Available online at www.scholarsresearchlibrary.com

Scholars Research Library

Annals of Biological Research, 2011, 2 (3) : 317-326
(http://scholarsresearchlibrary.com/archive.html)

ISSN 0976-1233
CODEN (USA): ABRNBW

Influence of potassium on aphid incidence and yield of vegetable African nightshades (*Solanum* L. section *Solanum*)

D. S. Ashilenje [1], M. E. Omunyin[2] and J. R. Okalebo[2]

[1]*Department of Seed, Crop and Horticultural Sciences, Moi University, P.O BOX 1125, Eldoret, Kenya*
[2]*Department of Horticulture, Kabianga University College, P.O BOX 2030, Kericho, Kenya,*
[3]*Department of Soil Science, Moi University, P.O Box 1125 Eldoret, Kenya*

ABSTRACT

The yield and quality of vegetable African nightshades are limited by poor soil fertility and damage by aphids (Aphis fabae solanella Theobald). A 4 x 4 factorial greenhouse experiment (RCBD) was carried out at Ikolomani in Western Kenya to establish the influence of potassium on incidence of aphids and yield of vegetable African nightshades (Solanum L. section Solanum). There were two factors; potassium and genotype represented by four species namely: Solanum villosum subsp. Villosum, Solanum villosum Miller subsp. Miniatum, Solanum scabrum Miller, Solanum sarrachoides sendtner. Each species received 0, 13.2, 26.4 and 39.6 mg K kg^{-1} of soil resulting in sixteen treatment combinations in three replicates. Soils had low exchangeable potassium (0.2 Cmol kg^{-1}). Aphid incidence was significantly influenced ($P \le 0.001$) by main effects of potassium and genotype. The mean aphid score (0-3) increased significantly ($P \le 0.05$) on plants treated with 13.2 mg K kg^{-1} (1.35) and 26.4 mg K kg^{-1} (1.48) compared to control (1.0) while 39.6 mg K kg^{-1} (1.04) was same as the control. Solanum scabrum Miller had the highest ($P \le 0.05$) aphid incidence (1.83) followed by Solanum villosum subsp. Villosum (1.48) while Solanum sarrachoides sendtner had the lowest (0.13). Genotype significantly interacted ($P \le 0.001$) with potassium in affecting the leaf dry weight $plant^{-1}$. Solanum scabrum Miller had significantly higher ($P \le 0.05$) values at 13.2 mg K kg^{-1} (19.32 g) and 26.4 mg K kg^{-1} (34.1 g) than the other species (9.8 to 12.9 g). Potassium did not affect aphid incidence directly ($y=0.91+0.25x$, $r^2=0.019$) but it improved plant's tolerance to these pests.

Key words: Potassium nutrition, vegetable African nightshade species, aphid incidence, crop yield.

INTRODUCTION

The yield and quality of vegetable African nightshades are limited by poor soil fertility and damage by aphids (*Aphis fabae solanella* Theobald). Farmers in Kenya realize very low yields from vegetable African nightshades, ranging between 1 to 3 tons ha^{-1}, which is far below the optimal levels of between 20-40 tons ha^{-1} [1]. Black aphids infest the underside of leaves causing them to curl hence young apices of affected plants fail to develop which reduces crop yield [2]. Farmers apply pesticides and in the process misuse them in an attempt to control pests [3]. Misuse of pesticides poses dangers to vegetable consumers and the environment. A poor balance between potassium, nitrogen and phosphorus is partly the cause of reduced yield due to attack by aphids [3]. Potassium deficiency has been reported to limit crop yields in some parts of western Kenya, such as Vihiga, Mumias and Kakamega [4]. According to Rudolf [5] potato crops receiving KCl fertilization do not experience intensive attack by aphids. Potassium deficient plants accumulate soluble nitrogen compounds like amino acids, amides and nitrates [6] which increase the severity of attack by sucking parasites [7]. Compost manure which has been found to contain significant levels of potassium increases the yield of vegetable African nightshades in Kenya when combined with inorganic sources of nitrogen and phosphorus [8, 9]. Plants require adequate supply of nitrogen phosphorus and potassium to optimize yields and reduce damage by aphids [6, 7].

According to Sithanantham *et al*. [10] beneficial cultural practices and use of pest resistant varieties could be safe, cheap and simple to adopt in production of African indigenous vegetables. Species of vegetable African nightshades differ in their plant growth, leaf yield and nutritive quality [11, 12]. These species have been taxonomically distinguished by Mwai *et al*. [13] as *Solanum sarrachoides* Sendtner (mature berries have a green flesh at physiological ripeness) *Solanum villosum* subsp. *villosum* (leaves have finely lobed dentate margins and mature berries are orange). Others are *Solunum villosum* Miller subsp. *miniatum* (Bernh. Ex Willd.) (leaves have entire, sinuate, sinuate-dented or dentate margins that may have clearly defined lobes or none. mature berries are orange) and *Solanum scabrum* Miller (leaves have entire to sinuate margins; mature berries are dark purplish black). Resistance to pests in plants of solanaceous family is related to presence of alkaloids in their leaves [14]. Alkaloids such as solanine and tomatine in the leaves of potatoes (*Solanum tuberosum*) are a source of resistance to both colorado beetles and aphids. Aphids avoid alkaloids by precisely selecting the phloem-feeding site [14]. This implies that these compounds are not present in the phloem except as non-toxic precursors. Glandular hairs produce sticky substances when ruptured by an aphid brushing against them [14]. This substance adheres to the legs of aphids and eventually immobilizes them. Insect infestation levels based on their numbers per unit plant or plant part, plant injury or damage level and crop yield measured as marketable or acceptable quality are parameters that can be used to estimate pest resistance and tolerance in indigenous vegetables [10]. Whereas previous work has elucidated the role of nitrogen and phosphorus on the yield and quality of vegetable African nightshades [8, 9, 15, 16], information on the possible influence of potassium on aphid incidence and yield of this crop is still lacking. Hence, the aim of this study was to establish the influence of potassium on incidence of aphids and leaf yield of vegetable African nightshades.

MATERIALS AND METHODS

Soil sampling and analysis

Soil used in this experiment was obtained from a farmer's field at Isulu location, Ikolomani division and analysed for both physical and chemical properties using procedures described in Okalebo *et al*. [17]. Soil analysis was carried out at Moi University Soil Science laboratory and agronomy department laboratory of Mumias Sugar Company Ltd. (exchangeable K and CEC). Ten soil samples were taken randomly from the top 0-20 cm depth and bulked for analysis. They were air-dried and crushed to pass through a 2 mm sieve and sub-samples were crushed further and passed through a 60 mesh screen for total N and organic carbon analyses. Soil pH was determined using a pH meter with a glass electrode where 2.5:1 water to soil suspension was used [17]. Exchangeable K determination involved extraction of the soil samples with excess 1 M NH_4OAc solution and flame photometry. Available P was determined by extracting soils using 0.5 M Sodium carbonate [18]. Orthophosphate ion in the extract was analysed by ascorbic acid based colorimetry [17]. Total organic carbon was determined by wet combustion oxidation using H_2SO_4 and K_2CrO_7 oxidation. Total nitrogen was determined by Kjeldahl oxidation method, which involves complete breakdown of soil organic matter by digesting the soil to 360^oC in order to convert organic N to ammonium nitrogen (NH_4-N) before its determination in the digest.

Experimental design

A 4 x 4 factorial experiment with two factors, genotype and potassium rate was setup in a Randomized Complete Block Design with three replicates. Every plot consisted of two pots each holding one plant, placed on a 1 m high bench. A 1 m space separated the blocks and 0.5 m was left between the plots. Genotype was represented by four species of vegetable African nightshades (*Solanum* L. Section *Solanum*): *Solanum villosum* subsp. *villosum*, *Solunum villosum* Miller subsp. *miniatum*, *Solanum scabrum* Miller, *Solanum sarrachoides* sendtner. Each of these species received four rates of potassium (KCl, 60 % K_20); K0-Control, K1-13.2 mg K kg^{-1} of soil, K2- 26.4 mg K kg^{-1} of soil, K3- 39.6 mg K kg^{-1} of soil resulting in sixteen treatment combinations. The K rates were obtained from a preliminary field study with 0, 33, 66 and 99 kg K ha^{-1} treatments assuming that 1 ha of land contains 2, 500 tons of soil at 20 cm depth [19]. The doses of potassium in the field were each converted to g ha^{-1} and divided by 2, 500, 000 kg of soil to obtain g of K kg^{-1} of soil. These values were further multiplied by 1000 to get mg K kg^{-1} of soil.

Raising of test plants

Procedures described by Rowell [19] were used to set up the pot experiment. The soil was air dried to the extent that it could be pressed through a garden sieve with 1 cm apertures. The above rates of potassium were each multiplied by two to convert to the equivalent amount of KCl fertilizer in mg required. Forty times the amount of KCl was diluted in one liter of water to obtain g l^{-1} of reagent for each pot. Some 25 ml of this solution was applied per kg of soil. A similar method was used to come up with rates of phosphorus except that 18.4 mg P_2O_5 kg^{-1} was converted to equivalent amount of DAP (18 % N, 46 % P_2O_5) by multiplying by 2.17. Some 10 kg of the air-dried soil was weighed into large and clean polythene bag. The various nutrient solutions were sprinkled over the soil while shaking to achieve a uniform distribution before being transferred into 30 cm diameter polythene bags (punched to allow for free drainage). The filled pots were arranged on a propagation bench based on the experimental layout. Five seeds of *Solanum villosum* subsp. *villosum*, *Solunum villosum* Miller subsp. *Miniatum* and *Solanum scabrum* Miller (from Kenya Seed Company) and *Solanum sarrachoides* Sendtner (from Moi University, Department of Seed, Crop and Horticultural Sciences farm) were sowed in each pot on 6th April 2007. Soils in the pots were kept moist with rain water and thereafter observations were made for germination date. Weeds were removed from the containers by pulling carefully to avoid uprooting the young seedlings. A dose of 61.6 mg N kg^{-1} was applied uniformly to each pot six week after seed emergence as calcium ammonium nitrate (CAN 27 % N). This was converted to the amount of CAN by multiplying by 3.85. Same procedure as in the other fertilizers above was applied to determine the rate of CAN fertilizer in solution for application per kg of soil.

Rearing of aphids and infestation of plants

One young black aphid (*Aphis fabae solanella* Theobald) was obtained from a healthy vegetable African nightshade (*Solunum villosum* Miller subsp. *miniatum*) plant growing on farmer's field at Bukura on 26th April 2007. They were immediately transferred to a mature vegetable African nightshade (*Solunum villosum* Miller subsp. *miniatum*) plant enclosed in a 1 m^3 cage and covered with 50 % shed netting under the greenhouse so as to avoid invasion by other insects. The developing colony of aphids was monitored for two weeks after introduction, by examining individuals under a binocular microscope (SZ- PT Olympus Japan at magnification *3.5) based on the morphological characteristics of this species as described by Blackman and Eastop [20]. One young aphid was again isolated onto a healthy black nightshade plants placed in the second cage, which was free of any insect. They were allowed to multiply for one week while being checked as above. Finally one young aphid from this cage was introduced to each experimental plant five weeks after emergence. Aphid population was monitored for 10 days to ensure equal infestation before scoring for aphid incidence begun. Apart from incidence, the movement of aphids on the plant following introduction was observed.

Parameter measures on aphid incidence and leaf yield

Aphid incidence was determined based on the aphid population per plant using a 1-3 scale as follows: 0 = No aphid, 1 = < 50 individuals per plant, 2 = 50 - 100 individuals per plant and 3 = >100 individuals per plant [21]. Leaves were harvested nine weeks after about 100 % seed emergence which was flowering stage. The leaves were immediately weighed to get the fresh weight in g $plant^{-1}$ at Moi University Soil Science Laboratory. They were then oven dried at a constant temperature of 70˚C for 72 hours after which they were weighed again to obtain the dry weight in g $plant^{-1}$. Percent dry matter in the leaves was determined from the leaf dry weight (g $plant^{-1}$) divided by leaf fresh weight (g $plant^{-1}$) times 100.

Analysis of data

The data collected was subjected to analysis of variance (ANOVA) using statistical analysis system [22] to determine whether the various treatments had significant effects ($P \leq 0.05$) on plant leaf yields, aphid incidence and damage to crops. Means were separated by LSD tests at $P \leq 0.05$. A simple linear correlation analysis was applied to establish the relationship between the aphid incidence and leaf yield parameters. A simple linear regression analysis determined the contribution of different rates of potassium to change in aphid incidence on vegetable African nightshades.

RESULTS

Initial soil physical and chemical properties

Results of soil chemical properties were as shown in table 1. The ratings stated in Landon [23] were used in interpretation of soil analysis results. The pH was low and this is rated as acidic [23]. Low levels of soil exchangeable potassium were also recorded. The level of soil nitrogen and CEC was medium whereas the OC content was very low. The soils were classified as clay loam.

Table 1. Initial chemical characteristics of soils from Ikolomani

pH	Total N (%)	Available P (ppm)	K Cmol kg^{-1}	O C (%)	CEC Cmol kg^{-1}
5.3	0.38	20.5	0.2	1.92	17.9

Aphid incidence

The aphid incidence was significantly affected by the rate of potassium and genotype at P≤0.001 each acting as the main effect. As shown in Fig.1, there was a significant increase (LSD, P≤0.05) in the mean aphid score $plant^{-1}$ to 1.35 and 1.48 when all species were subjected to 13.2 mg kg^{-1} and 26.4 mg kg^{-1} of potassium respectively. This is compared to the control whose mean aphid score was 1.0. The mean aphid incidence recorded on plants treated with 39.6 mg kg^{-1} of potassium was not significantly different (LSD, P≤0.05) from that of the control. *Solanum sarrachoides* sendtner had a significantly lower (LSD, P≤0.05) mean aphid incidence of 0.13 compared to the other species whose score ranged from 1.44 to 1.83 as indicated in Fig. 2. The values observed in *Solanum villosum* subsp. *villosum*, *Solanum villosum* Miller subsp. *Miniatum* and *Solanum scabrum* Miller did not vary significantly. There was no significant (P>0.05) interaction between genotype and potassium rate on aphid incidence.

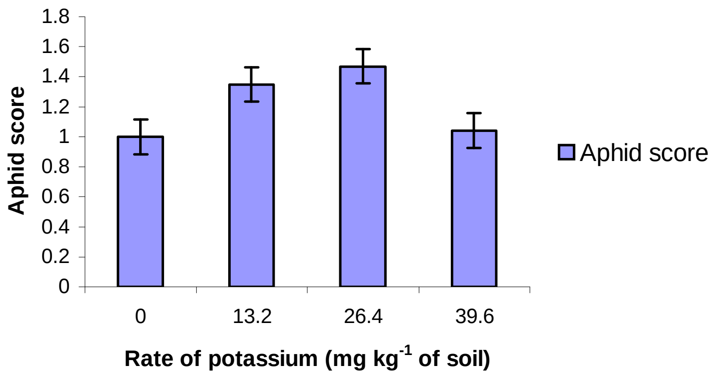

Fig. 1. Mean aphid incidence (0-3 score) from four species of vegetable African nightshade at varying rates of potassium in the greenhouse (LSD, P≤0.05).

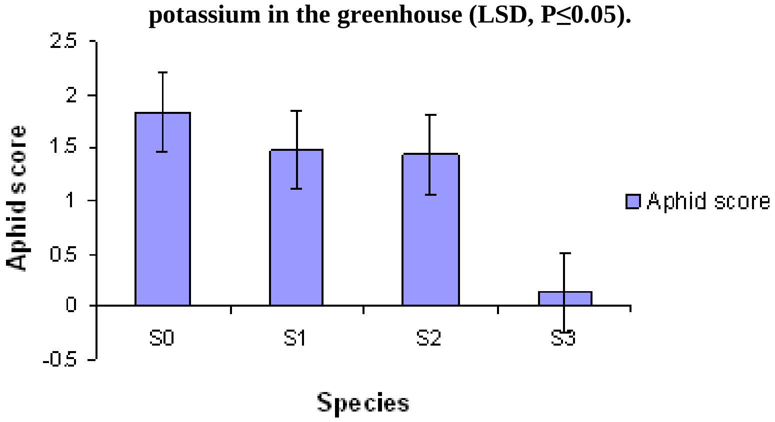

Fig. 2. Mean aphid incidence (0-3 score) on different species of vegetable African nightshade from all rates of potassium in the greenhouse (LSD, P≤0.05). The species were S0- *Solanum villosum* subsp. *villosum*, S1- *Solanum villosum* Miller subsp. *miniatum*, S2- *Solanum scabrum* Miller and S3- *Solanum sarrachoides* Sendtner

Period of pest infestation interacted with genotype with highly significant (P≤0.001) effects on the aphid incidence. Fig. 3 shows that *Solanum sarrachoides* sendtner experienced a significant reduction (LSD, P≤0.05) in mean aphid incidence two weeks after pest introduction, which remained at a score of zero two weeks later. Throughout the period of the experiment, the mean aphid incidence recorded in *Solanum sarrachoides* sendtner was consistently lower (LSD, P≤0.05) than that of the other species. In week four of pest's infestation, *Solanum scabrum* Miller had a score of 2.83, which was significantly higher than that recorded in the other species.

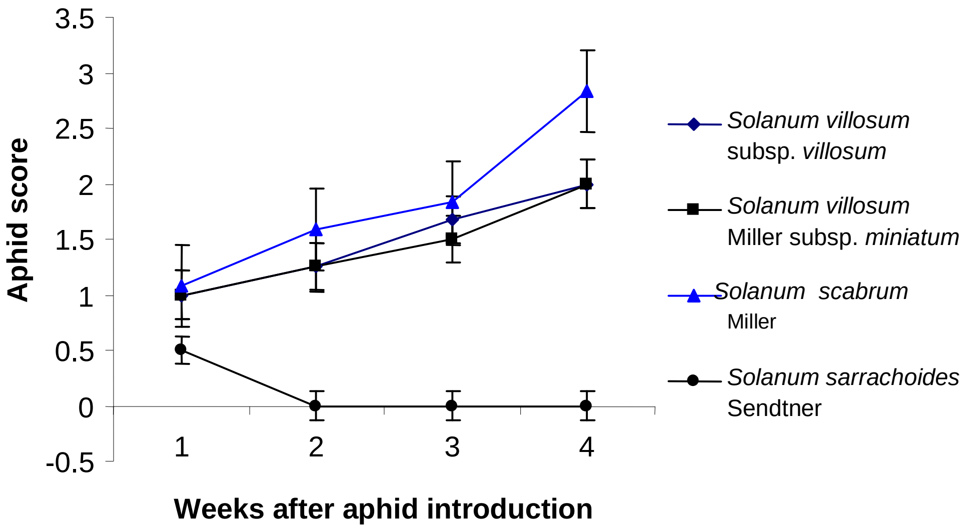

Fig. 3. Change in mean aphid incidence (0-3 score) on different species of vegetable African nightshade in a period of four weeks after pest introduction in the greenhouse (LSD P≤0.05).

Leaf dry weight

There was a highly significant interaction (P≤0.001) between genotype and rate of potassium in affecting leaf dry weight. The mean leaf dry weights recorded in *Solanum scabrum* Miller of 19.32 g plant^{-1} and 34.1 g plant^{-1} were significantly higher (LSD, P≤0.05) than those of the other species when supplied with 13.2 mg kg^{-1} and 26.4 mg kg^{-1} rates of potassium respectively (Fig. 4). The mean leaf dry weight of *Solanum scabrum* Miller however did not vary significantly (p>0.05) from that of *Solanum sarrachoides* Sendtner when treated with 39.6 mg kg^{-1} of potassium as well as the control. The mean leaf dry weights plant^{-1} of *Solanum villosum* subsp. *villosum* following treatment with 26.4 mg K kg^{-1} was 10.85 g and this was significantly higher (LSD P≤0.05) than that in the control recorded as 4.31 g plant^{-1}. *Solanum villosum* Miller subsp. *miniatum* also had a significant rise in its mean leaf dry weight from 8.11 g plant^{-1} in the control to 13 g plant^{-1} when treated with 26.4 mg K kg^{-1}. The mean leaf dry weight of *Solanum villosum* subsp. *villosum* and *Solanum villosum* Miller subsp. *miniatum* increased to a maximum at 26.4 mg kg^{-1} rate of potassium, but declined at 39.6 mg K kg^{-1}. For *Solanum sarrachoides* Sendtner, the leaf dry weight plant^{-1} declined to 5.7 g at the rate 24.6 mg K kg^{-1} compared to the control whose weight was 11.65 g. The weight of 5.7 g obtained in *Solanum sarrachoides* Sendtner was significantly lower (LSD, P≤0.05) than that of the other species. At the rate of 39.6 mg K kg^{-1}, the mean leaf dry weight of *Solanum sarrachoides* Sendtner increased significantly to 16.28 g plant^{-1} compared to the control.

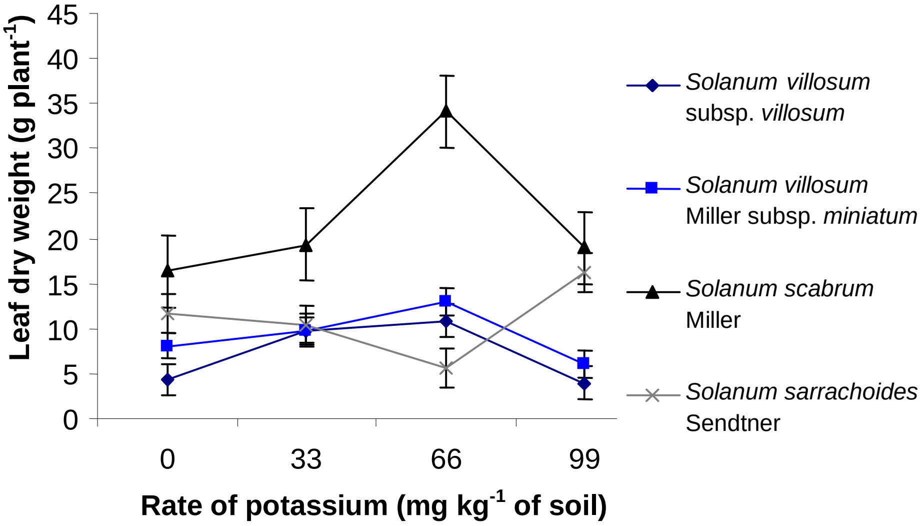

Fig. 4. Leaf dry weight of different species of vegetable African nightshade at varying rates of potassium, nine weeks after emergence in the greenhouse (LSD, P≤0.05).

Leaf dry matter as a percentage of fresh weight

Rate of potassium had a significant effect (P≤0.05) on the mean leaf dry matter as a percentage of the fresh weight per plant, from all the species. Plants in the control treatment had the highest value (LSD, P≤0.05), of 12.89 % followed by those receiving 39.6 mg K kg^{-1} which had 12.14 % while the rate 26.4 mg K kg^{-1} resulted in the lowest mean percent dry matter of 10.97 % (Fig. 5). The mean leaf percent dry matter did not differ significantly (LSD, P≤0.05) in plants treated with 39.6 mg K kg^{-1} when compared to the control. However, plants treated with 13.2 mg K kg^{-1} and 26.4 mg K kg^{-1} gave significantly lower mean leaf dry matter as a percentage of fresh weight than the control. Genotype as the main effect and when interacted with rate of potassium, did not have any significant effects (P≤0.05) on the leaf dry matter as percentage of the fresh weight.

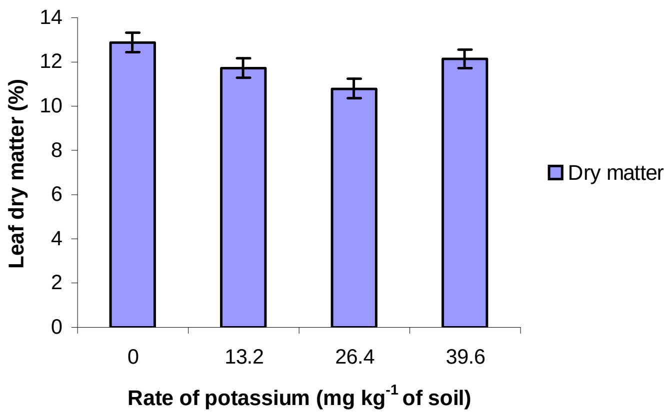

Fig. 5. Leaf dry matter as a percentage of fresh weight from four species of vegetable African nightshade supplied with varying rates of potassium at nine weeks after emergence in the greenhouse (LSD, P≤0.05).

Aphid incidence and plant yield parameters
Linear correlation coefficients between aphid incidence and leaf dry weight in all species; *Solanum villosum* subsp. *villosum* (r=0.917, p=0.083), *Solanum villosum* Miller subsp. *miniatum* (r=0.920, p=0.079), *Solanum scabrum* Miller. (r=0.465, p=0.535) and *Solanum sarrachoides* Sendtner (r=-0.622 p=0.378) were not significant. However, the lowest aphid incidences were observed in plants with the highest percent dry matter recorded in the control and plots receiving 39.6 mg K kg^{-1} (Fig 6). The regression analysis showed that 1.9 % of the change in aphid incidence was contributed by varying the rate of potassium (y=0.91+0.25x, r^2=0.019).

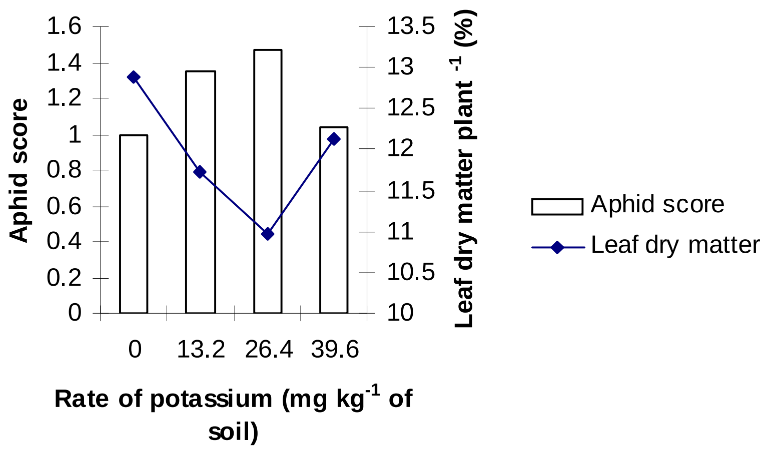

Fig. 6. Relationship between mean aphid incidence (0-3 score) and plant leaf dry matter as a percentage of fresh weight from four species of vegetable African nightshade at different rates of potassium, nine weeks after emergence, in the greenhouse.

DISCUSSION

The increase in aphid attack when potassium was applied at lower rates compared to the control contradicts the finding that potassium deficient plants experience more intense attack by pests than potassium sufficient plants [6]. The positive relationship between aphid incidence and plant leaf dry weight suggests that potassium affects plants by improving their tolerance to aphids. Low contribution of variable rates of potassium to change in aphid incidence in this study is comparable to results by Kitchen *et al*. [24] who reported improved growth and persistence of alfalfa when supplied with potassium despite attack and damage by potato leaf hopper.

It came out from this research that *Solanum sarrachoides* Sendtner more resistant to aphids compared to the other species which could be attributed to its characteristic of having dense pubescence. Following introduction, aphids had difficulties moving to the underside of the leaves in *Solanum sarrachoides* Sendtner whereas this was possible within approximately 50 seconds in the other species. It is therefore possible that aphid's ability to settle on the plant leaf surface and feed could have been impaired by physical entanglement caused by trichomes. This may have resulted in the pests starving hence the decline in aphid incidence to a score of zero two weeks after introduction. Luciana and Jonathan [25] reported that physical entrapment by trichome exudates as well as allelochemical activity are involved in the resistance of wild tomato *Lycopersicon Hirsitum* f. *glabratum* to pink potato aphid. The chance that allelochemicals produced by trichomes could have been toxic to aphids is a factor that was not established within the scope of this research, and could be a subject of future studies. Application of potassium could be associated with increased favourability of *Solanum villosum* subsp. *villosum* and *Solanum villosum* Miller subsp. *miniatum* to aphid attack from results of correlation analysis. Inversely, *Solanum sarrachoides* Sendtner had a negative linear relationship between aphid incidence and plant leaf dry weight which suggests adverse effects of applying low amounts of potassium on multiplication of aphids on this species. Aphid incidence on *Solanum scabrum* Miller was to a less extent dependent on leaf biomass as pointed out by a weak linear correlation between these two parameters. Instead increased attack of this species by aphids could be attributed to its succulent growth as revealed in the negative linear correlation between aphid incidence and leaf dry matter as a percentage of the fresh leaf weight. This agrees with Tisdale *et al*. [26] that excessive succulence is responsible for increased attack by insects. Moreover, increased application of potassium resulted in the reduction of leaf percent dry matter hence increased moisture content in the leaves. Sufficient supply of potassium is necessary for increased uptake of nitrogen, which contributes to a more succulent plant [26]. This is due to the proteins that are formed from manufactured carbohydrates. Therefore there are less carbohydrates being deposited in the vegetative portion. This results in the formation of more hydrated protoplasm.

CONCLUSION

Aphid incidence varies significantly among species of vegetable African night shades, a factor that is determined by leaf morphology; pubescence, dry weight and percent dry matter. Plants tolerance to aphids is improved with increased potassium supply together with adequate nitrogen and phosphorus. *Solanum sarrachoides* Sendtner is more resistant to aphids compared to the other species. *Solanum scabrum* Miller species has the highest yield despite its higher attack by aphids compared to the other species. The plant components such as pubescence and allelochemicals in the leaves of *Solanum sarrachoides* Sendtner should be analysed further to determine their effect on resistance to aphids. It is necessary that the effect of varying the rates of potassium on the tolerance of black nightshade to aphids be established in a field experiment where season and site vary. The possible effects of different sources of potassium on the tolerance of this crop to aphids should be studied in future.

Acknowledgment
We acknowledged the technicians of Moi University Soil Science laboratory and Agronomy Department laboratory of Mumias Sugar Company Ltd. for their assistance in soil analysis.

REFERENCES

[1] M. O. A. Onyango, J.C. Onyango, and B. Jama, Traditional crops in Western Kenya, (IRPS. Maseno University, Kenya, **1999**) vol. 3, 14-23.
[2] AVRDC, Broad-leaved Nightshade, International Cooperators Fact Sheet, Arusha, Tanzania, **2003,** 8.
[3] R. R. Schippers, African indigenous vegetables: an overview of the cultivated species, Catham, UK, **2000**, 176-187.

[4] E. W.Gikonyo, *et al*., In: G. Mureithi, *et al*. (Ed.), The Proceedings of the 18th Conference and end of Millennium Celebrations, 4-8 December **2000**, Mombasa, Kenya (Soil Science Society of East Africa, **2003**): 147.
[5] H. Rudolf, Crop and Plant Protection, Ellis Horwood Limited, New York. **1989**, 75.
[6] H. Marschner, Mineral nutrition of higher plants. Academic Press. London, **1995,** 2nd ed. 185, 454-455.
[7] P. S. Benepal and C. V. Hall, *Horticultural Science*, **1967,** 90: 304 – 312.
[8] E. K. N. Okoko *et al*. In: J. G. Mureithi *et al*. Participatory Technology Development for Soil Management by Small Holders in Kenya. vol. 3 (KARI, Kenya, **1997**) 11-18.
[9] E. Wanjekeche *et al*., In: G Mureithi *et al*. The Proceedings of the 18th Conference and end of Millennium Celebrations, 4-8 December **2000**, Mombasa, Kenya (Soil Science Society of East Africa, **2003**) 208-393.
[10] S. Sithanantham *et al.* In: MOA Onyango *et al.* Proceedings of Third Workshop on Sustainable Horticultural Production in the Tropics. 26-29 November 2003, Maseno University, Kenya (Maseno University, Kenya, **2003**) 37-42.
[11] C. N. Mwafusi, M. Sc Thesis, University of Nairobi, (Nairobi, Kenya, **1992**).
[12] M. A. Onyango, M. Sc Thesis, University of Nairobi, (Nairobi, Kenya, **1993**).
[13] G. N. Mwai, *et al*., In: M. O. A. Onyango *et al.* Proceedings of Third Horticulture Workshop on Sustainable Horticultural Production in the Tropics. Maseno University, Kenya (Maseno University, Kenya, **2003**) 79-86.
[14] P. J. Edwards and S. D. Wratten, Ecology of Insect Plant Interaction, Edward Arnold Publishers Ltd. England, **1980**, 16, 17.
[15] E. N. Murage, M. Sc Thesis, University of Nairobi, (Nairobi, Kenya **1990**).
[16] M. P. Powon, *et al*. In: G Mureithi *et al*., The Proceedings of the 18th Conference and end of Millennium Celebrations, 4-8 December **2000**, Mombasa, Kenya (Soil Science Society of East Africa, 2003) 395-399.
[17] J. R. Okalebo, K. W. Gathua, and P. C. Woomer, Laboratory methods of soil plant analysis. A working manual, SSSEA, KARI, TSBF, Sacred Africa. Kenya, **2002,** 2nd ed., 28, 29-31, 59, 78.
[18] S. R. Olsen *et al.*, Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circular, USA, **1954**, vol. 9, 39.
[19] L. D. Rowell, Soil Science: Methods and Applications, Longman Scientific and Technical, UK, **1994**, 184-186.
[20] R. L. Blackman and V. F. Eastop, Aphids on the Worlds Crops, Identification Guide. British Museum, Britain, **1984,** 16-27, 224, 426.
[21] J. A. Sutherland, G. N. Kiabata and G. Farrel, Field Sampling methods for Crop Pests and Diseases in Kenya. KARI, ODA. Kenya, **1996,** 5
[22] SAS Institute, SAS/Stat User guide, SAS Institute, Carry, NC, USA, **1998,** vol 2, version 6.12.
[23] J. R. Landon, Booker Tropical Soil Manual, Booker Tate. New York, **1991,** 112-139.
[24] N. R. Kitchen, D. D. Bulchhoz, and C. J. Nelson, *Agronomy Journal*, **1990**, 82: 137-146.
[25] M. Luciana and J. N. Jonathan, *Entomologia Experimentalis et applicata*, **1997**, 84, 137-146.
[26] S. L. Tisdale, L. E. Nelson and J. D. Beaton, Soil Fertility and Fertilisers, Macmillan Publishers. USA, **1985,** 4th ed. 67-71,250-258.