphorous supply resulted in highly significant difference ($P < 0.01$) of root yield among the levels. Apparently an increase in phosphorous supply from 0 to 20 kg ha^{-1} resulted in an increase of root yield by 30%. Although the difference was not significant in root diameter, length and average root weight/plant, the trend was increasing (Table 3). The current positive response of anchote to P supply is not in conformity with potato and sweet potato findings in which there was no response to P supply owing to the acidity of the soils and fixation of P probably in the forms of Fe and Al compounds (Girma *et al*., 2003 and Girma and Ravishankar, 2004). The positive response of anchote to P supply was probably related to its deep root growth that facilitates more soil P reserve exploitation as compared to potato and sweet potato. Usually anchote root grows downwards in to the soil and never requires ridging or mound making as compared to most other root and tuber crops. The NP interactions showed non-significant response to all parameters studied. No interaction effect of N and P does not warrant recommending application of the two nutrients separately

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Table 3. Influence of different rates of phosphorous fertilizer on tuberous root yield and yield components of anchote at Bako during 2002 to 2004 cropping seasons.

Phosphorous (kg ha^{-1})	RY (t ha^{-1})	RD (cm)	RL (cm)	FRW per plant (kg)
0	9.10	7.079	13.411	0.375
20	11.85	7.526	13.600	0.403
40	11.80	7.690	13.856	0.427
CV	19.07	13.24	10.62	13.83
LSD	1.49**	n.s.	n.s.	n.s.

*RY = Root yield; RD = Root diameter; RL = Root Length; FRW = Fresh root weight per plant; n.s = Non-significant at 5% probability level; *, ** = Significant at 5% and 1% probability level, respectively.*

3.2. Response of Anchote to Organic Fertilizer

The anchote plots which received FYM produced vigorous, deep green and strong vine. The plants remained vegetative and green for longer as compared to the plants that received inorganic fertilizers (Table not shown). The supply of FYM significantly influenced root yield (Table 4). Maximum root yield was recorded when 8 t ha^{-1} FYM was applied. The yield then declined afterward when the rate increased to 10 t ha^{-1} FYM. The supply of 5 and 8 t ha^{-1} FYM resulted in increased root yield by 44% and 63% over the control, respectively. The yield improvement achieved by applying FYM was double to triple in contrast to inorganic N and P fertilizers supply. The effects of NP combined levels however did not show clear trends as opposed to the FYM levels (Table 5). This could be explained that anchote prefers organic fertilizer sources that contain several macro and micronutrients because of good water holding capacity, cation exchange capacity and slow release of nutrients as to plants need; besides improving soil structure.

From practical experience, farmers mainly grow anchote on the fields of burned crop residues, household garbage and near homestead on manured plots. This may suggest that anchote demands more balanced N, K, P and micro-nutrient fertilizers than others, which is substantiated by the present findings of FYM supply (Abera, 1995; Girma, 1997). Hence, the superior response of anchote to FYM may, therefore, be linked to the balanced supply of N, P, K and micronutrient supply potential of FYM. It was reported by different researchers that K has more quality determinant effect in root crops than doing productivity. From the present finding, therefore, we recommend 46/20 kg ha^{-1} N/P or 5-8 t ha^{-1} FYM for anchote production as multiple options for farmers of different wealth status (Table 5). We also suggest further investigation of anchote response towards different organic sources and also to study the influences of nutrient supply on basic biochemical composition of anchote. In a nutshell, the positive response of anchote to both organic and inorganic fertilizer supply is corroborated by laboratory soil test that indicated the very low nutrient content of the study soil with regard to total N, available and total P and OM (Table 1). These indicate that the soils of Bako are poor in primary macronutrients to support successful plant growth and high yield, suggesting application of different sources of fertilizers to boost anchote and other food crops yield.

3.2. Spacing

The over years combined analysis of variance showed a highly significant difference ($P < 0.01$) among intra-row spacing on total root yield (Table 6). The increase of intra-row spacing from 10 to 30 cm resulted in reduction of plant population by 200%, and subsequently in reduction of total tuberous root yield by 137%. Production of dry matter depends on the conversion of radiant energy into carbohydrate through the process of photosynthesis which takes place in the leaves.

Table 4. Influence of different rates of farmyard manure on tuberous root yield and yield components of anchote at Bako during 2002 to 2004 cropping seasons.

FYM (t ha^{-1})	RY (t ha^{-1})	RD (cm)	RL (cm)	FRW per plant (kg)
0	9.84	7.022	13.133	0.401
5	13.68	7.500	13.400	0.413
8	15.42	7.701	14.356	0.454
10	14.95	8.122	14.767	0.414
CV	14.23	10.18	11.24	12.53
LSD	3.23**	n.s.	n.s.	n.s.

*RY = Root yield; RD = Root diameter; RL = Root Length; FRW = Fresh root weight per plant; n.s = Non-significant at 5% probability level; *, ** = Significant at 5% and 1% probability level, respectively.*

Table 5. Effect of combined NP and farmyard manure (FYM) fertilizer on tuberous root yield and yield components of anchote at Bako during 2002 to 2004 cropping seasons.

N x P (kg ha^{-1}) and FYM	RY (t ha^{-1})	RD (cm)	RL (cm)	FRW per plant (kg)
0 x 0	9.84	7.022	13.133	0.401
0 x 20	8.59	7.178	12.933	0.410
0 x 40	11.20	7.227	13.778	0.371
46 x 0	9.70	7.281	14.022	0.391
46 x 20	13.80	7.861	14.400	0.388
46 x 40	13.05	7.982	13.756	0.458
92 x 0	8.97	7.200	13.467	0.368
92 x 20	13.66	7.340	12.733	0.411
92 x 40	12.55	7.838	13.711	0.387
138 x 0	8.47	6.924	12.689	0.480
138 x 20	11.34	7.714	14.000	0.414
138 x 40	11.51	7.714	14.178	0.407
5 t FYM	13.68	7.500	13.400	0.413
8 t FYM	15.41	7.701	14.356	0.454
10 t FYM	14.95	8.122	14.767	0.414
CV	25.69	12.89	10.89	35.69
LSD	2.84**	n.s.	n.s.	n.s.

*RY = Root yield; RD = Root diameter; RL = Root Length; FRW = Fresh root weight per plant; n.s = Non-significant at 5% probability level; *, ** = Significant at 5% and 1% probability level, respectively.*

The present study did not show significant variation among intra-row spacing with regard to leaf number per plant (Table 6). The average leaf number recorded was 50 per plant while average vine length recorded was 2 m. However, quite tremendous variations in leaf number and leaf areas were expected per hectare in response to plant population variation recorded. Therefore, one might assume that the greater the number of leaves in a field, the better interception of sunlight and the higher the tuberous root yield and vice versa. However it was observed that root length, root diameter and root weight were found superior under wider intra-row spacing at the expense of total root yield (Table 6). Similar result on tuber size and yield response was reported to the number of tuber per plant, N application and intra-row spacing of potato (Arsenault *et al*., 2001).

On the other hand, inter row spacing resulted in significant difference in root yield, average root weight per plant and root diameter (Table 7). Similar to intra-row spacing, the increase in inter row spacing from 40-100 cm resulted in root yield reduction of 37% (Table 7). Therefore, there was a decreasing trend in root yield as intra-row and inter row spacing increased from 10 to 30, and 40 to 100 cm, respectively, explaining optimum population of anchote in the ranges of 40-60 cm for inter row spacing along with 10 cm intra-row spacing (Tables 6 and 7).

Table 6. Influence of intra-row spacing on root yield and yield components of anchote at Bako during 2002 to 2004 cropping seasons.

Intra-row (cm)	RY (t ha^{-1})	RL (cm)	RD (cm)	FRW per plant (kg)	Leaf No. per plant
10	29.06	13.194	7.183	0.298	61
20	16.94	13.928	7.195	0.320	52
30	12.27	13.736	7.474	0.333	
					44
CV	13.41	11.78	13.89	26.97	10.90
LSD	3.05**	n.s.	n.s.	n.s.	n.s

RY = Root yield; RD = Root diameter; RL = Root Length; FRW = Fresh root weight per plant;
*n.s = Non-significant at 5% probability level; *, ** = Significant at 5% and 1% probability level, respectively.*

Table 7. Influence of inter row spacing on root yield and yield components of anchote at Bako during 2002 to 2004 cropping seasons.

Inter row (cm)	RY ($t\ ha^{-1}$)	RL (cm)	RD (cm)	FRW per plant (kg)	Leaf No. per plant
40	22.05	13.341	7.068	0.263	51
60	20.63	13.389	6.827	0.297	40
80	18.96	13.807	7.580	0.333	38
100	16.05	13.941	7.541	0.376	42
CV	13.41	11.78	13.89	26.97	12.50
LSD	3.53**	n.s.	0.547*	0.045**	n.s

*RY = Root yield; RD = Root diameter; RL = Root Length; FRW per plant = Fresh root weight per plant; n.s = Non-significant at 5% probability level; *, ** = Significant at 5% and 1% probability level, respectively.*

Anchote is a prostrating vine which can spread its branches up to 2 meters and above. Hence, the high yield under high plant population is attributed to high photosynthesis as there is not much shading effect of the leaves due to the spreading type of plant architecture.

On the other hand, the spacing at which anchote produced optimum yield is quite narrow, when compared to potato (Girma *et al*., 2005). This would be due to the fact that anchote produces only one tuberous root that grows downwards and requires less space and soil cover for optimum yield.

The interaction effect of intra-row and inter-row spacing was not significant on root yield and other yield components. The root yield decreased with an increase of intra-row spacing and inter-row spacing (Table 7). This implies that the recommendation can be based on the separate intra-row and inter-row spacing levels at which optimum yield was registered. Therefore, based on the present finding, 40-60 cm inter-row with 10 cm intra-row spacing is recommendable for anchote production in western Oromia, Ethiopia.

4. Conclusion

From these studies we observed that anchote production was predominantly influenced by spacing or by plant population adjustment. This is because crop canopy has often been manipulated by row spacing and population adjustments in an attempt to improve yields, production efficiencies, and profits by enhancing photosynthetic efficiency.

The study pointed out that anchote was more responsive to organic fertilizer source than inorganic fertilizer sources. Contrary to potato and sweet potato, anchote was found highly responsive to P supply under the acidic soil condition. But, except we postulate that anchote has deep root system rather than potato and sweet potato, the mechanism was not well explored. Therefore, the study suggested the inclusion of more organic sources to reach at conclusive result of anchote response in contrast to the inorganic sources. There is also a need of investigating the mechanism how anchote response was enhanced under such acidic soil condition.

Essentially, based on the present studies, we recommended different options for different wealth categories of farmers for sustainable anchote production in the sub-humid agro-ecologies of western Oromia, Ethiopia. These recommendations are 5-8 $t\ ha^{-1}$ FYM which is usually affordable by poor farmers, while the inorganic fertilizer at the rates 46/20 N/P $kg\ ha^{-1}$ is suggested as optimum fertilizer for the well to do farmers. Correspondingly, 10 cm intra-row spacing and 40-60 cm inter-row spacing were found superior in optimum quality tuberous root yield production and, hence, found to be very practical for anchote production.

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