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# Scaling up Production of Traditional Green Leafy Vegetables in Kenya: Perspectives on Water and Nitrogen Management

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## ABSTRACT

Traditional green leafy vegetables are promising alternative vegetable crops consumed in Kenya and other African countries. The crops whose consumption is on the increase include vegetable amaranth (*Amaranthus* spp.), African nightshades (*Solanum* spp.) and spiderplant (*Cleome/Gynandropsis gynandra*). They are popular in the Kenyan retail markets and key supermarket chains as surveys have shown. This offers the urban dwellers access to these vegetables on one hand, while offering a reliable market for growers on the other hand. They are also potential export crops as the consumption continues to widen in most parts of Asia too. For a long time these crops have not been integrated into mainstream agriculture. Consequently, they have received little attention in terms of research and development, resulting in many gaps in information. Production continues to be on small-scales, with the farmers being the major custodians of the genetic materials and production technologies. With the current upsurge of interest in traditional vegetables, there is need to raise production to meet the increasing demand. Some agronomic studies aiming to develop optimal cultivation practices for improved yield and nutritive quality of these crops have been reported. More research work on these crops is necessary to facilitate increased production. In this paper, research into the water and nitrogen use in traditional leafy vegetables is reviewed. The paper aims to show the current status of research, major gaps in information in an effort to scale up production of these crops to meet the increasing demand.

**Keywords:** *Amaranthus* spp., *Cleome gynandra*, nitrogen use, plant growth, *Solanum* spp.

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## INTRODUCTION

Past surveys have shown that traditional vegetables in Kenya are produced mainly in “kitchen gardens” (Chweya and Eyzaguirre 1999). In these surveys, it was noted that large-scale production of traditional vegetables was hampered by lack of promotion and markets. Okeno *et al.* (2003) argue that the introduction of “exotic vegetables” has contributed to the confinement of the traditional vegetables into small backyard gardens. We have done similar surveys recently in 2003 and 2004 (Agong and Masinde 2006) and it is clear that production has remained largely on kitchen garden scales. However, it is apparent that the consumption has continued to increase. There have been successful campaigns and promotional activities aimed at encouraging the consumption of traditional green vegetables mainly by non-governmental organisations like FORMAT, KENRIK and SACRED-Africa. Consequently, production and consumption of these vegetables is spreading out of the traditional rural areas to urban and peri-urban areas. The increased demand has resulted in shortages, which are rou-

tinely reported in the Ministry of Agriculture yearly reports. Consequently the crops are highly priced, both the leafy vegetable and the seed for planting.

The crops whose consumption is on the increase include vegetable amaranth (*Amaranthus* spp.), African nightshades (*Solanum* spp.) and spiderplant (*Cleome/Gynandropsis gynandra*). They are popular in the Kenyan retail markets as all surveys have shown. Besides, they are also consumed in various African countries (Chweya and Eyzaguirre 1999). These crops have nutritional value comparable or even higher than that of the well established “exotic vegetables” (Grubben and Denton 2004). Increased utilization of these vegetables will go a long way in alleviating malnutrition in communities whose staple food is maize and have few other sources of vitamins and minerals. Welch and Graham (2004) suggest that developing micronutrient-enriched staple plant food through traditional plant breeding or molecular techniques could be one way to counter micronutrient malnutrition. Use of traditional leafy vegetables may be an easier and cheaper way to intervene in micronutrient malnutrition among the vulnerable populations in Kenya. It is

important to note that these vegetables have already entered the supermarkets, and are sold alongside the well established "exotic vegetables" like cabbage (*Brassica oleracea* var. *capitata*) and kales (*Brassica oleracea* var. *acephala*). This offers the urban dwellers access to these vegetables on one hand, while offering a reliable market for growers on the other hand. Scaling up production of these vegetables to meet the demand has to be addressed urgently. This paper reviews the current status of research and major gaps in information for vegetable amaranth, African nightshade and spiderplant, especially in the aspects of water and nitrogen application.

## WATER MANAGEMENT DURING PRODUCTION OF TRADITIONAL GREEN LEAFY VEGETABLES

Previously, it was thought that traditional vegetables were tolerant to water stress, considering that they grew unattended to in the wild. This resulted in a general feeling that traditional vegetables are low input crops, which are more tolerant to abiotic and biotic stresses as compared to exotic vegetables (Okeno *et al.* 2003; Adebooye and Opabode 2004). Studies have shown that the response of traditional green leafy vegetables depends on the species. Vegetable amaranth is thought to be tolerant to water stress (Schippers 2000; Palad and Chang 2003). Liu and Stützel (2002a) found that vegetable amaranth was characterised by a high capacity of osmotic adjustment in the range of 1.08-1.24 MPa that could sustain turgor maintenance and hence dry matter production during drought stress. They also showed that under drought stress, the reduction of transpiration of vegetable amaranth was mainly due to reduction of stomatal conductance, rather than reduction of leaf expansion, and that the responses depended on the genotypes (Liu and Stützel 2002b). Despite showing significant osmotic and stomatal adjustments as mechanisms, drought stress causes reductions in vegetative growth of amaranthus. Ayodele (2000) found that imposing water stress at the vegetative stage reduced amaranthus leaf area by 18-20%. He also showed that water stress generally reduced plant height, number of leaves and root length irrespective of the stage at which water stress was imposed. Spiderplant and African nightshades are highly sensitive to drought (Chweya and Mnzava 1997; Edmonds and Chweya 1997). Leaf expansion and stem elongation for both crops declined significantly when the soil moisture fell below 40-60% of available soil water and they showed limited osmotic adjustment in the range of 0.10-0.33 MPa (Masinde *et al.* 2005a, 2006). In addition, well watered plants had 3-5 fold higher leaf area and up to 45% more dry weight than plants exposed to water deficit. These crops therefore respond to drought mainly by drastic reductions in leaf area and vegetative growth. Plants growing under drought stress may accumulate proline as one of the compatible solutes during osmotic adjustment (Chaves and Oliveira 2004). In soybean (*Glycine max* L. cv. 'Williams'), plants growing in a soil allowed to dry to 70% field capacity accumulated up to 9-fold more proline in shoots and up to 30-fold more proline in roots as compared to plants maintained at near 100% field capacity (Porcel and Ruiz-Lozano 2004). Sarker *et al.* (2005) subjected eggplants (*Solanum melongena* L.) to four moisture stress treatments: irrigation to pot capacity after every 7 days (control), 14 days (short term stress), 28 days (long term stress) and no irrigation (severe stress). They found that at 56 days after the start of the treatments, proline levels in leaves were 74-115 times greater in the stress treatments as compared to the control. David *et al.* (1984) have shown that spiderplant can accumulate up to 9-fold more proline when plants are grown under water deficit. They however found that this accumulation did not change net photosynthesis or leaf conductance leading to the conclusion that proline had no role in inducing drought tolerance.

Soil water deficit has negative effects on the physiological functions of the plant such as transpiration, stomatal conductance and photosynthesis as well as reducing the

plant water status. In vegetable amaranth (*Amaranthus* spp.), Liu and Stützel (2002b) found that transpiration and stomatal conductance declined when plants were subjected to soil moisture below 22-53%, and 32-60% of available soil water, respectively. The stomatal conductance ranged from 0.8 mol m<sup>-2</sup> s<sup>-1</sup> at the time of water deficit imposition to close to zero at the time when all the available plant water had been exhausted from the soil. In both spiderplant and African nightshades, transpiration declines when the soil moisture falls below 46-77% of the available soil water while the leaf relative water content declined to 54-60% as compared to above 70% in control plants (Masinde *et al.* 2005a, 2006). Eggplants grown under short term, long term and severe moisture stress (irrigating to field capacity at 14, 28-days interval and no irrigation, respectively) had total dry biomass of 54-63%, 33-40% and 14-25% of the control, respectively (Sarker *et al.* 2005). In these plants, photosynthesis rate was highest in control plants in the range of 6-24 μmol m<sup>-2</sup> s<sup>-1</sup> at 32 days after the start of the treatments as compared to values of 0.83-0.99 μmol m<sup>-2</sup> s<sup>-1</sup> under severe stress at 42 days after the start of the treatments (Sarker *et al.* 2005). Withholding water for 18 days reduced beans (*Phaseolus vulgaris* L.) dry weight by about 55% compared with control plants (Ferrat-Lazcano and Lovatt 1999). Monti *et al.* (2006) found that in sugarbeet (*Beta vulgaris* L. var. *Monodoro*), plants grown under adequate water supply had 34-52% higher total dry weight than plants exposed to transient and permanent drought stress. In addition, they found that photosynthesis rate was 120% higher in control plants than in drought stressed plants. In these crops, the final impact of water deficit on the yield will depend on dry matter partitioning to the fruit in eggplant, seed in beans and root in sugarbeet. However, with the leaf as edible part for traditional leafy vegetables, water deficit has a direct impact on the yield. Generally, for spiderplant and African nightshades, decline in leaf growth and yields begin once the soil moisture declined below 60% of the available plant soil water (Masinde *et al.* 2005a, 2006).

In scaling up production of traditional leafy vegetables, it is crucial to address the question of water management. Irrigation should be part and parcel of the increased production. Water-saving irrigation strategies such as deficit irrigation (DI) and partial root drying (PRD) (Kang and Zhang 2004) may be of use in vegetable crops. In both cases, plants undergo partial stomatal closure in response to root signals probably the hormone abscisic acid (ABA) from drying soil (Sobeih *et al.* 2004; Liu *et al.* 2006) and this may maintain high plant water status. Root signals include ABA and inorganic ions like nitrates, K<sup>+</sup> and Ca<sup>2+</sup> (Davies *et al.* 2002). Deficit irrigation and partial root drying have been tried in various crops. In pepper (*Capsicum annum* L.) Dorji *et al.* (2005) have shown that leaf water potential was lower in plants grown under DI and PRD than in control plants, with values of -1.1 MPa, -0.9 MPa and -0.7 MPa, respectively at 130 days after sowing. They found significant differences in fresh fruit yield with values of 3778.6, 3054.5 and 2468.0 g/plant for the control, PRD and DI respectively, but no significant differences were observed in the dry fruit weight per plant. Leaf water potential did not differ significantly between well watered (WW) and PRD tomato (*Lycopersicon esculentum* Mill.) plants even though the PRD plants received half the water of WW plants (Sobeih *et al.* 2004). The stomatal conductance of these PRD plants was 64% that of WW plants. Trials with potato (*Solanum tuberosum* L. cv. 'Folva') showed that leaf water potential between WW, DI and PRD remained similar at -0.53 MPa in early stages of treatments (Liu *et al.* 2006). At later stages, WW and DI plants had similar leaf water potential of -0.73 MPa as compared to a lower value of -0.85 MPa in PRD plants. Sobeih *et al.* (2004) suggested that exploiting genotype variation in generation of and response to chemical signals in order to maintain leaf growth under soil drying maybe a better crop-improvement strategy in leafy crops. There is need for a comprehensive evaluation of the spiderplant, African nightshade

and amaranthus genotypes to quantify their ability to generate root signals under drying soil. This information is critical for the development of appropriate water saving irrigation strategies that will enable affordable production of traditional leafy vegetables without relying on rainfall.

## NITROGEN MANAGEMENT DURING PRODUCTION OF TRADITIONAL GREEN LEAFY VEGETABLES

Our recent surveys (Agong and Masinde 2006) have shown that most farmers of traditional leafy vegetables do not use mineral fertilizers, opting to apply manures instead. However, in peri-urban areas where production was more market oriented, fertilizers were in use. Scaling up production will require application of fertilizers to supply the necessary nutrients, except under organic farming systems. There are conflicting reports on the nitrogen requirements of the various traditional vegetables grown in Kenya. Various fertilizer recommendations for traditional leafy vegetables are available in the literature (**Table 1**).

Being green leafy vegetables, they may be high nitrogen consumers with optimum levels of up to 5 g N/plant reported for African nightshades (Murage 1990). At this level, plants gave leaf yields of 51 t/ha compared to 20 t/ha in control plants. However, this level of N increased leaf nitrate content 7 times more than in the control plants. Khan *et al.* (1995) found that applying 1.80 g N/plant in a pot experiment gave 14.4% higher plant dry weight, 13.2%, 42.3% and 12.0% higher leaf N, P and K content, respectively, than control plants. In a field experiment, Opiyo (2004) applied 52-104 kg N/ha (0.23-0.94 g N/plant) to black nightshade (*Solanum nigrum* L.) and found leaf yields of up to 15 t/ha as compared to 9 t/ha in control plants. He found no significant effects on the levels of oxalates and phenolics in the leaves. In amaranth (*Amaranthus cruentus* L.), application of 3 t/ha (12 g/plant) maize-stover compost with 30 kg N/ha (0.12 g N/plant) gave plant height, number of leaves, leaf area/plant and cumulative fresh shoot yield of 46 cm, 9.2 leaves, 469.1 cm<sup>2</sup> and 24.3-25.2 t/ha, respectively as compared to respective values of 20.4 cm, 7.1, 31.8 cm<sup>2</sup> and 12.1-12.5 t/ha in control plants (Akanbi and Togun 2002). In addition, plants supplied with 3 t/ha compost and 30 kg N/ha gave the highest contents of N, P, K, with values of 2.42%, 0.41%, 0.64%, respectively, while control plants had N, P, K contents of 0.92%, 0.18%, 0.59%, respectively. For spiderplant, Onyango *et al.* (1999) obtained yield of 65.2 g edible part/plant when 2.5 t compost and 50 kg/ha Diammonium phosphate (18N:46P:0K) were applied as compared to yields of 1.5 g edible part/plant in control plants.

Nitrogen recommendations for nightshades ranged from 1.8 g N/plant to 5 g N/plant. Recommendations for spiderplant and vegetable amaranth were also variable. Schulte auf'm Erley *et al.* (2005) have shown that application of 80-120 kg N/ha in grain amaranth gave grain yields of up to 2767 kg/ha with harvest index of 0.23 as compared to 1986 kg/ha with harvest index of 0.22. Similarly, Pospišil *et al.* (2006) found that applying 50-100 kg N/ha significantly increased grain amaranth yield to 1434-1525 kg/ha compared to 1042 kg/ha under control treatment but had no significant effect on plant height and dry matter. Application of nitrogen has the potential to increase leaf yields and change the nutritive values of traditional leaf vegetable crops.

## Plant responses to nitrogen stress

It is known that nitrogen deficiency exerts its effects on plant growth through reduced leaf area index and hence low light interception and low dry matter production (Jones 1992; Grindlay 1997). The leaf nitrogen content correlates well with the leaf chlorophyll content, hence a low leaf N content as occurs during N deficiency leads to reduced photosynthesis resulting in lower biomass accumulation (Sinclair and Horie 1989; Zhao *et al.* 2005). Potato (*Solanum tuberosum* L.) plants supplied with 1500 mg N/plant at 7-10 day interval (non-limiting N) had 3 times higher area of leaf numbers 8 and 10 as compared to plants supplied with 250 mg N/plant (limiting N) at the same interval (Vos and van der Putten 1998). Similarly, Zhao *et al.* (2005) showed that in sorghum (*Sorghum bicolor* (L.) Moench), leaf area was 3-fold higher in plants supplied with half strength Hoagland's nutrient solution (100% N, adequate nitrogen) as compared with those receiving no N in the nutrient solution (0% N, nitrogen-deficient). On the other hand, maize increased leaf area only by 30% in plants supplied with 6.0 g N/plant (non-limiting N) as compared with those supplied with 0.5-0.84 g N/plant (limiting N) (Vos *et al.* 2005). Understanding the strategy adopted by traditional leafy vegetable crops when faced with nitrogen limitation is important in their nitrogen management. A strategy that leads to larger reductions in leaf area under nitrogen stress as the case in potato will result in larger reductions in leaf yield as compared to the case of maize, which experiences less reduction in leaf area.

Increasing nitrogen supply to 100-200 kg N/ha (equivalent of 3.1-6.3 g N/plant) in tomato (*Lycopersicon esculentum* Mill.) gave optimum leaf area index and increased absorbed photosynthetically active radiation to 2222-2923 mol m<sup>2</sup> as compared to 1860-2272 mol m<sup>2</sup> in control plants (Tei *et al.* 2002). Nitrogen supply of 25-100 kg N/ha significantly increased dry matter production in soybean (*Glycine max* (L.) Merr) to levels of 705-860 kg/ha as compared to 630 kg/ha in control plants (Taylor *et al.* 2005). In sunflower (*Helianthus annuus* L. var. CATISSOL-01), plants supplied with 70% of full strength Long Ashton solution containing 282 ppm N (high nitrogen) produced nearly four-fold the dry matter produced by plants supplied with the same solution containing 2.82 ppm N (low nitrogen) (Cechin and de Fátima Fumis 2004). As plants restrict their leaf area probably to maintain a high leaf nitrogen concentration under nitrogen stress, they may end up with a reduction in specific leaf area (SLA). Meziane and Shipley (2001) working on 22 herbaceous species have shown that supplying 6 mM N in Hoagland's solution under low irradiance (200 μmolm<sup>-2</sup>s<sup>-1</sup> photon flux density) gave a higher SLA in the range of 169-473 cm<sup>2</sup>/g as compared to a range of 93-348 cm<sup>2</sup>/g under high irradiance (1100 μmol m<sup>-2</sup> s<sup>-1</sup> photon flux density) or 120-355 cm<sup>2</sup>/g under 1 mM N and low irradiance. However, Cechin and de Fátima Fumis (2004) found that in sunflower, nitrogen supply had no effect on the specific leaf weight, the reciprocal of specific leaf area. A low SLA suggests thicker leaves as opposed to thinner leaves which have a high SLA. A reduction in SLA under nitrogen deficiency has also been associated with accumulation of starch in leaves (Grindlay 1997) as has been observed in tomato (Le Bot *et al.* 1998). It is thought that whereas thicker leaves have a greater concentration of the photosynthetic apparatus per unit leaf area, broad thinner leaves can intercept more light (White and Consuelo Mon-

**Table 1** Recommendations for nitrogen application to selected traditional vegetables.

Crop	Experiment site	Recommendation/ treatments giving highest yield	Reference
Amaranthus	Field	3.0t/ha compost+30 kg N/ha	Akanbi and Togun 2002
	-	10t/ha compost+94 kg/ha	Palad and Chang 2003
African nightshade	Field	5 g N/plant	Murage 1990
	Greenhouse	1.8 g N/plant	Khan <i>et al.</i> 1995
Spiderplant	Field	2.5 t/ha manure + 500 kg/ha DAP	Onyango <i>et al.</i> 1999
	-	200 t/ha farm yard manure + 260 kg N/ha	Chweya and Mnzava 1997

tes 2005). Thin large leaves are desirable for traditional leafy vegetables since leaf size is a quality attribute. Thus genotypes that maintain a relatively high SLA under low nitrogen conditions are high yielding. Lemaire *et al.* (1992) found that as the aerial biomass increased, the leaf to stem ratio of lucerne (*Medicago sativa* L.) declined in a power function irrespective of the nitrogen supply. In this case, as the plants increased in size, they were allocating relatively more dry matter to the stem for support than leaves. Traditional leafy vegetables that can allocate relatively more dry matter to leaf blades than the stem with increasing plant size may be more suitable since the plants will have a relatively larger leaf (edible part) fraction.

Leaf nitrogen concentration is an important physiological parameter that indicates the plant nitrogen status. Plants supplied with nitrogen have higher plant nitrogen concentration as has been shown in soybean (*Glycine max*) (Taylor *et al.* 2005), wheat (*Triticum aestivum* L.) (Sinclair *et al.* 2000), sorghum (Zhao *et al.* 2005) and various herbaceous species (Meziane and Shipley 2001). Lemaire *et al.* (2005) showed a linear relationship between shoot nitrogen content and leaf area in lucerne (*Medicago sativa* L.) irrespective of the growing conditions. They argued that the amount of nitrogen in the shoot represents the N available for leaf expansion. A clear understanding of the response of traditional leafy vegetable crops to nitrogen supply in terms of leaf area expansion, leaf nitrogen concentration and dry matter production is vital in the efforts to develop appropriate nitrogen management strategies.

### Use of nitrogen critical dilution curves in nitrogen management

Nitrogen uptake rate is regulated by both soil N availability and crop growth rate (Gastal and Lemaire 2002). Notably, the N concentration in plants declines as they grow even when the N supply is ample suggesting that the relationship between N uptake and plant growth is complex (Gastal and Lemaire 2002). Decline in N concentration with plant growth has been attributed to a dilution effect related to greater plant dry matter increase than N accumulation rate. This has been demonstrated in canola (*Brassica napus* L. ssp. *oleifera* var. *annua*) in which plants supplied with 150 kg N/ha had 3.97% N at the flower bud stage, but declined to 1.47% N at maturity stage (Chamorro *et al.* 2002). Espinola *et al.* (2001) also found that greater dry matter accumulation rate than N accumulation rate resulted in decline in nitrogen concentration in pickling cucumber (*Cucumis sativus* L.). This dilution is brought about by self shading in closed canopies and a change in leaf to stem ratio as the plant grows. Shaded leaves have low N content. Leaves with a large protein content are formed early in growth, but as growth proceeds, proportionally more structural tissues of low N content are formed, reducing the leaf to stem ratio and contributing to the decline in plant N with growth (Gastal and Lemaire 2002; Lawlor 2002).

Stem nitrogen concentration of spiderplant under well watered conditions declined from 5% when dry weight was below 5 g/plant (seedling stage) to 1.5% when dry weight was above 30 g/plant (flowering stage) (Masinde *et al.* 2005b). Under water deficit, there was a similar decline but the concentration remained about 2.5% with final plant dry weight at 16 g/plant. Similar declines were consistently demonstrated for petioles and roots under glasshouse and field conditions, but for leaf blades the decline was only slight or absent. The slower decline in N concentration of plant tissues observed in plants exposed to water deficit was attributed to reduced dry matter production hence low dilution. Similar results have been reported in strawberry (*Fragaria × ananassa* Duch.), where plants irrigated according to a climatic water balance model had 2.94% N in leaves, which was significantly lower than 3.04% N in leaves of plants not irrigated although these differences were not significant in other experimental years (Krüger *et al.* 1999).

Modelling approaches have the potential to improve

crop nutrition husbandry. Use of empirical models like critical nitrogen concentration curves can be an important tool in nitrogen management (Greenwood *et al.* 1990, 1991; Lemaire *et al.* 1992). Seginer *et al.* (2004) and Tei *et al.* (2002) reported such curves in lettuce (*Lactuca sativa* var. *capitata*) and tomato (*Lycopersicon esculentum* Mill.), respectively. The curves take a general form of  $% N = aW^{-b}$ , where W refers to plant dry weight and a and b are coefficients which could depend on the plant species. These curves show the plant N concentration declining in a power function of the increasing plant dry weight. Use of critical nitrogen curves has been suggested for an accurate diagnosis of wheat (*Triticum aestivum*) N nutrition (Justes *et al.* 1994). In this case, nitrogen nutrition level is represented by a nitrogen nutrition index (NNI), which is obtained as a ratio of total nitrogen concentration measured in the plant to the critical nitrogen concentration corresponding to the amount of plant dry matter produced. The nitrogen nutrition is optimal when NNI is 1, limiting when it is lower than 1, and in excess when its higher than 1. There is need to establish the critical nitrogen concentration curves for traditional leafy vegetables for optimal nitrogen management. Extensive evaluation of nitrogen requirements for the various traditional vegetables in different agro-ecological zones will be necessary to calibrate the curves.

### Nitrate accumulation in traditional leafy vegetables

As traditional leafy vegetable crops become commercial, field-scale growers may resort to supplying high amounts of fertilizers in order to obtain high leaf yields. This may be harmful to the consumers since these vegetables are known to accumulate phytochemicals like phenolics, alkaloids, nitrates and oxalates, whose concentrations may depend on the level of fertilizer use. Khan *et al.* (1995) showed that the alkaloid solasodine found in *Solanum nigrum* L. was 118% higher in plants supplied with 1.80 g N/plant than in control plants. Slower growth rate of plant crops under moisture stress prevents the dilution effect of nutrient elements (Alam 1999). This as well as luxury N uptake may result in accumulation of nitrates in plant tissues (Wright and Davison 1964).

Nitrate accumulation in vegetable crops is a well recognized problem that poses health hazards to consumers. Nitrates once ingested by humans are reduced in the liver to nitrites, which in turn combines with haemoglobin rendering it unable to bind oxygen, a condition called methemoglobinemia (Taiz and Zeiger 1998). Nitrates can also be converted into nitrosamines that are known to be potent carcinogens and are associated with various cancers (Hill 1991; Taiz and Zeiger 1998). Lettuce (*Lactuca sativa* L.) is known to accumulate high amounts of nitrates depending on the source of nitrogen. Maršić and Osvald (2002) used nitrates as a source of nitrogen in a Resh solution at 13 mM and 5 mM and found nitrate contents in the outer parts of lettuce of 2591-3277 mg/kg and 825-1608 mg/kg, respectively. When they used ammonium at similar levels of 13 mM and 5 mM, nitrate content of outer parts of lettuce were 32.9-38.8 mg/kg and 31.7-46.2 mg/kg, respectively. van der Boon *et al.* (1990) found nitrate levels in lettuce of 2542-2850 mg/kg when the nitrogen source was 80% ammonium as compared to 5053-5148 mg/kg when nitrate was the only source of nitrogen. In celery (*Apium graveolens*), Martignon *et al.* (1994) found nitrate levels of 5321-6130 mg/kg fresh weight when nitrate fertilizers were used as compared to levels of 2721-3695 mg/kg fresh weight when nitrate fertilizers were avoided a week before harvesting. Increasing  $NO_3^-$ -N from 30% to 70% in a nutrient solution (8 mM N) increased the  $NO_3^-$  concentration in endive (*Cichorium endivia* L. var. *crispum* Hegi) from 2400 to 6100 mg/kg fresh mass (Santamaria and Elia 1997). Guvenc (2002) compared radish (*Raphanus sativus* L.) plants grown at 0, 100 and 200 kg N/plant and found that nitrogen application significantly increased nitrate contents in the roots. In a pot experiment, Gonzalez-Ponce and Salas (1999) found that black night-

shade (*Solanum nigrum*) accumulated close to 800 mg NO<sub>3</sub><sup>-</sup>/plant at 45 days age compared to below 400 mg NO<sub>3</sub><sup>-</sup>/plant for same age tomato (*Lycopersicon esculentum* Mill. Duke), pepper (*Capsicum annuum* cv. 'Dulce Italiano') and thorn apple (*Datura ferox* L.) even though all had been supplied with 0.9 g N/plant.

Plants absorb nitrates from the soil solution (Marschner 1986; Taiz and Zeiger 1998). The nitrates are then reduced to nitrites and further to ammonia through two reactions catalysed by nitrate and nitrite reductases, respectively. Finally, ammonia is converted into amino acids using organic acids from photosynthesis in enzymatically catalysed reactions (Taiz and Zeiger 1998; Lawlor 2002). Nitrate assimilation can occur in both leaves and roots depending on plant species and on the concentration of nitrates available (Lawlor 2002). In chicory (*Cichorium intybus* L. var. Witloof cv. 'Turbo'), Druart *et al.* (2000) found that nitrate assimilation in young plants occurred mainly in the roots, with the nitrate reductase activity peaking at 42 days age. The assimilation then shifted to the leaves as the roots formed cambium and underwent thickening. The roots had a peak nitrate content of above 5.0 mg NO<sub>3</sub><sup>-</sup>/g dry weight (DW) at 42 days age, declining to the lowest of 3 mg NO<sub>3</sub><sup>-</sup>/g DW at 63 days age, while in the same period, the foliar nitrate levels increased to a peak of 6.2 mg NO<sub>3</sub><sup>-</sup>/g DW. Unfavourable environmental conditions like low light, low temperature or extremely high temperatures which inhibit photosynthesis can lead to nitrate accumulation. Roorda van Eysinga and van der Meijs (1985) reported that under conditions of higher light intensity in Netherlands about mid-April, the nitrate content of lettuce without nitrogen application was less than 3000 mg NO<sub>3</sub><sup>-</sup>/kg fresh mass while plants under low light conditions in winter accumulated more than 3000 mg NO<sub>3</sub><sup>-</sup>/kg fresh mass. Under unfavourable growth conditions, the plant's requirement for protein synthesis decreases, amino acids accumulate and the demand for nitrates declines prior to any decline in nitrate uptake resulting in nitrate accumulation (Lawlor 2002). Absorption of nitrates reduces in a drying soil (BassiriRad and Caldwell 1992). However, drought is known to decrease the activity of nitrate reductase and this could lead to nitrate accumulation (Maynard *et al.* 1976).

Spiderplant and African nightshade are known to accumulate nitrates (Chweya and Mnzava 1997; Edmonds and Chweya 1997). Spiderplant has been shown to contain up to 7-fold more NO<sub>3</sub><sup>-</sup>-N in petioles than blades (Masinde *et al.* 2005b). Accessions of spiderplant also showed differences in NO<sub>3</sub><sup>-</sup>-N accumulation. There was a general decline in NO<sub>3</sub><sup>-</sup>-N over time observed in plant tissues, which could be attributed to a dilution effect as the plants grow. It is possible that the dilution was due to increase in dry matter production although this presupposes that the rate of dry matter accumulation was higher than that of NO<sub>3</sub><sup>-</sup>-N accumulation. However, water stressed plants maintained higher NO<sub>3</sub><sup>-</sup>-N concentration as compared to watered plants (Masinde *et al.* 2005b). This was thought to be due to inhibited growth under drought as it coincided with decreased dry matter production when soil moisture fell below 50% water holding capacity in pots and 57% field capacity in the field.

The equivalent NO<sub>3</sub><sup>-</sup> concentration in fresh leaf blades for spiderplant ranged from 1949 mg/kg in the early stages to 334 mg/kg at the end of the droughted plants, while in watered plants it ranged from 1949 to 53 mg/kg (Masinde *et al.* 2005b). These concentrations suggest that spiderplant, especially at the early vegetative stages can be classified together with species like endives, leeks, parsley and rhubarb which are known to accumulate up to 2500 mg/kg of nitrates (Hill 1991; Santamaria and Elia 1997).

The NO<sub>3</sub><sup>-</sup> concentration of spiderplant blades may seem to pose little health risk to consumers considering the maximum acceptable contents of nitrates in vegetables. For instance, Andersen and Nielsen (1992) and van der Boon *et al.* (1990) quoting relevant sources have outlined the maximum acceptable content of nitrates in lettuce as 3500-4500 mg/kg

in Germany and The Netherlands. Maynard *et al.* (1976) put the fatal dose of nitrates in adult humans at 15 to 70 mg NO<sub>3</sub><sup>-</sup>-N per kg body weight (65-304 mg NO<sub>3</sub><sup>-</sup>/kg body weight). While these levels are high and unlikely to be attained at once by consuming spiderplant blades, infants could be at considerable risk considering that their fatal dose is less than 10% of that for adults (Maynard and Barker 1972). Moreover, the acceptable daily intake levels are much lower, at 0-3.65 mg/kg body weight for NO<sub>3</sub><sup>-</sup> and 0-0.13 mg/kg body weight for NO<sub>2</sub><sup>-</sup> (Santamaria and Elia 1997). Thus there is always the risk of exceeding the acceptable daily intake levels by consuming spiderplant even in adults especially if the crop has been exposed to severe stress.

## CONCLUSION

There is a clear need to scale up production of vegetable amaranth (*Amaranthus* spp.), African nightshades (*Solanum* spp.) and spiderplant (*Cleome/Gynandropsis gynandra*) in Kenya in order to meet the increasing demand. This should entail intensifying the production systems, increasing the acreages or both. The success of the scaling up will depend partly on adoption of appropriate production methods. Nitrogen and water management is key to this success. On one hand, nitrogen deficiency reduces leaf yields to uneconomical levels, while on the other hand excessive nitrogen application poses the risk of NO<sub>3</sub><sup>-</sup>-N accumulation. Production of these vegetables in Kenya is mainly rainfed. However, water deficits, especially where soil moisture fall below about 60% FC can lead to high levels of NO<sub>3</sub><sup>-</sup>-N in the plant tissues. It is therefore important that more research be conducted to develop precise water and nitrogen management practices in different agro-ecological zones of Kenya to ensure high yield and quality produce.

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