PERFORMANCE OF SELECTED INDIGENOUS FRUIT TREES IN DIFFERENT NURSERY POTTING MEDIA

By

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DECLARATION

I, Davis Fyangu Mwansasu, hereby declare that all the work presented in this dissertation is my own and has not been submitted for the award of a degree at this or any other University.

Signature .....

Date 31/05/2005

CERTIFICATE OF APPROVAL

This dissertation of Davis Fyangu Mwansasu is approved as fulfilling part of the requirements for the award of the degree of Master of Science in Agronomy by the University of Zambia.

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ABSTRACT

There is an increasing concern about the loss of indigenous fruit trees from deforestation and other human activities that cause loss of biodiversity. Hence the need to domesticate these trees and re-afforestate is imperative. A study was conducted at the Zambia Centre for Horticultural Training in Chapula near Kalulushi in 2004 to evaluate the plant height and leaf number of indigenous fruit tree species *Uapaca kirkiana* and *Strychnos cocculoides* and a common exotic fruit tree species, *Citrus jambhiri* in different nursery potting media, in two separate experiments. In the first study, garden soil, forest soil and sand were compared as growing media for *Uapaca kirkiana, Strychnos cocculoides* and *Citrus jambhiri.* The experiment was arranged in a randomised complete block design with four replicates. In the second study, garden or forest soil was combined with sand and an organic amendment (water hyacinth, pine sawdust or kraal manure) in a mixing ratio of 0.5:1:1, 1:1:1 or 2:1:1 and potted in 15cm polyethylene bags. The pots were arranged in a split-split-split-plot design with three test species (*U. Kirkiana, S. cocculoides* and *C. jambhiri*) as main-plot treatments, two soil types (garden soil and forest soil) as sub-plot treatments, three mixing ratios as sub-sub-plot treatments and three organic amendments as sub-sub-sub-plot treatments and each treatment replicated four times. In each of the experiments, ten seedlings of the plant were transplanted per treatment. The chemical and physical characteristics of the potting media were determined before planting. Twenty-four weeks after transplanting, plant height and leaf number were measured or counted. The plant height for Uapaca kirkiana was higher ($P \leq 0.05$) in forest soil (19.3mm) when compared to garden soil (13.9mm) or sand (13.3mm). Plant height of *Strychnos cocculoides* was higher in garden soil (46.9 mm) and forest soil (37.7 mm) when compared to sand (16.4 mm). Unlike *Citrus jambhiri*, the indigenous tree species seemed to thrive in mixtures that had lower ratios of organic matter. Substrates containing water hyacinth generally showed higher values of nutrient elements compared to kraal manure and pine sawdust substrates and gave good plant growth. Plant height of *Uapaca kirkiana* was higher in water hyacinth substrates (15.4 mm) and pine sawdust substrates (14.1 mm) than in kraal manure substrates (11.75 mm). In *Strychnos cocculoides* plant height was highest in kraal manure substrates (35.8 mm) compared to that in water hyacinth substrates (23.1 mm) and pine sawdust substrates (10.43 mm). In *Citrus jambhiri* plant height was highest in kraal manure substrates (338.9 mm) compared to that in water hyacinth substrates (251.0 mm) and was lowest in pine sawdust substrates (8.2 mm). Plant height was significantly correlated to physical and chemical properties of the growth media.

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ACRONYMS

ANAFE	African Network for Agroforestry Education
FK	Forest soil + Kraal manure substrates
FP	Forest soil + Pine sawdust substrates
FS	Forest soil
FW	Forest soil + Water hyacinth substrates
GK	Garden soil + Kraal manure substrates
GP	Garden soil + Pine sawdust substrates
GS	Garden soil
GW	Garden soil + Water hyacinth substrates
ICRAF	International Centre for Research in Agroforestry
KM	Kraal manure
PSD	Pine sawdust
TS	Test species
WH	Water hyacinth

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Chapter 1

Introduction

Increasing activities of deforestation by growing and encroaching human population is causing rapid loss of biodiversity, loss of indigenous edible fruit trees and environmental degradation. In order to stop this trend, afforestation needs to be promoted (MithÖfer et al., 2004; IUCN, 1997; Chilufya and Tengnäs, 1996). Indigenous fruit trees could be particularly suited because they will in addition provide food to the growing population. However, it has not been easy to propagate these fruit trees from seed, unlike their exotic counterparts.

The information available on propagation techniques for indigenous fruit trees in Southern Africa is limited (Prins and Maghembe, 1994). In Zambia organized conservation and domestication strategies have been sporadic and unsustained, mainly due to financial constraints (Mkonda and Lungu, 2000). In the absence of appropriate technologies, attempts have been made to raise indigenous plants using conventional methods such as those used for exotic trees like Citrus, which place a lot of importance on soil fertility or the addition of fertilizer to the growth media. However, it has been observed that indigenous trees perform very poorly when grown under these nursery methods. The main observations have been poor germination, slow growth rate and the very long juvenility (Mkonda et al., 2002). It is therefore important that domestication efforts aim at creating plant conditions that are as close to the natural environment as possible (Dupriez and De Leener, 1995).

For centuries, wild uncultivated fruit trees and medicinal plants have provided the small scale farmers on forest-margins with food, medicine and income- generating opportunities (IFAD, 2003; Boffa, 1999). Most of these fruits are still collected from the wild. Domestication of these indigenous fruits on the farm would, among other benefits, result in increased supply and variety of fruits available to people. Being better adapted, indigenous fruit species can contribute toward household food security during periods of natural disasters such as droughts (Mingochi, 1998). The International Centre for Research in Agroforestry (ICRAF) has adopted the domestication of indigenous fruit trees as part of the wider strategy to improve human nutrition in rural areas and to "put money into farmers' pockets" in order to improve their living conditions (Jaenicke et al., 2000). *Uapaca kirkiana, Strychnos cocculoides* and *Parinari curatellifolia* have been determined as the most most popular species in Southern Africa (Anon., 2004). Apart from being sources of fruit, a number of these trees also supply material for poles and timber, natural medicines, fodder, and fuel wood. Products like wine and jam can also be made from the fruits (Mwamba, 1989). Increased use of indigenous tree species in agroforestry systems would therefore ensure continued access to food and many other products.

The ICRAF recognised the commercial value of indigenous fruits as early as the 1980s and this led to the launch of the Indigenous Fruit Tree Domestication Programme in southern Africa in the 1990s. The programme aimed at halting the loss of biodiversity of indigenous fruit trees due to indiscriminate tree cutting (MithÖfer et al., 2004 and Jaenicke et al., 2000). The programme aimed at enhancing indigenous fruit tree planting on farm thus enhancing indigenous fruit availability for own-consumption and marketing, and at the same time preserving

the trees and genetic variability. Production of plants for sale is also becoming an important income generating activity. Consequently, domestication activities may offer great opportunities to many people. Additionally, increased efforts in tree growing near settlements would, in the long run, reduce the pressure on woodlands and forests for fuel wood, thus checking deforestation and promoting the development of sustainable agriculture.

In a number of countries it has become an established practice to recycle agricultural and industrial waste by using them in plant propagation media (Calkins, 1978). Such practices reduce pressure on the land. In the central African region a variety of propagation media ranging from natural soils to manure, sands, and plant residues are used to raise plants. Meanwhile a lot of plant residues such as sawdust and Water hyacinth or Kafue weed (*Eichhornia crassipes*) lie unutilised, sometimes contaminating the environment. The efficacies of materials in current use on growth rates, and the possibility of transmission of pests and diseases, have not been determined. The active mycorrhizae species required for the symbiotic relations are yet to be elucidated.

The objective of this study was to evaluate soils and selected organic materials as suitable potting media for propagating Masuku (*Uapaca kirkiana*) and Mahuluhulu or Kasongole (*Strychnos cocculoides*) from seed. An exotic species, the rough lemon (*Citrus jambhiri*), was used as a standard.

Chapter 2

Literature Review

Plant propagation.

Poor quality propagation media are known to reduce survival and growth rates of indigenous fruit trees in the nursery (Gupta, 1992). A good propagation medium is one that is able to give anchorage and support to the plant, and store water, nutrients and air required for plant growth (Hartmann et al., 1990). For containerised plants, particularly, the media should also release the stored nutrients slowly.

Spontaneous plants describe wild plants growing naturally and freely in a wild state while semi-spontaneous plants are also wild but are encouraged, indirectly, by man to grow (Dupriez and De Leener, 1995). Indigenous trees, therefore, refer to spontaneous or semi-spontaneous trees indigenous to an area. In the Central-Southern African region, there has been very little systematic work done on nursery production practices for indigenous tree species (Prins and Maghembe, 1994). Consequently, there is a paucity of production process recommendations such as propagation media. There is no established propagation media for the domestication of candidate tree species such as *Uapaca kirkiana* and *Strychnos* cocculoides although they are identified as priority species.

Mycorrhizae in plant growth media.

Soils in the forest areas where indigenous trees grow have been shown to be beneficial when used in the propagation media, probably because they inoculate the

media with mycorrhizae (Simute et al., 1998; Mwamba, 1995). The study by Mwamba (1995) revealed that mycorrhizae significantly stimulated new root growth and enhanced seedling survival of *Uapaca kirkiana*. This is of practical importance to seedling regeneration and eventual success in any reforestation work. In the symbiotic association the host plant supplies the fungus with organic carbon compounds (carbohydrates) and the fungus assists the roots in exploiting the soil for water and inorganic nutrients, particularly phosphate in low phosphate soils. Plants with root systems of low specific surface areas with fleshy roots and few root hairs benefit most in phosphate uptake from the vesicular arbuscular mycorrhiza (VAM), root association (Mengel and Kirkby, 1987). These plants include citrus and grapevine. Significant increases in seedling growth parameters (such as plant height and leaf number) and leaf P and K contents have been observed due to VAM inoculation (Maksoud et al., 1994). Russel (1973) states that a given species of fungus will usually form mycorrhiza on a number of tree species and a given tree can carry mycorrhiza formed from a number of fungal species. This author gives three fairly definite soil conditions under which mycorrhizas develop freely: a supply of organic matter in the soil, well-aerated conditions and a restricted, but not too restricted, supply of nutrients. In a laboratory, Mulenga (2001) showed that VAM population in soil from a field that had regularly received inorganic fertilizer was much lower than in a soil from a field that had not received inorganic fertilizer for several years.

Using 25% sawdust and 75% forest soil for propagating *Uapaca kirkiana* was shown to improve seed germination. (Mhango, 2002) This was because of the improvement to potting mixture pore structure by sawdust which led to higher water holding capacity and better aeration.

Containerised plant production.

In the nurseries, tree plants are most commonly being raised in containers (Edmond et al., 1994; Hartmann et al., 1990; Mathew and Karikari, 1990; Rice et al., 1990). Container grown plants seem to have an advantage over field grown ones with respect to transportation and survivability after transplanting (Flegmann and George, 1977). However, the volume of soil in the container is exceedingly small; the root system is greatly restricted; the nutrient supply is limited; and the necessity for frequent watering is conducive to the leaching of nitrates and possibly other essential elements (Edmond et al., 1994; Mataa and Tominaga, 1998; Nishizawa and Saito, 1998). Pot mixtures should therefore be re-inforced with other materials that will enhance their water and nutrient holding capacities. Plants or plantlets remain in the containers (or polyethylene sleeves) for long periods, sometimes exceeding one year, yet the changes in soil physical structure, which have an impact on aeration and retention of water and minerals, have not been given due consideration.

Various containers are used in the propagation of different types of plants. The types of containers used will depend upon the method of propagation, kind of plants propagated and the period of expected use of the containers (Mathew and Karikari, 1990). For example, containers used for raising seedlings of vegetables and flowering annuals will differ from those used for perennial plant stocks raised for

grafting, rooted cuttings or indeed fruit tree seedlings. When plants are expected to stay in a container until maturity and continue to stay for decorative purposes, containers made from more permanent materials are used. Trees or ornamental plants raised from seeds or cuttings are planted in various sizes of polyethylene bags and therefore, are only used as semi-permanent containers. In most cases they do not last for more than one to one and half years (Mathew and Karikari, 1990). UV stabilized polyethylene materials are more durable compared to non-UV stabilized ones (Mataa and Tominaga, 1998). The bags are filled with light, rich compost mixtures. A few holes are made in the bottom of the bag to let excess water drain away. One seed or one cutting is placed in each bag. In this way each seedling will be protected by its own ball of soil when it is transplanted. Polyethylene bags are easy to use and are fairly cheap but other containers such as raffia baskets, pieces of bamboo, earthen pots, plastic pots and those made of fibre can be used. Whatever the container, water must be able to drain through the bottom. It is a new practice in Zambia to recycle containers of some brands of opaque beer to raise stocks of ornamental plants and Citrus plants.

Organic amendments in growth media.

One of the common problems with the production of containerised nursery plants is the use of soils from cultivated lands are used as growth media. (Rice et al., 1990). Field or garden soils are usually unsuitable for use as potting soils. These soils are associated with applications of inorganic fertilizers. Properties of these soils undergo drastic changes when containerised. Field soils may become suitable only after amendments. One common amendment to field soils is the addition of humus. Not only does this contain essential elements but it is the agent by which soils with poor

texture and structure are best remedied (Calkins, 1978). Any bulky organic waste – animal manure, leaves, grass clippings, sawdust, and kitchen scraps – are useful as sources of organic matter. A sufficient quantity of organic matter is very important in a nursery whether for preparing pot mixtures or improving the soil generally. However, for any material to be useful as manure, it must have undergone thorough decomposition. Growth media containing high organic matter such as compost tends to release nutrients slowly when plants are small (Streeter and Barta, 1984), a desirable condition for pot mixtures.

The dung and urine of animals which is called manure is an invaluable material in compost making activities. Its use as a soil amendment and fertilizer is a time honoured tradition that can be traced from the earliest written words (Martin and Gershuny, 1992). The most common domestic sources of manure are horses, cattle, goats, sheep, pigs, rabbits and poultry. Dung consists of undigested portions of foods ground into fine bits and saturated with digestive juices in the alimentary tract. As a rule, it contains one third of the total nitrogen, one-fifth of the total potash, and nearly all of the phosphoric acid voided by the animals (Martin and Gershuny, 1992). The manure is so valuable to the compost heap because of its high concentrations of bacteria. The addition of animal manure provides the necessary bacteria that will quickly break down the other material. Experiments at the Horticultural Research Station, Nadia, India, showed that growth media containing cow dung gave the best growth in tamarind (*Tamarindicus indica* L.) seedlings (Chatopadhyay and Mohanta, 1988).

Saw dust has given quite good results as a composting material, although it is better used as mulch (Martin and Gershuny, 1992). Not only is it valuable as a carbon source but also as a bulking agent, allowing good air penetration. It also improves structure of heavy soils. In the case of sawdust from pine, additional nitrogen may be needed in an amount sufficient for the decomposition requirements of the material (nitrogen needs of soil organisms), plus an additional amount for use by the plants (Edmond et al., 1994; Hartmann et al., 1990). These authors state that some types of sawdust, when used fresh, may contain toxic materials, so they require composting for 10 to 14 weeks before using. Chemical characteristics can also be influenced by the wood or trees used to produce the organic matter; for instance, sawdust from indigenous or exotic trees.

Water hyacinth, *Eichhornia crassipes* (Mart) Solms-Laub, originated in Brazil, where it was described from the San Fransisco river in 1824 (Bock, 1966). Because of its aesthetic qualities as an ornamental plant, it has now spread to many parts of the world, including Africa, through movement of people (UNDP, 2004). Water hyacinth, as a plant, is considered a menace to agriculture, fisheries, sanitation and health in areas where it grows (Martin and Gershuny, 1992). It is now known to occur in most of Sub-Sahara Africa, including Zambia. Unfortunately, Water hyacinth infestations throughout Africa have resulted in social problems due to the inhibition of fishing, an increase in various diseases such as malaria as well as the reduced utilisation of waterways for transport and recreation as well as other negative issues created by this introduced aquatic plant (Findlay and Jones, 1996). The problem is currently on the increase in Africa. Water hyacinth is a fast growing weed that is highly efficient in absorbing inorganic mineral nutrients that are eroded

into various water bodies. Like other aquatic plants, water hyacinth is a good source of organic fertiliser since it has considerable levels of nitrogen, phosphorus and potassium (Chará, 1997). It can, therefore, be useful if recycled as compost for plant growing.

In a study to compare water hyacinth straw, wheat straw and soybean straw as substrates for mushroom production, Mkhatshwa (2002) found that water hyacinth was best for producing oyster mushrooms (*Pleurotus sajor caju* and *Pleurotus Hk 35*). Use of water hyacinth resulted in higher protein content of mushrooms compared to the other substrates. It has been suggested that for better results in plant propagation media, the water hyacinth should be shredded and mixed with other materials (Martin and Gershuny, 1992). Besides their nutrient contribution, these materials improve soil structure and increase water retention capacity.

Soil Physical and Chemical Properties.

Bulk density gives useful information in assessing the potential for leaching of nutrients, erosion, and crop productivity (Evanylo and McGuinn, 2000). Soil bulk density is also associated with soil strength. Soil strength increases as the soil dries, restricting emergence and plant growth in the soil (Cardwell, 1984). Studies have also shown that lack of aeration limits plant growth and that the storage and supply of air and water are controlled by pore size and abundance (Allaire et al., 1996). A soil moderately high in nutrient holding capacity does not usually require additional supply of micronutrients when used for short-term crops such as bedding plants (Lee et al., 1996). However, for long-term crops soils will normally lose nutrient elements through leaching and will harden as organic matter is depleted (Edmond et al.,

1994). In addition, plants that have adequate nutrition and water generally tend to have a higher shoot-to-root ratio than plants that are deficient in either (Roe et. al., 1997). Studies have shown that the shoot-to-root ratio of tomato seedlings was always the lowest in sand compared to richer substrates. Soil reaction (or pH) is a measure of the concentration of hydrogen ions in the soil. Although not directly influencing plant growth, it has a number of indirect effects, such as the availability of various nutrients and the activity of beneficial micro organisms. Soil pH and nitrate levels have been shown to be correlated with plant growth (Allaire et al., 1996). Except for acid-loving plants, it is generally agreed that plant growth is optimal in media of pH between 5.0 and 6.5. Excessive salts in the propagating or growing mixes or in irrigation water of over 2 $mScm^{-1}$ can reduce plant growth and optimise it at lower salt levels (Goh and Haynes, 1977; Hartmann et al., 1990).

Chapter 3

Materials and Methods

A field experiment was carried out at the Zambia Centre for Horticultural Training, Chapula (12° 55′ – 12° 56′ S and 28° 01′ – 28° 04′ E), 1,200 metres above sea level, between January and November 2004.

Experimental treatments and design.

Forest soil, garden soil and sand were used as base materials with water hyacinth (*Eichhornia crassipes),* pine sawdust and kraal manure as organic soil amendments. Forest soil was collected from the 0-10cm layer in Chief Lumpuma's area in Lufwanyama District (12° 55′ - 13° 00′ S and 27° 55′ – 28° 00′ E) where the indigenous test species were endemic, and garden soil was collected from the 0-10 cm layer in a field that had alternatively been cropped to maize, cabbage and tomato for several years but had lain fallow for a year prior to collection at Chapula (12° 55′ – 12° 56′ S and 28° 01′ – 28° 04′ E). Sand was collected from the roadside and pine sawdust, mostly of Pine (*Pinus oocarpa*), was collected from a saw mill in Kalulushis while the kraal manure was from a cattle kraal at Chapula.

The test plants comprised two species determined by the International Center for Agroforestry (ICRAF) as priority trees for domestication – *Uapaca kirkiana* (Muell. Arg.) and *Strychnos cocculoides* (Baker) (Maghembe et al. (eds), 1998). A common rootstock for citrus fruit trees in Zambia, the rough lemon (*Citrus jambhiri*), was included as a standard. Seeds of the test species were extracted from fruits collected

from a forest in Chief Lumpuma's area, washed thoroughly and sowed in sand to germinate. Two experiments were conducted in the study.

The first experiment compared garden soil (GS), forest soil (FS) and sand as growing medium for *Uapaca kirkiana, Strychnos cocculoides* and *Citrus jambhiri.* The materials were potted into 15cm plastic (polyethylene) bags. The three species were treated separately and each was arranged as a single experiment in a randomised complete block design with four replicates.

In the second experiment garden soil or forest soil were combined with sand and organic amendment [water hyacinth (WH), pine sawdust (PSD) or kraal manure KM)] in a soil:sand:organic amendment mixing ratio of 1:1:1, 1:2:2 or 2:1:1 and put in 15cm plastic pots. The pots were arranged in a split-split-split-plot design with three test species (*U. Kirkiana, S. cocculoides* and *C. jambhiri*) as main-plot treatments, two soil types (garden soil and forest soil) as sub-plot treatments, three mixing ratios as sub-sub-plot treatments and three organic amendments as sub-sub-sub-plot treatments and each treatment replicated four times.

Ten weeks after germination, the seedlings of Masuku (*Uapaca kirkiana*), Kasongole or Mahuluhulu (*Strychnos* cocculoides) and rough lemon (*Citrus jambhiri*) were transplanted into the different pot materials and mixtures of both experiments. Ten seedlings of the plant were transplanted per treatment. The experiments were conducted in diffused light under a shade cloth giving 25% neutral shade.

Management of the experiment.

Except for the nursery, which was started in late January under rain season conditions, the main experiment was conducted during the dry season. Each plant pot received an average of 17mm of water every three days. Only Citrus experienced insect pest attack by the orange dog caterpillar (*Papilio demodocus*) and this was easily controlled by picking. Weeds (mostly *Eleucine indica, Oxalis* and *Cyperus* spp.) were more predominant in garden soil, and garden soil mixtures containing kraal manure or water hyacinth and these necessitated hand weeding every two weeks.

Data collection.

Plant height was measured from soil surface in the pot to highest node while plant leaf number was obtained by counting, 24 weeks after transplanting. The growth media were sampled at potting time and also from the pots at 10cm soil height during the course of the experiment. The soil properties measured included soil bulk density and total pore space (TPS). The analytical work was carried out in the laboratories of the Department of Soil Science, School of Agricultural Sciences, University of Zambia. The bulk density (D_b) was determined using samples collected in standard core rings. These were weighed, dried at 105°C for 24 hours and the dry weight determined (Songolo and Pauwelyn, 1998; Gill and Songolo, 1981). The total pore space (T.P.S.) was determined using standard formulae (Songolo and Pauwelyn, 1998; Gill and Songolo, 1981). The chemical properties of the media determined included the soil pH, electrical conductivity (EC), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnessiun (Mg), iron (Fe), boron (B), zinc (Zn), manganese (Mn), and copper (Cu). The soil pH was

determined by using a 1:2.5 soil solution in 0.01M $CaCl_2$ (Songolo and Pauwelyn, 1998). The electrical conductivity (EC) was determined by using a 1:5 soil:solution ratio in distilled water (Lungu and Songolo, 1993). Total nitrogen (N) was determined using the Kjeldahl method while phosphorus was determined using the Bray 1 procedure (Songolo and Pauwelyn, 1998). The cations (K, Ca, and Mg) were determined by using a 1:5 soil:solution ratio in neutral ammonium acetate solution (Songolo and Pauwelyn, 1998). The elements were then read on an atomic absorption spectrophotometer (AAS). Boron was determined in a 1:2 soil:solution in 0.01M $CaCl_2$, boiled for 15 minutes, then cooled. Azomethrin H was used to develop colour and the element read on a Spectrophotometer by colour intensity (Cottenie et al., 1982 and Songolo, 1993).

Data analysis.

Plant height and leaf number were subjected to analysis of variance using the Genstat 5 Release 3.2 software, and mean separation by Least Significant Difference (LSD) test at $p < 0.05$. Regression and correlation analyses were also performed between different variables.

Chapter 4

Results

Physical and chemical properties of materials used.

The physical and chemical properties of the base materials and organic amendments used in this study are given in Table 1. Garden soil had the highest nutrient element amounts among the base materials with respect to total N (0.19%), extractable P (22.37mg/kg), K (0.51me/100g), Ca (13.47me/100g), Mg (2.50me/100g), and B (0.82mg/kg). Sand had the lowest amounts of nutrient elements, total N (0.09%), extractable P (1.89mg/kg), K (0.40me/100g), Ca (3.41me/100g), Mg (1.61me/100g) and boron (0.12mg/kg) but highest values with regard to pH (6.01)and bulk density (1.57g/cm^3) compared to the lowest pH (3.97) and lowest bulk density (1.20g/cm^3) for forest soil and garden soil, respectively. Of the organic amendments, water hyacinth had the highest amounts of total N (0.91%), extractable K (0.40me/100g), Ca (2.34me/100g), Mg (4.33me/100g), and B (6.28mg/kg) against the lowest amounts recorded in pine sawdust, total N (0.42%), extractable K (0.03me/100g), Ca (0.60me/100g), Mg (0.21me/100g) and boron (2.90mg/kg). The water hyacinth electrical conductivity, EC (6.63 mS/cm) and P (108.15 mg/kg) were high compared to (6.63mS/cm) and 0.28mg/kg), respectively, for kraal manure. Water hyacinth and kraal manure had pH values of 8.02 and 8.50, respectively, while pine sawdust had a low pH value of 4.09. Table 2 shows physical and chemical properties of basic substrate mixtures when made in equal amounts of soil, sand and organic amendment (1:1:1) ratio. The treatment with pine sawdust substrate had the lowest pH level (4.57) compared to (6.64) recorded in kraal manure and (6.56) for water

hyacinth substrates. Mixtures with garden soil generally had lower bulk densities than mixtures with forest soil. Kraal manure substrates had the highest amounts of total N, extractable P, K, Mg and B. Kraal manure substrates also had the highest bulk density values. Water hyacinth substrates had the highest amounts of Ca.

Table 1: Physical and chemical properties of base soils and organic amendments used in the study.

Base Material	pH ($CaCl_2$)	EC (mS/cm)	Total N (%)	P (mg/kg)	K (me/100g)	Ca (me/100g)	Mg (me/100g)	B (mg/kg)	D_b (g/cm^3)	TPS (%)
Base soils										
Garden soil	4.70	0.14	0.19	22.37	0.51	13.47	2.50	0.82	1.20	52.78
Forest soil	3.97	0.10	0.14	11.55	0.48	8.01	1.20	0.48	1.28	49.80
Sand	6.01	0.07	0.09	1.89	0.04	3.41	1.61	0.12	1.57	34.86
Organic amendments										
Water hyacinth	8.02	6.63	0.91	108.15	0.40	2.34	4.33	6.28	0.17	96.25
Pine sawdust	4.09	0.49	0.42	23.42	0.03	1.27	0.21	2.90	0.21	81.90
Kraal manure	8.50	0.28	0.53	69.86	0.02	0.60	0.24	2.87	0.25	57.93

EC - Electrical conductivity TPS - Total pore space

Table 2: Physical and chemical properties of basic substrate mixtures made in 1:1:1 ratios of soil, sand and organic amendment.

Mixture	D_b (g/cm^3)	pH ($CaCl_2$)	EC (mS/cm)	Total N (%)	P (mg/kg)	K (me/100g)	Ca (me/100g)	Mg (me/100g)	B (mg/kg)	TPS (%)
GW	1.21	6.56	0.23	0.20	10.84	0.74	4.99	0.78	0.37	44.42
GP	1.12	4.91	0.10	0.23	6.96	0.34	2.44	0.37	0.31	46.85
GK	1.25	6.64	0.37	0.31	20.95	2.82	3.97	1.39	1.00	42.92
FW	1.27	6.37	0.19	0.22	10.89	0.57	4.72	0.72	0.40	41.33
FP	1.14	4.57	0.08	0.26	8.53	0.29	2.02	0.32	0.27	45.94
FK	1.30	6.50	0.36	0.27	24.91	2.52	4.20	1.36	0.59	41.09

Key: GW =Garden soil + Sand + Water hyacinth. GP = Garden soil + Sand + Pine sawdust. GK = Garden soil + Sand + Kraal manure.
FW = Forest soil + Sand +Water hyacinth. FP = Forest soil + Sand + Pine sawdust. FK = Forest soil + Sand + Kraal manure.
TPS = Total Pore Space

Experiment 1

Effect of garden soil, forest soil and sand on plant height and leaf number.

Plant heights and leaf numbers of *Uapaca kirkiana* grown on different base materials are shown in Table 3. Differences ($P < 0.05$) among the treatment means for plant height were observed. Plant height was higher in forest soil (19.3mm) compared to garden soil (13.9mm) or sand (13.3mm). No differences were observed between garden soil and sand. Forest soil gave higher (16.3) number of leaves than garden soil (8.2) or sand (9.1).

The growth media were also different with respect to plant height ($P > 0.01$) and leaf number ($P > 0.01$) of *Strychnos cocculoides* (Table 4). Garden soil and forest soil gave higher plant height 46.9mm and 37.7mm, respectively, compared to sand (16.4mm). Leaf numbers were higher in garden soil (18.8) and forest soil (16.9) than in sand (13.3).

Similar differences among growth media ($P < 0.01$) both for plant height and leaf number of *Citrus jambhiri* were observed (Table 5). Plant heights were higher in garden soil (136.5mm) and forest soil (156.8mm) than in sand (31.9mm), while forest soil was higher for leaf number with (23.9) than garden soil (14.3) or sand (10.3).

Table 3: Means of plant height and leaf number of *Uapaca kirkiana* seedlings grown garden soil, forest soil and sand, determined 24 weeks after transplanting.

Growth medium	Plant height[z] (mm)	Leaf number[y]
Garden soil	13.88	8.22
Forest soil	19.33	16.28
Sand	13.25	9.14
Mean	15.49	11.21
$LSD_{(0.05)}$	4.7	3.13
CV (%)	15.8	16.10

[z] [Plant height at 24 weeks after transplanting] – [Plant height at transplanting].
[y] [Leaf number at 24 weeks after transplanting] – [Leaf number at transplanting].

Table 4. Means of plant height and leaf number of *Strychnos cocculoides* seedlings grown on garden soil, forest soil and sand, determined 24 weeks after transplanting.

Growth medium	Plant height[z] (mm)	Leaf number[y]
Garden soil	46.90	18.83
Forest soil	37.70	16.92
Sand	16.40	13.25
Mean	33.70	16.33
$LSD_{(0.05)}$	10.80	2.11
CV (%)	18.50	7.50

[z] [Plant height at 24 weeks after transplanting] – [Plant height at transplanting].
[y] [Leaf number at 24 weeks after transplanting] – [Leaf number at transplanting].

Table 5. Means of plant height and leaf number of *Citrus jambhiri* seedlings grown garden soil, forest soil and sand, determined 24 weeks after transplanting.

Growth medium	Plant height[z] (mm)	Leaf number[y]
Garden soil	136.50	14.32
Forest soil	156.80	23.87
Sand	31.90	10.27
Mean	108.40	16.15
$LSD_{(0.05)}$	26.80	4.68
CV (%)	14.3	16.7

[z] [Plant height at 24 weeks after transplanting] – [Plant height at transplanting].
[y] [Leaf number at 24 weeks after transplanting] – [Leaf number at transplanting].

Experiment 2

Effect of potting media made up of garden or forest soil combined with sand and an organic amendment in three mixing ratios, on plant height and leaf number of *Uapaca kirkiana, Strychnos cocculoides* and *Citrus jambhiri.*

Single-factor effects on plant height and leaf number.

Appendix 7 presents the analysis of variance for plant height. Significant ($P < 0.01$) differences were observed between test species, mixing ratios and organic amendments.

Plant heights and leaf numbers for the four treatment factors under study are given in Table 6. Test species were different ($P < 0.01$) for plant height with *Citrus jambhiri* being highest (199.4mm) and *Uapaca kirkiana* having the lowest (13.8mm). Differences ($P < 0.05$) were also observed between mixing ratios with 1:1:1 being higher (82.4mm) than 0.5:1:1 (77.3mm) or 2:1:1 (76.6mm). Soil type had no effect on plant height. Organic amendments were also different ($P < 0.01$) with kraal manure giving the highest (128.8mm) plant height followed by water hyacinth (96.5mm) while pine sawdust gave the lowest (10.9mm).

Appendix 8 presents the analysis of variance for leaf number. Significant differences were observed between test species ($P < 0.01$), soil types ($P < 0.05$) and organic amendments ($P < 0.01$).

Test species were also different ($P < 0.01$) for leaf number (Table 6) with *Citrus jambhiri* giving the highest (16.0) and *Uapaca kirkiana* giving the lowest (6.8). Soil types were also different ($P < 0.05$) for leaf number with forest soil giving higher (11.1) than garden soil (10.4). Mixing ratios were not different for leaf number. On the other hand, organic amendments were different ($P < 0.05$) for leaf number with kraal manure giving highest (18.7) and pine sawdust the lowest (3.2).

Table 6. Means of plant height[y] (mm) of test species for the treatment factors used in the study, determined 24 weeks after transplanting.

Treatment factors							
Test species		Soil type		Mixing ratio[z]		Organic amendment	
Uaapaca Kirkiana	13.8	Garden soil	77.6	0.5:1:1	77.3	Water hyacinth	96.5
Strychnos cocculoides	23.1	Forest soil	79.9	1:1:1	82.4	Pine sawdust	10.9
Citrus jambhiri	199.4			2:1:1	76.6	Kraal manure	128.8
Mean	78.8		78.8		78.8		78.8
$LSD_{(0.05)}$	7.7		-		4.5		6.6
CV (%)	5.6		8.8		9.8		25.5

[z] Denotes (soil: sand: organic amendment) ratio.
[y] [Plant height at 24 weeks after transplanting] – [Plant height at transplanting].

Table 7. Means of leaf number[y] of test species for the treatment factors used in the study, determined 24 weeks after transplanting.

Treatment factors							
Test species	Leaf	Soil type		Mixing ratio[z]		Organic amendment	
	No.		No.		No.		No.
Uaapaca Kirkiana	6.81	Garden soil	10.42	0.5:1:1	10.29	Water hyacinth	10.42
Strychnos cocculoides	9.50	Forest soil	11.13	1:1:1	10.67	Pine sawdust	3.23
Citrus jambhiri	16.00			2:1:1	11.35	Kraal manure	18.67
Mean	10.77		10.77		10.77		10.77
$LSD_{(0.05)}$	1.27		0.56		-		0.83
CV (%)	6.80		5.70		14.50		23.40

[z] Denotes (soil: sand: organic amendment) ratio.
[y] [Number of leaves at 24 weeks after transplanting] – [Number of leaves at transplanting].

Interaction effects on plant height and leaf number of the test tree species.

The interaction between test species and soil type was not significant for both plant height and leaf number (Appendices 7 and 8). The interaction between test species and media mixing ratio was significant ($P < 0.01$) for plant height (Table 8). Plant height of the indigenous species *Uapaca kirkiana* and *Strychnos cocculoides* increased with changing mixing ratio but for *Citrus jambhiri*, an initial increase was followed by a sharp decrease.

The change in mixing ratios was accompanied by significant differential responses by the test species with respect to leaf number (Table 8).For *Uapaca kirkiana* there was a steady increase from the 1:2:2 ratio to the 2:1:1 ratio. Strychnos cocculoides showed an initial drop in the leaf number before increasing sharply to 11.2 while *Citrus jambhiri* had an initial increase followed by a decrease.

The effects of the interaction between test species and organic amendment was significant ($P < 0.01$) with respect to both plant height and leaf number (Table 7). The use of pine sawdust as organic amendment in growth media reduced plant height of *Citrus jambhiri* to below those recorded in media with water hyacinth or kraal manure as organic amendments. This reduction, however, was different for different test species with Strychnos cocculoides and Citrus jambhiri showing bigger reductions of 55% and 97%, respectively, than 8% for Uapaca kirkiana. Similar interactions were observed between test species and organic amendments for leaf number. The number increased from water hyacinth to kraal manure for all test species, but dropped when pine sawdust was used only for Strychnos cocculoides and Citrus jambhiri. Again the reductions were different for the test species with

Citrus jambhiri and Strychnos cocculoides having bigger reductions, 95% and 52%, respectively. Uapaca kirkiana had an increase in the number from water hyacinth to pine sawdust

Interactions between soil type and media mixing ratio were significant ($P < 0.05$) for plant height (Table 8). As the amount of soil increased in the mixtures plant height initially increased for both soil types. In garden soil, however, plant height sharply reduced by 12% compared to a 2% reduction in forest soil as the soil proportion was increased further in the mixtures. Increasing soil proportion beyond the 1:1:1 ratio in the mixture was detrimental when garden soil was used but had no effect in case of forest soil.

Increasing garden soil in the mixtures had no effect on the number of leaves whereas increasing forest soil proportions of soil increased number of leaves from 10 to 13. At lower proportions of soil there was no observed difference on the number of leaves for the two soils, but at higher proportions forest soil resulted in higher number of leaves.

The interaction between soil type and organic amendment was significant ($P < 0.01$) for plant height (Table 10). Using water hyacinth as an amendment to soil gave taller plants when forest soil was used (105.6mm vs 87.4mm). Adding sawdust drastically suppressed plant height with plants averaging 10.9mm and forest plant measuring 8.3mm only. Kraal manure enhanced plant height in garden soil more than in forest soil (132mm vs 125.6mm).

Similar observations were realized for leave number. Lowest counts were when sawdust was used and highest when kraal manure was used in all cases.

The interaction between mixing ratio and organic amendment was not significant. The soil type, mixing ratio and organic amendment interaction was significant ($P < 0.01$) for leaf number but was not significant for plant height. The interaction of test species, soil type and organic amendment was significant ($P < 0.01$) for plant height but not significant for leaf number. The test species, mixing ratio and organic amendment interaction was significant ($P < 0.01$) for leaf number but not significant for plant height.

Table 8. Means of plant height and leaf number of *Uapaca kirkiana, Strychnos cocculoides* and *Citrus jambhiri* seedlings grown on potting media made in different mixing ratios determined 24 weeks after transplanting.

	Plant height[x] of test species (mm)					Leaf number[y] of test species			
Mixing ratio[z]	*Uapaca kirkiana*	*Strychnos cocculoides*	*Citrus jambhiri*	Mean	Mixing ratio	*Uapaca kirkiana*	*Strychnos cocculoides*	*Citrus jambhiri*	Mean
1:2:2	13.40	18.40	200.20	73.30	1:2:2	6.63	8.91	15.34	10.29
1:1:1	13.80	24.00	209.30	82.40	1:1:1	6.89	8.42	16.71	10.67
2:1:1	14.10	27.00	188.60	76.60	2:1:1	6.92	11.17	15.97	11.35
Mean	13.76	23.13	199.40	78.80	Mean	6.81	9.50	16.00	10.80
$LSD_{(0.05)}$				9.24	$LSD_{(0.05)}$				1.69
CV (%)				9.80	CV (%)				14.50

[z] Denotes (soil: sand: organic amendment) ratio.
[y][Leaf number at 24 weeks after transplanting] – [Leaf number at transplanting].
[x] [Plant height at 24 weeks after transplanting] – [Plant height at transplanting].

Table 9. Plant height and leaf number of *Uapaca kirkiana, Strychnos cocculoides* and *Citrus jambhiri* seedlings grown on different organic amendments, determined 24 weeks after transplanting.

	Plant height[z] of test species (mm)					Leaf number[y] of test species			
Organic amendment	*Uapaca kirkiana*	*Strychnos cocculoides*	*Citrus jambhiri*	Mean	Organic amendment	*Uapaca kirkiana*	*Strychnos cocculoides*	*Citrus jambhiri*	Mean
Water hyacinth	15.4	23.1	251.0	96.5	Water hyacinth	3.05	9.54	18.67	10.42
Pine sawdust	14.1	10.4	8.2	10.9	Pine sawdust	4.22	4.57	0.91	3.23
Kraal manure	11.8	35.8	338.9	128.8	Kraal manure	13.18	14.39	28.44	18.67
Mean	13.8	23.1	199.4	78.8	Mean	6.8	9.5	16.0	10.8
$LSD_{(0.05)}$				11.38	$LSD_{(0.05)}$				1.61
CV (%)				25.5	CV (%)				23.4

[z] [Plant height at 24 weeks after transplanting] – [Plant height at transplanting].
[y] [Leaf number at 24 weeks after transplanting] – [Leaf number at transplanting].

Table 10. Means of plant height and leaf number from the interaction between soil type and organic amendment, determined 24 weeks after transplanting

	Soil types			
	Garden soil	Forest soil	Garden soil	Forest soil
Organic amendment	Plant height[z] (mm)		Leaf number[y]	
Water hyacinth	87.4	105.6	9.92	10.92
Pine sawdust	13.5	8.3	3.59	2.87
Kraal manure	132.0	125.6	17.75	19.59
Mean	77.63	79.82	10.42	11.13
$LSD_{(0.05)}$		9.58		1.08
CV (%)		25.4		23.4

[z] [Plant height at 24 weeks after transplanting] – [Plant height at transplanting].
[y] [Leaf number at 24 weeks after transplanting] – [Leaf number at transplanting].

Correlations between plant height and soil parameters.

Physical and chemical parameters of the potting mixtures were correlated to plant height using simple linear regressions (Gomez and Gomez, 1984). The correlation coefficients are given in Table 11. The physical properties, D_b and TPS, were significantly correlated to plant height in *Strychnos cocculoides* and *Citrus jambhiri* but not in *Uapaca kirkiana.* Of the chemical parameters, substrate pH and EC were significantly correlated to plant height of all the test species. The element P was significantly, but negatively correlated to plant height in *Citrus jambhiri* only. Potassium was significantly correlated to plant height in *Citrus jambhiri.* Ca was correlated to plant height in *Uapaca kirkiana* and *Strychnos cocculoides..* Magnessium showed correlation to plant height *Citrus jambhiri.* Boron was the only micronutrient that showed any correlation to plant height and this was only with respect to *Uapaca kirkiana.* Plant height was also correlated to leaf number using simple linear regressions (Table 12). Correlations were significant between the two parameters only in *Strychnos cocculoides* and *Citrus jambhiri.*

Table 11: Correlation coefficients between plant height of *Uapaca kirkiana, Strychnos cocculoides* and *Citrus jambhiri* and physical and chemical properties.

Soil properties	Test species		
	Uapaca kirkiana	*Strychnos cocculoides*	*Citrus jambhiri*
Physical properties			
D_b	-	0.80^{**}	0.71^{**}
TPS	-	-0.74^{**}	-0.64^{**}
Chemical properties			
pH	0.71^{**}	0.69^{**}	0.88^{**}
EC	-0.64^{**}	0.66^{**}	0.88^{**}
Total N	-	-	-
P	-	-	-0.57^{**}
K	-0.20^{NS}		0.72^{**}
Ca	0.45^{*}	0.48^{*}	0.19^{NS}
Mg	-0.11^{NS}	-	0.63^{**}
B	-0.54^{*}	-	-

D_b = Bulk density, TPS = Total pore space, EC = Electrical conductivity,
(-) = No correlations detected
$^{NS, *, **}$ Non-significant or significant at P = 0.05 and 0.01, respectively.

Table 12: Correlation coefficients between plant height and leaf number of *Uapaca kirkiana*, *Strychnos cocculoides* and *Citrus jambhiri*, 24 weeks after transplanting.

Regression parameter	Test species		
	Uapaca kirkiana	*Strychnos cocculoides*	*Citrus jambhiri*
Correlation coefficient	0.21	0.74	0.98
Regression coefficient (b)[z]	-0.224	2.953	12.024
Significance[y]	NS	**	**

[z] Height growth regressed on leaf number.

[y] NS, ** Denote non-significance or Significance at $p < 0.01$, respectively

Figure 1. Seedlings of *Citrus jambhiri* and *Uapaca kirkiana* 16 weeks after transplanting in kraal manure (1), water hyacinth (2) and pine sawdust (3) substrates, respectively. Seedlings in pine sawdust substrates became chlorotic while those in water hyacinth and kraal manure substrates responded positively.

Figure 2. Seedlings of *Strychnos cocculoides* 16 weeks after transplanting. The seedlings in water hyacinth substrates (centre) generally retained their green colour longer than in other organic amendments.

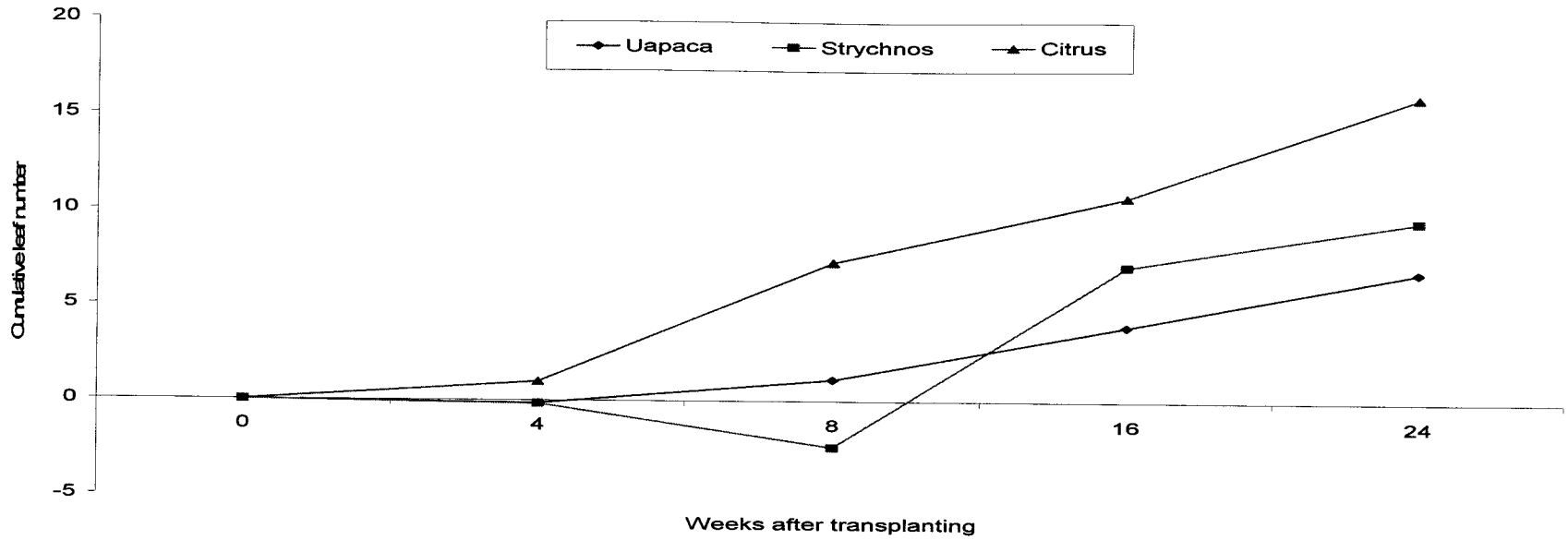

Figure 3. Cumulative leaf number of *Uapaca kirkiana, Strychnos cocculoides* and *Citrus jambhiri.* Note the negative cumulative leaf number due to leaf shedding in the initial stages.

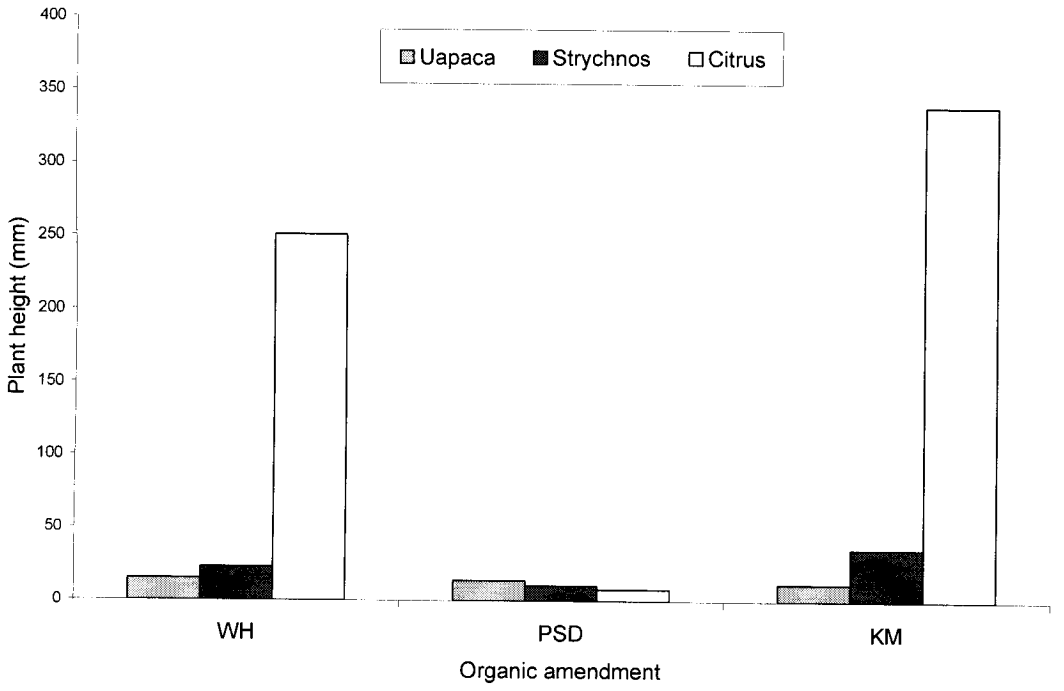

Figure 4. Effect of test species and organic amendment on plant height, where the organic amendments are water hyacinth (WH), pine sawdust (PSD), and kraal manure (KM).

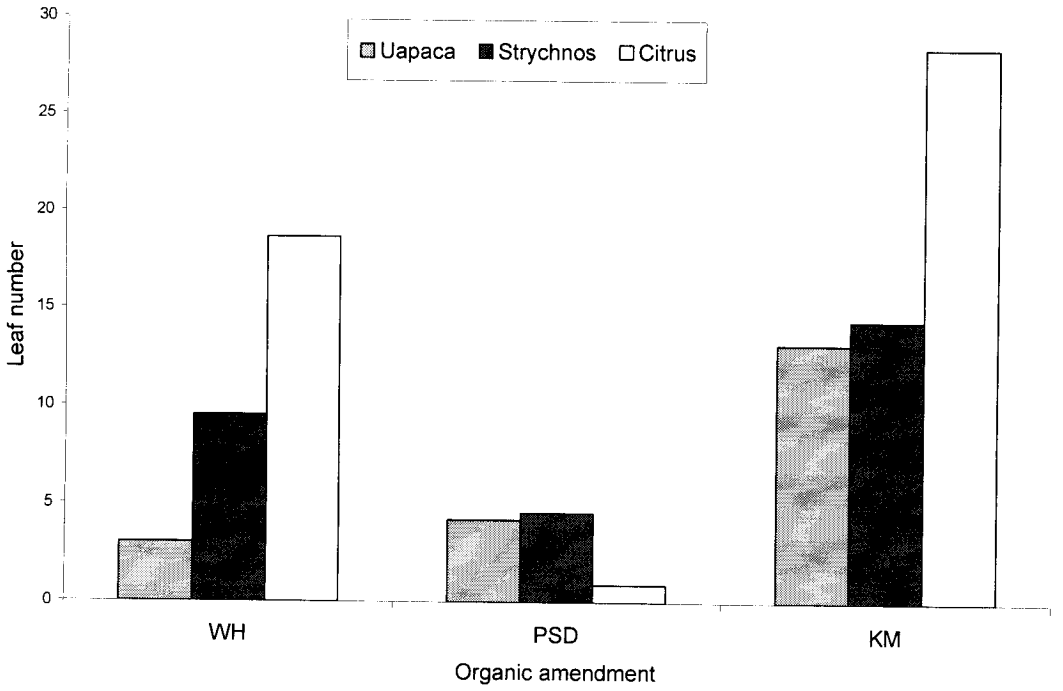

Figure 5. Effect of test species and organic amendment on leaf number, where the organic amendments are water hyacinth (WH), pine sawdust (PSD), and kraal manure (KM).

Chapter 5

Discussion

Germination in *Uapaca kirkiana, Strychnos cocculoides* and *Citrus jambhiri* was normal with 80% emergence or more. The species behaved differently during growth. *Citrus jambhiri* plants in pine sawdust substrates were chlorotic up to three months after transplanting and then began to recover (Figure 1). This is supported by the low values of plant height and leaf number obtained in this study for *Citrus jambhiri* in pine sawdust media. In contrast, plants remained green in water hyacinth and kraal manure substrates, developing a deep green colour. The chlorotic behaviour in the pine sawdust substrates was less evident in *Uapaca kirkiana* and *Strychnos cocculoides*. In the kraal manure substrates, *Uapaca kirkiana* tended to form branches at the expense of height growth. Generally, *Strychnos cocculoides* tended to shed its leaves initially and this bevaviour was more pronounced in pine sawdust and kraal manure substrates mixed in forest soil. Plants in water hyacinth substrates generally retained their leaves and green colour much longer (Figure 2). Subsequently, all plants experienced new leaf growth. Weed problems were more predominant in garden soil, and garden soil substrates containing kraal manure or water hyacinth and these necessitated hand weeding every two weeks.

Generally garden soil had higher nutrient values (especially in terms of total N and extractable P, K, Ca, Mg and B) than forest soil and sand. Sand, as would be expected, generally had the lowest of the attributes except soil pH and bulk density (D_b) which were the highest. The results also show that, in general, plant growth was influenced by the physical and chemical characteristics of the propagation media as indicated by the

significant correlations between plant height and these characteristics. Results obtained from the first experiment indicate that forest soil had the greatest influence on *Uapaca kirkiana* and *Citrus jambhiri* plant growth while there was no significant difference between garden and forest soil with regard to plant growth in *Strychnos cocculoides*. The high plant height of *Strychnos cocculoides* under garden soil is supported by the classification of *Strychnos cocculoides* as a semi-cultivated crop (FAO, 2004). The effect of forest soil on plant height and leaf number in *Uapaca kirkiana* and *Citrus jambhiri*, on the other hand, must be attributed to factors other than its nutrient values since these were lower.

The relatively better performance of forest soil with regard to seedling growth in *Uapaca kirkiana* supports its importance in plant propagation efforts particularly with regard to indigenous fruit trees as espoused by Mwamba (1995) and Simute et al. (1998) who have recommended the incorporation of forest soil in growth media as a source of inoculum for mycorrhizae. The symbiotic mycorrhizal activities expectedly present in greater quantities in forest soil may be strongly responsible for its good performance, through the enhanced nutrient uptake by way of the symbiotic associations (Simute et al., 1998; Mwamba, 1995; Mengel and Kirkby, 1987). The performance of *Uapaca kirkiana* in sand medium was comparable to that in garden soil, possibly indicative of the species adaptability to survive and tolerate poorer soils (FAO, 2004 and Simute et al., 1998). Alternatively, both sand and garden soils have low mycorrhizal populations and diversity.

Results from the second experiment show that there are highly significant differences among the three test tree species with regard to plant height and leaf number (Table 6). The regression coefficients obtained for the indigenous tree species when plant height was regressed on leaf number points to their slow growth relative to the exotic *Citrus jambhiri*. This is supported by results from this study which have shown significant differences ($P < 0.01$) in plant height across the test species. *Citrus jambhiri* had highest plant height and leaf number over the same period of time followed by *Strychnos cocculoides* while *Uapaca kirkiana* had the lowest, indicating differences in growth rates.

The soil type used for the growth media appeared to influence leaf number but had no effect on plant height. Forest soil was a better base material than garden soil with regard to leaf number. The results show that the media mixing ratio of 1:1:1 (soil:sand:organic amendment) was the best across test species.

Generally, *Citrus jambhiri* and *Strychnos cocculoides* grew better in kraal manure while *Uapaca kirkiana* grew better in water hyacinth and pine sawdust. The performance of kraal manure are in support the findings by Chatopadhyay and Mohanta (1988) who concluded that use of cow dung as growth media gave the best growth in tamarind (*Tamarindicus indica*) seedlings, when compared to six other media: sand, loamy soil, sand + soil, sand + cow dung, and sand + soil + cow dung. Results indicate that generally water hyacinth had a higher nutrient status than pine sawdust or kraal manure and this could, in part, explain its better performance in *Uapaca kirkiana* growth. Kraal manure generally had a negative initial effect on *Strychnos cocculoides* and *Uapaca kirkiana* as it appeared to promote leaf shedding, possibly due to the negative effect of manure in the

kraal manure substrates, according to Martin and Gershuny (1992) who have said that when manure is added directly to soil, it can, just like chemical fertilizer, burn plant roots. A graph of cumulative leaf number against time (in weeks) is shown in Figure 3. It will be seen that cumulative leaf number for *Uapaca kirkiana* and *Strychnos cocculoides* became negative in the first eight weeks.

The interaction between soil type and organic amendment showed that water hyacinth performed better as an organic amendment for forest soil than for garden soil with respect to plant height while pine sawdust gave higher plant height as an amendment to garden soil. A similar result was obtained for leaf number. Garden soil had higher values of nutrient elements than forest soil hence making up for the low nutrient levels in sawdust which are in organic form and not readily available (Mengel and Kirkby, 1987). Kraal manure was better as an amendment to garden soil than for forest soil for plant height but was better as an amendment to forest soil for leaf number. Growth of *Strychnos cocculoides* and *Citrus jambhiri* in both garden and forest soil was greatest in kraal manure substrates and least in pine sawdust with water hyacinth remaining consistently comparable to kraal manure as an organic amendment. This could be explained by the low levels of D_b, pH, EC, and extractable K, Ca, Mg, and B in the pine sawdust substrates. In general *Citrus jambhiri* had little or no growth in pine sawdust substrates.

The correlations between physical and chemical properties of potting mixtures and plant height were generally high suggesting the extent to which these properties influenced growth with regard to plant height. Both physical and chemical properties seem to have had strong influence on *Citrus jambhiri* plant as indicated by the highly significant correlations. They also seem to have influenced indigenous plant growth to various

extents. *Uapaca kirkiana* growth was significantly but negatively correlated to electrical conductivity (EC) and may explain its better performance in pine sawdust substrate mixtures which had lower EC values. This suggests that the non-cultivated *Uapaca kirkiana* will do well in media with lower salt concentrations than the levels (EC $\leq$ 2.0 mS/cm) given as acceptable for other plants (Goh and Haynes, 1977). Plant height of *Strychnos cocculoides* and *Citrus jambhiri* were significantly and positively correlated to EC and performed better in kraal manure and water hyacinth which had higher EC levels.

The high and positive correlation of bulk density (D_b) to plant height indicates that higher bulk densities may have promoted growth of *Strychnos cocculoides* and *Citrus jambhiri* through greater retention of moisture and nutrients in water hyacinth and kraal manure substrates. Growth of the two species was lowest in pine sawdust substrates which had the lowest bulk density values. Bulk densities of the potting mixtures were below levels that may restrict plant growth. Evanylo and McGuinn (2000) state that plant growth may be restricted when bulk densities of the growth media exceed 1.70 g/cm^3. TPS was negatively correlated to plant growth. The negative correlation between plant growth and the level of P in the growth media is in agreement with reports that extremely high phosphate levels in the root medium can depress growth (Loneragan and Asher, 1967). Results from solution culture experiments showed that very high uptake rates of phosphate were associated with reduced growth in some plant species. Laboratory experiments at the University of Zambia have produced similar results with respect to Citrus growth (M. Mataa*, pers. comm.). However, these effects may be due to depressed uptake of other nutrient elements by the high levels of phosphates (Mengel and Kirkby, 1987).

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Mg was only correlated to *Citrus jambhiri* growth and so may not be a limiting factor in indigenous tree growth. The negative correlation between boron and plant growth may indicate that boron was toxic to *Uapaca kirkiana* and this is supported by information that boron toxic to many plant species at levels only slightly above that required for normal plant growth. Toxicity effects may occasionally occur on growth media with high boron contents such as those derived from marine sediments (Mengel and Kirkby, 1987). Generally kraal manure growth media had the highest levels of boron and performed poorly with respect to *Uapaca kirkiana* plant height.

The test species and soil type interaction was not significant. The effect of test species and media mixing ratio was significant with regard to plant height ($P < 0.01$) and leaf number ($P < 0.05$). It was significant with respect to plant height of *Citrus jambhiri* but not significant within species in case of *Uapaca kirkiana* and *Strychnos cocculoides*. Generally, plant height of the indigenous species *Uapaca kirkiana* and *Strychnos cocculoides* increased with increasing mixing ratio (higher proportion of soil) while plant height decreased with increasing mixing ratio in case of *Citrus jambhiri*. A similar trend was evident with respect to leaf number of the test species. The leaf number of *Strychnos cocculoides* was higher in the 2:1:1 mixing ratio when compared to the 1:1:1 or 0.05:1:1 ratios. This means the indigenous species showed higher performance in higher soil amount than in the lower soil amount media while the reverse was true for *Citrus jambhiri*.

In general, more soil meant more mycorrhizae, when soil is considered the source of the inoculum for mycorrhizae; so for *Uapaca kirkiana* mycorrhizae may be the critical component in the growth media and this is also true for *Strychnos cocculoides*. It would appear therefore that indigenous plants need more soil (more mycorrhizae) than organic matter, but exotic plants need more organic matter than mycorrhizae.

The effect of the interaction between test species and organic amendment was significant ($P < 0.01$) with respect to both plant height and leaf number (Figures 3 and 4). The use of pine sawdust as organic amendment in growth media reduced plant height of *Citrus jambhiri* to below those recorded in mixtures with water hyacinth or kraal manure as organic amendment and was the lowest plant height across the three species. In contrast, with pine sawdust as organic amendment, the highest plant height was that of *Uapaca kirkiana*. *Citrus jambhiri* leaf number was also lowest in mixtures with pine sawdust as organic amendment but highest under water hyacinth and kraal manure as organic amendment. Under both water hyacinth and kraal manure as organic amendment, *Uapaca kirkiana* recorded the lowest plant height and leaf number.

Chapter 6

Conclusions

The results produced in this study were obtained from observations made on plants grown from transplanting to 24 weeks after transplanting (6 months). My conclusions are based, therefore, on results obtained within these time limitations. The study has shown that forest soil is beneficial to the establishment of both exotic and indigenous species. *Citrus jambhiri* generally had greater growth in media with higher organic matter amounts than for indigenous plant species. It is postulated that soil could be important as a source of microbial inoculant for indigenous plants but may not be critical for *Citrus jambhiri.* Generally, water hyacinth proved to be a good organic amendment particularly for *Uapaca kirkiana* and showed potential as a material to be used in propagation media. Meanwhile, pine sawdust performed well with regard to *Uapaca kirkiana.* However, there is need to look at costs and the possibility of contaminating other water bodies.

Physical and chemical parameters of the growth media had an effect on plant growth. *Citrus jambhiri* recorded the highest plant height and leaf number across species over the same period of time, indicating that it had the highest growth rate with regard to plant height and leaf number. The results of interaction between test species and growth media showed that pine sawdust was the poorest organic amendment for *Citrus jambhiri* but quite comparable to water hyacinth for *Uapaca kirkiana.* The best organic amendment for *Citrus jambhiri* and *Strychnos cocculoides* was kraal manure, comparably followed by water hyacinth.

Chapter 7

Recommendations

The results of this study support the recommendation to incorporate forest soil in growth media used to raise indigenous trees from seed. For areas where water hyacinth is readily available, it would be a good material for utilization as an organic amendment in tree propagation media, more so for the indigenous tree plants. Water hyacinth is recommended as an organic amendment when forest soil is to be used as a base material while pine sawdust is recommended for garden soil in propagation of the indigenous fruit tree species. The mixing ratio of soil:sand:organic amendment could be 0.5:1:1 but should not exceed 1:1:1 by volume for the exotic species while the higher ratio of 2:1:1 would be best for the indigenous species. This study cannot be conclusive due to limitations of time, only six months was available from transplanting to final data collection. Indigenous species are slow growing such that long term effects are still unknown, particularly for *Uapaca kirkiana.* Another limitation was probably due to after-transplanting effects. Further studies are therefore suggested to last at least 12 months, to include the determination of toxicity of pine sawdust, mycorrhizae identification and population dynamics, response to mycorrhizae in soils (may need to heat-treat forest soil), nutrient depletion rates, soil physical changes and possibly plant survival rates.

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Appendices

Appendix 1: Analysis of variance (RCBD) of *Citrus jambhiri* height growth in millimetres (mm).

Source of Variation	DF	SS	MS	F value	P
Replications	3	259.1	86.4	0.36	
BM	2	35925.6	17962.8	74.71**	<.001
Residual	6	1442.5	240.4		
Total	11	37627.2			

CV = 14.3 %

** = highly significant at $P \leq 0.01$

Appendix 2: Analysis of variance (RCBD) of *Citrus jambhiri* leaf number.

Source of Variation	DF	SS	MS	F value	P
Replications	3	68.394	22.798	3.12	
BM	2	390.587	195.293	26.74**	0.001
Residual	6	43.815	7.302		
Total	11	502.795			

CV = 16.7 %

** = highly significant at $P \leq 0.01$

Appendix 3: Analysis of variance (RCBD) of *Strychnos cocculoides* plant height growth in millimetres (mm).

Source of Variation	DF	SS	MS	F value	P
Replications	3	135.07	45.02	1.16	
BM	2	1953.88	976.94	25.14**	0.001
Residual	6	233.19	38.86		
Total	11	2322.13			

CV = 18.5 %

** = highly significant at $P \leq 0.01$

Appendix 4: Analysis of variance (RCBD) of *Strychnos cocculoides* leaf number.

Source of Variation	DF	SS	MS	F value	P
Replications	3	37.100	12.367	3.79	
BM	2	156.001	78.000	23.89**	0.001
Residual	6	19.594	3.266		
Total	11	212.694			

CV = 16.1 %

** = highly significant at $P \leq 0.01$

Appendix 5: Analysis of variance (RCBD) of *Uapaca kirkiana* plant height growth in millimetres (mm).

Source of Variation	DF	SS	MS	F value	P
Replications	3	10.159	3.386	0.57	
BM	2	89.434	44.717	7.51*	0.023
Residual	6	35.719	5.953		
Total	11	135.312			

CV = 15.8 %

* = significant at $P \leq 0.05$,

Appendix 6 Analysis of variance (RCBD) of *Uapaca kirkiana* leaf number.

Source of Variation	DF	SS	MS	F value	P
Replications	3	37.100	12.367	3.79	
BM	2	156.001	78.000	23.89**	0.001
Residual	6	19.594	3.266		
Total	11	212.694			

CV = 16.1 %

** = highly significant at $P \leq 0.01$

Appendix 7: Analysis of variance for plant height of *Uapaca kirkiana, Strychnos cocculoides* and *Citrus jambhiri* determined 24 weeks after transplanting.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	3	697.0	232.3	0.66	
Test species (TS)	2	1574553.5	787276.8	2231.65	<.001
Residual	6	2116.7	352.8	0.82	
Soil	1	271.0	271.0	0.63	0.449
TS.Soil	2	408.6	204.3	0.47	0.638
Residual	9	3891.2	432.4	2.43	
Mixing ratio (MR)	2	1431.4	715.7	4.02	0.027
TS.MR	4	4686.8	1171.7	6.58	<.001
Soil.MR	2	1268.7	634.3	3.56	0.039
TS.Soil.MR	4	2149.7	537.4	3.02	0.030
Residual	36	6406.4	178.0	0.44	
Amend	2	534757.4	267378.7	665.52	<.001
TS.Amend	4	881694.1	220423.5	548.64	<.001
Soil.Amend	2	6941.5	3470.7	8.64	<.001
MR.Amend	4	348.5	87.1	0.22	0.929
Soil.MR.Amend	4	2081.1	520.3	1.29	0.276
TS.Soil.Amend	4	15813.5	3953.4	9.84	<.001
TS.MR.Amend	8	5181.5	647.7	1.61	0.129
Residual	116	46604.2	401.8		
Total	215	3091302.8			

Appendix 8: Analysis of variance for leaf number of *Uapaca kirkiana, Strychnos cocculoides* and *Citrus jambhiri* determined 24 weeks after transplanting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	3	51.301	17.100	1.76	
Test species (TS)	2	3215.087	1607.544	165.19	<.001
Residual	6	58.389	9.732	2.90	
Soil	1	26.889	26.889	8.02	0.020
TS.Soil	2	4.540	2.270	0.68	0.532
Residual	9	30.169	3.352	0.46	
Mixing ratio (MR)	2	41.394	20.697	2.82	0.073
TS.MR	4	85.860	21.465	2.92	0.034
Soil.MR	2	89.311	44.656	6.08	0.005
TS.Soil.MR	4	52.048	13.012	1.77	0.156
Residual	36	264.622	7.351	1.16	
Amend	2	8593.850	4296.925	676.01	<.001
TS.Amend	4	3387.483	846.871	133.23	<.001
Soil.Amend	2	60.711	30.355	4.78	0.010
MR.Amend	4	59.949	14.987	2.36	0.058
Soil.MR.Amend	4	107.004	26.751	4.21	0.003
TS.Soil.Amend	4	28.029	7.007	1.10	0.359
TS.MR.Amend	8	202.834	25.354	3.99	<.001
Residual	116	737.331	6.356		
Total	215	17096.801			