World Applied Sciences Journal 7 (8): 1016-1022, 2009
ISSN 1818-4952

Chemical Properties of Some Organic Materials Available in Kenya as Components of Potting Substrate

[1]*D.O. Andika and* [2]*K. Ngamau*

[1]Department of Botany and Horticulture, Maseno University, Kenya
[2]Department of Horticulture, Jomo Kenyata University of Agriculture and Technology, Kenya

Abstract: Production of quality nursery potted seedlings requires a proliferous root system that enables adequate acquisition of water, air and soil nutrients and this depends on the quality of substrate used. Soil has always been used as nursery and pot substrate but it has problems which include: aeration; drainage; non uniformity and chemical suitability. Therefore, development of alternative potting substrates with optimal chemical properties is necessary. The main objective of this study was to identify, formulate and characterize chemical suitability of forest soil, compost, pine bark and rice husks as alternative components of potting substrates. The experiment was conducted at Maseno University, Kenya between February and December 2004. Materials including pine bark (PB), rice husks (RH), forest soil (FS) and compost (CS) were collected and formulated into ten substrates; (100% FS), (75% CS: 25% PB), (50% CS: 50% PB), (25% CS: 75% PB), (75% CS: 25% RH), (50% CS: 50% RH), (25% CS: 75% RH), (100% CS), (100% PB) and (100% RH). These were potted and arranged in a CRD with four replications. The chemical properties; macronutrients, micronutrients, CEC, pH and EC were evaluated. The data was subjected to analysis of variance and separation of means done by Duncan Multiple Range Test. The levels of macronutrients and micronutrients were significantly (P#0.05) higher in substrate formulations of 75% CS and 50% CS formulated with either PB or RH than the control. The pH was significantly (P#0.05) different and generally acidic in all the substrates. Substrate formulations of 75% CS and 50% CS formulated with either PB or RH had CEC and EC within the optimal ranges of 6-15meq/100cc and 1.5-2mS/cm respectively. The substrate formulations of; 75% CS: 25% PB, 50% CS: 50% PB, 75% CS: 25% RH and 50% CS: 50% RH had chemical properties within the recommended ranges and are therefore suggested as potting substrates. These results provide alternative potting substrate formulations to soil and give means of better utilization of agricultural and industrial waste materials.

Key words: Organic materials % Substrate % Chemical suitability

INTRODUCTION

The development of horticulture industry in Kenya has taken place at a rapid pace in the last years. The volume of horticultural export and the number of horticultural nurseries, which have mushroomed all over the country, attest to this. From a technical point of view, this development and the increase of production intensity has set new demands for high quality inputs including growing media/substrate. Suitable plant development depends to a large extent on the substrate used [1]. Reinkinen [2], Gretchen *et al.* [3] and Hans *et al.* [4] reported some of the chemical optimal ranges for quality container and field production. The pH range of 6.2 to 6.8 is desirable for soil based production while 5.4 to 6.0 is desirable for soilless production. The electrical conductivity of between 1.5 and 2.0ms/cm is adequate for soilless production while 3.0ms/cm can be tolerated by most crops in soil culture production. Cation exchange capacity of between 6-15meq/100cc is desirable for both soil and soilless culture though a higher CEC is more beneficial. Nitrogen, phosphorous and potassium in the range of 15-25g/kg, 5-12g/kg and 5-10g/kg respectively are desirable but this might vary slightly depending on the plant species [3, 4].

The use of peat-based substrates in Kenya is confined to few large or established horticultural enterprises whose products are meant for external trade [5]. However, most horticultural enterprises producing seedlings of vegetables, fruit trees, trees for landscaping,

Correspoding Author: Dr. D.O. Andika, Department of Botany and Horticulture, Maseno University, Kenya

environmental protection and conservation, research nurseries, floriculture, ornamentals and other users, use substrates made of a mixture of topsoil, organic supplements and sand in varied proportions in containers or use a bed prepared on the soil [1]. These types of growing media/substrates are limited in quality in terms of physical and chemical properties and negatively affect the development of plant roots [2, 6]. Mining the soil also affects its quality for use for other economic and beneficial activities [7]. This, therefore, calls for an urgent development of more cost effective and good quality substrates from locally available alternatives including industrial and agricultural wastes for quality nursery production. Therefore, the main objective of this study was to identify and formulate substrates from forest soil, pine bark, compost and rice husks and chemically characterize them for use as potting substrates.

MATERIALS AND METHODS

The study was undertaken in pots under shade net situated in the demonstration farm of Department of Horticulture, Maseno University, Maseno, Kenya. The potting materials used in the study included; Compost, pine bark and rice husks. Compost was prepared from farm yard manure mixed with grass clippings. Compost was prepared according to [8]. Pine bark was obtained from Webuye Paper Mills, Webuye, Kenya and was cut into smaller pieces of 1cm to 2 cm sizes. Rice husks were obtained from Ahero rice farmers, Ahero, Kenya. Forest soil was obtained from a commercial ornamental plant nursery in Kisumu, Kenya. All the substrate formulations were sterilized by solarisation, a practice normally used by the small nurseries operators [1]. The compost was mixed with the pine bark, rice husks and forest soil in different proportions using a drum and a peddle mixer. These constituted the media formulations to be used in the experiment. These were arranged in a Completely Randomized Design with four replications of ten treatments (media formulations) as follows;

Forest soil was used as the control. This is the standard growth media used by local nursery operators. 100 g of each of the prepared media was sampled and placed in polythene bags and labeled for laboratory chemical analyses.

Chemical characterization: Chemical properties determined included; pH, electrical conductivity, Cation exchange capacity (CEC), macronutrients (N, P, K, Ca, Mg, S) and micronutrients (Na, Fe, Al, Mn, Cu, Pb, Mo, B, Zn) contents.

The pH of the substrates was determined by potentiametric methods according to Tan [9] (1996). Electrical conductivity was determined from the mixture used to obtain pH by obtaining the filtrate from Whatman paper and using electrical conductivity meter (Rowell, 1994).

The mineral elements were extracted according to Tan [9]. potassium (K), sodium (Na), calcium (Ca), magnesium (Mg), a luminium (Al) and molybdenum (Mo) were extracted using ammonium acetate. Manganese (Mn), copper (Cu), zinc (Zn) and iron (Fe) were extracted using ethylenediaminetetraaceticacid (EDTA). Phosphorus (P) was determined by Olsen method. Sulphur was determined by turbidimetric method. While the cation exchange capacity (CEC) was determined by ammonium acetate method and Nitrate Nitrogen (NO_3-N) extracted by potassium chloride (KCl) method.

The data obtained was subjected to analysis of variance (ANOVA) to determine if the treatment effects were significant at 5%, 1% and 0.1% level. Separation of means was done by Duncan Multiple Range Test (DMRT) at 5% level.

RESULTS

Chemical characterization

pH: Figure 1 shows that pH was significantly (P#0.05) affected by the substrate formulations. Substrates 75% CS: 25% RH and 50% CS: 50% RH had significantly higher pH than substrates 100% PB, 100% RH and the control. Substrates 100%RH and 100% PB had significantly (P#0.05) lower pH (4.2 and 4.4, respectively) than all other substrates. The substrates 75% CS: 25% RH and 50% CS: 50% RH had the highest and similar value of the pH, though they were not significantly (P>0.05) different from the other substrates, except, 100% RH and 100% PB. The pH of all the substrates tended to be acidic.

Nitrogen (N): The substrate formulations significantly (P#0.05) affected the nitrogen content (Table 2). Substrates 75% CS: 25% RH, 50% CS: 50% RH and 100% CS had the highest N content. They had significantly (P#0.05) higher nitrogen contents than 100% RH and 100% FS. The other substrates were not significantly (P#0.05) different. Generally the nitrogen concentration was observed to increase with the increase in the amount of the compost.

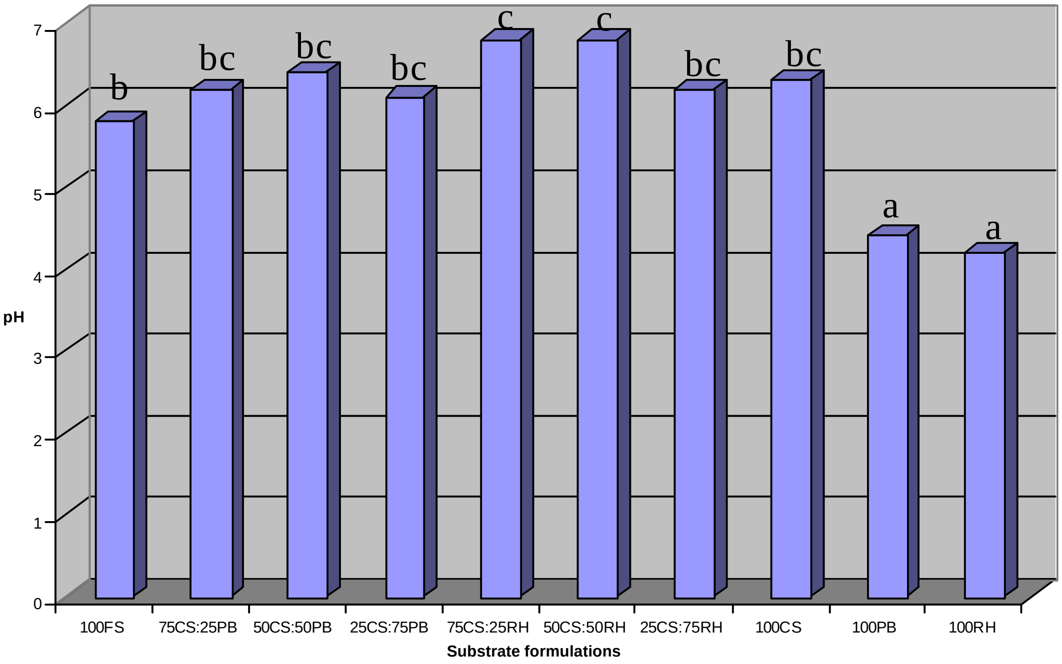

Fig. 1: Effect of substrate formulations on the pH

[1] Means separation within columns by Duncan Multiple Range Test at 5% and Means with the same letter are not significantly different at the 5% level

Table 1: The substrate formulations in varying percentage composition from compost, pine bark and rice husks used in the study

	Substrate formulations	% Components composition
1	Forest soil (Control)	100
2	Compost: Pine bark	75: 25
3	Compost: Pine bark	50: 50
4	Compost: Pine bark	25: 75
5	Compost: Rice husk	75: 25
6	Compost: Rice husk	50: 50
7	Compost: Rice husk	25: 75
8	Compost	100
9	Pine bark	100
10	Rice husk	100

Table 2: Macronutrients content, CEC and EC of the formulated substrates

Substrate formulations	N	K	P	Mg	Ca	S	CEC	EC
	----------g kgG^{1}----------						meq/100cc	ms/cm
100%FS	14.1a[1]	5.1a	4.8a	3.6a	8.7a	3.3b	12.4bc	2.8c
75%CS:25%PB	16.2a-c	5.7ab	5.9b	4.0a	12.5cd	2.0a	17.7d	1.6b
50%CS: 50%PB	15.7ab	5.7ab	5.3ab	4.0a	12.2cd	2.0a	15.3c	1.5b
25%CS: 75%PB	15.9ab	5.2a	5.7b	3.9a	1.6bc	2.0a	10.7b	1.5b
75%CS: 25%RH	17.1bc	5.8ab	6.0b	4.1a	11.8bc	2.7b	18.2d	1.7b
50%CS: 50%RH	17.4bc	5.1a	6.1b	4.4ab	12.3cd	2.0a	14.7c	1.8b
25%CS: 75%RH	16.1a-c	5.0a	5.2a	4.3ab	10.1b	1.9a	10.9b	1.7b
100%CS	17.6bc	6.1b	5.7a	4.6ab	12.8d	2.6b	21.1e	3.1cd
100%PB	14.9ab	4.9a	4.5a	3.4a	7.7a	1.3a	1.8a	0.6a
100%RH	14.4a	5.0a	4.4a	3.5a	8.0a	1.4a	1.1a	0.4a

[1] Means separation within columns by Duncan Multiple Range Test at 5% and means with the same letter are not significantly different at the 5% level.

Table 3: Micronutrients content in the formulated substrates

Substrate formulations	Fe	Mn	Na	Cu	Zn	Mo	Pb
	------------------------------------g kgG^{1}--				----------------------mg kgG^{1}----------------------		
100%FS	13.8bc[1]	1.7b	4.6b	0.3b	0.9bc	5.8b	15.5b
75%CS: 25%PB	10.0a	0.3a	3.1a	0.2a	0.5b	2.8a	14.3ab
50%CS: 50%PB	9.9a	0.2a	3.2a	0.1a	0.5b	3.8ab	12.3a
25%CS: 75%PB	11.0ab	0.1a	3.2a	0.2a	0.4ab	4.8ab	12.3a
75%CS: 25%RH	10.7a	0.9a	3.0a	0.2a	0.5b	4.3ab	14.3ab
50%CS: 50%RH	10.2a	0.1a	3.0a	0.1a	0.5b	2.3a	13.3ab
25%CS: 75%RH	10.9ab	0.1a	3.0a	0.1a	0.4ab	2.0a	13.8ab
100%CS	11.1b	1.0ab	4.0b	0.2a	0.6b	5.0ab	15.8b
100%PB	9.3a	0.1a	2.6a	0.1a	0.2a	1.6a	11.3a
100%RH	8.9a	0.1a	2.4a	0.1a	0.3a	1.7a	12.3a

[1] Means separation within columns by Duncan Multiple Range Test at 5% and means with the same letter are not significantly different at the 5% level.

Potassium (K): The K content was significantly (P#0.05) affected by the substrate formulations (Table 2). The potassium content in substrate 100% CS was significantly (P#0.05) higher than that of all other substrates except substrates 75% CS: 25% RH, 50%CS: 50% PB and 75%C: 25% PB. Potassium levels in substrates 100% CS was also significantly (P#0.05) higher than in substrates 25% CS: 75% PB, 50% CS: 50% RH, 25% CS: 75% RH, 100% PB and 100% RH.

Phosphorus: The substrate formulations significantly (P#0.05) affected the P content (Table 2). Substrates 75% CS: 25% RH, 50% CS: 50% RH and 25% CS: 75% PB had significantly higher phosphorus content than all other substrates except for substrates 50% CS: 50% PB. All the substrates had significantly (P#0.05) higher phosphorus levels than the control (100% FS) except 100% PB and 100% RH. Phosphorus levels in the control substrate (100% FS) was not significantly (P>0.05) different from substrate 25% CS: 75% RH, 50% CS: 50% PB, 100% CS, 100% RH and 100% PB but was significantly (P#0.05) different from all the other substrates. The 50% CS: 50% RH substrate had the highest phosphorous level of 6.1 g/kg while the 100% FS had the lowest P level of 4.8 g/kg.

Magnesium (Mg): The magnesium concentration was significantly (P#0.05) affected by the substrate formulations used in the experiment (Table 2). Substrates 50% CS: 50% RH and 100% CS were not significantly (P>0.05) different. Similarly they were significantly (P#0.05) higher than all the other substrates. The rest of the substrates were did not differ significantly (P>0.05) amongst themselves. The 100% FS (Control) substrate had the lowest magnesium level of 3.6 g/kg.

Calcium (Ca): The Ca content was significantly (P#0.05) affected by the substrate formulations (Table 2). Substrate 100% CS had significantly (P#0.05) higher Ca than all the substrates except 75% CS: 25% PB, 50% CS: 50% RH and 50% CS: 50% PB. The 100% CS substrate had the highest calcium level of 12.8 g/kg while the 100% FS had the lowest calcium level (8.7 g/kg).

Sulphur (S): The substrate formulations significantly (P#0.05) affected Sulphur content (Table 2). The S levels in the substrates 100% CS, 100% FS and 75% CS: 25% RH were not significantly (P>0.05) different. Similarly, these substrates had significantly (P#0.05) higher Ca contents than the other substrates. Substrate 75% CS: 25% RH had the highest level of S of 2.7 g/kg while the 100% PB substrate had the lowest S level.

Iron (Fe): The substrate formulations had a significant (P#0.05) effect on the Fe content (Table 3). The control (100% FS) substrate had significantly (P#0.05) higher iron content than most other substrates. Iron levels in substrates 100% CS, 25% CS: 75% RH, 25% CS: 75% PB and 100% FS were not significantly (P>0.05) different. Similarly the iron level in all other substrates was not significantly (P>0.05) different. The 100% RH substrate had the lowest iron content of 8.9 g/kg.

Manganese (Mn): The Mn content was significantly (P#0.05) affected by the substrate formulations (Table 3). The manganese contents in all the substrates were significantly lower than the control except 100% CS. The control had the highest manganese content than the rest of the substrates. Manganese contents in the rest of the substrates were not significantly (P>0.05) different.

Sodium (Na): The substrate formulations significantly (P#0.05) affected the Na content (Table 3). The sodium content in the substrates was significantly (P#0.05) lower than the control except for substrate 100% CS. The rest of the substrates were not significantly (P>0.05) different in their sodium content.

Molybdenum (Mo): The substrate formulations had a significant (P#0.05) effect on the Mo contents (Table 3). Molybdenum in substrate 100% FS was significantly (P#0.05) higher from substrates 50% CS: 50% RH, 25% CS: 75% RH, 75% CS: 25% PB, 100% PB and 100% RH, but was not significantly (P#0.05) different from substrates 50% CS: 50% PB, 25% CS: 75% PB, 75% CS: 25% RH and 100% CS.

Lead (Pb): The substrate formulations had a significant (P#0.05) effect on the Pb contents (Table 3). Lead in substrates 25% CS: 75% PB, 50% CS: 50% PB, 100% PB and 100% RH was significantly (P#0.05) different from lead content in substrates 100% FS and 100% CS. The lead in all the other substrates was not significantly (P>0.05) different. The 100% CS substrate had the highest lead content among the substrates.

Copper (Cu): The substrate formulations significantly (P#0.05) affected the Cu content. All the substrates had significantly (P#0.05) lower Cu content than the control.

Zinc (Zn): The substrate formulations significantly (P#0.05) affected the Zn contents (Table 3). Substrates 75% CS: 25% RH, 75% CS: 25% PB, 50CS: 50% RH, 50% CS: 50% PB, 100% CS and the control were not significantly (P>0.05) different. However, they had significantly (P#0.05) higher Zn contents than the 100% PB and 100% RH substrates.

Cation Exchange Capacity: The CEC was significantly (P#0.05) affected by the substrate formulations (Table 3). The CEC of the 100% PB substrate was not significantly (P>0.05) different from 100%RH, but they were significantly lower than all the other substrates. All the substrates had CEC levels higher than the control (100% FS), except, substrates 75% CS: 25% PB, 75% CS: 25% RH and 100% CS. The 100% CS substrate had significantly (P#0.05) higher CEC (21.1me/100cc) than all other substrates.

Electrical Conductivity (EC): The electrical conductivity was significantly (P#0.05) affected by the substrate formulations (Table 3). The 100% CS and 100% FS substrate had significantly higher electrical conductivity than all the other substrates which were not significantly (P>0.05) different except substrates 100% PB and 100% RH. All the substrates had an electrical conductivity lower than that of the control except the substrate 100%C. The substrates 100% PB and 100% RH had the lowest electrical conductivity values (0.6mS/cm and 0.4mS/cm, respectively) and were significantly lower than all other substrates.

DISCUSSION AND CONCLUSIONS

pH: The pH was significantly (P#0.05) affected by the substrate formulations in the experiment. These results are in agreement with Nelson [10] who reported that, the pH of the substrate formulations controls the nutrients availability to the plant roots. According to Blom [11], most plants grow best in slightly acidic pH ranges of 6.2-6.8 in soil based substrate formulations and 5.4-6.0 in soilless media. Generally all the substrate formulations had pH levels below 6.8 depicting the acidic nature of most of the substrate formulations in experiments.

The pine bark and rice husks are acidic in nature owing to their composition [10]. Pine bark contains chemical substances which are acidic while rice husks have an outer covering composed of silica materials making it acidic. Very low pH values could result in toxic concentrations of ions such as Al, Zn and copper while pH above 7.5 can result in chemical binding [12]. All these lead to nutrients unavailability to the plants, causing stunted growth.

DeBoodt and Verndonck [13], reported that optimum pH of container substrate formulations differs with plant species but a pH of 5.0-6.5 can be tolerated by most plants provided the physical environment of the substrate is well controlled [4].

Electrical Conductivity (EC): The substrate formulations significantly (P#0.05) affected the electrical conductivity in the experiments. These results were in agreement with Hans *et al.* [4], Lemaire *et al.* [14] and Eames [15], who reported poor plant growth in substrate formulations with excessively high EC above 3.5 mS/cm. Electrical conductivity values below 2.0mS/cm are generally considered optimal for support of the plant growth in container production systems [16]. The electrical conductivity which is a measure of soluble salts concentrations in the substrate formulations was generally low in all the substrate formulations except in substrate 100% CS. The control (100% FS) and 100% CS substrate formulations had higher EC values in the experiment. The 100% FS and 100% CS substrate formulations showed a slightly higher content of both the macronutrients and the micronutrients. This could possibly explain their higher EC values as compared to the other substrate formulations. According to Milks *et al*. [16], EC measured shortly after planting are higher as compared to the EC values measured in the course of growth, provided the salt additions to the substrate formulations are controlled.

In the course of growth of container plants, changes in the substrate occur which affect the physical qualities of the substrate formulations. These may have negatively affected the drainage of the substrate formulations leading to waterlogging causing higher salt concentrations [17]. As a result of this, the nutrients released from the compost and salts which may have been contained in the irrigation water were not drained away causing salt build up and consequently higher EC. Excessively high EC values are detrimental for container plant production [18]. However, Chong *et al.* [18], indicated that, some plant species in container substrate formulations can tolerate EC values in excess of 8mS/cm. Therefore, a well controlled irrigation program and frequent EC measurements of the substrate formulations are among the possible methods for maintaining the EC in the required ranges for the given production system.

Macronutrients and Micronutrients: The macronutrients and the micronutrients were significantly (P#0.05) affected by the substrate formulations in the experiments. These results are in agreement with the work done Chong *et al.* [18]. Macronutrients and micronutrients are vital components of any rooting substrate for successful plant growth [18]. The substrate analyses showed higher levels of nearly all the plant nutrients. Nitrogen and calcium were present in almost similar concentrations. Potassium and phosphorous similarly had almost equal concentrations. All the micronutrients were present in very low concentrations except iron.

According to Milks *et al.* [16], all the elements with the exception of Mo and Cu were within the recommended ranges of the root substrate. The optimal range of nitrogen was reported to be 15-25g/kg but this may vary depending on the species under consideration [4]. Generally the nutrient concentrations in the substrate formulations used in the study were within the optimal levels. Potassium and phosphorous levels of 5-12 g/kg and 5-10 g/kg respectively were observed by Gretchen *et al.* [3] as ideal for pot plants but monitoring was required to avoid deficiencies caused by leaching.

The mineral nutrients have specific and essential functions within the plant metabolism, though some of these functions may be loosely correlated to either quantity of requirement or physiochemical properties. These mineral nutrients function as constituents of organic structure, activator of enzyme reactions or as charge carriers and osmoregulators in the plant system [19].

Nutrients supply to the plants roots is dependent on the water availability in the root substrate for dissolution of the nutrients before absorption [10].

Cation Exchange Capacity (CEC): The CEC was significantly (P#0.05) affected by the substrate formulations in the experiments. These results are in agreement with Nelson [10] and Tisdale *et al.* [20], who reported that rice husks and pine bark and other non-composted materials do not hold nutrients well and as a result have low CEC of below 1.6meq/100cc. The cation exchange capacity (CEC) is a measure of the magnitude of the fixed negative electrical charges which are essential in electrically attracting and holding nutrients, so that they are not washed away by heavy irrigation [10]. According to Nelson [10], CEC level of 6-15 meq/100cc is considered optimal for container root substrate, though higher CEC values are desirable. Substrate formulations of 25% CS: 75% PB and 25% CS: 75% RH had their CEC values lower below 6meq/100cc, similar to the CEC of substrate formulations 100% PB and 100% RH. Similarly, only substrate formulations 25% CS: 75% PB and 25%C: 75% RH had their CEC values lower than that recommended.

These electrically held nutrients are available to the plants for growth and development. Hence a higher CEC level is desirable [10]. Some of the nutrients are washed away by the irrigation water while some are fixed making them unavailable to the plants [21].

Optimal CEC can be achieved by fertilization programs which ensure replacement of the nutrients in the substrate formulations. The nutrients availability to the plants entirely depends on the physical environment of the substrate formulations that promote the active root growth and development. Lower CEC values indicate little or no capacity of the substrate formulations to supply nutrients and hence may cause complete plant failure due to nutrient deficiency. Compost has a high CEC and thus serves as a good reservoir of nutrients and that in addition it is a good source of both macronutrients and micronutrients [10].

In conclusion the pH of the substrates was acidic. The substrates had lower electrical conductivity and within the optimal range of below 2.0ms/cm for soilless culture, except for 100% forest soil and compost. The cation exchange capacity of all the substrates was higher than the minimum required value of 6meq/100cc, except for substrate 100% pine bark and rice husk which had very low CEC values. The values for macronutrients and micronutrients within the substrates were generally acceptable for containerized production, though this normally varies with the management practices and sometimes specific plant requirements.

The substrate formulations which incorporated 75% CS: 25% PB, 50% CS: 50% PB, 75% CS: 25% RH and 50% CS: 50% RH had their chemical qualities within the optimal ranges. The substrates formulations of 75% CS: 25% PB, 50% CS: 50% PB, 75% CS: 25% RH and 50% CS: 50% RH are recommended for use in nursery and pot plants production due to their optimal chemical qualities. The physical qualities and stability of the pine bark and rice husks to microbial decomposition during pot and nursery production should be evaluated.

ACKNOWLEDGEMENTS

The late Prof C.O. Gerroh and Maseno University.

REFERENTES

1. Jaenicke, H., 1999. Substrates. In ‘Good Tree Nursery Practices. Practical Guidelines for Research Nurseries’. ICRAF. Programme 2. Nursery Manual. Nairobi, pp: 30-44.
2. Reinkinen, O., 1993. Choice of growing media for pot plants. Acta Hort, 342: 357-360.
3. Gretchen M. Bryson and Allen V. Barker, 2002. Determination of optimal fertilizer concentration range for tomatoes grown in peat-based medium. Commun. Soil Sci. Plant Anal., 33(5and6): 759-777.
4. Hans R. Gi, S. Ravichandran, O.A. Kwadwo and K.H. Anne, 2005. Macro- and micronutrient nutrition of plants in greenhouses, hydroponic systems and in vitro culture on gelled media in A.K. Hvoslef-Eide and W. Preil (Eds.), Liquid Culture Systems for in vitro Plant Propagation, 475-492. © 2005 Springer. Printed in the Netherlands.
5. Mulandi, M.A.S., 1998. The status of the horticultural industry. Challenges and strategies now and beyond year 2000. HCDA Special report.
6. Kuepper, G. and Katherine, 2002. Organic Potting Mixes for Certified production: Appropriate Technology Transfer for rural Areas. National Sustainable Agriculture Information Service, Horticulture Technical notes.
7. Aguila, S.J.F., 1988. The present status of the substrate as an ecosystem component and its function and importance in crop productivity. Acta Hort, 221: 53-74.
8. Gabriel, R. and O. Verdonck, 1992. I.S.H.S Reference method for physical and chemical characterization of growing media. Acta Hort, 302: 169-179.
9. Tan, K.H., 1996. Soil sampling, preparation and analysis. Marcel Dekker Inc, New York.
10. Nelson, P.V., 1991 Greenhouse operations and management. Prentice Hall Int. (UK).
11. Blom, J.J., 1983. Working with soil less mixes. Florists’ Rev., 173(4480): 29-34.
12. Nappi, P. and R. Barberis, 1993. Compost as a growing medium: chemical, physical and biological aspects. Acta Hort, 342: 249-256.
13. DeBoodt, M. and O. Verndonck, 1972. The Physical Properties of Substrates in Horticulture. Acta. Hort, 26: 37-44.
14. Lemaire, F., A. Dartingues and L.M. Riviera, 1985. Properties of substrates made with spent mushrooms compost. Acta. Hort, 72: 13-29.
15. Eames, A.G., 1977. Could spent mushroom compost be used for container shrubs? Mushroom J., 52: 114 (Abstracts).
16. Milks, R.R., W.C. Fonteno and R.A. Larson, 1989. Hydrology of horticultural substrates: Predicting properties of media in containers. J. Amer. Sc. Hort. Sci., 114: 53-56.
17. Jerpersen, L.M., 1993. The production of compost in a heat composting plant and test compost mixtures as growing media for greenhouse cultures. Acta Hort., 342: 127-131.
18. Chong, C., Cline, R.A. Rinker and O.B. Allen, 1991. Growth and mineral nutrients status of containerized woody species in media amended with spent mushroom compost. J. Amer. Soc. Hort. Sci., 116: 242-247.
19. Marschner, H., 1995. Mineral Nutrition of Higher Plants. 2nd (Ed). Academic press. pp: 889.
20. Tisdale, S.L., L. Warner, D.B. James and L.H. John, 1993. Soil Fertility and Fertilizers. 5th (Ed). Prentice Hall. pp: 597.
21. Mastalerz, J.W., 1977. The Greenhouse Environment. John Wiley and Sons Inc.