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DECLARATION

**GROWTH RESPONSE OF SEEDLINGS OF SELECTED TREE SPECIES TO
NUTRIENT ENRICHMENT AND COMPETITION IN KAKAMEGA FOREST**

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REG NO: I56/13139/2005**

**A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF MASTER OF SCIENCE (PLANT ECOLOGY)
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seedlings of*



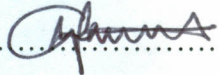
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I, Charles P. Mwangi, declare that this thesis is my original work and has not been presented for the award of a degree in any other University or any other award.

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Supervisors Approval

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DEDICATION

This work is dedicated to my mother Anastasiah who loves me so dearly, my wife Laura and my son Maurice.

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ABSTRACT

Prunus africana Hook F, *Olea capensis* Wright and *Markhamia lutea* Benth are some of the indigenous tree species growing in Kakamega forest. These species are of great economic importance to the communities living around the forest. However, Kakamega Forest soils on which these species grow are acrisols of low fertility. They are also acidic with a pH value of less than 5.5. Acidic soils are known to have low levels of phosphorus and potassium which are important in improving the availability of microelements. Their deficiency can lead to deficiency of minerals such as iron, manganese, zinc and copper in the soil. Several studies have revealed that soil amendment can improve soil structure, aeration, water retention and nutrient availability. Previous studies have shown that about 80 % of the farms around Kakamega are deficient in phosphorus, nitrogen and potassium. However, limited information is available on the effect of this nutrient deficiency on seedlings of indigenous tree species in Kakamega forest. The aim of this study was to assess the response of the selected tree seedlings to soil amendments with commonly limiting nutrients. Seedlings of the three species were grown individually in tubes containing soil fertilised with nitrogen, phosphorus, potassium and combinations of the three fertilizers. Forest soil, farm soil and a mixture of the two soil types were used for comparison purposes. Nitrogen and phosphorus were found to be co-limiting nutrients to the growth of *Prunus africana* seedlings. Nitrogen, phosphorus and potassium were all found to be limiting for *Markhamia lutea* seedlings, while potassium was found to be limiting for *Olea capensis* seedlings. To determine the effect of intraspecific competition on seedlings growth, three seedlings of each species were grown together in the same tube. To assess the effect of interspecific competition, one seedling of each species were grown in combination in each tube. The seedlings grown individually were used as the control. *Prunus africana* and *Markhamia lutea* seedlings grown in absence of competition invested more in mean height and leaves compared to the competing seedling while none competing *Olea capensis* seedlings invested more on mean height and mean diameter compared to the competing seedlings. Experimental studies conducted in shade houses and in the field have demonstrated that differences in light availability differentially affect seedlings growth and mortality of tree species in wet tropical forests. In Kakamega forest, the seedlings of *Prunus africana* have recorded unusually high mortality rate of 3.9%. Despite the important role of light in seedlings survival, its effect on seedlings survival in Kakamega forest has not been explored. The findings of this study reveal that seedlings grown in high light regime had larger mean height, mean diameter, mean number of leaves and mean leaf area compared with the seedlings grown in low light regimes.

CHAPTER 1: INTRODUCTION

1.1 Background to the study

Tropical rainforests are among the most complex and species rich ecosystems in the world (Whitmore, 1993). However, for many years, tropical forests have been faced with the problem of continued unsustainable exploitation (Lieslie, 1994; Boots and Gullison, 1995). These forests have experienced high levels of deforestation, fragmentation and degradation (Musila, 2007). Kakamega forest is one of the few remaining indigenous forests in Kenya. It is the eastern most remnant of Guineo-Congolese rainforest, which spanned from west to central Africa. The forest has been heavily logged in the past and area specific differences within the forest have been attributed to these past disturbances (Tsingalia, 1989).

Regeneration is a central component of forest ecosystem dynamics. Sustainable forest utilisation is only possible if adequate information on regeneration of the exploited species is available (Boots and Gullison, 1995). Previous studies have revealed that spatial heterogeneity of abiotic factors like water, light and nutrients affect the establishment of tree species seedlings (Dalitz *et al.*, 2005). Positive feedback mechanisms are expected between the abiotic factors and the regeneration of tree species and hence the maintenance of the high tree species diversity in tropical rain forests (Dalitz *et al.*, 2005).

The factors regulating the species composition of vegetation seem to depend on the availability of soil resources and light (Mamolos and Veresoglou, 2000). In fertile soils, competition for light is often the most important factor (Chapin and Shaver, 1985; Tilman 1988); vegetation in such soils is species poor and is dominated by species with high rates of growth and nutrient uptake, extensive root distribution and large aboveground biomass (Mamolos and Veresoglou, 2000). On

the other hand, vegetation in low-nutrient soils is species-rich (Tilman, 1982; Marrs, 1993; Janssens *et al.* 1998). Different theories have been proposed to explain this high diversity. According to Grime (1973), the intensity of competition between plants in such environments is very low, thus favouring the co- existence of plant species adapted to a low-nutrient environment. Newman (1973) and Tilman (1988), on the other hand, proposed that competition is intense even in low-nutrient environments. There are various theories that explain this co- existence with many invoking the role of spatial and temporal differentiation in growth and nutrient uptake between plant species (McKane *et al.*, 1990).

The main cause of biodiversity losses in Kakamega forest has been the rapidly increasing human population at a rate of about 3% per year (Nyanjua *et. al*, 2009). This was worsened by the population structure, which had too many forest dependants, and few job opportunities. The result of this has been excessive exploitation of species and natural areas for resources. Forestland excision and forest clearing for agriculture and development by both national and international developers have affected the forest regeneration negatively. However, since January 2003 this destructive practice has been halted and some positive effects on forest conservation are being felt at the Kakamega forest (Nyanjua *et. al*, 2009). Plants like *Trichilia emetica*, *Olea capensis*, *Zanthoxylum* sp., *Prunus africana*, and *Markhamia lutea* amongst species which have been heavily targeted for medicine and wood have also affected and need attention. Fuel and timber extraction, for example, for domestic use, construction, and industry such as paper mills, tea curing and bricks baking have also contributed to over exploitation of this forest. For now, there is a government ban on timber extraction even from the planted forest blocks. Habitat fragmentation has been found to contribute to degradation (Mitchell, 2004). It is clear that the

niche of the community bordering the forest is expanding at the expense of the forest resulting in fragmentation, loss of biotic communities in areas bordering edges of the fragments thus created and sometimes species extinctions (Nyanjua *et. al*, 2009).

The forest has two management strategies for protection (Nyanjua *et. al*, 2009). Protection is executed well on the KWS side. However on the Kenya Forest Service side, it is evident that there is too much extraction from the forest and already makes forest sustainability doubtful (Nyanjua *et. al*, 2009). *In Situ* conservation and Species enrichment of the forest has been encouraged and needs further strengthening. This has been common in the Kenya Forest Service side of the forest especially in areas that had been previously logged, farmed, or disturbed in a way. Illegal harvesting and poaching have however watered down the impact of this form of conservation thus strengthening the need for *ex situ* conservation (Mitchell, 2004). The taxa deliberately planted in species enrichment and conservation programs have still been adversely affected further strengthening the need for *ex situ* efforts. Taxa targeted include: *Azadirachta indica*, *Prunus africana*, *Zanthoxylum* spp. *Olea capensis*, *Markhamia lutea* *Trichilia emetica* among others.

Prunus africana, *Olea capensis* and *Markhamia lutea* are among the over exploited species in Kakamega forest. *Prunus africana* is a secondary forest canopy tree species that has been declining over much of its geographical range in sub-Saharan Africa during recent decades due to unsustainable harvesting of its bark for the international medicinal plant trade. Kakamega forest (Schippmann, 2001). According to a research done between 1997 and 2003, 21% of the *Prunus africana* (≥ 10 cm DBH) at kakamega forest died and an additional 9% experienced \geq

50% canopy dieback. However, scars from bark harvesting on *Prunus africana* were found to be relatively small and scarred trees were not more likely to be dead or dying than unscarred trees, suggesting that bark exploitation is not a leading cause of *Prunus africana* mortality in Kakamega forest (Fashing, 2004). Other possible causes that require further evaluation include disease, insect attack, nutrient deficiency, and climatic fluctuation.

The poor regeneration of *Prunus africana* in Kakamega forest can likely be explained by the relative lack of recent disturbance coupled with the thick undergrowth layer at this site. *Prunus africana* mortality is of concern not only because the species is listed as Vulnerable by IUCN, but also because black and white colobus monkeys in Kakamega forest exploit it as their top food species and are particularly reliant on its leaves during times of Moraceae fruit scarcity. The anticipated continued decline of *Prunus africana* may have adverse effects on *Colobus guereza* feeding habits, intergroup relations, and population density in Kakamega forest. Conservation of *Prunus africana* offers a formidable challenge since the species appears to require disturbance for regeneration, yet at sites where disturbance is occurring. *Prunus africana* is often a target of bark harvesters engaging in unsustainable levels of exploitation (Fashing, 2004).

Prunus africana populations have been declining in many forests due to unsustainable bark exploitation for international trade (Cunningham and Benkum, 1993). Following the discovery in 1966 that an extract from *Prunus africana* bark effectively treats prostate gland hypertrophy and prostate hyperplasia, pharmaceutical companies began hiring local community members to collect *Prunus africana* bark for export to Europe (Cunningham and Mbenkum, 1993). Subsequently, between 1980-1999 exploitation of the species increased over 17 times (Cunningham and Mbenkum, 1993).

Kenya has been exporting 193 tonnes of *Prunus africana* bark to Europe annually from 1993 with one kilogram of the bark fetching about 2 US dollars (Schippmann, 2001). Owing to the high rate of exploitation and the consequent rapid population decline, *Prunus africana* has been listed as vulnerable in the world list of threatened species (Schippmann, 2001). In many cases, much of this exploitation has been irresponsible with entire trees being girdled of their bark and left to die or, in other cases, felled to facilitate easier access to their bark (Cunningham and Mbenkum, 1993; Ndibi and Kay, 1997). Several studies and surveys have provided evidence of the adverse effects of large-scale bark harvesting on *Prunus africana* populations (Cunningham *et al.*, 2002; Ndibi and Kay, 1997; Sunderland and Tako, 1999). However, the decline in *Prunus africana* population is not only related to unsustainable bark harvesting practices. Though *Prunus africana* declines have been reported for forests in several African countries (Cunningham *et al.*, 2002; Cunningham and Mbenkum, 1993; Sunderland and Tako, 1999), comparatively few efforts have attempted to determine the role of soil nutrients and light in the establishment and growth of *Prunus africana*.

The population of *Olea capensis* in Kakamega forest has also registered a progressive decline. This is because it is a hardwood that produces high quality timber and has irregular and slow germination. This hardwood species has been attractive to timber dealers since 1950's. In 1957, statistics showed that half of the timber obtained from Kakamega forest came from *Olea capensis* (Mitchell, 2004). Surveys carried out in 1980s and 1990s still showed that *Olea capensis* was the leading timber source in Kakamega forest. In a study to assess the impacts of logging on the population structure and dynamics of *Olea capensis* which is a canopy dominant species in Kakamega forest, it was found out that logging was the major factor that explains the

differences in population structure and stem density in different parts of Kakamega forest. And while intermittent recruitment may explain clumped distribution, logging appears to explain the variation in the degree of clumping (Mungatsia, 2010)

Markhamia lutea has a high germination rate and it is fast growing. However, it has also been overexploited due to its highly valuable timber, which is resistant to attack by insects (ICRAF, 1992). A policy was put in place in 1957 to allow regeneration of the valuable species in Kakamega forest. Natural regeneration was supported by 100 hectares of group plantings in the forest gaps that had been created by extensive logging. Species like *Markhamia lutea*, *Olea capensis*, and *Prunus africana* among others were planted. However, the establishment success of the seedlings in the forest was low perhaps due to limited understanding of the establishment requirements of these species.

1.2 Problem statement

The soil properties of Kakamega forest have in the past changed drastically with nutrients levels declining every year. Studies have reported decline in nutrient levels in Kakamega at the rate of 112 kg nitrogen per hectare, 3 kg phosphorus per hectare and 70 kg potassium decline per year (Smaling, 1997). Presently the forest soils are characterized by low phosphorus level, low nitrogen content and localized potassium deficiency (Musila, 2007). Generally, the nutrients levels decrease with depth and their availability decreases from calcium to magnesium to potassium (Musila, 2007). A survey carried out by ICRAF in 1992 revealed that 80 % of the farms around Kakamega are deficient in phosphorus, nitrogen and potassium. However, limited information is available on the effect of this nutrient deficiency on indigenous tree seedling

establishment in Kakamega forest. Hence the role of soil resources in the establishment of seedlings in the forest is not well known (Silvia and Robin, 2005).

Prunus africana is experiencing localized decline in Kakamega forest (Cunningham and Mbenkum, 1993; Sunderland and Tako, 1999). Its mortality rate of 3.9% per year in Kakamega forest is much higher than the typical 2% reported for most tropical forests (Hart, 2001; Lieberman *et al.*, 1985; Phillips *et al.*, 1994; Swaine *et al.*, 1987b). This decline cannot be explained by unsustainable harvesting only because this mortality largely occurs at the seedling stage of growth. The contribution of diseases and nutrient deficiency to seedling mortality have not been intensively investigated (Hart, 2001). *Olea capensis* and *Markhamia lutea* have been preferred for years due to the high quality of their poles. This high demand is already a threat because the rate at which the species are being harvested does not match the rate at which the species are maturing.

1.3 Justification

The slow establishment of *Prunus africana*, *Markhamia lutea* and *Olea capensis* seedlings in Kakamega forest is a problem that needs to be addressed. This is because the demand for their products is increasing thus leading to over exploitation of the species. This knowledge would be important in conservation of these endangered tree species. The farmers living around Kakamega forest may also benefit from the findings of this study in that they need to know the type of nutrients that are limiting in these soils. This is important in determining the type and the amount of the fertilizers they need to apply. Unsustainable harvesting is threatening the existence of these tree species. This makes it necessary to promote *ex situ* conservation to save these species. For a successful *ex situ* conservation, knowledge about the establishment of the species is

necessary. This involves information on nutrient requirement of the species and the effect of competition on the establishment of their seedlings. The available information is currently limited and therefore there is a need for further investigation.

1.4 Research questions

1. What is the impact of amending soils from Kakamega farmlands and Kakamega forest with nitrogen, phosphorus and potassium on the growth of seedlings of *Prunus africana*, *Markhamia lutea* and *Olea capensis* in Kakamega forest?
2. How does competition affect the growth of the seedlings of *Prunus africana*, *Markhamia lutea* and *Olea capensis* when grown under different nutrient regimes?
3. What is the effect of low and high light regimes on the growth dynamics of *Prunus africana* seedlings?

1.5 Hypotheses

1. Ho: Soil amendment with nitrogen, phosphorus and potassium has no effect on *Prunus africana*, *Markhamia lutea* and *Olea capensis* seedlings development in soils from Kakamega farmlands and Kakamega forest.
2. Ho: Interspecific and intraspecific competition has no effect on *Prunus africana*, *Markhamia lutea* and *Olea capensis* seedlings development.
3. Ho: Low and high light regimes do not differ in their effect on the growth of *Prunus africana* seedlings

1.6 Objectives

1.6.1 Main objective

The main objective of this study was to assess the effect of soil amendment with fertilisers and competition on the growth of *Prunus africana*, *Markhamia lutea* and *Olea capensis* seedlings grown in soils from farmlands and Kakamega forest.

1.6.2 Specific objectives

1. To determine the effect of soil amendment with nitrogen, phosphorus and potassium on the growth and development of seedling of *Prunus africana*, *Markhamia lutea* and *Olea capensis* in soils from Kakamega farmlands and Kakamega forest.
2. To assess the effect of interspecific and intraspecific competition on growth of *Prunus africana*, *Markhamia lutea* and *Olea capensis* the seedlings.
3. To assess the impact of different light regimes on the growth of *Prunus africana* seedlings in Kakamega forest

CHAPTER 2: LITERATURE REVIEW

2.1 Nutrient limitation

Nutrient limitation can be demonstrated when the growth and development of a species is increased by addition of the limiting nutrient (Chapin *et al.*, 1986). Whereas an ecosystem may overall be nutrient limited, not all species in the ecosystem may be affected; even within a single species, some individuals could be affected while others are not (Tanner, 1998). In many terrestrial ecosystems, primary production and other ecosystem processes are constrained by the low rate of nutrient supply (Walker and Syers, 1976).

One of the reasons for the low soil nutrient availability is low soil pH. Acidic soils develop as a consequence of excessive leaching of basic cations, mainly magnesium and potassium ions, in climatic conditions characterized by excessive rainfall relative to evapotranspiration (Kanyanjua, 2002). Leaching of these ions from the soil may lead to their deficiency in the soil. Previous studies have revealed that potassium supply is important in improving the availability of microelements and therefore its deficiency can lead to deficiency of iron, manganese, zinc and copper in the soil (Kanyanjua, 2002). Low soil pH leads to low mineralization, which has often been associated with nitrogen deficiency (Ballard and Carter, 1986).

Phosphorus is an essential macronutrient for plant growth (Raghotama, 1999). However, phosphorus is usually a limiting factor in many ecosystems. Unavailability of phosphorus is due to precipitation with calcium carbonate. Under low pH conditions, there is usually a high concentration of aluminum ions in the soil solution. Aluminum ions bind with orthophosphate ions and form insoluble compounds resulting in low levels of available phosphorus (Pearce and Summer, 1997). As a result, phosphorus is usually less available for uptake in the acidic soils.

The acid weathered soils of the tropics and subtropics are particularly prone to phosphorus deficiency (Sanchez and O'hara, 1980). One of the most important mechanisms by which plants adapt to low phosphorus is by increasing their ability to acquire phosphorus (Raghotama, 1999). A high phosphorus acquisition occurs through enhanced phosphorus uptake kinetics, production of cluster roots and increased root phosphates activity. Many plants also enhance root absorption by increasing root length (Kirk, 1997).

The effect of phosphorus on seedlings growth varies from species to species (Gunther and Lehmann, 2000). A study done on *Grevillea robusta* A. Cunn in acrisols revealed that phosphorus availability is crucial in the early stages of seedlings establishment (Karanja *et al.*, 1999). In Kakamega forest, the mineral nutrient content of its soils is generally low and generally declines on moving from the forest through shrublands to grasslands (Musila, 2007). This demonstrates the adverse effect of deforestation on soil nutrients (Musila, 2007). Similarly, the agricultural farmlands have suffered a decline in nutrient levels especially nitrogen. This decline in soil fertility is caused by land use intensification (Laurence, 1999). Although seedlings of various tree species show varied responses to fertilizer applications, seedlings occupying infertile soils are not always the most responsive to nutrient additions. However, studies that attempt to correlate vegetation growth with soil features have not been successful since many soil parameters are inter-related and therefore confounding factors may obscure effects of some variables (Laurence, 1999). A failure to find significant correlations between vegetation growth and soil properties can also occur because samples encompass only part of the range of variation in a soil parameter, or because threshold effects create nonlinearities between variables (Sollins, 1998). Hence, studies on the relations between vegetation development and soil properties should be followed by field experiments (Tanner, 1998).

Studies on nutrients and their uptake by plants have received a lot of attention (Hussaini *et al*, 2001). However, it is usually difficult to predict whether application of nitrogen, phosphorus and potassium will increase their concentration in plant tissues (Ogunlela *et. al*, 2008). This depends much on the influence of other nutrients in the soil. Various nutrients either work in antagonism or in synergy to produce an effect on nutrient absorption and plant growth (Ogunlela *et. al*, 2008). For instance nitrogen fertilization has been shown to increase concentration of nitrogen, phosphorus and potassium in plant tissues. A certain degree of synergy between nitrogen and phosphorus has been reported for some field crops. Workers have reported that the addition of nitrogen influences the uptake by the plant of phosphorus (Hussaini *et al*, 2001). This phenomenon can be explained by the fact that the supply of nitrogen enhances the production of small roots and root hairs which increases the absorption capacity (Hussaini *et al*, 2001). Other studies have revealed that nitrogen concentration is usually highest for the highest level of nitrogen application and significantly increases the concentrations of nitrogen, phosphorus, calcium and magnesium. Nutrient concentrations in plants has also been shown to responded differently to fertilizer phosphorus application. nitrogen and phosphorus concentrations have been shown to increase when phosphorus fertiliser is applied (Ogunlela *et. al*, 2008). More studies are necessary in order to document responses of various tree species to application of nitrogen phosphorus and potassium.

2.2 Effects of light on seedlings

Spatial and temporal heterogeneity in light availability is a major driver of tropical forest dynamics (Brown, 1996). Past studies have clearly indicated the potential for niche partitioning among tropical forest seedlings along gradients of light availability (Brown, 1996, Whitmore,

1993). It has been argued that functional traits that promote high seedling growth under high light conditions lower seedlings survival under low light conditions (Brown, 1996). Although many factors such as fire, grazing and browsing influence plant regeneration and succession, light maybe the most limiting factor in multi-layered canopies of the tropical rainforests (Whitmore, 1993).

Experimental studies conducted in shade houses and in the field have demonstrated that differences in light availability differentially affect seedling growth and mortality of tree species in wet tropical forests (Brown, 1996; Oesker, 2006). This is particularly true for pioneer species. Unlike the climax species which can regenerate on a wide range of ecological conditions, pioneer species are restricted to suitable light conditions. It has been observed that the pioneer species that settle their offspring before or immediately after an opening of the canopy have the highest regeneration success (Runkle, 1989). Reduction in the amount of light reaching seedlings makes the seedlings to respond by increasing the above ground biomass allocated to leaves, reducing branching, increasing specific mean leaf area and changing the shape of the leaves (Morgan and Smith, 1981). Studies done on the seedling growth and survival of tropical tree species have been challenged owing to conflicting results on tradeoffs between low light mortality and growth responses to light. These inconsistencies often reflect on the collection of species examined, the breadth of the light gradient used, type of growth responses measured and the length of the experimental design.

Species have often been observed to respond differently to different light regime (Montgomery and Chazdon, 2002). A higher increase in biomass, stem mean diameter and stem length under

higher light levels but lower survival at lower light levels has been reported for *Dipteryx panamensis* Pittier as compared to *Virola koschnyi* Warb.

2.3 Effects of competition on plants

There is a lot of data that supports the idea that in the absence of plant to plant competition, resource availability influence biomass allocation (Wilson and Keddy, 1986). The mean shoot: root ratio often decreases under limited nutrient availability and increases under high nutrient availability. However, it is still not clear whether plants reallocate biomass in the same way when resources are reduced by competition from other plants.

A recent study by Gersani (2001), suggests that plants sharing a resource supply with other plants produce more root biomass and less shoot biomass than plants grown alone with access to as much as half the resources. This is in line with a model developed by Hardin (1968) known as the tragedy of the commons model which states that individuals competing for a resource that both have free access to will invest more in acquiring it than when it was not accessible to both. Thus plants competing for soil based resources should allocate higher proportion of their biomass to roots than non- competing individuals provided with the same resources.

The role and the relative importance of inter-specific competition in structuring plant communities can strongly be affected by soil resources and light conditions (Grime, 1988). This is especially true at the seedling stage where the interaction of the environment with competitive pressures may result in subtle inter-specific difference in growth that may increase in magnitude over time, determining the structure of the mature population (Tilman, 1982). Previous research has shown that the substrate on which the seedling is growing is one of the most important environmental properties determining seedling survival and growth. The quality of the substrate

determines how competitive the species become in the presence of other species (Knox, 1995). Although the relationship between the soil nutrients and productivity has been intensively investigated, the impact of this relationship on plant competition is still a subject of much debate, particularly in terms of how competition intensity is affected by resource availability (Davis and Gregg, 1998).

Grimes Competition-Stress-Resource model (C-S-R model) states that the intensity of competition increases as the disturbance and stress declines (Grime, 1988) or comparably that competition intensity increases with increasing resource abundance, productivity and neighbour biomass (Grimes and Hodigson, 1987). Results from field studies are varied with some supporting the C-S-R theory and others refuting it (Watkinson, 1982).

Some researchers have argued that competition intensity in plants may be high even in stressful and unproductive environment (Grubb, 1985). The findings of a study carried out by Davis and Gregg, (1998) did not agree with the C-S-R model, which predicts that competition intensity should be positively correlated with resource abundance, habitat productivity and the neighbour's biomass. According to their findings, this model ignores variation in resource supply; what matters to a species is not a change in the abundance of its competitor, and hence in resource demand, but the extent to which the net resource availability is affected by changes in both supply and demand. Studies carried out on competition analysis revealed that, without fertilization, competition for nutrients is the primary factor limiting seedling growth, while competition for light and moisture was found to be greater after fertilizer addition (Moses and Victor, 1999).

Others have argued that competition may be low in very productive environments (Taylor and Loehle, 1990). Many of the inconsistencies and conflicting results that have characterized the recent literature on competition calls for further studies on competition (Davis and Gregg 1998).

CHAPTER 3: MATERIALS AND METHODS

3.1 Study area

3.1.1 Locational setting

Kakamega Forest is situated in the Western Province of Kenya, north-west of the capital Nairobi and approximately 40 km north-west of Lake Victoria. The forest lies at an altitude of about 1500 m to 1700 m above sea level (KIFCON, 1994). Kakamega Forest is one of the few remaining indigenous forests in Kenya. It is the eastern most remnant of Guineo-Congolese rainforest, which spanned from west and central Africa, with its easternmost edge in western Kenya (Fashing and Gathua, 2004a).

The forest is well known for its diversity of unique and numerous flora and fauna. The first boundary demarcating this forest was established around 1908-1910. This boundary was modified in 1912-1913 and much later in 1929-1932 (Mitchell, 2004). The forest boundary encloses about 240 km², of which less than half is still nearly indigenous forest. Around the forest is an agricultural area, which is densely populated (600 people km⁻²) (KIFCON 1994). The farmlands are interspersed with fields of sugarcane, maize, tea or grassland with some single large forest trees and shrubs (Althof, 2005).

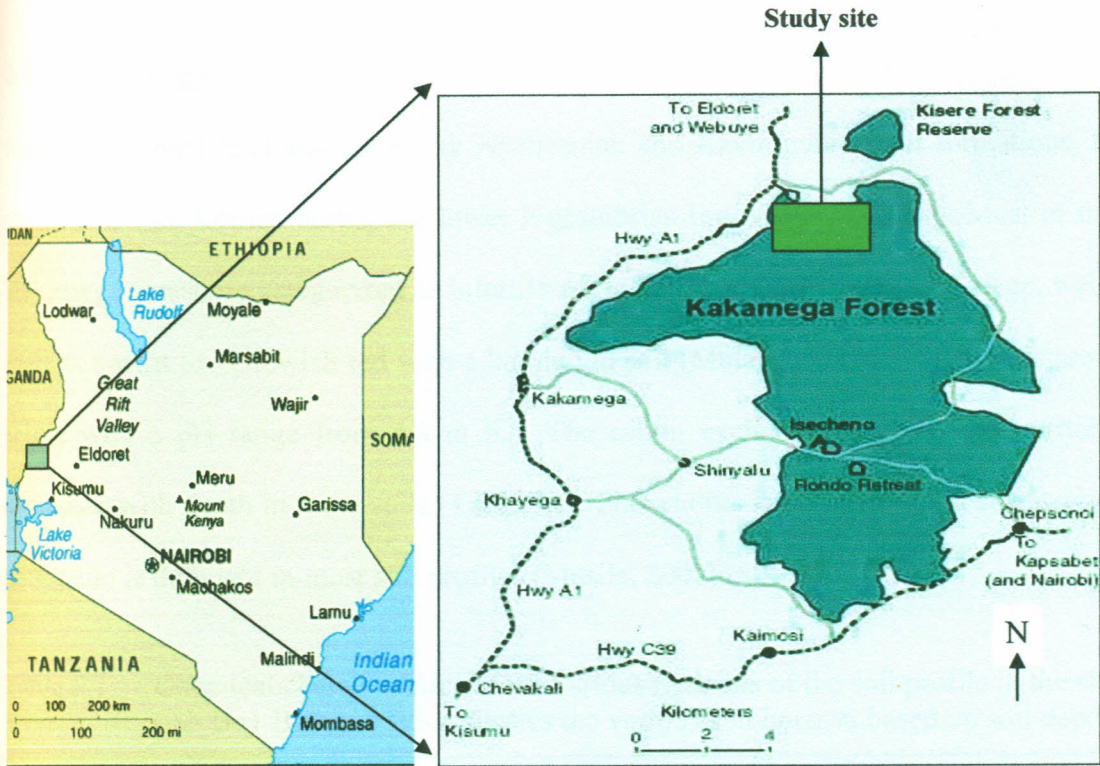


Fig. 3.1. A map of Kakamega Forest showing the study site (Source: International Center of Insect Physiology and Ecology (ICIPE))

3.1.2 Climate

Kakamega forest experiences heavy precipitation and thunderstorm due to its position near the equator and proximity to Lake Victoria (Musila, 2007). There are two main rain seasons in the district: the long rains, which start in March and end in June; and the short rains that begin in July and end in September with a peak in August (Todt *et al.*, 2004.) The reliable rainfall and warm temperatures make the area conducive for growing of food crops like maize, beans, tea, sugarcane and also horticultural crops. The area receives an average annual total rainfall of 2000 mm while temperature ranges from 10.6 °C to 26.7 °C (KIFCON, 1994).

3.1.3 Geology

Kakamega forest is characterised by Nyanzian and Kavirondian rock formations, the oldest rocks in Kenya formed during the lower Precambrian time (Musila, 2007). Most of the soils in Kakamega forest are categorized as infertile Acric Ferralsols, which are very deep, well-drained, reddish brown to yellowish red with a humic top soil (Mutangah, 1996). The soils are generally acidic with a pH range from 4.5 to 6.5. The cation exchange capacity and nutrient content decreases with depth in these soils (Table 3.1). Phosphorus is deficient in all soil horizons while potassium is deficient in most soil profiles (Musila, 2007).

Table 3.1: Chemical characteristics of the various horizons of the soil profile in the study area (Ah, Bu1 Bu2 and Bcs indicates the various soil horizon based on soil depth)

Horizon	Depth cm	pH	%C	%N	C:N	Exchangeable bases in C mol Kg ⁻¹				
						P	Ca	Mg	K	CEC
Ah	0-33	6.5	2.51	0.27	0.4	11	34	1.93	0.1	20
Bu 1	33-83	5.9	0.96	0.09	0.2	7	17.7	1.56	0.1	20
Bu 2	83-150	5.1	0.6	0.06	0.1	7	2.3	1.06	0.1	12
Bcs	150-162	5.0	0.41	0.04	0.15	6	0.5	0.66	Trace	10

3.1.4 Flora and fauna

Kakamega forest holds unique flora and fauna which have been seen to share similar characteristics with those of the western African equatorial rainforests (Kokwaro, 1988). The enormous diversity of the forest comprises of 380 different plants species comprising 150 species of woody trees, shrubs and climbers, about 90 dicotyledonous herbs, almost 80 monocotyledonous herbs (60 orchids) and about 62 species of ferns (KIFCON, 1994).

The canopy with a mean height of 25-40 m contains trees like *Strychnos usambarensis* Gilg ex Engl., *Polyscias fulva* Harms or *Cordia africana* Lam. and also lianas and climbers. The lowest

layer, the understorey or shrub layer includes smaller trees and shrubs such as *Kigelia africana* (Lam.) Benth., *Celtis gomphophylla* Baker and *Dracaena fragrans* (L.) Ker-Gawl. Few ferns, herbs and orchids can be found on the forest floor (Althof, 2005). There are 35 bird species and 75 large mammals, which are forest dependent and are considered threatened (Onyango and Nyunja, 2004).

3.2 Test species

The plant species in this study were *Prunus africana*, *Markhamia lutea*, and *Olea capensis*. Details of their global distribution and growth characteristics are provided in Table 2. The three species are found within a nearly similar altitude where each species grows to different mean heights (Table 2.3).

Table 3.2: A comparison of the distribution and characteristics of *Prunus africana*, *Markhamia lutea* and *Olea capensis*

SPECIES	ECOLOGICAL DISTRIBUTION	GROWTH CHARACTERISTICS
<i>Prunus africana</i>	Found in Tropical African mountain forests at an altitude between 1100-2200 meters above sea level.	It is a slow growing species; it grows to a mean height of between 10-24 meters and has simple, alternate glossy dark leaves (Schipman, 2001).
<i>Markhamia lutea</i>	Common in lake basins and highland area of eastern of Africa at an Altitude between 900-2000 meters above sea level.	It is an evergreen tree with a narrow and irregular crown and a light brown bark. The species grows to a mean height between 4.5-9 meters and produces yellow flowers (Beentje, 1994).
<i>Olea capensis</i>	Occurs throughout sub Saharan Africa at altitude of between 800-2000 meters above sea level.	Bushy, grow slowly, average mean height of 10 meters (Beentje, 1994).

3.3 Source of the seedlings

Prunus africana, *Olea capensis* and *Markhamia lutea* seedlings were obtained from the Kakamega Environmental Education Programme Nursery in Kakamega Forest. This nursery was selected because it is in the same ecological zone with the study site as it is located at Isicheno

forrest station in Kakamega forest. All the seedlings that were selected were 8 cm in mean height plus or minus 1 cm.

3.4 Soil treatments

Soil samples were treated with pure salts free of growth hormones. The final amount of nitrogen, phosphorus and potassium in the samples represented the amount already in the soil increased by a factor of 10 (Musila, 2007). To compare the performance of the seedlings in the different soil types, seedlings were grown in three soil types; forest soil, farm soil and a mixture of forest and farm soils. The forest soil was obtained from Kakamega forest with permission from the Kenya Wildlife Service. Before the soil was collected from the forest, debris was removed by clearing the area targeted for collection of the soil to a depth of 10 cm. A soil sample was dug up to a depth of 20cm and placed in a heap. The farm soil sample was similarly obtained from the surrounding farms and also sieved and put in a heap. From each site 3520 kg of soil was set aside for treatment. Another soil type of similar weight comprising of 50% forest soil and 50% farm soil was prepared resulting in three soil types (forest soil, farm soil and a mixture of the two). Each soil type was divided into eight equal samples, each weighing 440 kg. The eight samples were amended as follows:

- Sample 1 - amended with $0.0533 \text{ g N kg}^{-1}$ using ammonium nitrate fertiliser
- Sample 2- amended with $0.5318 \text{ g P kg}^{-1}$ using triple super phosphate fertilizer.
- Sample 3- amended with $1.285 \text{ g K kg}^{-1}$ using potassium sulphate fertiliser.
- Sample 4- amended with $0.0533 \text{ g N kg}^{-1}$ and 0.5318 P kg^{-1} of soil using ammonium phosphate fertiliser.
- Sample 5- amended with $0.0533 \text{ g N kg}^{-1}$ and $1.285 \text{ g K kg}^{-1}$ using potassium nitrate and potassium sulphate fertilisers.

- Sample 6- amended with 1.285 g K kg⁻¹ and 0.5318 P kg⁻¹ potassium dihydrogen phosphate and potassium sulphate fertilisers.
- Sample 7- amended with 0.0533 g N kg⁻¹, 1.285 g K kg⁻¹ and 0.5318 P kg⁻¹ using potassium nitrate, dipotassium hydrogen phosphate, potassium dihydrogen phosphate and potassium nitrate fertilisers.
- Sample 8- remained unamended.

Each soil sample was distributed in five kilogram seedling planting bags. The figures presented represent the nutrient concentration of the study site increased by a factor of 10.

3.5 Field experiments

3.5.1 Experiment 1: Determination of limiting nutrients

The aim of this experiment was to determine which of the three nutrients (N, P and K) are limiting to the growth of *Prunus africana*, *Olea capensis* and *Makhamia lutea* in forest soil, farm soil and in the mixture of the forest soil and farm soil. One seedling of each of the three species was grown individually in tubes containing 5 kg of soil from each of the three soil types treated as shown in Table 3.3. A completely randomized design was used in the arrangement of the pots in the green house.

Table 1.3: Diagrammatic illustration of the experimental design used to assess the effect of soil amendments on growth properties of the three species

Nutrient	Number of seedlings of each species								
	<i>Prunus africana</i>			<i>Markhamia lutea</i>			<i>Olea capensis</i>		
	Forest Soil	Farm Soil	Mixed Soil	Forest Soil	Farm Soil	Mixed Soil	Forest Soil	Farm Soil	Mixed Soil
N	11	11	11	11	11	11	11	11	11
P	11	11	11	11	11	11	11	11	11
K	11	11	11	11	11	11	11	11	11
NP	11	11	11	11	11	11	11	11	11
NK	11	11	11	11	11	11	11	11	11
KP	11	11	11	11	11	11	11	11	11
NPK	11	11	11	11	11	11	11	11	11
NONE	11	11	11	11	11	11	11	11	11

Seedling characteristics that included the mean diameter at the base, mean height and mean number of leaves per seedling were recorded. Seedling mean height from the base to the apex was taken with a ruler and recorded in centimeters. The stem mean diameter was measured with a digital caliper and recorded in millimeters. Three seedlings out of eleven per treatment were sampled randomly after 70 days and the growth characteristics measured on the first day were measured again. The seedlings were then harvested. Harvesting was done by removing the soil around the roots of the seedlings after which the shoots and the roots were separated. The roots were washed in a 2 mm sieve to remove the soil. The leaves were then plucked from the shoot and placed on a white sheet of paper where they were photographed for the determination of the mean leaf area. The mean leaf area was then determined using Image- J computer programme. Both the roots and the shoots were dried to a constant weight at 80 °C in an oven at KEFRI-

Maseno and Muguga. The aboveground and belowground biomass was then determined by weighing in an electrical balance. This procedure was repeated after 140 days, 210 days and 280 days

The data collected was coded and entered in Excel spreadsheet and later imported to STATISTICA (Stat soft 6.0) for analysis. An ANOVA was carried out to determine whether there was a significant difference in mean growth properties of seedlings subjected to the eight different fertilizer treatments in the three soils. Growth properties included: mean height, mean diameter, mean number of leaves, mean shoot: root ratio and the mean leaf area. Mean separation tests were performed for significant differences using LSD- test.

3.5.2 Experiment 2: Effect of competition on seedlings growth

The aim of this experiment was to determine the effect of competition for nutrients on the growth of seedlings of *Prunus africana*, *Markhamia lutea* and *Olea capensis* in farm soil, forest soil and a mixture of farm and forest soil. To determine the effect of inter-specific competition, *Prunus africana*, *Markhamia lutea* and *Olea capensis* seedlings were selected at random and planted together in one tube. The test for intraspecific competition involved growing three seedlings of each species in one tube. A completely randomized design was used in the arrangement of the pots in the green house.

Table 3.4: Effects of competition on the seedling growth properties under different soil and nutrient regimes

Nutrient	Number of replicates per soil type for the three species											
	<i>Prunus africana</i>			<i>Markhamia lutea</i>			<i>Olea capensis</i>			The three species		
	Forest	Farm	Mixture	Forest	Farm	Mixture	Forest	Farm	Mix	Forest	Farm	Mix
N	11	11	11	11	11	11	11	11	11	11	11	11
P	11	11	11	11	11	11	11	11	11	11	11	11
K	11	11	11	11	11	11	11	11	11	11	11	11
NP	11	11	11	11	11	11	11	11	11	11	11	11
NK	11	11	11	11	11	11	11	11	11	11	11	11
KP	11	11	11	11	11	11	11	11	11	11	11	11
NPK	11	11	11	11	11	11	11	11	11	11	11	11
NONE	11	11	11	11	11	11	11	11	11	11	11	11

Seedlings characteristics that included the mean diameter at the base, mean height and mean number of leaves per seedling were recorded in the first day of planting for all the seedlings. Seedlings mean height from the base to the apex was taken with a ruler and recorded in centimeters. The stem mean diameter was measured with a digital caliper and recorded in millimeters. Three seedlings out of eleven per treatment were sampled randomly after 70 days and the growth characteristics measured on the first day were re-measured again. The seedlings were then harvested following the procedure outlined in experiment 1. The data collected was coded and entered in Excel spreadsheet and later imported to STATISTICA (Stat soft) for analysis. An ANOVA test was carried out to determine whether there was a significant difference in mean growth properties of seedlings subjected to the eight different fertilizer treatments in the three soils. Growth properties measured included: mean height, mean diameter, mean number of leaves, mean shoot: root ratio and the mean leaf area.

3.5.3 Experiment 3: Effects of different light regimes on growth of *Prunus africana*

To determine the effect of different light regimes on growth of *Prunus africana* seedlings grown in different soil types and each amended with different nutrient combinations, one seedling per tube was grown in a shade inside the green house where light was reduced to 20.8 percent of photosynthetic active radiation while other seedlings treated in a similar way were grown in an area exposed to light outside the green house at 100 percent of photosynthetic active radiation. The amount of light in the green house and outside the greenhouse was recorded at intervals of three weeks using a sun scan machine and a BF2 logger machine. Growth characteristics (see section 3.5) were recorded four times at an interval of 70 days. Each treatment in the three experiments was replicated 11 times (Table, 5.3).

Table 3.5: The experimental design used to assess the influence of light in growth dynamics of *Prunus africana*

Nutrients	Number of seedlings under high light regime			Number of seedlings under low light regime		
	Forest Soil	Farm Soil	Mixed Soil	Forest Soil	Farm Soil	Mixed Soil
N	11	11	11	11	11	11
P	11	11	11	11	11	11
K	11	11	11	11	11	11
NK	11	11	11	11	11	11
KP	11	11	11	11	11	11
NP	11	11	11	11	11	11
NPK	11	11	11	11	11	11
NONE	11	11	11	11	11	11

Seedlings characteristics that included the mean diameter at the base, mean height, mean number of leaves per seedling, and the proportion of the mean number of leaves with fungal infections was recorded in the first day of planting for all the seedlings. Seedlings mean height from the

base to the apex was taken with a ruler and recorded in centimeters. The stem mean diameter was measured with a digital caliper and recorded in millimeters. Three seedlings out of eleven per treatment were sampled randomly after 70 days and the growth characteristics measured on the first day were measured again. The seedlings were then harvested following the procedure outlined in experiment 1.



Fig. 3.2: Leaf arrangement for mean leaf area determination procedure

3.5.4 Chemical analysis of the samples

A sample of the above ground biomass of the seedlings harvested after 70 days and those harvested after 210 days were selected for the determination of the concentration of total nitrogen, total phosphorus and potassium. The samples were dried to a constant weight in an oven set 80 °C. The samples were then ground into powder for analyses. Dried and ground samples for the analyses of total nitrogen and potassium were digested using a digestion mixture prepared by mixing 350 ml H₂SO₄, 14 g lithium sulphate, 0.4 g selenium powder and 420 ml hydrogen peroxide (APHA, 1998). An amount of 0.1 g of the sample was mixed with 4.4 ml of the digestion mixture. The mixture was then heated until the digestate cleared after which the

samples were diluted with distilled water to make a 50 ml solution. Samples for the analysis of total phosphorus were digested using the persulphate method (APHA, 1998). Some 0.1 g of the sample was diluted to make 50 ml of the solution to which 1ml of H₂SO₄ and 0.4 g of (NH₄)₂S₂O₈ were then added. The mixture was then heated in an autoclave for two hours to allow for complete digestion.

Total nitrogen and total phosphorus in digested samples were determined using phenate and ascorbic acid methods respectively (APHA, 1998). Potassium concentration in the samples was determined by flame photometry method. Standards for each nutrient were subjected to the same treatment as the samples.

3.5.5 Data analysis

Data was entered in an Excel spreadsheet and later imported to STATISTICA (Stat soft version 6.0) for analysis. A student's t- test was used to test the effect of light on growth dynamics of *Prunus africana* seedlings. The t-test was done to establish whether seedlings grown under low light regime in the greenhouse and those grown in higher light regime were significantly different. ANOVA tests were used to assess whether there were significant differences in means of growth properties between the seedlings grown without competition and under intra and inter specific competition.

CHAPTER 4: RESULTS

4.1 Response of seedlings of the test species to soil amendments with fertilizers

4.1.1 *Prunus africana*

The mean height of the seedlings grown in farm soil amended with a combination of nitrogen and phosphorus was the highest with a maximum mean height of 27.4 cm while the lowest mean height of 16.2 cm was recorded in mixed soil amended with nitrogen combined with potassium (Fig. 4.1). Using a two way ANOVA test, the mean seedling mean height was found to be significantly different among fertilizer treatments ($P = 0.001$, $df = 7$). Means separation using the Least Significant Difference (LSD) technique showed that soils fertilized with phosphorus alone and soils fertilized with a combination of phosphorus and nitrogen had a significantly greater seedlings mean height compared to the other fertiliser treatments (Table 4.1). The rest of the fertiliser treatments were not significantly different from each other. Mean seedling mean heights in the three soil types (forest soil, farm soil and mixed soil) were not significantly different ($P > 0.05$, $df = 2$). The interaction between the nutrient amendments and soil type on the mean height of the seedlings did not significantly affect seedling mean height ($P > 0.05$, $df = 2$).

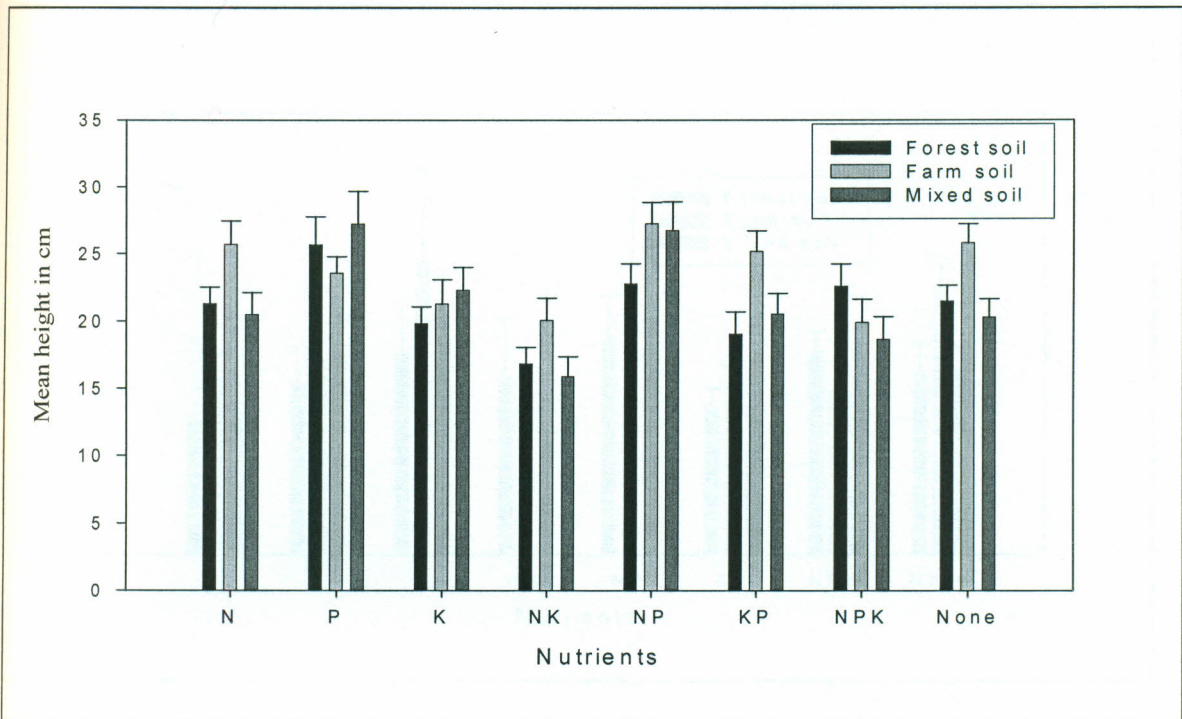


Fig. 4.1: Mean height of *Prunus africana* seedlings in three soil types amended with various fertilizers (vertical bars represent +1SE)

The largest mean diameter was recorded in soil amended with potassium in farm soil where 4.7 mm was recorded. The smallest mean diameter was recorded in mixed soil amended with combination nitrogen and potassium where 2.1 mm was recorded (Fig. 4.2). However, the differences in mean diameter were not significant ($P < 0.05$, $df = 7$) as revealed by ANOVA test. The soil types did not significantly affect the mean diameter ($P < 0.05$, $df = 2$). The interaction between the nutrients and the soil types on seedlings mean diameter significantly affected the mean diameter of the seedlings ($P < 0.05$, $df = 14$).

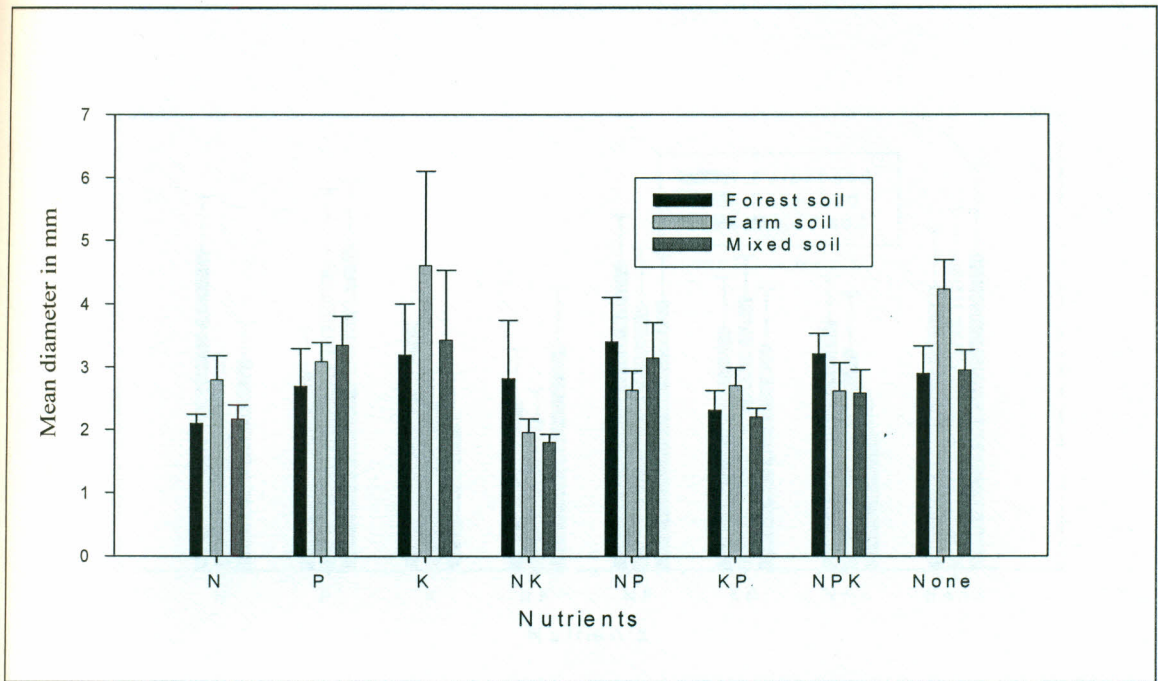


Fig. 4.2: Mean diameter of *Prunus africana* seedlings in three soil types amended with various fertilizers (vertical bars represent +1SE)

Mean shoot: root ratio was greatest (5.2) in mixed soil amended with phosphorus alone while the smallest ratio of 2.2 was recorded in mixed soil amended with a combination of nitrogen, phosphorus and potassium. (Fig. 4.3) However, using the ANOVA test, the differences in mean shoot: root ratio among the different fertilizer treatments and the different soil types were not significantly different ($P > 0.05$, $df = 2$). The interaction between the soil types and the nutrients did not significantly affect the seedlings mean shoot: root ratio ($P > 0.05$, $df = 14$).

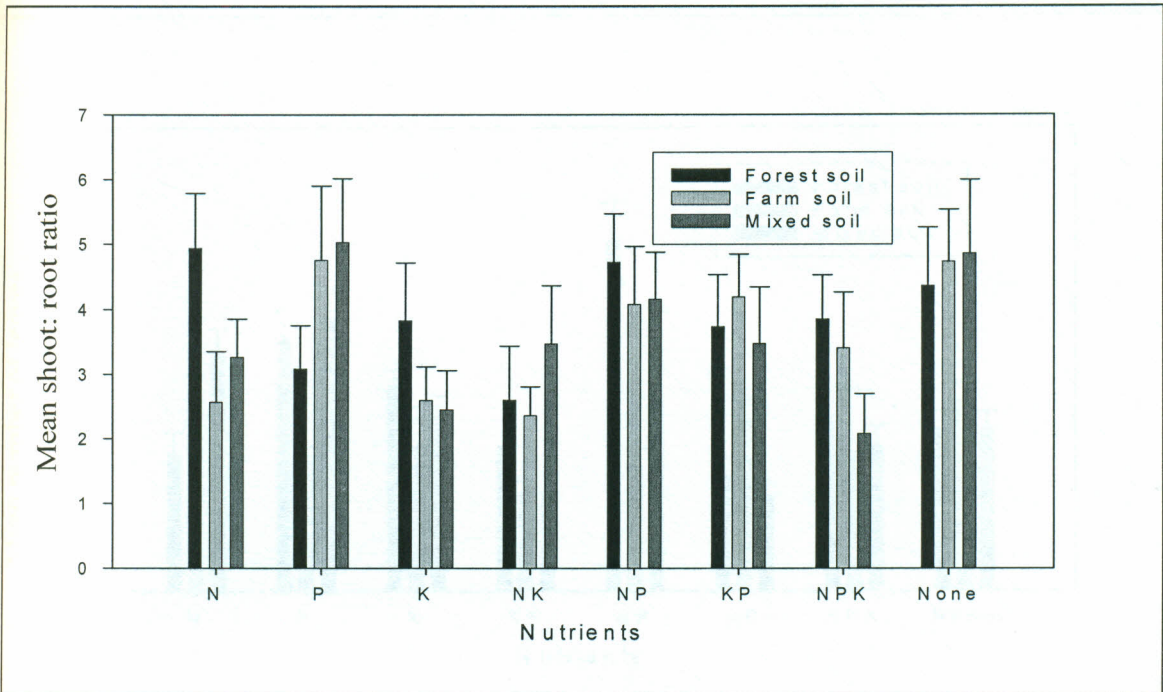


Fig. 4.3: Mean shoot: root ratio of *Prunus africana* seedlings grown in three soil types amended with various fertilizers (vertical bars represent +1SE).

The largest mean number of leaves was recorded in forest soil amended with a combination of nitrogen and phosphorus where a total of 29 leaves were counted. Seedlings grown in a combination of nitrogen and potassium produced 6 leaves, which represented the smallest mean number of leaves among the treatments. (Fig. 4.4) The differences in the mean number of leaves were not significant ($P = 0.046$, $df = 7$) as revealed by the ANOVA test.

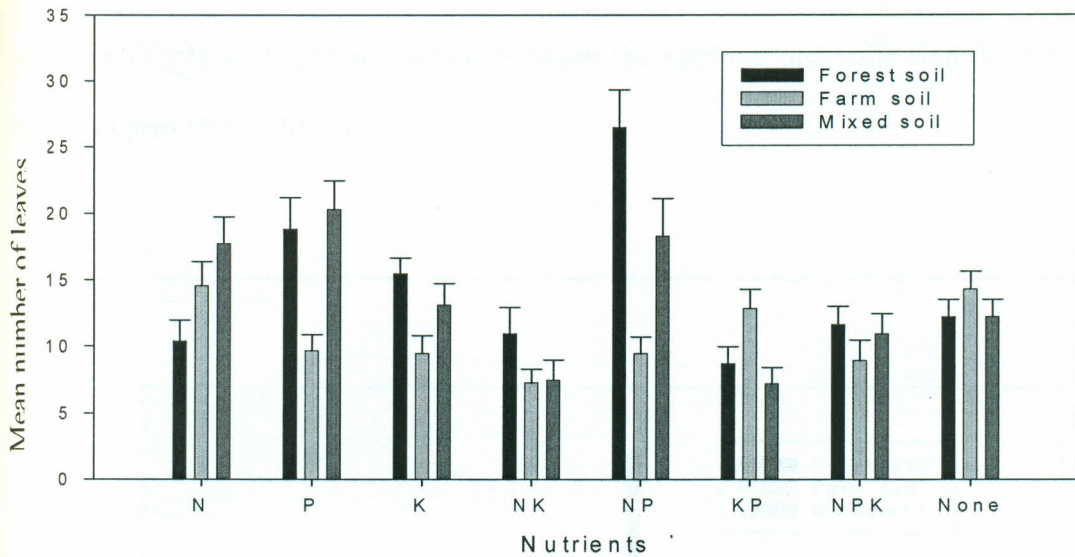


Fig. 4.4. Mean number of leaves of *Prunus africana* seedlings grown in three soil types amended with various fertilizers (vertical bars represent +1SE).

The largest mean leaf area of 290 cm² was recorded in forest soil amended with a combination of nitrogen and phosphorus while the least mean leaf area of 90 cm² was recorded in the forest soil amended in a combination of potassium and nitrogen (Fig. 4.5). The mean leaf area of the different soil treatments ranged from 145.9 cm² in forest soil to 132.6 cm² in mixed soil. Differences in mean seedling mean leaf area of the different fertilizer treatments were found to be significant ($P = 0.0001$, $df = 7$) based on ANOVA test. Mean separation using LSD technique revealed that the seedlings grown in soil amended with potassium only and those grown in soil amended with a combination of nitrogen and phosphorus had a significantly greater mean leaf area compared to the other fertilizer treatments. Mean leaf area of seedlings grown in different soil types were found to be significantly different ($P = 0.08$, $df = 2$) based on ANOVA test.

The mean leaf area for seedlings grown in forest soil was significantly higher than the seedlings grown in farm soil and mixed soil based on Least Significant Difference means separation technique (Table 4.1). The interaction between the nutrients and soils significantly affected the mean leaf area ($P = 0.001$, $df = 14$).

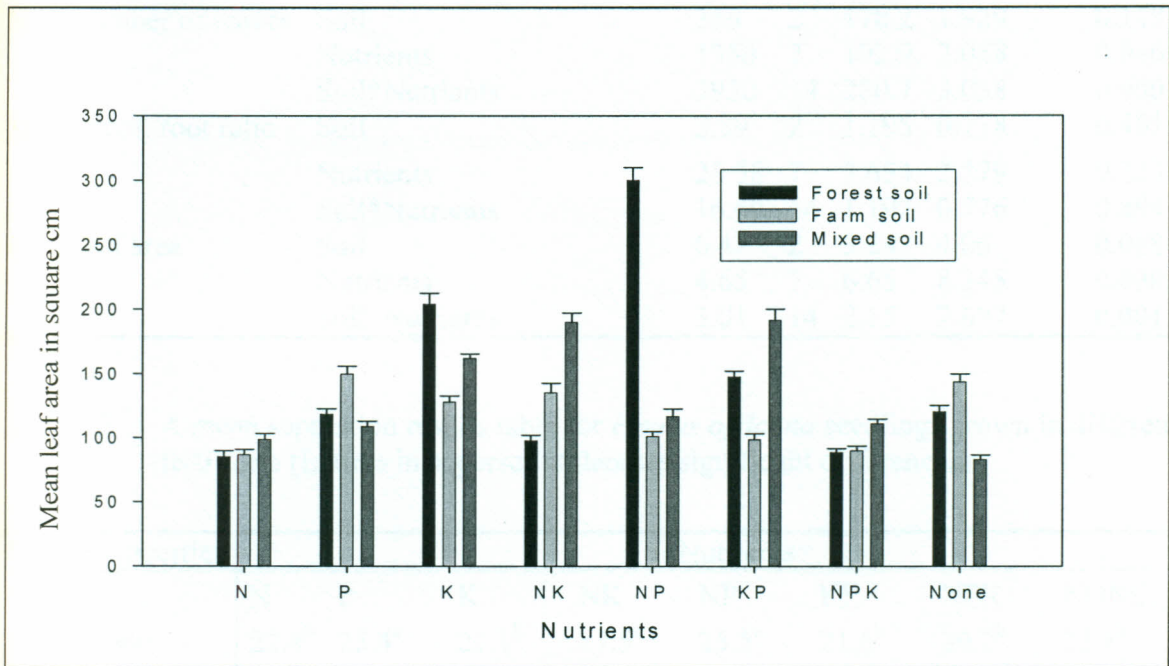


Fig. 4.5: Mean leaf area of *Prunus africana* seedlings grown in three soil types amended with various fertilizers (vertical bars represent +1SE).

Table 4.1: Results of the analysis of variance test on the effects of soil source and soil amendment with nutrient types on growth properties of *Prunus africana* (ns= not significant, * = P< 0.05, ** = P< 0.001, *** = P < 0.001) n =11

PARAMETER	SOURCE OF VARIATION	SS	df	MS	F-VALUE	P-VALUE
Mean height	Soil	653	2	326.5	1.448	0.237 ns
	Nutrients	6017	7	859.5	3.813	0.001 **
	Soil*Nutrients	4998	14	357	1.583	0.085 ns
Mean diameter	Soil	19.7	2	9.85	1.149	0.319 ns
	Nutrients	90.9	7	12.98	1.515	0.163 ns
	Soil*Nutrients	215.4	14	15.38	1.795	0.040 *
Mean number of leaves	Soil	356	2	178.2	1.929	0.148 ns
	Nutrients	1350	7	192.9	2.088	0.046 ns
	Soil*Nutrients	3930	14	280.7	3.038	0.000 ***
Mean shoot: root ratio	Soil	2.39	2	1.195	0.778	0.461 ns
	Nutrients	25.58	7	3.654	2.379	0.223 ns
	Soil*Nutrients	16.69	14	1.192	0.776	0.694 ns
Mean leaf area	Soil	6.47	2	3.24	4.06	0.018 *
	Nutrients	4.65	7	6.65	8.345	0.0001 ***
	Soil*Nutrients	3.01	14	2.15	2.697	0.001 **

Table 4.2: A mean separation results table for *Prunus africana* seedlings grown in different fertilizers (Letters in superscript denotes significant differences)

Growth properties	Nutrients							
	N	P	K	NK	NP	KP	NPK	NONE
Mean height	22.4 ^b	25.4 ^a	21.1 ^b	17.5 ^b	25.5 ^a	21.6 ^b	20.2 ^b	22.4 ^b
Mean leaf area	90 ^d	125.6 ^c	164.6 ^a	140.9 ^b	172.6 ^a	145.7 ^b	96.6 ^d	115.7 ^d

Table 4.3: A mean separation results for *Prunus africana* seedlings grown in different soil types (Letters in superscript denotes significant differences)

Growth property	Forest soil	Farm soil	Mixed soil
Mean leaf area	145.9 ^a	116.5 ^c	132.6 ^b

4.1.2 *Markhamia lutea*

Seedlings grown in mixed soil amended with the combination of nitrogen, phosphorus and potassium recorded the greatest mean height of 36.9 cm while the un-amended mixed soil had the least mean height of 12.6 cm. Based on a two way ANOVA test, the differences in mean seedling mean height among the fertilizer treatments were found to be significant ($P = 0.01$, $df = 7$). Means separation using the Least Significant Difference technique indicated that the seedlings grown in soil amended with a combination of nitrogen, phosphorus and potassium had a significantly greater mean height than all the other fertiliser treatments. From the same test, it was observed that, the difference in seedling mean height between the soils types was not significant ($P > 0.05$, $df = 2$). The interaction between the soil and nutrients did not significantly affect seedling mean height ($P > 0.05$, $df = 14$) (Table 4.4).

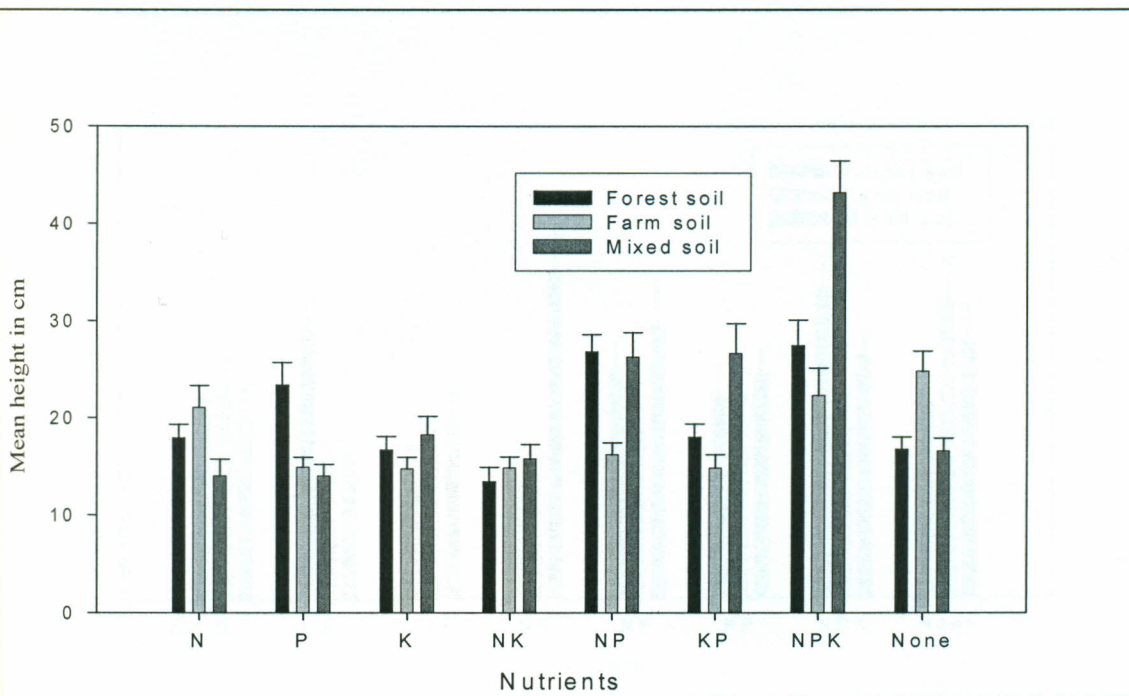


Fig. 4.6: Mean height of *Markhamia lutea* seedlings grown in three soil types amended with various fertilizers (vertical bars represent +1SE)

Seedlings grown in mixed soil amended with a combination of nitrogen, phosphorus and potassium recorded the largest mean diameter of 5.4 mm while the seedlings grown in forest soil amended with a combination of nitrogen and potassium recorded the smallest mean diameter of 2.3 mm (Fig. 4.7). A two way ANOVA test conducted to compare mean seedling mean diameter revealed a significant difference in seedling mean diameter among the nutrient treatments ($P = 0.02$, $df = 7$). Mean separation using the LSD test revealed that the mean diameter of the seedlings grown in the soil amended with a combination of nitrogen, phosphorus and potassium and a combination of nitrogen and phosphorus was significantly greater than that of other treatments. ($P > 0.05$, $df = 14$). The interaction between the soil type and nutrients did not significantly affect seedling mean diameter ($P = 0.73$, $df = 14$).

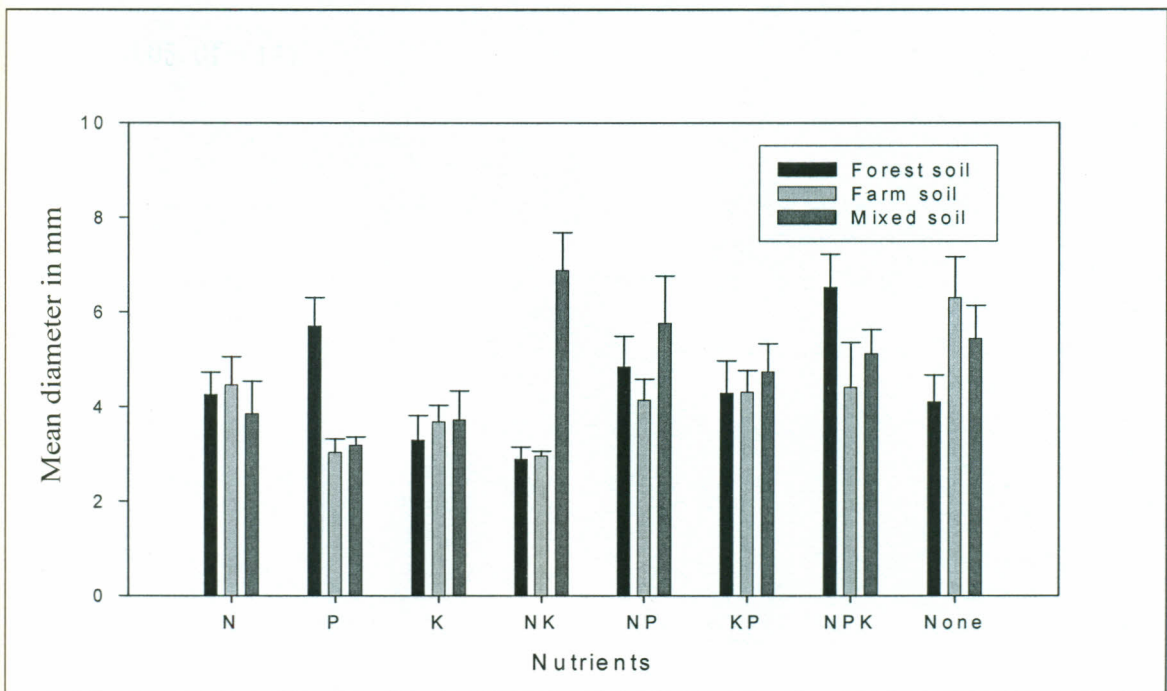


Fig. 4.7: Mean diameter of *Markhamia lutea* seedlings grown in three soil types amended with various fertilizers (vertical bars represent +1SE)

Seedlings grown in soil amended with a combination of nitrogen, phosphorus and potassium in farm soil had a mean shoot: root ratio of 2.5, which was the greatest among the treatments while the smallest ratio of 1.1 was recorded in forest soil amended with nitrogen alone (Fig. 4.8). The differences in mean mean shoot: root ratio among the fertilizer treatments were significantly different ($P < 0.006$, $df = 7$) as indicated by the two way ANOVA test. Mean separation using the LSD technique confirmed that seedlings grown in soil amended with a combination of nitrogen and phosphorus and those grown in soil amended with a combination of nitrogen, phosphorus and potassium had significantly larger mean shoot: root ratio compared to other treatments while the rest of the treatments were not significantly different. The differences in mean shoot: root ratio among the three soil types were not significant ($P > 0.05$, $df = 2$, Table 4.4). The interaction between the soil and nutrients did not significantly affect the mean shoot: root ratio ($P > 0.05$, $df = 14$).

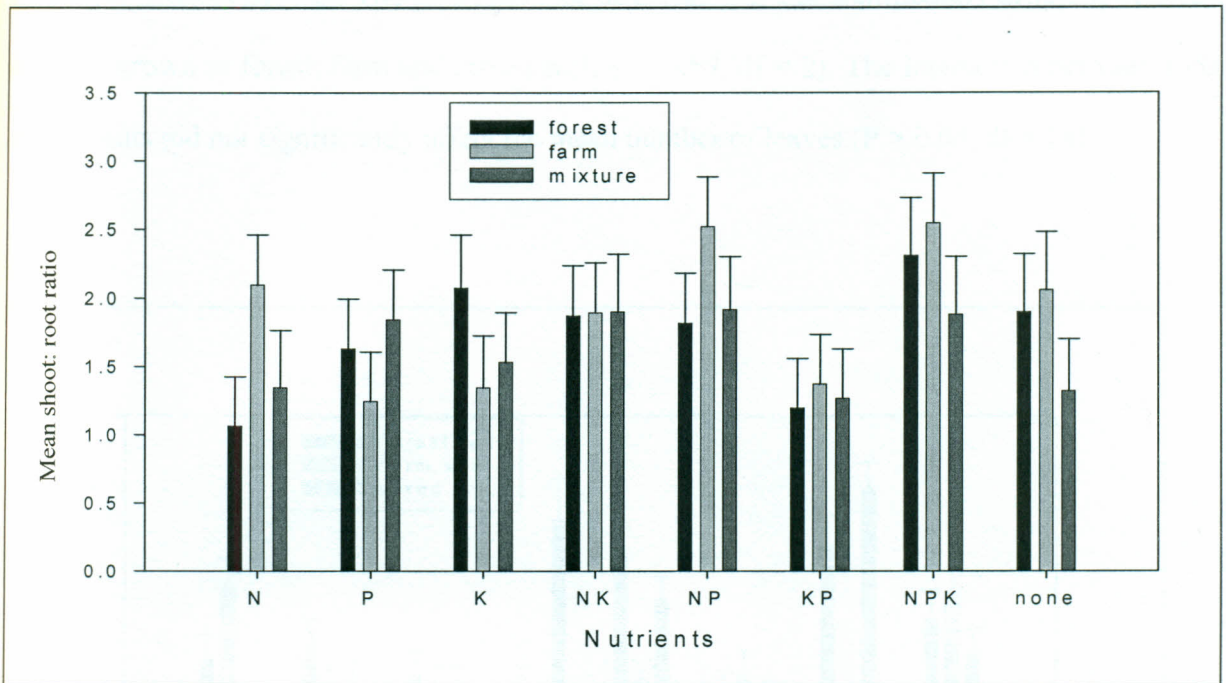


Fig. 4.8: Mean shoot: root ratio of *Markhamia lutea* seedlings grown in three soil types amended with various fertilizers (vertical bars represent +1SE).

Mixed soil amended with nitrogen, phosphorus and potassium produced 25 leaves, which was the largest number while the farm soil amended with a combination of nitrogen and potassium produced six leaves representing the smallest number (Fig. 4.9). An ANOVA test revealed that the differences in mean number of leaves among the fertilizer treatments were significant ($P = 0.01$, $df = 7$).

Using LSD technique, it was observed that seedlings grown in soil amended with a combination of nitrogen and phosphorus and those grown in soil amended with a combination of nitrogen, phosphorus and potassium had a significantly larger mean number of leaves than the other treatments (Table 4.5), which were not significantly

different ($P > 0.05$, $df = 2$). The mean number of leaves was not significantly different between seedlings grown in forest, farm and mixed soils ($P = 0.69$, $df = 2$). The interaction between soils and nutrients did not significantly affect the mean number of leaves ($P > 0.05$, $df = 14$).

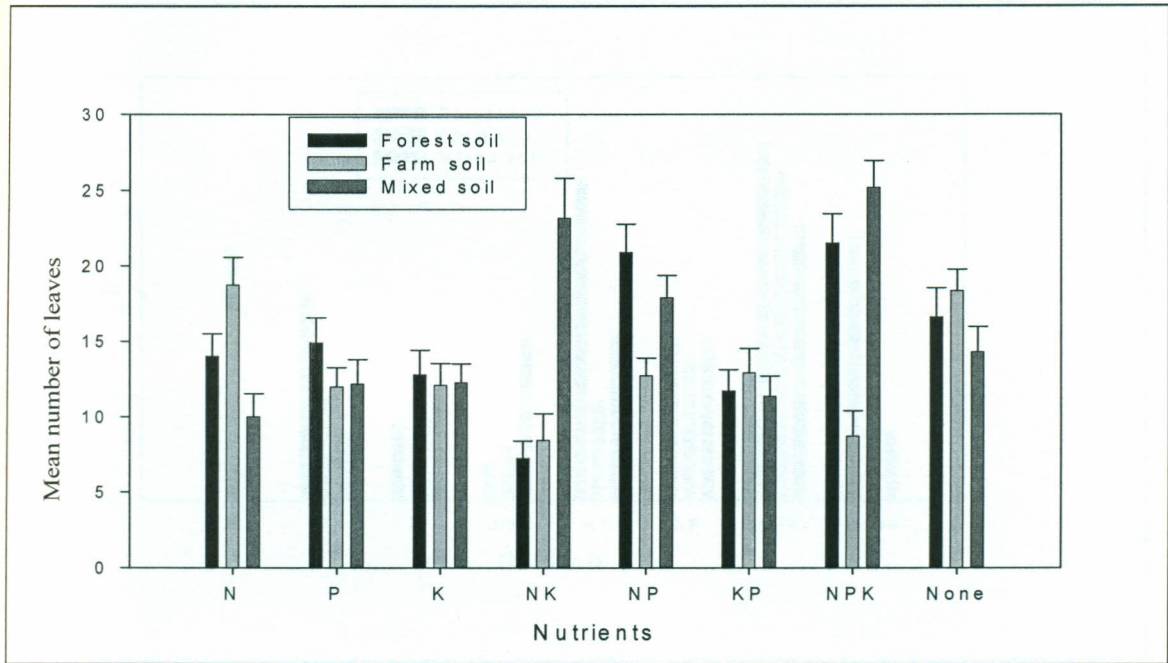


Fig. 4.9: Mean number of leaves of *Markhamia lutea* seedlings grown in three soil types amended with various fertilizers (vertical bars represent +1SE).

The largest mean leaf area was recorded in forest soil amended with a combination of nitrogen, phosphorus and potassium (650 cm^2), while the smallest mean leaf area was recorded in soil amended with a combination of nitrogen and potassium (78 cm^2) (Fig 4.10). Based on a two ANOVA test, a significant difference in the mean leaf area among fertilizer treatment ($P < 0.01$, $df = 7$) was observed. Application of the Least Significant Difference (LSD) technique revealed that the seedlings grown in the soil amended with a combination of nitrogen, phosphorus and potassium had a significantly larger mean leaf area compared to the other

treatments. The other treatments were not significantly different from each other ($P > 0.05$, $df = 2$). The interaction between the soils and nutrients did not significantly affect mean leaf area ($P > 0.05$, $df = 14$) (Table 4.4).

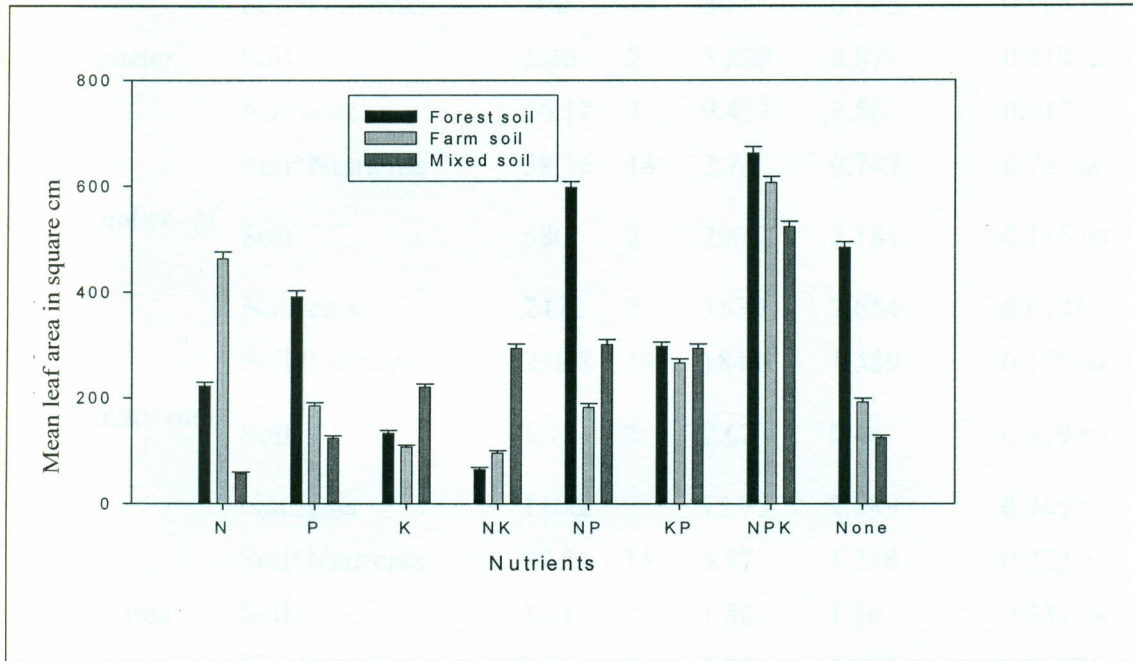


Fig. 4.10: Mean leaf area of *Markhamia lutea* seedlings grown in three soil types amended with various fertilizers (vertical bars represent +1SE).

Table 4.4: Results of the analysis of variance test on the effects of soil source and soil amendment with nutrient types on growth properties of *Markhamia lutea* (ns= not significant, * = $P < 0.05$, ** = $P < 0.001$, *** = $P < 0.001$) n = 11)

PARAMETER	SOURCE OF VARIATION	SS	df	MS	F-VALUE	P-VALUE
Mean height	Soil	299	2	149.3	1.625	0.199 ns
	Nutrients	1594	7	227.7	2.478	0.018 *
	Soil*Nutrients	700	14	50	0.545	0.905 ns
Mean diameter	Soil	6.46	2	3.229	0.874	0.419 ns
	Nutrients	66.17	7	9.453	2.56	0.015*
	Soil*Nutrients	38.36	14	2.74	0.742	0.731 ns
Mean number of leaves	Soil	580	2	290.2	2.181	0.115 ns
	Nutrients	2472	7	353.1	2.654	0.012*
	Soil*Nutrients	258.8	14	184.8	1.389	0.159 ns
Mean shoot: root ratio	Soil	5.2	2	2.62	0.48	0.619 ns
	Nutrients	110.2	7	15.75	2.889	0.006*
	Soil*Nutrients	97.5	14	6.97	1.278	0.222 ns
Mean leaf area	Soil	3.61	2	1.80	1.10	0.334 ns
	Nutrients	2.07	7	2.95	1.805	0.0087
	Soil*Nutrients	3.95	14	2.82	1.721	0.052 ns

Table 4.5: Mean separation results for *Markhamia lutea* seedlings grown in different fertilizers (Letters in superscript denotes significant differences)

GROWTH PROPERTIES	NUTRIENTS							
	N	P	K	NK	NP	KP	NP K	NONE
Mean height	17.6 ^b	17.4 ^b	16.5 ^b	14.6 ^b	22.9 ^b	19.7 ^b	30.9 ^a	17.4 ^b
Mean diameter	4.1 ^b	3.9 ^b	3.5 ^b	4.2 ^b	4.8 ^a	4.4 ^b	5.3 ^a	4.8 ^b
Mean number of leaves	14 ^b	13 ^b	12 ^b	13 ^b	17 ^a	12 ^b	18 ^a	13 ^b
Mean shoot: root ratio	1.5 ^b	1.6 ^b	1.6 ^b	1.8 ^b	2.1 ^a	1.4 ^b	2.2 ^a	1.8 ^b
Mean leaf area	247.5 ^b	233.4 ^b	156 ^b	151.5 ^b	362.1 ^b	285.1 ^b	597 ^a	271 ^b

4.1.3 *Olea capensis*

The seedlings grown in forest soil amended with a combination of nitrogen and phosphorus were the tallest with a mean height of 35.4 cm while the least mean mean height of 18.8 cm was recorded in farm soil amended with a combination of nitrogen and potassium (Fig. 4.11). Based on a two way ANOVA test, the differences in mean seedling mean height among the fertilizer treatments were significant ($P < 0.001$, $df = 7$). The LSD mean separation technique revealed that the seedlings grown in soil amended with a combination nitrogen and phosphorus and those grown in soil amended with potassium alone were significantly taller than those grown under the other fertilizers treatments (Table 4.7) except for the seedlings grown in soil amended with nitrogen alone. Mean seedling mean height of different soil treatments ranged between 27.2 cm in forest soil and 22.8 cm in mixed soil. Using the two way ANOVA test, the differences in seedling mean height among the soil types were significant ($P = 0.03$, $df = 2$). The interaction between soil type and nutrients had a significant effect on seedling mean height ($P = 0.009$, $df = 14$).

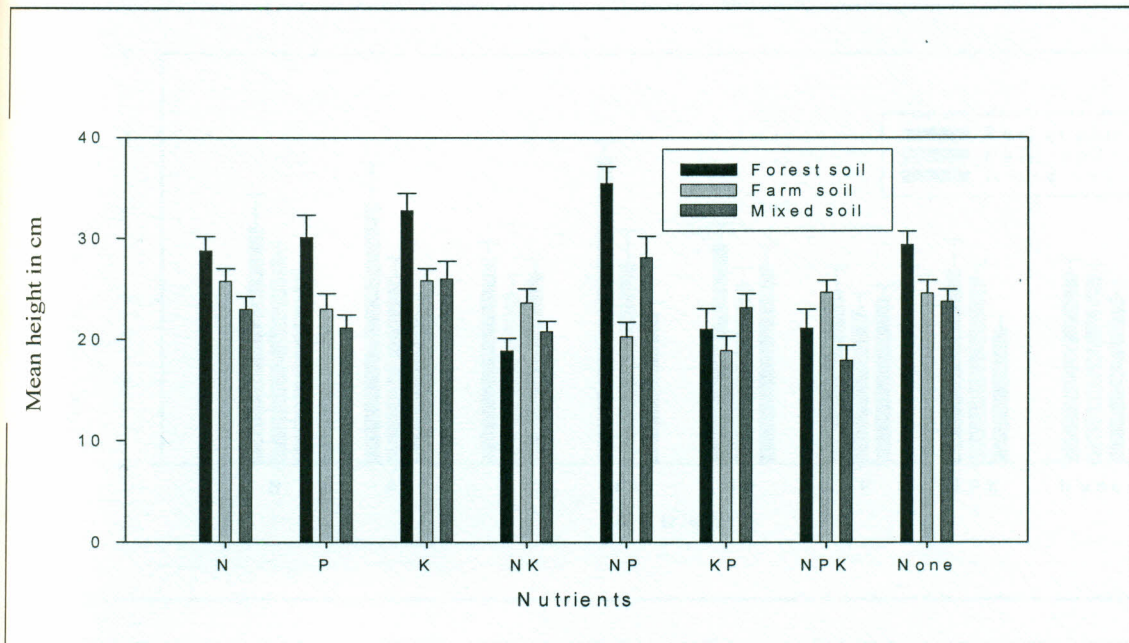


Fig. 4.11: Mean height of *Olea capensis* seedlings grown in three soil types amended with various fertilizers (vertical bars represent + 1 SE).

Seedlings grown in forest soil amended with a combination of nitrogen and potassium recorded the greatest mean diameter of 7.6 mm while the smallest mean diameter of 3.8 mm was recorded in the mixed soil amended with a combination of nitrogen, phosphorus and potassium. However, a two way ANOVA test revealed that seedling mean diameter differences among the fertilizer treatments were not significant ($P > 0.5$, $df = 7$). Similarly, mean seedling mean diameter recorded in forest soil, farm soil and mixed soil were not significantly different ($P = 0.44$, $df = 2$). The interaction between the soil and fertilizer treatments did not significantly affect seedling mean diameter ($P > 0.05$, $df = 14$).

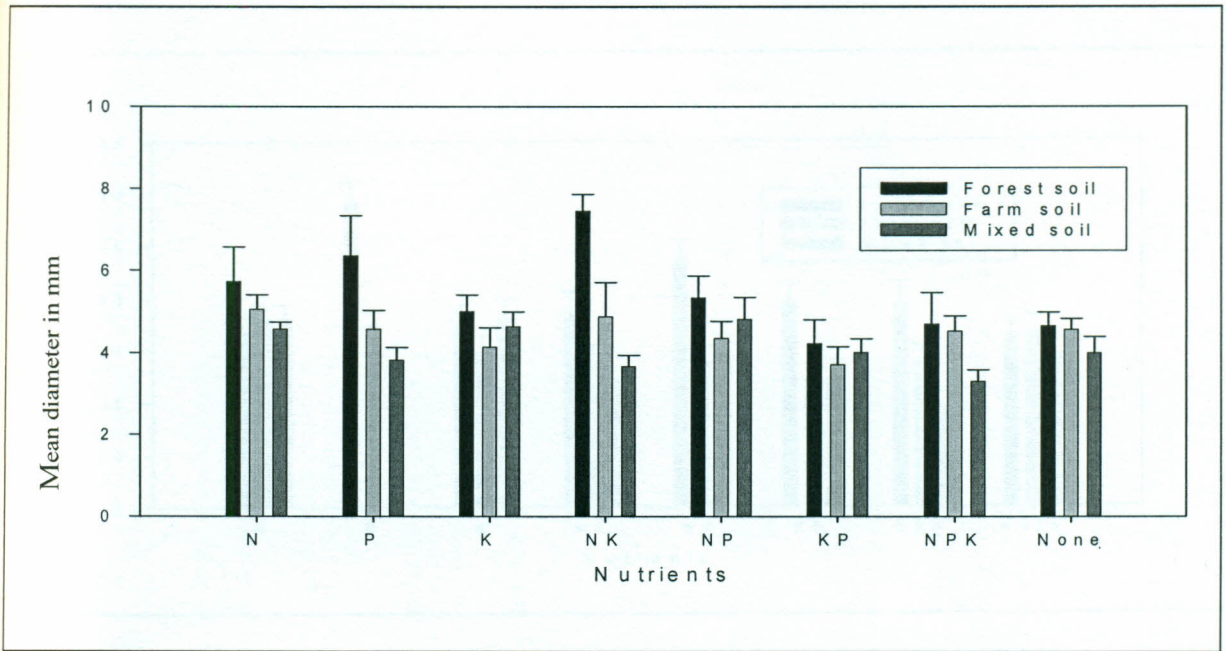


Fig. 4.12: Mean diameter of *Olea capensis* seedlings grown in three soil types amended with various fertilizers (vertical bars represent + 1SE).

The seedlings grown in forest soil amended with phosphorus produced highest mean number of leaves (with a mean of 28 leaves). Mixed soil amended with a combination of nitrogen, phosphorus and potassium produced the least mean number of leaves (11) of all fertilizer treatments. Based on a two way ANOVA, it was observed that differences in the mean leaf numbers among fertilizer treatments were not significant ($P > 0.5$, $df = 7$). The interaction between the soil and fertilizer treatments did not significantly affect the mean number of leaves ($P > 0.05$, $df = 14$). The mean number of leaves produced by the different soils varied between 20 in forest soil and 14 in mixed soil. Based on the two-way ANOVA test, it was observed that there was a significant difference in leaf numbers among soil types ($P = 0.002$, $df = 2$). Mean separation using the LSD technique revealed that leaf numbers were significantly greater in forest soils than in farm and mixed soils (Table 4.7).

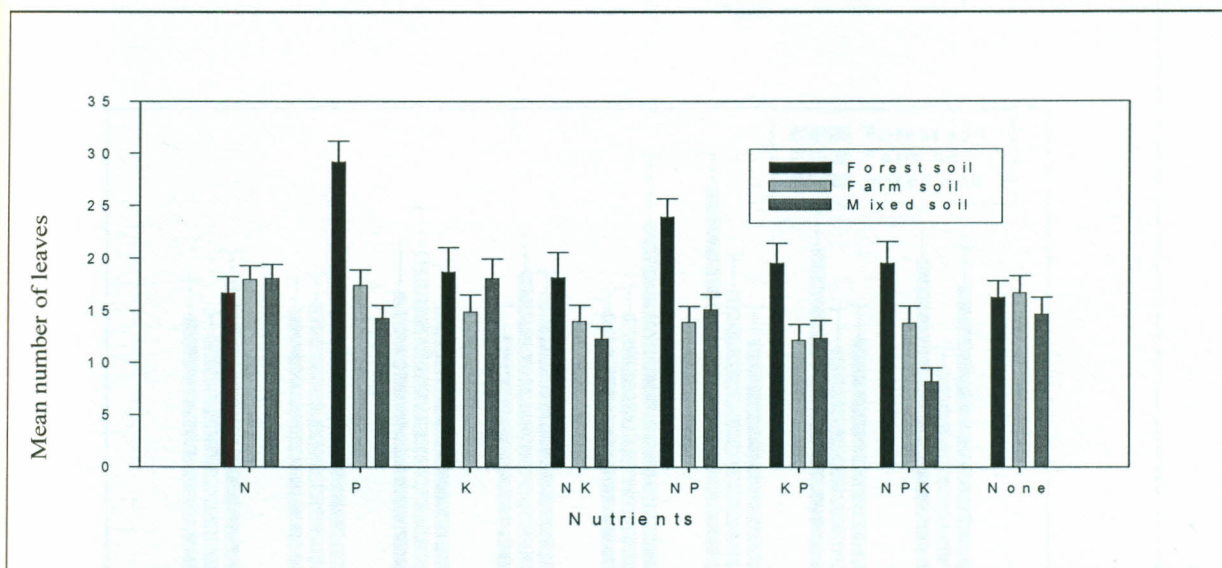


Fig. 4.13: Mean number of leaves of *Olea capensis* seedlings grown in three soil types amended with various fertilizers (vertical bars represent + 1SE).

The mean shoot: root ratio was highest in forest soil amended with a combination of potassium and phosphorus, which recorded a ratio of 3.4. The smallest ratio of 1.8 was recorded for seedlings grown in farm soil amended with a combination of nitrogen, phosphorus and potassium. The differences in mean shoot: root ratio among fertilizer treatments were not significant ($P > 0.05$, $df = 7$). The interaction between the soil and fertilizer treatments did not significantly affect shoot root ratio ($P > 0.05$, $df = 14$), as revealed by a two way ANOVA test. The mean shoot: root ratio among the different soil treatments ranged from 2.4 in forest soil to 2.2 in farm soil. A two way ANOVA test revealed that the difference in mean shoot: root ratio was not significant ($P > 0.05$, $df = 2$).

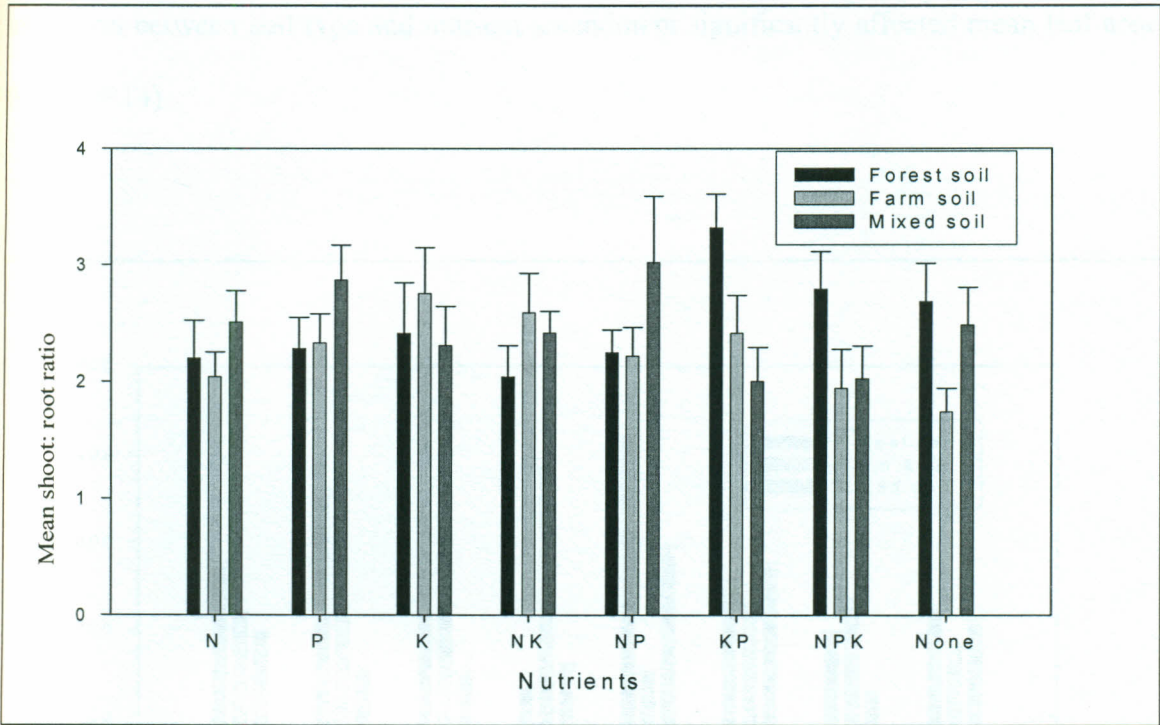


Fig. 4.14: Mean shoot: root ratio of *Olea capensis* seedlings grown in three soil types amended with various fertilizers (vertical bars represent +1SE).

Mean leaf area of seedlings grown in the soil amended with a combination of nitrogen and phosphorus was largest in forest soil where a mean value of 420 cm² was recorded. The smallest mean leaf area of 120 cm² was recorded in forest soil amended with a combination of nitrogen and potassium. A two way ANOVA test showed that there were no significant differences in mean leaf area among fertilizer treatments ($P > 0.05$, $df = 7$). Mean leaf area among the different soil treatments varied between 263.3 cm² in forest soil and 188.2 cm² in mixed soil. A two-way ANOVA test revealed that there was significant difference in mean leaf area among the soil types ($P = 0.007$, $df = 2$). Mean separation using the LSD technique revealed that the mean leaf area in forest and farm soils was significantly greater than in mixed soil (Table 4.8). The

interaction between soil type and nutrient amendment significantly affected mean leaf area ($P < 0.01$, $df = 14$).

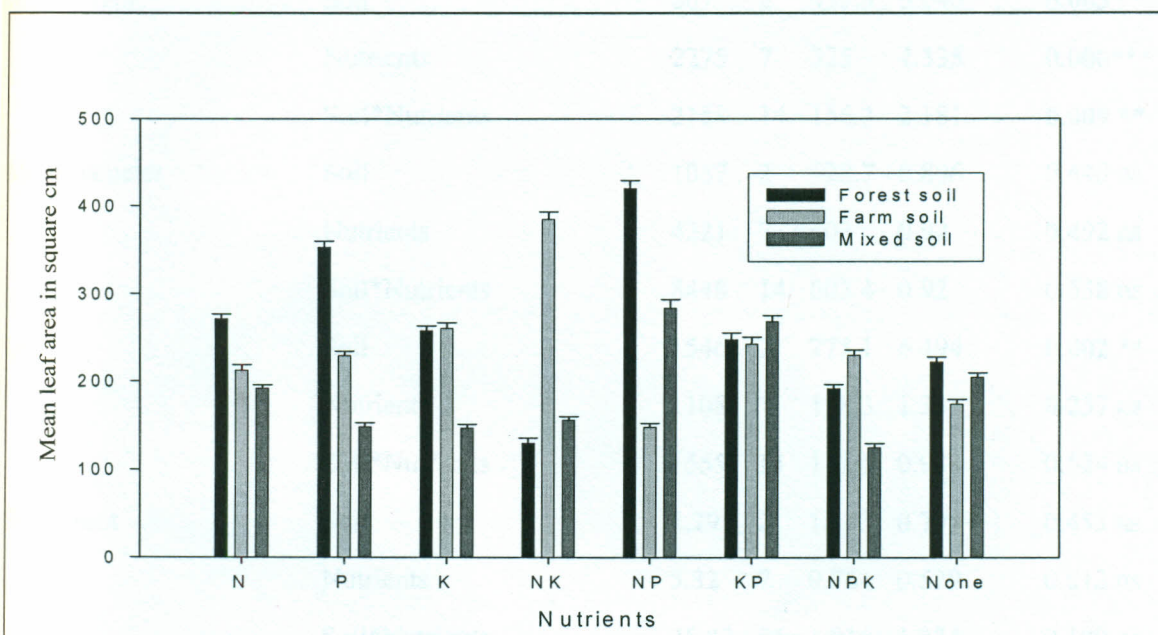


Fig. 4.15: Mean leaf area of *Olea capensis* seedlings grown in three soil types amended with various fertilizers (vertical bars represent +1 SE).

Table 4.6: Results of the analysis of variance test on the effects of soil source and soil amendment with nutrient types on growth properties of *Olea capensis*. (ns= not significant, * = P< 0.05, ** = P< 0.001, *** = P <0.0001).

GROWTH PARAMETER	SOURCE OF VARIATION	SS	df	MS	F-VALUE	P-VALUE
Mean height	Soil	867	2	433.3	6.046	0.003 **
	Nutrients	2275	7	325	4.535	0.000***
	Soil*Nutrients	2188	14	156.3	2.181	0.009 **
Mean diameter	Soil	1057	2	528.7	0.806	0.448 ns
	Nutrients	4221	7	603	0.92	0.492 ns
	Soil*Nutrients	8448	14	603.4	0.92	0.538 ns
Leaves	Soil	1546	2	773.1	6.494	0.002 **
	Nutrients	1108	7	158.3	1.33	0.237 ns
	Soil*Nutrients	1555	14	111.1	0.933	0.524 ns
Shoot: root	Soil	2.29	2	1.143	0.795	0.453 ns
	Nutrients	5.32	7	0.76	0.529	0.812 ns
	Soil*Nutrients	26.82	14	1.916	1.334	0.189 ns
Mean leaf area	Soil	2.18	2	1.09	5.146	0.007 **
	Nutrients	2.36	7	3.38	1.593	0.138 ns
	Soil*Nutrients	1.06	14	7.59	3.579	0.000 ***

Table 4.7: Means separation results table for fertilizer treatments for *Olea capensis* (Letters in superscript denotes significant differences)

Growth property	N	P	K	NK	NP	KP	NPK	NONE
Mean height	25.8 ^{ab}	24.7 ^b	28.1 ^a	21 ^b	27 ^a	20 ^b	21.1 ^b	23 ^b

Table 4.8: Means separation results table for soil treatments for *Olea capensis* (Letters in superscript denotes significant differences)

Growth properties	Forest soil	Farm soil	Mixed soil
Mean height	27.2 ^a	23.2 ^b	22.8 ^b
Mean number of leaves	20 ^a	15 ^b	14 ^b
Mean leaf area	263.3 ^a	235.6 ^a	188.2 ^b

4.2 The response of seedlings of test species to competition

4.2.1 *Prunus africana*

The greatest mean height of 29 cm was recorded in seedlings grown under intraspecific competition in forest soil amended with a combination of nitrogen, phosphorus and potassium while the least mean height was recorded in seedlings grown under interspecific competition in mixed soil amended with a combination of nitrogen and phosphorus (Fig. 4.16). Overall mean seedling mean height was greatest for seedlings grown in absence of competition (23.5 cm) while the least mean mean height was recorded in seedlings grown under interspecific competition (14.6 cm). A two-way ANOVA test revealed that the difference in seedlings mean height among the competition treatment was significant ($P < 0.01$, $df = 2$; (Table 4.9). LSD mean separation technique revealed that seedlings grown in the absence of competition had a significantly greater mean height than seedlings grown under interspecific competition (Table 4.10). The interaction between competition and nutrients also affected seedlings mean height significantly ($P=0.002$, $df=14$) (Table 4.9).

Seedlings mean diameter varied between 2.78 mm for seedlings grown under interspecific competition in forest soil to 2.3 cm for seedlings grown under intraspecific competition in mixed soil (Fig. 4.17). A two way ANOVA test showed that mean seedling mean diameter was not significantly different among the competition treatments ($P = 0.16$, $df = 2$). Based on the same

test, the various fertilizer treatments were found not to differ significantly in their effect on seedling mean diameter ($P = 0.44$, $df = 7$). However, the interaction between competition and nutrients affected seedlings mean diameter significantly ($P = 0.01$, $df = 14$; Table 4.10).

The mean number of leaves ranged from 14 for seedlings grown without competition in forest soil to 8 leaves for those grown under intraspecific competition in mixed soil (Fig. 4.18). Based on the two-way ANOVA test, the difference in the mean number of leaves among the competition treatments was significantly different ($P = 0.0001$, $df = 2$). Mean separation using LSD technique revealed that the mean number of leaves for seedlings grown in absence of competition was significantly higher than for seedlings grown under interspecific and intraspecific competition. The same test also revealed that the mean number of leaves was also significantly different among the fertilizer treatments. An LSD test revealed that the seedlings grown without competition recorded larger mean number of leaves (14.9) compared leaves produced by the seedlings grown under interspecific and intraspecific competition (Table 4.10). The interaction between competition and nutrients significantly affected the mean number of leaves ($P = 0.026$, $df = 14$).

The mean shoot: root ratio ranged from 4.5 mm for seedlings grown under interspecific competition in forest soil to 3.9 mm in seedlings grown under intraspecific competition in mixed soil (Fig. 4.9). However, using the two-way ANOVA test, it was found that the difference in mean shoot: root ratio among competition treatments was not significant ($P = 0.86$, $df = 2$). The same test also revealed that the difference among the various fertilizer treatments was not significant ($P > 0.05$, $df = 7$). Similarly, the interaction between competition and nutrients did not significantly affect the mean shoot: root ratio ($P > 0.01$, $df = 14$).

Seedlings grown without competition in forest soil had the largest mean leaf area of 369.2 cm² while seedlings grown in mixed soil under intraspecific competition had the smallest mean leaf area of 70.6 cm² (Fig. 4.20). Based on a two-way ANOVA test, it was observed that the difference in mean leaf area among the competition treatments was significant (P = 0.026, df = 2). The same test also revealed a significant difference among the various fertilizer treatments (P = 0.02, df = 7). Mean separation using the LSD technique revealed that seedlings grown under interspecific competition had the greatest mean leaf area value that was significantly different from that of the other competition treatments value (Table 4.10). The interaction between the nutrients and competition significantly affected mean leaf area (P = 0.0001, df = 14).

Source	df	MS	F	P
Competition	2	18.07	1.46	0.236
Fertilizer	7	17.74	1.40	0.121
Competition * Fertilizer	14	1.33	1.03	0.0001

Table 4.10. Mean leaf area (cm²) for *Pinus oocarpa* seedlings grown in mixed soil under interspecific and intraspecific competition (values in subscript are not significant (P > 0.05)).

Competition	Intraspecific	Interspecific	No competition
Mean (cm ²)	204.8 ^a	313 ^a	369.2 ^b
Standard error	5.8 ^a	11.3 ^a	14.9 ^a
Leaf area (cm ²)	70.6 ^a	136.6 ^a	369.2 ^b

Table 4.9: ANOVA test results on the effect of competition and nutrients on mean height, mean diameter, mean number of leaves, mean shoot: root ratio and mean leaf area on *Prunus africana* seedlings (ns = not significant, * = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$)

GROWTH PARAMETER	SOURCE OF VARIATION	SS	df	MS	F-VALUE	P-VALUE
Mean height	Competition	2025	2	1013	12.29	0.0001***
	Nutrients	1610	7	230	2.79	0.007**
	Competition*Nutrients	2838	14	203	2.46	0.002**
Mean diameter	Competition	16.3	2	8.135	1.779	0.169 ns
	Nutrients	31.3	7	4.477	0.979	0.445 ns
	Competition*Nutrients	127.9	14	9.135	1.997	0.015*
Leaves	Competition	3186	2	1593	25.35	0.0001***
	Nutrients	2594	7	371	5.9	0.0001***
	Competition*Nutrients	1638	14	117	1.86	0.026*
Shoot: root	Competition	3.6	2	1.82	0.148	0.863 ns
	Nutrients	126.5	7	18.07	1.469	0.174 ns
	Competition*Nutrients	249.1	14	17.79	1.446	0.125 ns
Mean leaf area	Competition	8.78	2	4.39	3.645	0.026*
	Nutrients	1.99	7	2.84	2.358	0.021*
	Competition*Nutrients	5.95	14	4.25	3.533	0.0001***

Table 4.10: Mean separation results for *Prunus africana* seedlings subjected to interspecific, intraspecific and no competition (Letters in superscript denotes significant differences)

GROWTH PROPERTIES	Intraspecific	Interspecific	No competition
Mean height (cm)	20.48 ^{ab}	18.8 ^b	23.5 ^a
Mean number of leaves	9.8 ^b	11.1 ^b	14.9 ^a
Mean leaf area in square cm	70.6 ^b	156.6 ^a	70.9 ^b

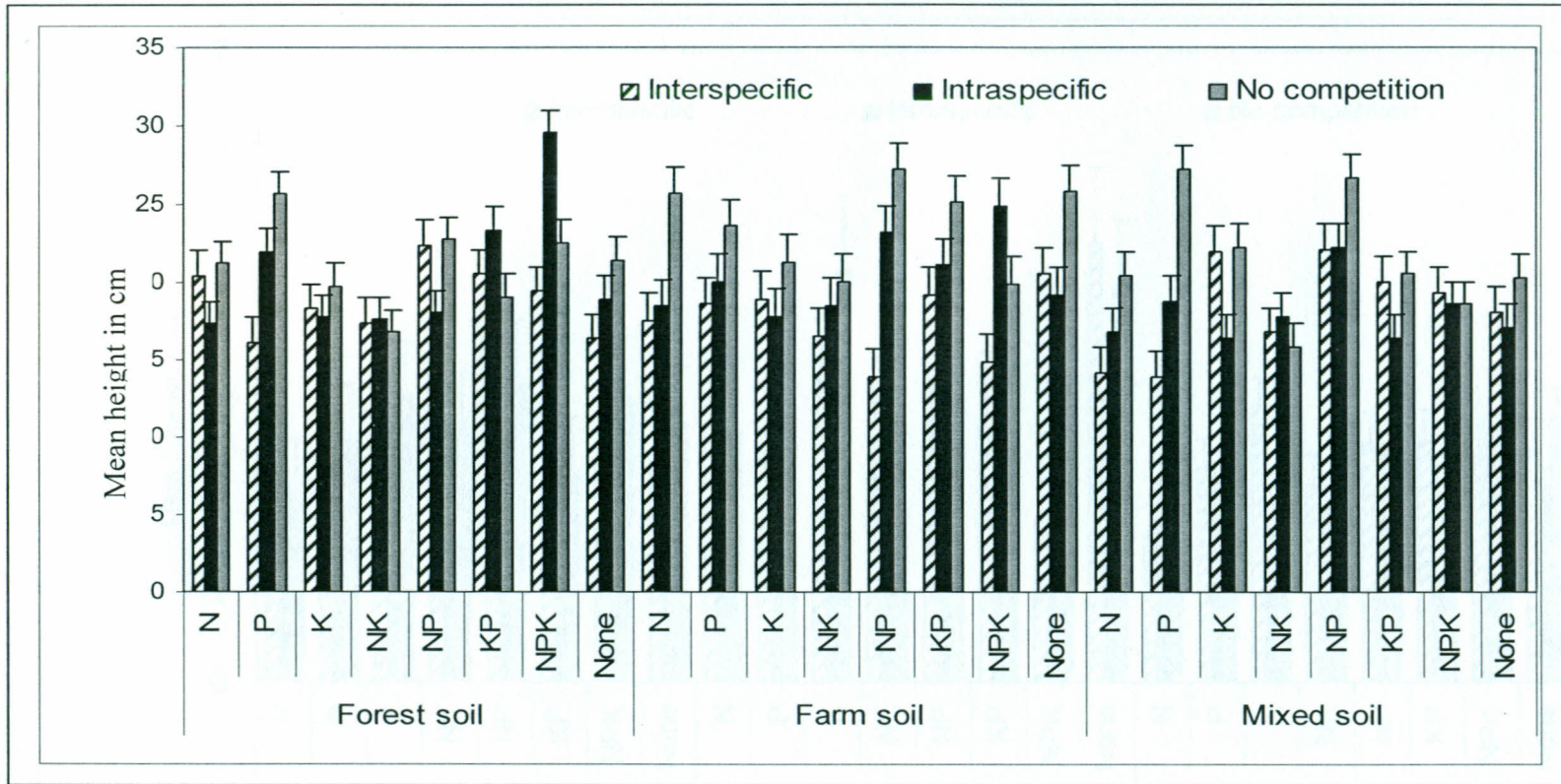


Fig. 4.16: Effects of competition on mean height of *Prunus africana* seedlings grown under different soil types and subjected to different nutrient regimes (vertical bars represent +1SE).

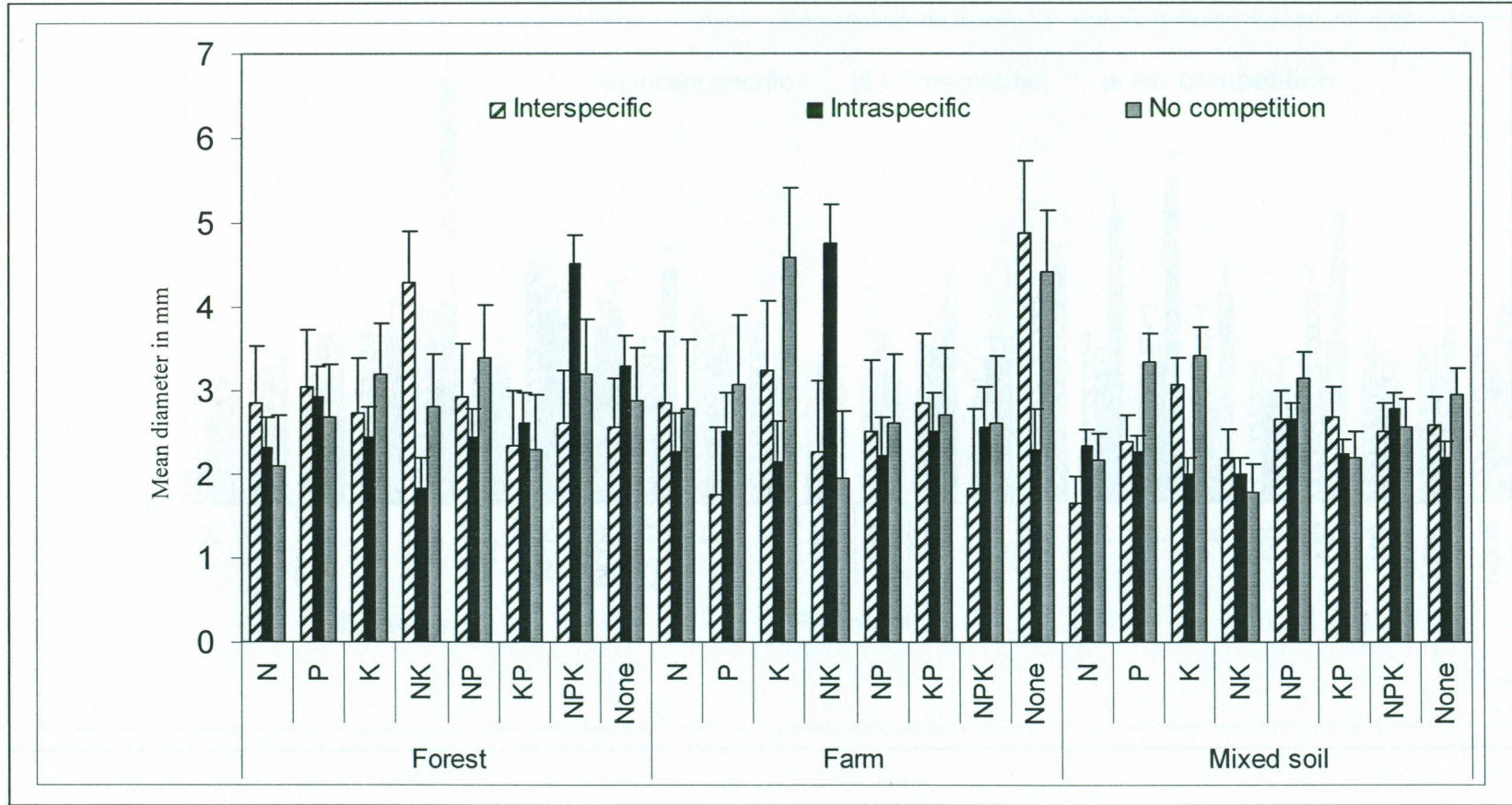


Fig. 4.17: Effects of competition on mean diameter of *Prunus africana* seedlings grown under different soil types and subjected to different nutrient regimes (vertical bars represent +1SE).

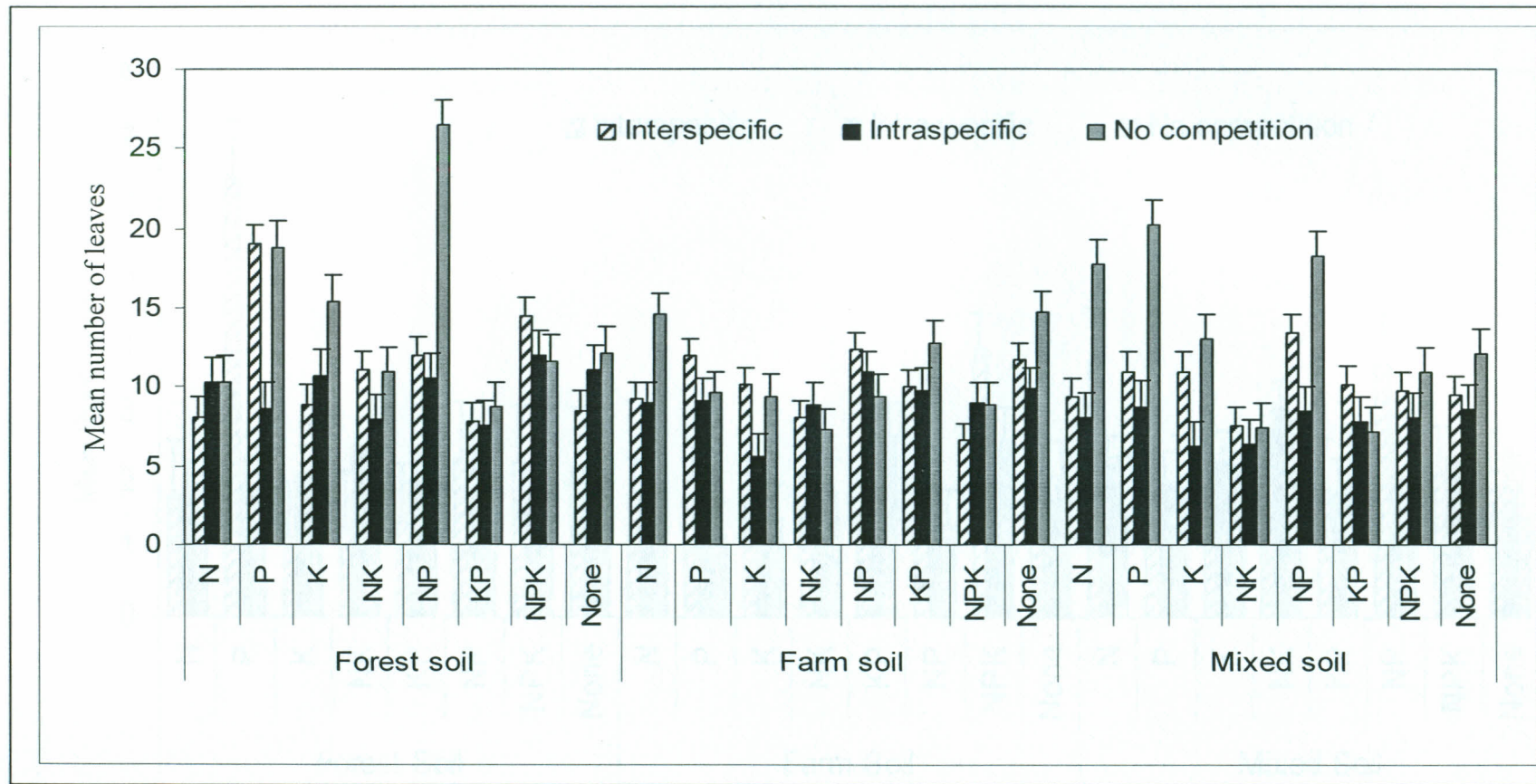


Fig. 4.18: Effects of competition on the mean number of leaves of *Prunus africana* seedlings grown under different soil types and subjected to different nutrient regimes (vertical bars represent +1SE).

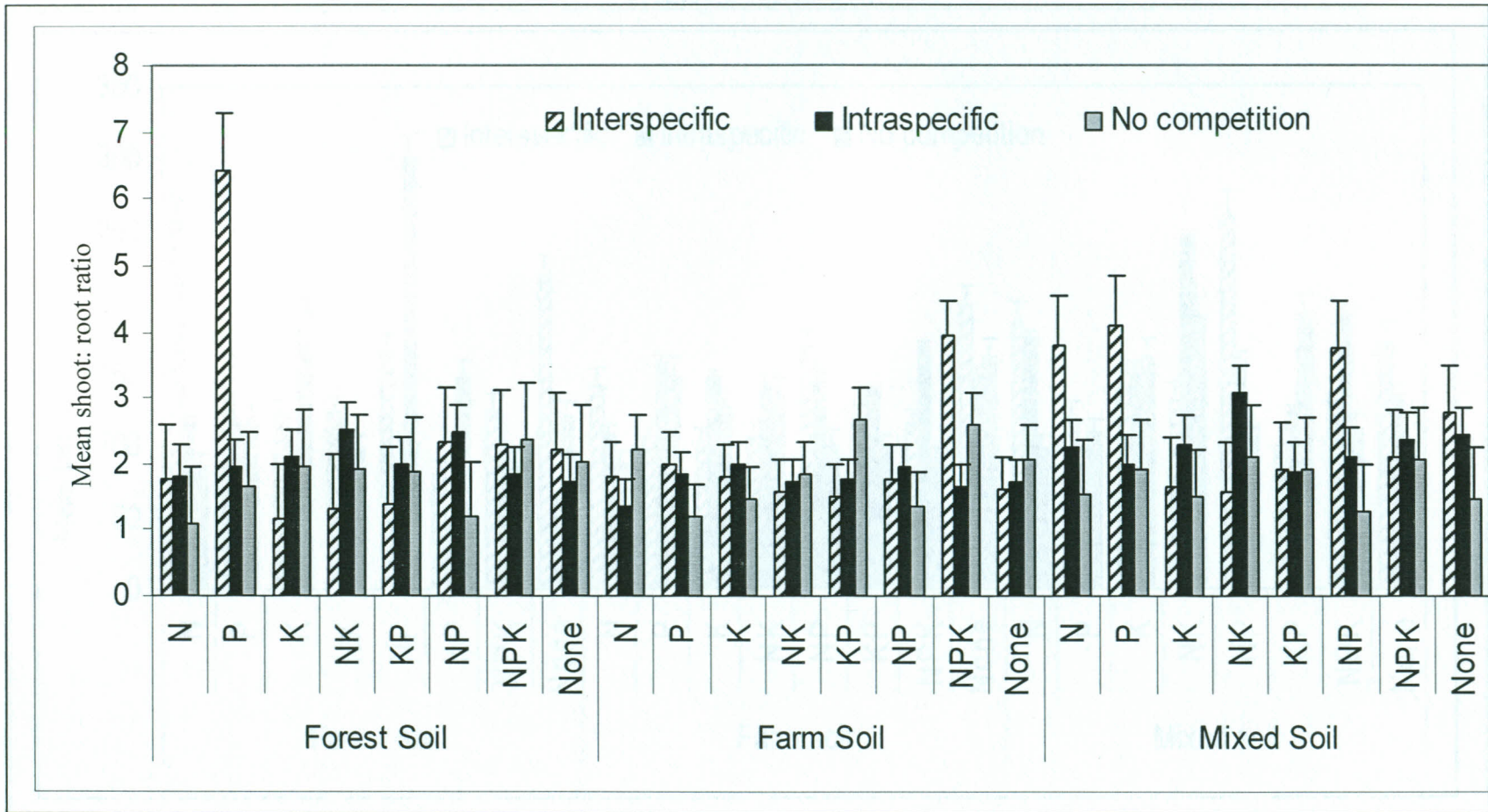


Fig. 4.19: Effects of competition on mean shoot: root ratio of *Prunus africana* seedlings grown under different soil types and subjected to different nutrient regimes (vertical bars represent +1SE).

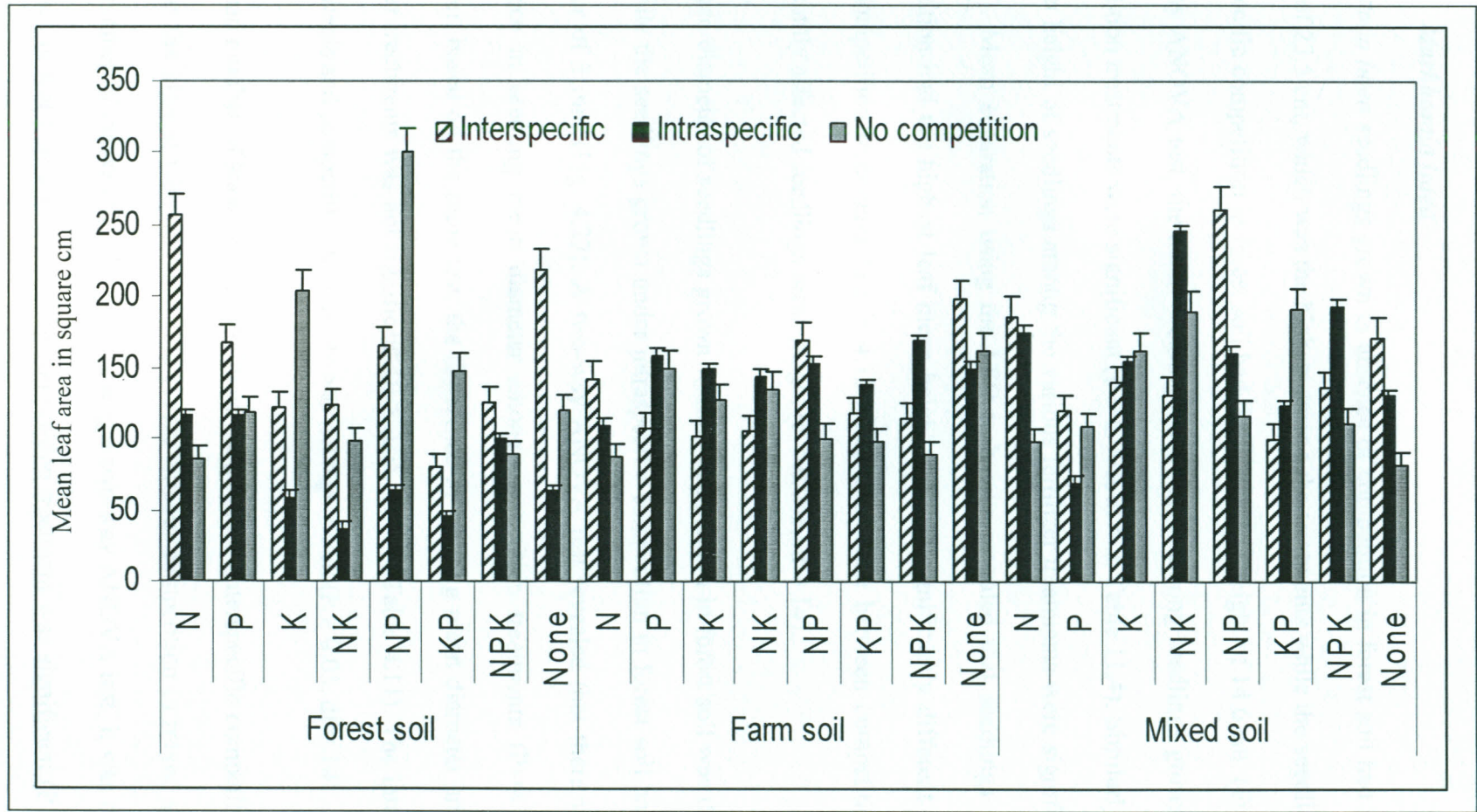


Fig. 4.20: Effects of competition on mean leaf area of *Prunus africana* seedlings grown under different soil types and subjected to different nutrient regimes (vertical bars represent +1SE).

4.2.2 *Markhamia lutea*

Markhamia lutea seedlings grown in absence of competition in forest soil had an average mean height of 23.5 cm, which was the highest among the treatments while the seedlings grown under intraspecific competition in forest soil had the least mean height of 14.6 cm. (Fig. 4.21). Using a two way ANOVA test, the mean seedling mean height among seedlings grown under different competition treatments were significant ($P < 0.001$, $df = 2$; Table 11.4). Similarly, the differences in mean height of seedlings among the various fertilizer treatments were significant ($P < 0.001$, $df = 7$). Mean separation using the LSD technique revealed that seedlings grown under no competition had the highest leaf mean height that was significantly different from that of the other competition treatments (Table 4.12). The interaction between competition and nutrients significantly affected seedlings mean height ($P < 0.001$, $df = 14$).

The mean diameter of seedlings grown without competition in forest soil was the greatest at 4.5 mm while the seedlings grown under intraspecific competition in forest soil had the least mean diameter of 3 mm (Fig. 4.22). A two-way ANOVA test revealed that there was a significant difference in seedling mean diameter among competition treatments ($P = 0.026$, $df = 2$). However, based on the same test, the difference in seedling mean diameter among the various fertilizer treatments was not significant ($P > 0.05$, $df = 7$; Table 4.11). The interaction between the nutrients and competition treatments was not significant ($P > 0.05$, $df = 14$).

The mean number of leaves of the seedlings grown under interspecific competition in forest soil (16) was the highest while the seedling grown without competition in mixed soil had the least mean number of leaves (8) (Fig. 4.23). Using a two-way ANOVA test, it was observed that the difference in leaf numbers among the competition treatment was significant ($P < 0.001$, $df = 2$;

Table 4.11). The same test also revealed a significant difference in the mean number of leaves among the various fertilizer treatments were ($P = 0.003$, $df = 7$). Mean separation using the LSD technique revealed that seedlings grown under interspecific competition had the largest mean number of leaves that was significantly different from that of the other competition treatments (Table 4.12).

The mean shoot: root ratio in forest soil was largest in the seedlings grown under interspecific competition (3.68) while the seedlings grown without competition in forest and mixed soils had the smallest mean shoot: root ratio (1.7) (Fig. 4.24). Based on a two-way ANOVA test, it was observed that the difference among competition treatments was significant ($P = 0.026$, $df = 2$; Table 4.11). However, based on the same test, the difference in mean shoot: root ratio among the various fertilizer treatments was not significant ($P > 0.05$, $df = 7$). The interaction between the competition treatments and nutrient treatments was significant ($P = 0.002$, $df = 14$).

The mean leaf area of the seedlings grown without competition in forest soil had the largest mean leaf area of 369.2 cm^2 while the seedling grown under interspecific competition in mixed soil had the smallest mean leaf area of 136 cm^2 (Fig. 4.25). Based on a two-way ANOVA test, the difference in the mean leaf area among competition treatments was significant ($P < 0.001$, $df = 2$; Table 4.11). The same test also revealed a significant difference in mean leaf area among the various fertilizer treatments ($P < 0.001$, $df = 7$). Mean separation using the LSD technique revealed that seedlings grown in the absence of competition had the greatest mean leaf areas that were significantly different from that of the other competition treatments (Table 4.12). The interaction between the nutrients and competition significantly affected the mean leaf area ($P < 0.001$, $df = 14$).

Table 4.11: ANOVA result for the effect of competition and nutrients on mean height, mean diameter, mean number of leaves, shoot to root ratio and mean leaf area on *Markhamia lutea* seedlings (ns= not significant, * = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$).

GROWTH PARAMETER	SOURCE OF VARIATION	SS	df	MS	F-VALUE	P-VALUE
Mean height	Competition	7460	2	3730	32.73	0.000***
	Nutrients	2.43	7	3.556	9.13	0.000*
	Competition*Nutrients	4547	14	325	2.85	0.000***
Mean diameter	Competition	154.6	2	77.31	4.668	0.010*
	Nutrients	228.9	7	32.7	1.975	0.055 ns
	Competition*Nutrients	68.9	14	4.92	0.297	0.994 ns
Mean number of leaves	Competition	2550	2	1275	13.85	0.000***
	Nutrients	1973	7	282	3.06	0.003**
	Competition*Nutrients	2073	14	148	1.61	0.07 ns
Mean shoot: root ratio	Competition	40.8	2	20.42	3.663	0.026*
	Nutrients	59.7	7	8.52	1.528	0.153 ns
	Competition*Nutrients	195.8	14	13.98	2.508	0.002**
Mean leaf area	Competition	3.90	2	1.95	51.26	0.000***
	Nutrients	2.43	7	3.47	9.13	0.000***
	Competition*Nutrients	4.28	14	3.06	8.03	0.000***

Table 4.12: LSD mean separation results for *Markhamia lutea* seedlings grown under competition and in the absence of competition (Letters in superscript denotes significant differences).

	Intraspecific	Interspecific	No competition
Mean mean height (cm)	14.6 ^c	21.9 ^b	23.05 ^a
Mean diameter	3.68 ^b	4.2 ^{ab}	4.5 ^a
No of leaves	14 ^b	16.2 ^a	14.4 ^b
Mean shoot: root ratio	2.005 ^{ab}	2.33 ^a	1.76 ^b
Mean leaf area	169.4 ^b	151.9 ^b	369.2 ^a

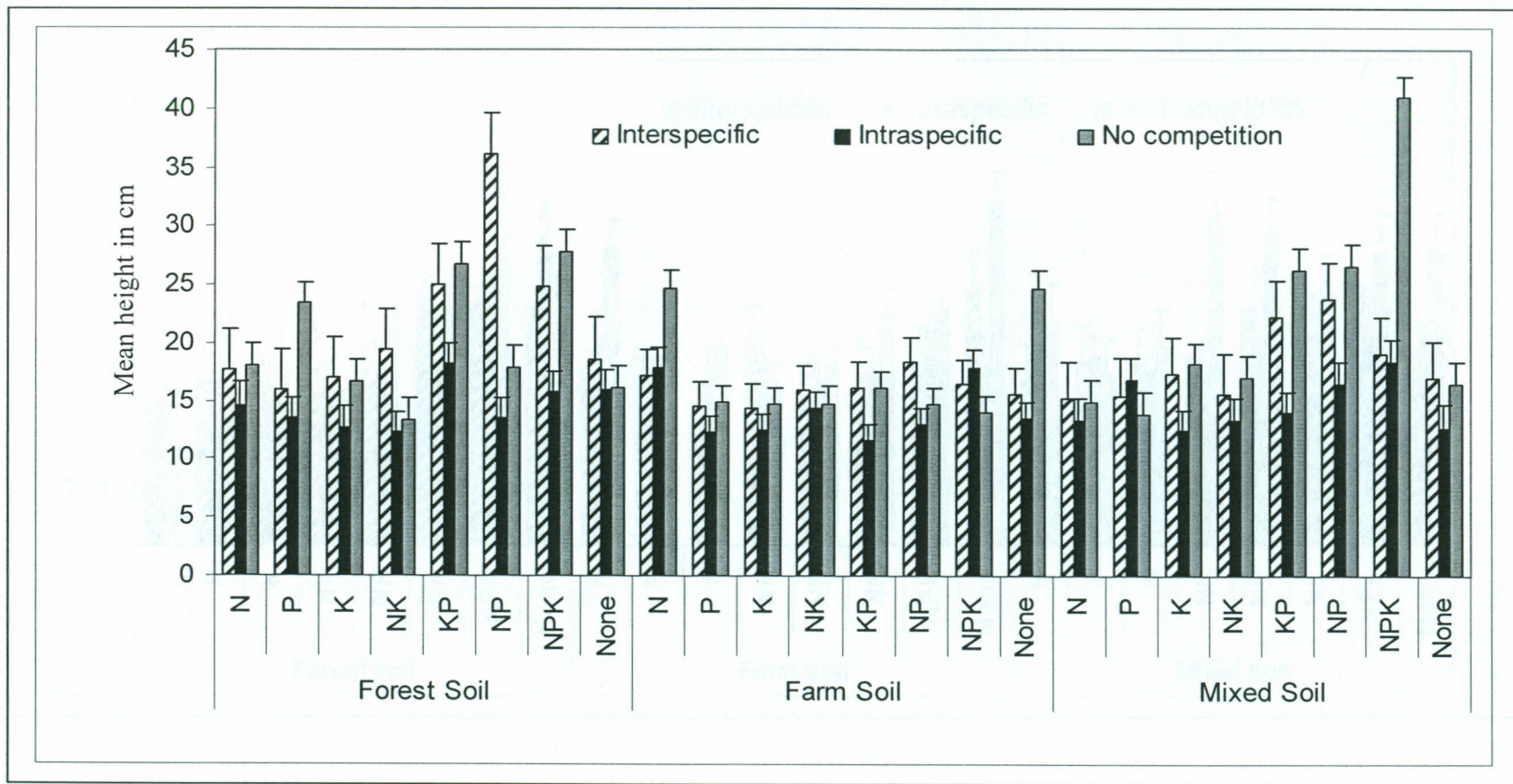


Fig. 4.21: Effects of competition on mean height of *Markhamia lutea* seedlings grown under different soil types and subjected to different nutrient regimes (vertical bars represent +1SE).

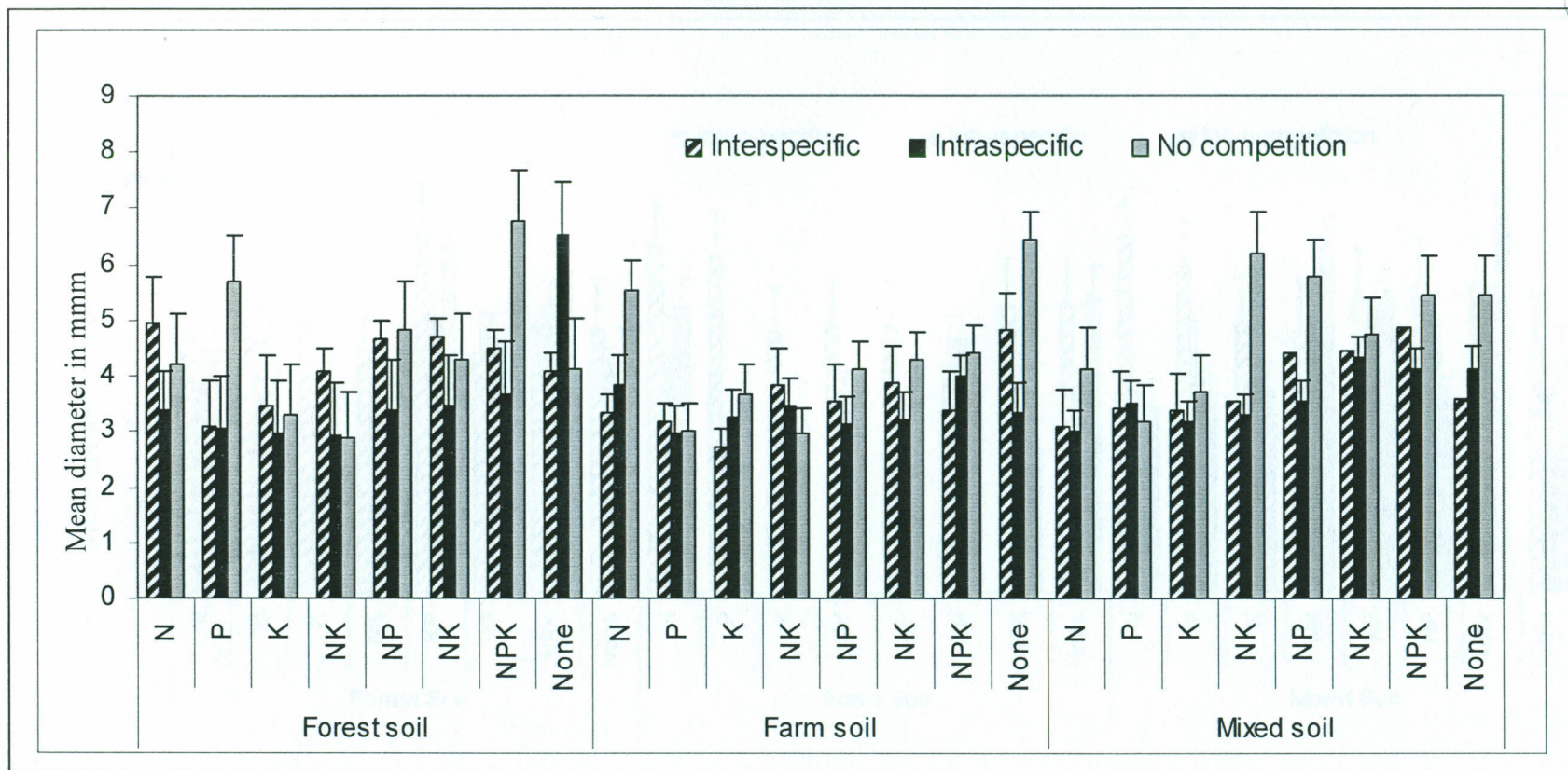


Fig. 4.22: Effects of competition on mean diameter of *Markhamia lutea* seedlings grown under different soil types and subjected to different nutrient regimes (vertical bars represent +1SE).

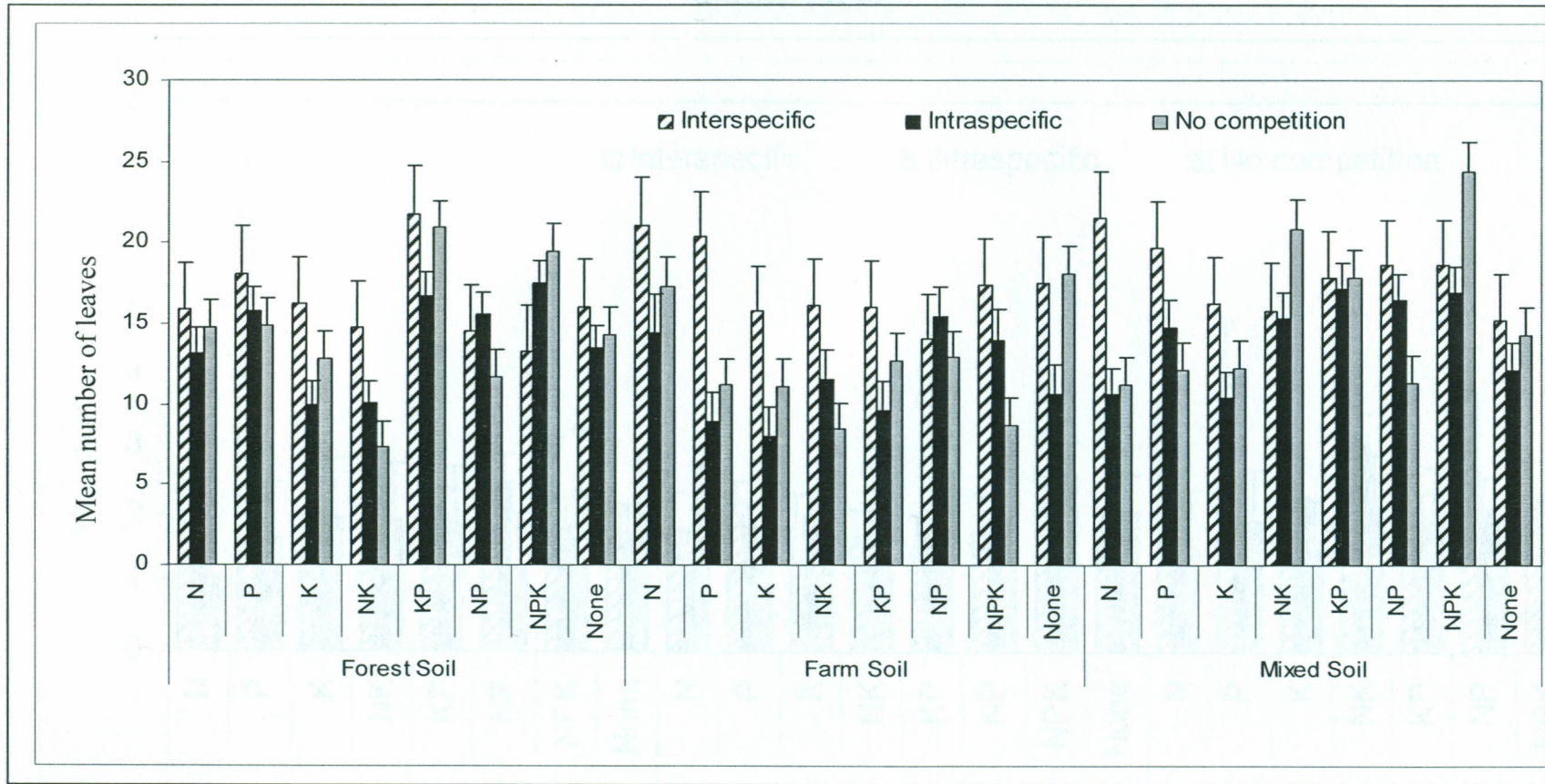


Fig. 4.23: Effects of competition on the mean number of leaves of *Markhamia lutea* seedlings grown under different soil types and subjected to different nutrient regimes (vertical bars represent +1SE).

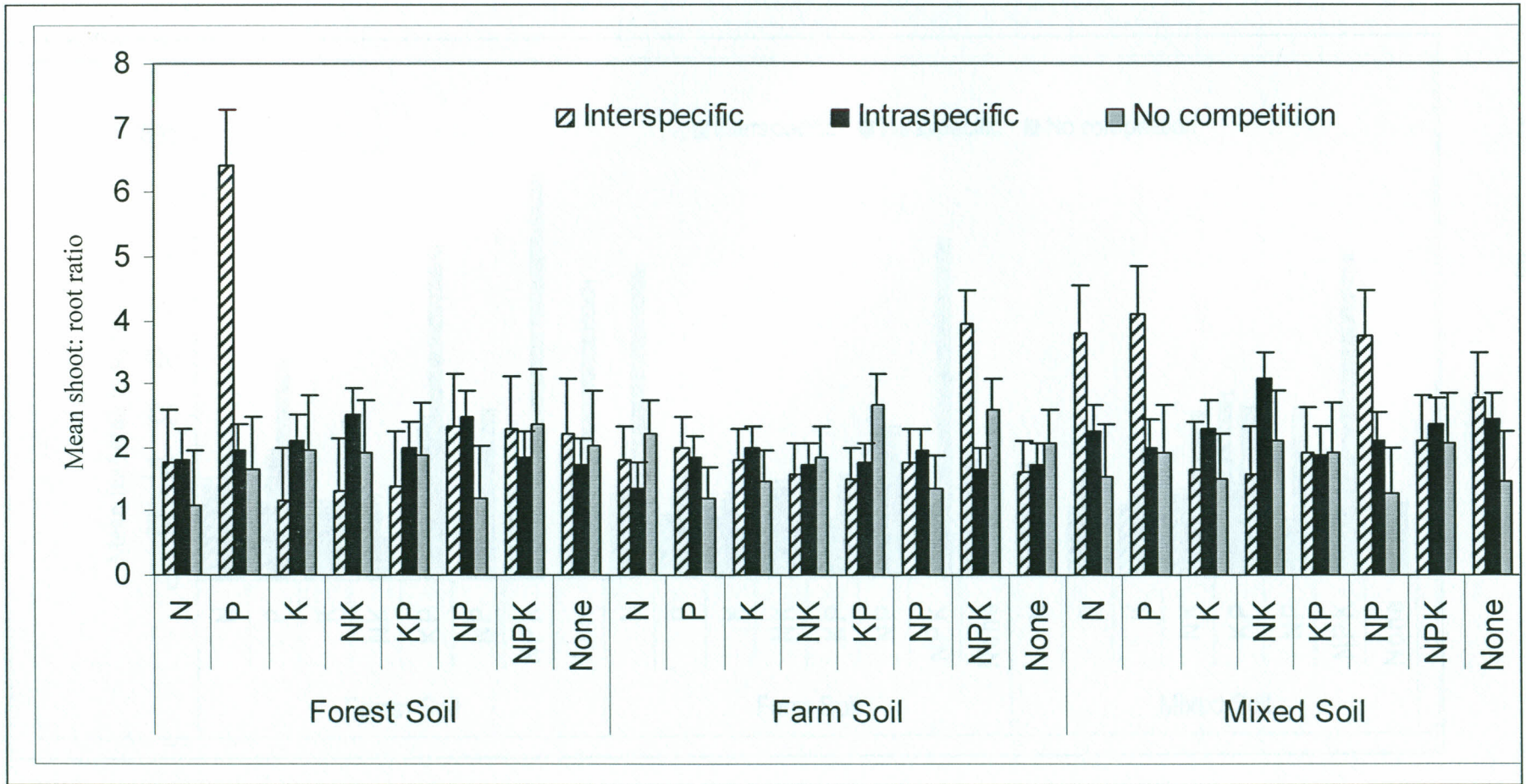


Fig. 4.24: Effects of competition on mean shoot: root ratio of *Markhamia lutea* seedlings grown under different soil types and subjected to different nutrient regimes (vertical bars represent +1SE).

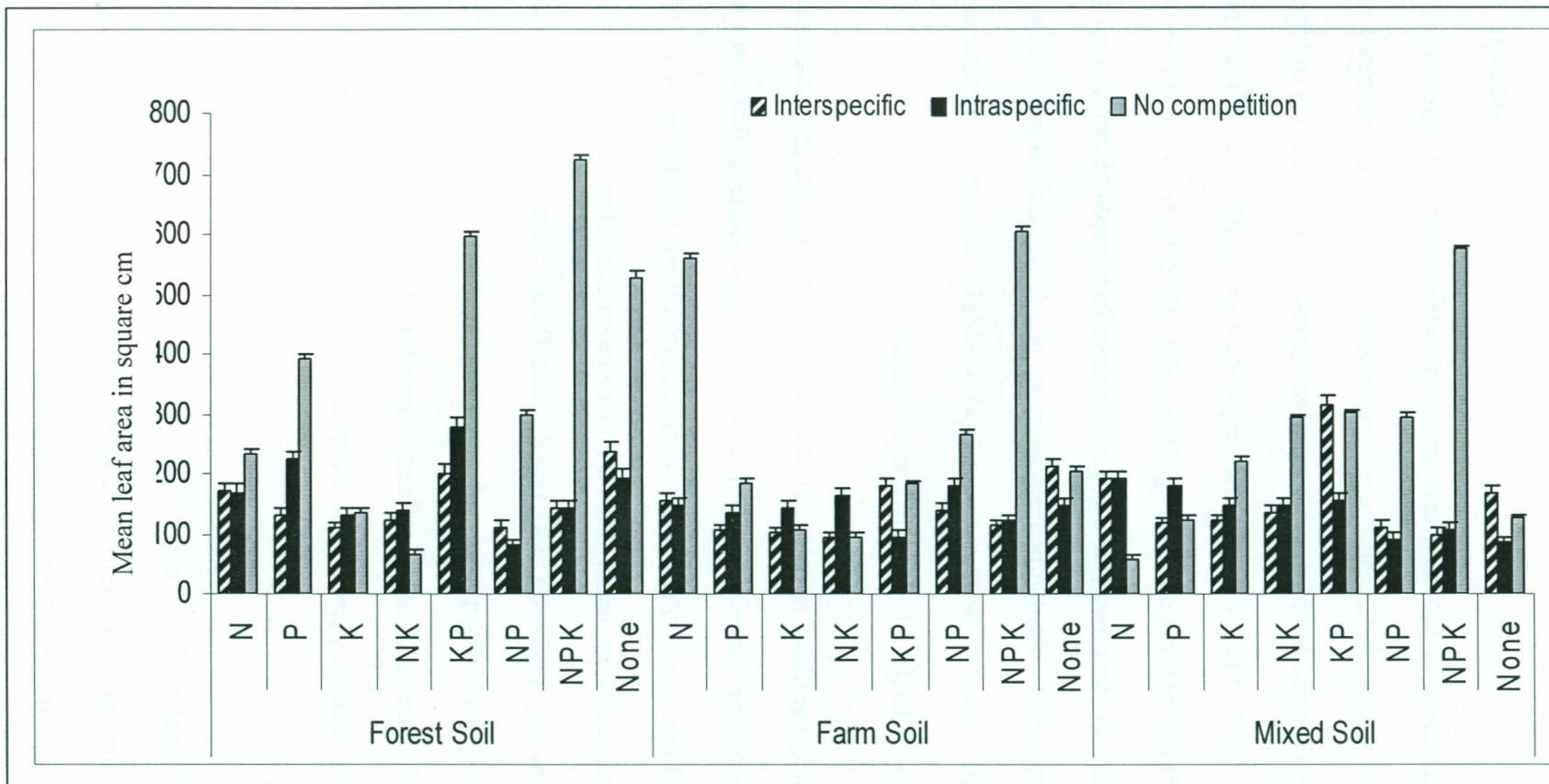


Fig. 4.25: Effects of competition on the mean leaf area of *Markhamia lutea* seedlings grown under different soil types and subjected to different nutrient regime (vertical bars represent +1SE).

4.2.3 *Olea capensis*

The largest mean height among fertilizer treatment was recorded in seedlings grown without competition in forest soil amended with potassium alone where 36.1 cm was recorded while the least mean height of 8.1 cm was recorded in seedlings grown without competition in unamended forest soil (Fig.4.26). These differences were significant ($P < 0.01$, $df = 7$) as revealed by a two way ANOVA test (Table 4.13). Overall mean seedlings mean height was significantly larger for seedlings that were grown in absence of competition (29.6 cm) compared to the seedlings grown under intraspecific competition (20.8) and interspecific competition (19.9 cm) as revealed by LSD mean separation technique (Table 4.14). The interaction between the nutrients and competition did not significantly affect seedlings mean height ($P < 0.01$, $df = 7$).

The largest mean diameter among the treatments was recorded in seedlings grown in absence of competition in forest soil amended with a combination of nitrogen and potassium (Fig. 4.27). A two way ANOVA revealed that the differences in mean diameter were significant ($P < 0.01$, $df = 2$). LSD Mean separation technique revealed that overall mean mean diameter for seedlings grown without competition was significantly larger for seedlings grown in absence of competition (5.4), while the seedlings grown under intraspecific competition (3.8) and interspecific competition (3.8) had significantly smaller mean diameter (Table 4.14). The interaction between competition and nutrient treatments significantly affected the mean diameter of the seedlings ($P < 0.01$, $df = 14$).

The mean number of leaves for the seedlings grown under interspecific competition in forest soil (19) was the largest while the seedling grown without competition in mixed soil had the smallest mean number of leaves (11) (Fig. 4.28). Using a two way ANOVA test the mean differences in

the mean number of leaves were found to be significantly different ($P < 0.01$, $df = 2$). LSD Mean separation technique revealed that the mean number of leaves for seedlings grown in absence of competition (19.8) was significantly larger than for seedlings grown in both intraspecific (12.5) competition and interspecific competition (16.6) (Table 4.14). The interaction between competition and nutrients treatments did not significantly affect leaf production ($P > 0.05$, $df = 14$).

The mean shoot: root ratio in farm soil was largest in the seedlings grown under interspecific competition (3.4) while the seedlings grown without competition in farm soil had the smallest mean shoot: root ratio of 1.7 (Fig. 4.29). A two way ANOVA test revealed that the differences in the mean shoot: root ratio among the treatments were significantly different ($P = 0.02$, $df = 2$). LSD mean separation technique further revealed that the seedlings grown under interspecific competition had significantly larger shoot:root ratio (2.7) compared to seedlings grown under intraspecific competition (2.4) and without competition (2.4). The interaction between the nutrients and competition significantly affected mean shoot: root ratio ($P = 0.001$, $df = 2$).

The seedlings mean leaf area was largest in forest soil amended with a combination of nitrogen and phosphorus (420 cm^2) while the least mean leaf area (69 cm^2) was recorded in mixed soil amended with a combination of potassium and phosphorus (Fig. 4.30). A two way ANOVA test revealed that differences in mean leaf area among competition treatments were significant at ($P < 0.01$, $df = 0.03$). LSD mean separation technique revealed that the overall mean leaf area of the seedlings grown without competition had significantly larger mean leaf area (324.3 cm^2) compared to seedling grown under intraspecific competition (126.4 cm^2) and seedlings grown

under interspecific competition (138.08) (Table 4.14). The interaction between competition and nutrient treatments also significantly affected the mean leaf area ($P < 0.01$, $df = 14$)

Table 2: ANOVA result for the effect of competition and nutrients on mean height, mean diameter, mean number of leaves, shoot to root ratio and mean leaf area on *Olea capensis* seedlings (ns= not significant, * = P, ** = $P < 0.01$, ***= $P < 0.001$)

GROWTH PARAMETER	SOURCE OF VARIATION	SS	df	MS	F-VALUE	P-VALUE
Mean height	Competition	5270	2	2635	48.5	0.000***
	Nutrients	2078	7	297	5.46	0.000***
	Competition*Nutrients	2319	14	166	3.05	0.000***
Mean diameter	Competition	1335	2	667.	4.956	0.007***
	Nutrients	2140	7	305.7	2.269	0.027*
	Competition*Nutrients	3980	142	284.3	2.11	0.009***
Mean number of leaves	Competition	5846	2	2923	14.09	0.000***
	Nutrients	3875	7	554	2.67	0.110
	Competition*Nutrients	3850	14	275	1.33	0.185 ns
Mean shoot: root ratio	Competition	47.6	2	23.82	3.614	0.027*
	Nutrients	74.5	7	10.64	1.615	0.127 ns
	Competition*Nutrients	252	14	18	2.731	0.001**
Mean leaf area	Competition	6.78	2	3.39	8.996	0.000****
	Nutrients	1.05	7	1.5	3.97	0.000****
	Competition*Nutrients	9.33	14	6.66	1.767	0.039*

Table 3: LSD Post-hoc test for *Olea capensis* seedlings grown under competition and in the absence of competition (Letters in superscript denotes significant differences)

<i>GROWTH PROPERTIES</i>	<i>Interspecific</i>	<i>Intraspecific</i>	<i>No competition</i>
Mean mean height (cm)	19.9 ^b	20.8 ^b	26.9 ^a
Mean diameter in mm	3.8 ^b	3.8 ^b	5.4 ^a
Mean number of leaves	16.6 ^b	12.5 ^c	19.8 ^a
Mean shoot: root ratio	2.7 ^a	2.4 ^b	2.4 ^b
Mean leaf area in square cm	138.08 ^b	126.4 ^b	324.3 ^a

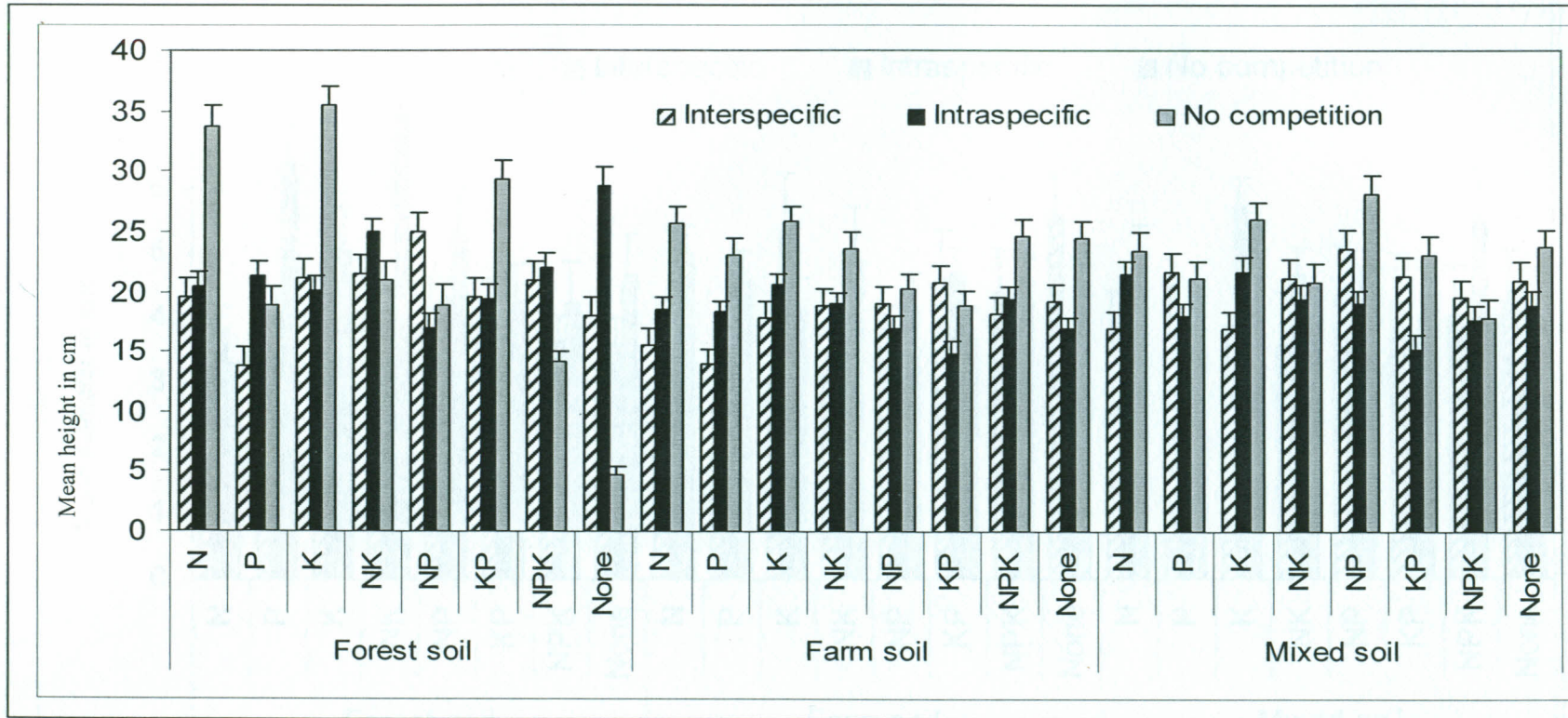


Fig.4.26: Effects of competition on mean height of *Olea capensis* seedlings grown under different soil types and subjected to different nutrient regimes (vertical bars represent +1SE).

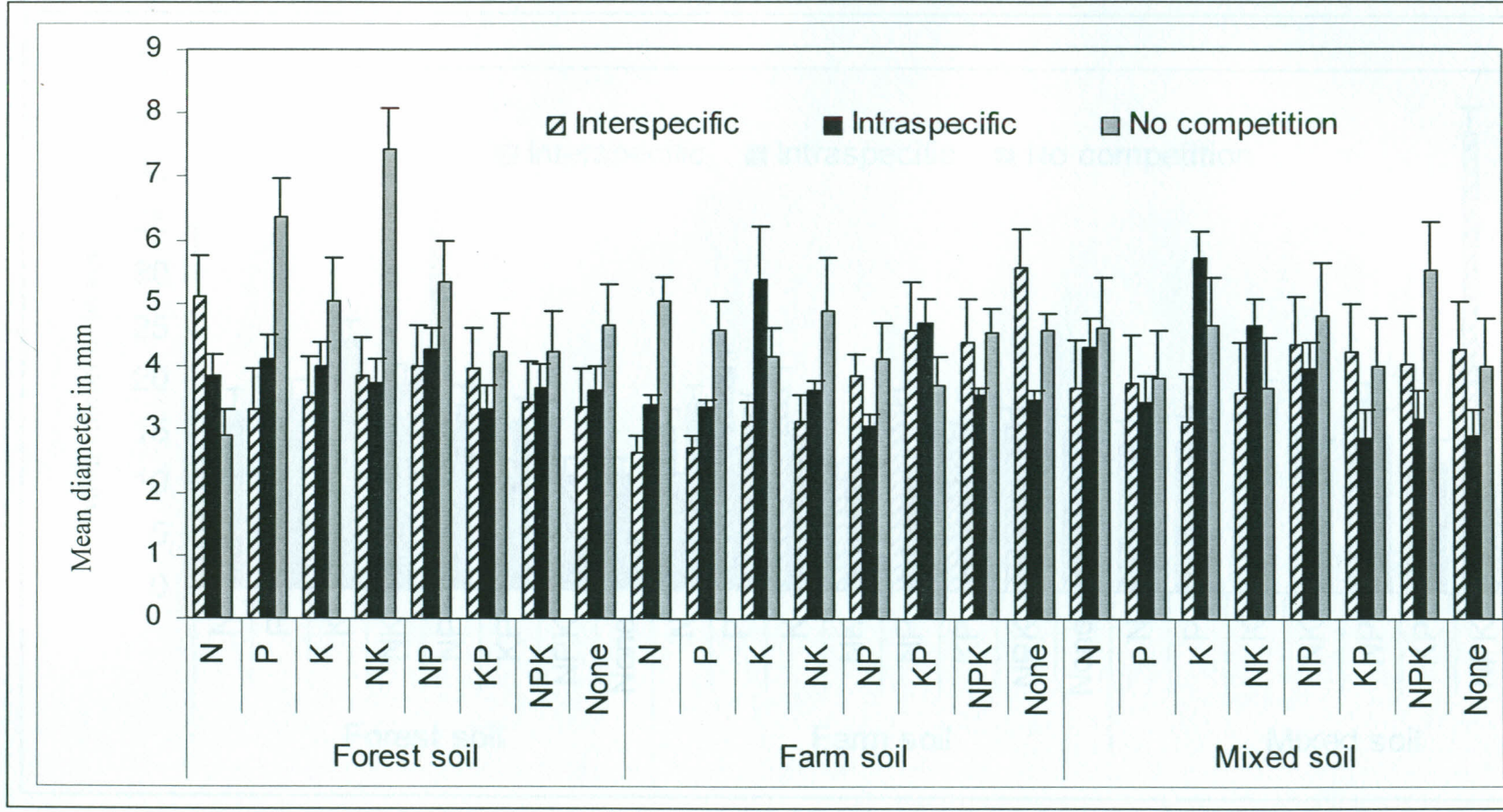


Fig. 4.27: Effects of competition on mean diameter of *Olea capensis* seedlings grown under different soil types and subjected to different nutrient regimes (vertical bars represent +1SE)

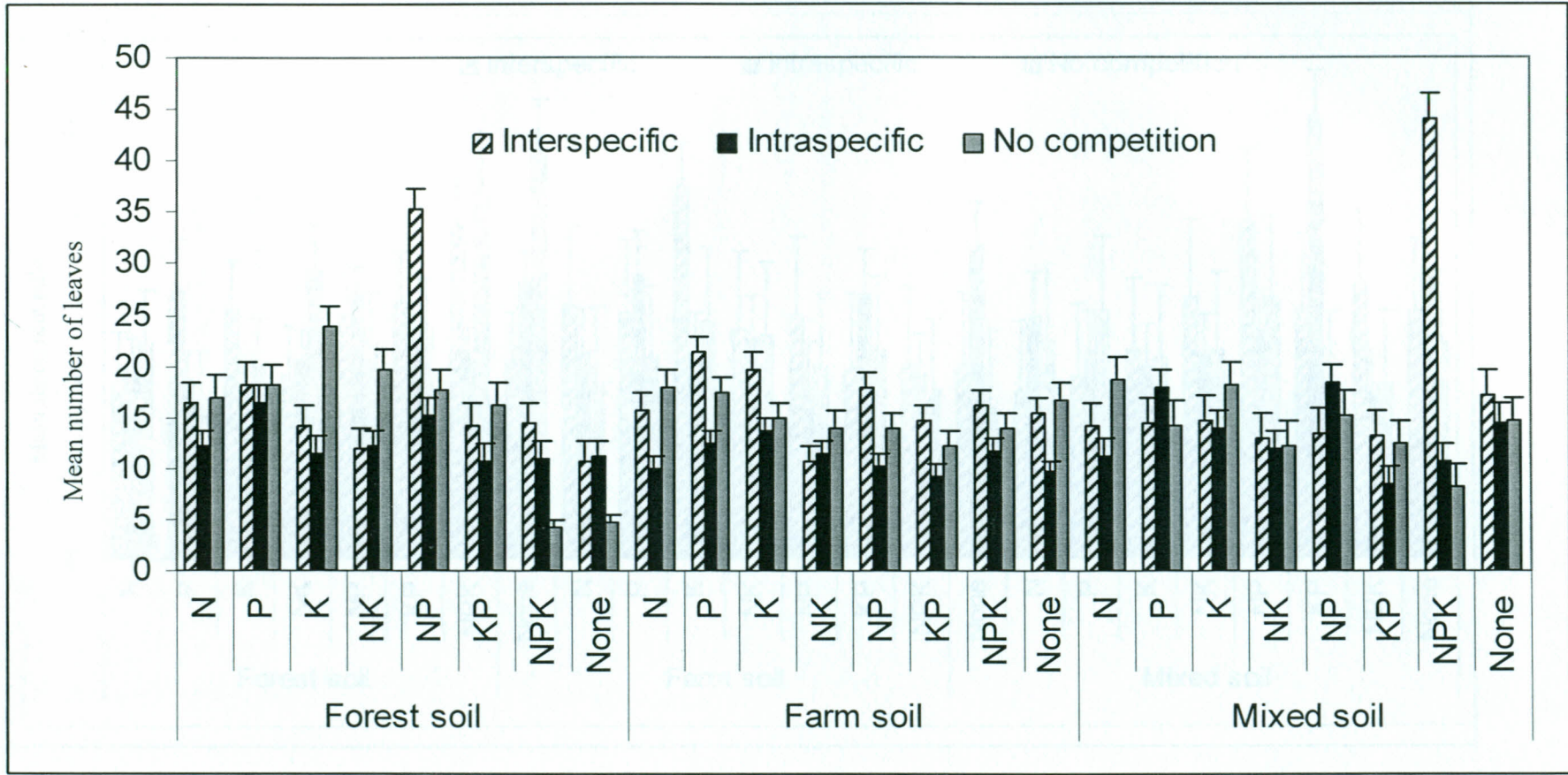


Fig. 4.28: Effects of competition on the mean number of leaves of *Olea capensis* seedlings grown under different soil types and subjected to different nutrient regimes (vertical bars represent +1SE).

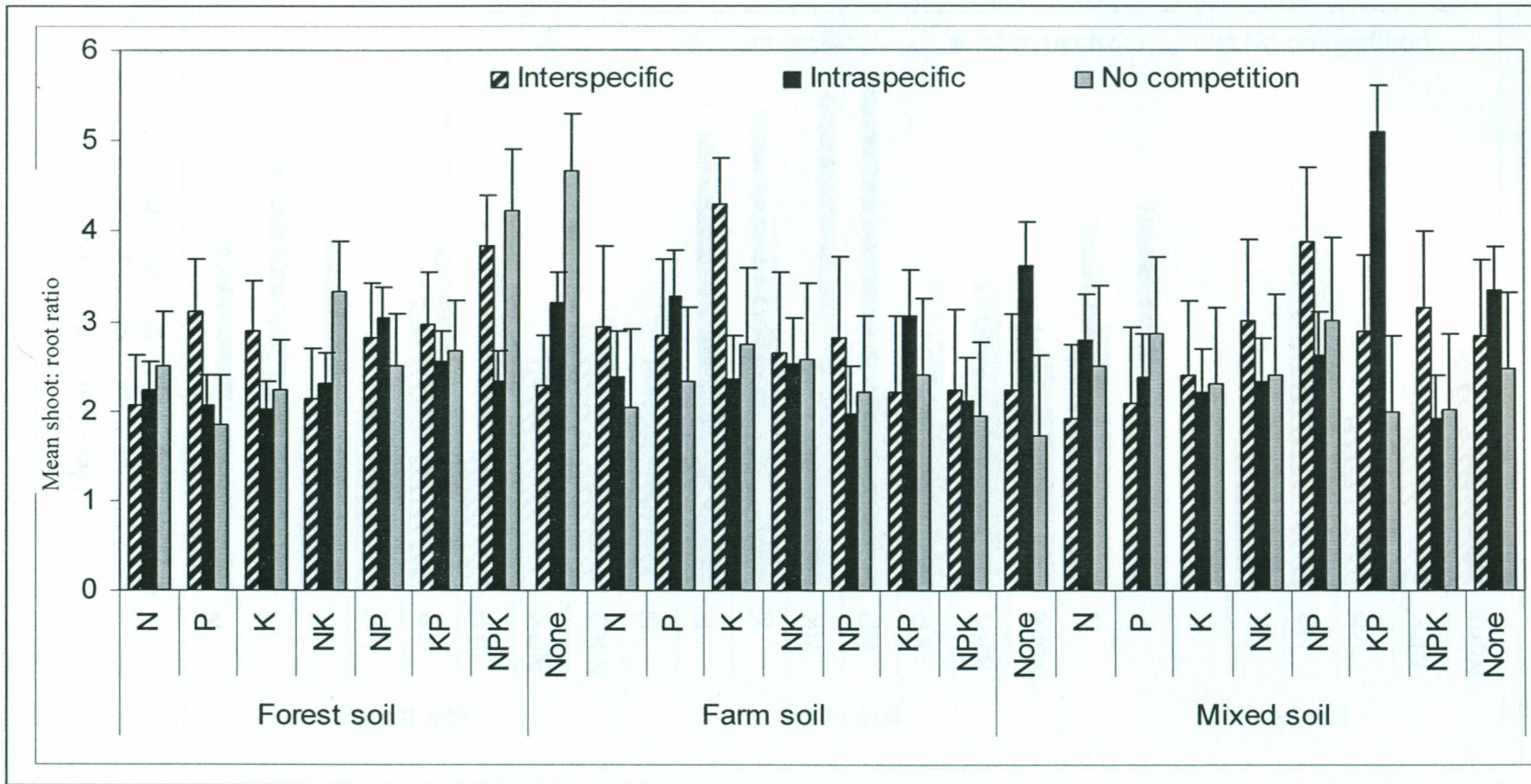


Fig. 4.29: Effects of competition on the mean shoot: root ratio of *Olea capensis* seedlings grown under different soil types and subjected to different nutrient regimes (vertical bars represent +1SE).

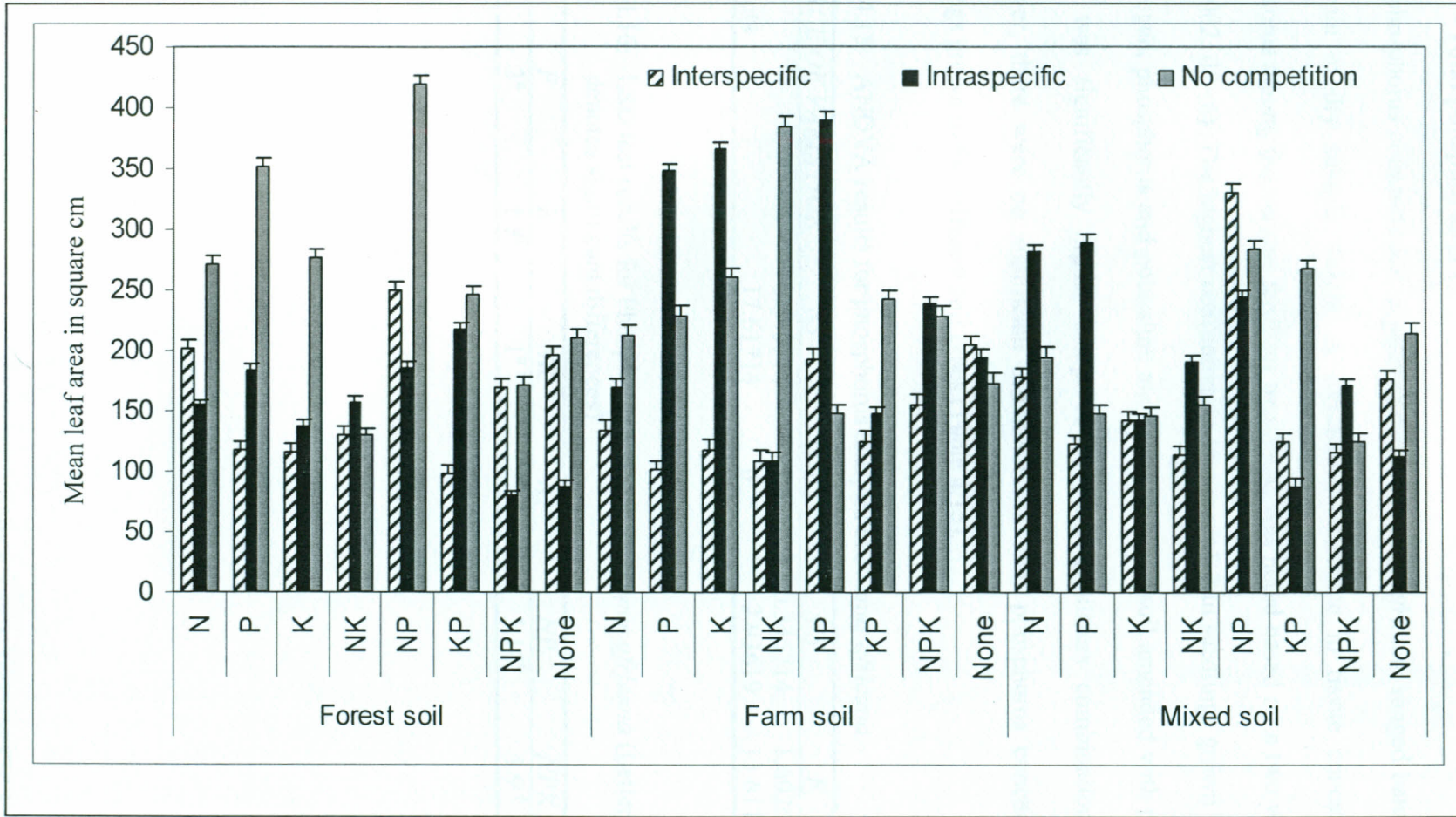


Fig. 4.30: Effects of competition on the mean leaf area of *Olea capensis* seedlings grown under different soil types and subjected to different nutrient regimes (vertical bars represent +1SE).

4.3 Plant samples analysis

4.3.1 Total phosphorus (TP)

Total phosphorus concentration in plant tissues of *Prunus africana* ranged between 0.4 to 2 mg per gram of dry sample weight. A significant difference in tissue concentration of total phosphorus among the various fertilizer treatments was noted based on a two way ANOVA test ($P= 0.002$, $df =6$). The highest concentration was recorded in seedlings grown in a combination of nitrogen, phosphorus and potassium and those grown in soil amended with phosphorus alone which was significantly higher compared to other fertilizers combinations (Table 4.16). However, there were no significant differences in total phosphorus concentration between seedlings grown in the different soil types (Table 4.15).

Table 4.15: ANOVA results for phosphorus analysis in *Prunus africana*

SOURCE OF VARIATION	SS	df	MS	F	P-value
Soil	0.345714	1	0.345714	1.602649	0.25246 ns
Nutrients	17.61714	6	2.93619	13.61148	0.002886**

Table 4.16: LSD test results for Phosphorus analysis in *Prunus africana* (Letters in superscript denotes significant differences)

N	P	K	NK	KP	NP	NPK	C
0.46 ^b	3 ^a	1.8 ^b	1 ^b	2.7 ^a	1.16 ^b	3.9 ^a	1.13 ^b

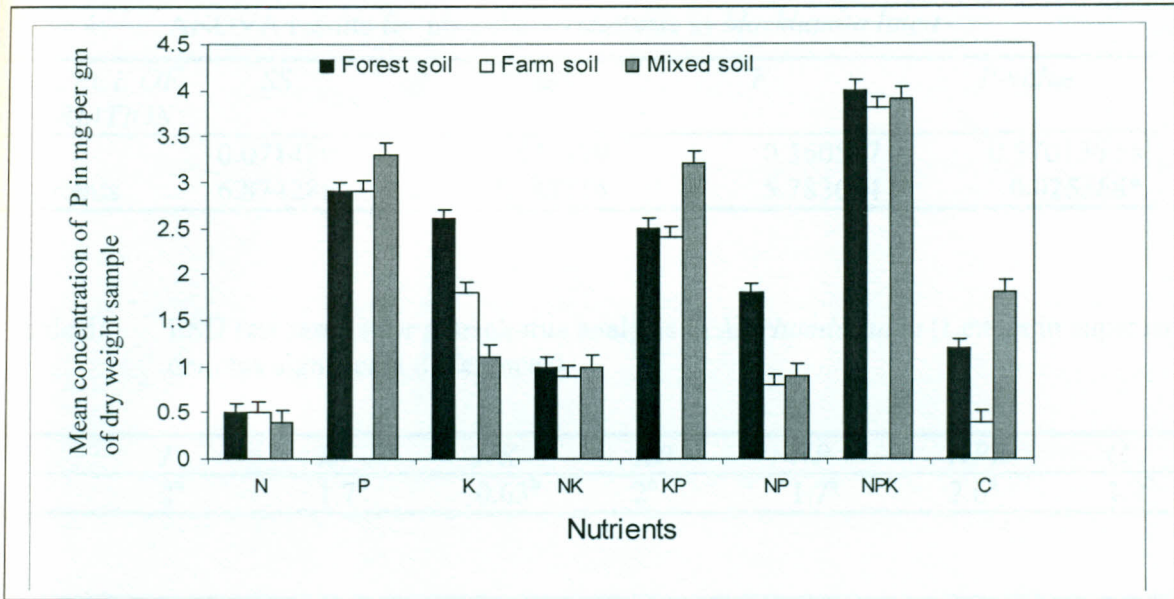


Fig.4.31: Mean total phosphorus concentration in plant tissues of *Prunus africana* grown in different nutrient combinations (vertical bars represent +1 SE)

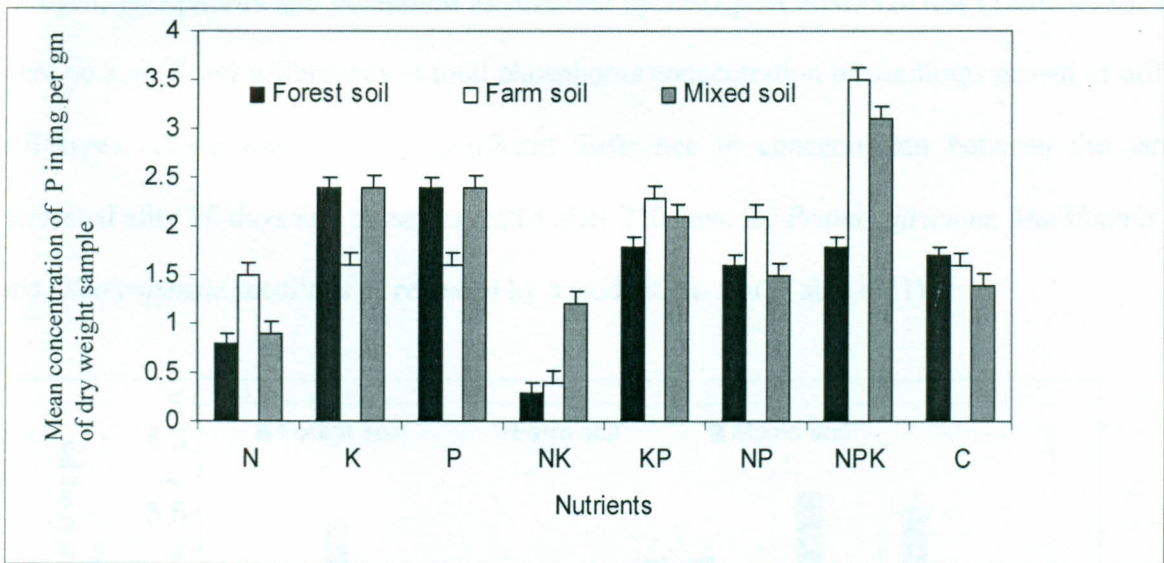
The concentration of total phosphorus (TP) in plant tissues of *Markhamia lutea* ranged from 0.2 to 3.25 mg per gram of dry sample weight. Based on a two way ANOVA test, a significant difference in tissue concentration of TP among the various fertilizer treatments was noted ($P=0.02$, $df=6$). The highest concentration was recorded in seedlings grown in a combination of nitrogen, phosphorus and potassium and those grown in soil amended with phosphorus alone which were significantly higher compared to other fertilizers combinations as revealed by an LSD post ANOVA test (Table 4.18). However, there were no significant differences in the total phosphorus concentration of seedlings grown in different soil types (Table 4.17).

Table 4: ANOVA results for phosphorus analysis in *Markhamia lutea*

SOURCE OF VARIATION	SS	df	MS	F	P-value
Soil	0.071429	1	0.071429	0.360577	0.570156 ns
Nutrients	6.874286	6	1.145714	5.783654	0.025368*

Table 5: LSD test results for phosphorus analysis in *Marhamia lutea* (Letters in superscript denotes significant differences)

N	P	K	NK	KP	NP	NPK	C
1 ^b	2 ^a	1.7 ^b	0.63 ^b	2 ^a	1.7 ^a	2.6 ^a	1.2 ^b

Fig.4.32: Mean total phosphorus concentration in plant tissues of *Markhamia lutea* grown in different nutrient combinations (vertical bars represent +1 SE)Table 6: ANOVA results for phosphorus analysis in *Olea capensis*

SOURCE OF VARIATION	SS	df	MS	F	P-value
Soil	0.017857	1	0.017857	0.051582	0.827874 ns
Nutrients	22.17714	6	3.69619	10.67675	0.005502**

Table 4.20: LSD test results for phosphorus analysis in *Olea capensis* (Letters in superscript denotes significant differences)

N	P	K	NK	KP	NP	NPK	C
0.7 ^b	2.7 ^a	0.9 ^b	0.6 ^b	2.9 ^a	3.5 ^a	3.2 ^a	0.8 ^b

Total phosphorus concentration in *Olea capensis* seedlings ranged from 0.2 to 3.6 mg per gram of dry sample weight. A two way ANOVA revealed that there were significant differences in the tissue concentration of TP among the seedlings grown in different fertilizer combinations ($P = 0.005$, $df = 6$). The highest concentration was recorded in seedlings grown in a combination of nitrogen, phosphorus and potassium as revealed by LSD post ANOVA test (Table 4.20). There were no significant differences in total phosphorus concentration of seedlings grown in different soil types. There was also no significant difference in concentration between the samples harvested after 70 days and those harvested after 210 days for *Prunus africana*, *Markhamia lutea* and *Olea capensis* seedlings as revealed by a student's t- test (Table 4.21).

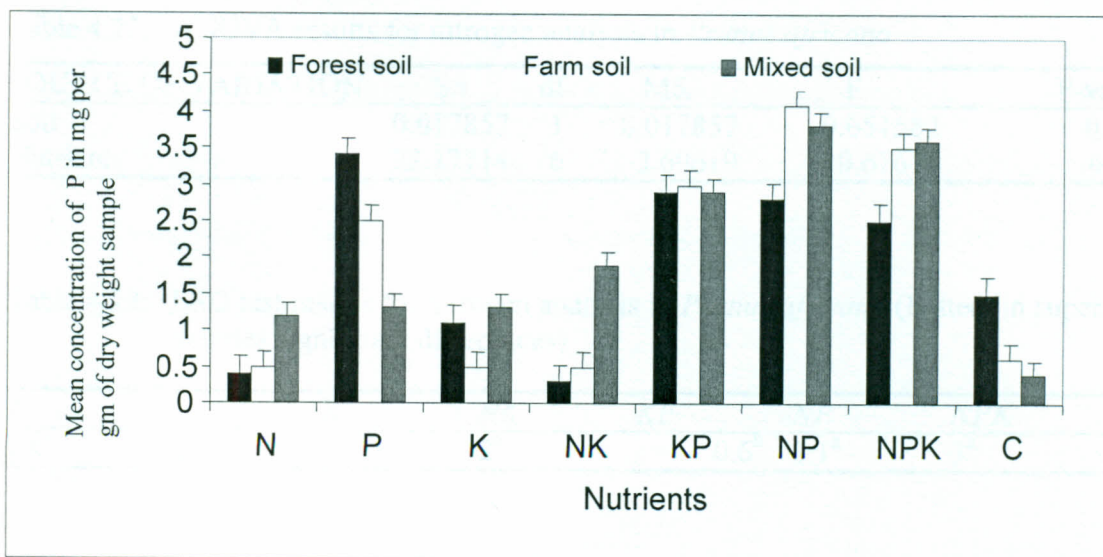


Fig. 4.33: Mean total phosphorus concentration in plant tissues of *Olea capensis* grown in different nutrient combinations (vertical bars represent +1 SE)

Table 4.21: Results of t- test to compare mean values of total phosphorus in plant tissues of the seedlings of the three species

Species	Mean 70 days	Mean 210 days	t-value	df	P
<i>Prunus africana</i>	2.5	2.45	0.3236	48	0.7476
<i>Markhamia lutea</i>	1.8	1.8	0.16	48	0.8
<i>Olea capensis</i>	2.2	2.19	1.12	48	0.26

4.3.2 Total nitrogen

The concentration of tissue nitrogen in *Prunus africana* ranged from 0.3 to 1.55 mg per gram of dry sample weight. A two way ANOVA revealed that there were significant differences in the tissue concentration of nitrogen among the seedlings grown in different fertilizer combinations ($P=0.005$, $df=6$). The highest concentration was recorded in seedlings grown in a combination of nitrogen and phosphorus and in soil amended with a combination of the three nutrients as revealed by LSD post ANOVA test (Table 4.23). However, there were no significant differences between the total nitrogen concentrations in the different soil types ($P= 0.82$, $df=1$).

Table 4.22: ANOVA results for nitrogen analysis in *Prunus africana*

SOURCE OF VARIATION	SS	df	MS	F	P-value
Soil	0.017857	1	0.017857	0.051582	0.827874 ns
Nutrients	22.17714	6	3.69619	10.67675	0.005502**

Table 4.23: LSD test results for nitrogen analysis in *Prunus africana* (Letters in superscript denotes significant differences)

N	P	K	NK	KP	NP	NPK	C
2.4 ^a	1.1 ^b	0.9 ^b	2 ^b	0.6 ^b	3.1 ^a	3 ^a	0.8 ^b

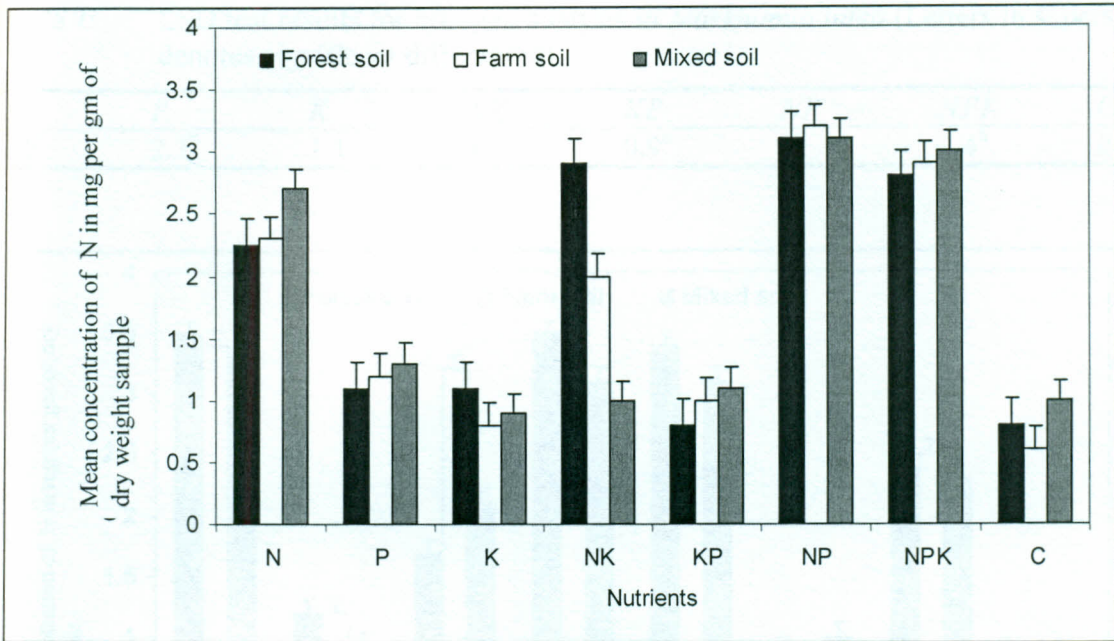


Fig. 4.34: Mean total nitrogen concentration in plant tissues of *Prunus africana* grown in different nutrient combinations (vertical bars represent +1 SE)

The concentration of total nitrogen in *Markhamia lutea* seedlings ranged from 0.37 to 1.75 mg per gram of dry sample weight in *Markhamia lutea*. A two way ANOVA test showed a significant difference in tissue concentration of nitrogen between the various fertilizer treatments ($P=0.0001$, $df=6$). LSD post ANOVA test revealed that the highest concentration was recorded in seedlings grown in soil amended with nitrogen fertiliser (Table 4.25). However, there were no significant differences between the total nitrogen concentrations in the different soil types as revealed by student's t- test ($P=0.72$, $df=1$) (Table 4.26).

Table 4.24: ANOVA results for nitrogen analysis in *Markhamia lutea*

SOURCE OF VARIATION	SS	df	MS	F	P-value
Soil	0.223333	2	0.111667	0.324119	0.728448 ns
Nutrients	24.56292	7	3.508988	10.18504	0.000147***

Table 7: LSD test results for nitrogen analysis in *Markhamia lutea* (Letters in superscript denotes significant differences)

<i>N</i>	<i>P</i>	<i>K</i>	<i>NK</i>	<i>KP</i>	<i>NP</i>	<i>NPK</i>	<i>C</i>
3.4 ^a	2.3 ^b	1.1 ^c	3.3 ^a	0.9 ^c	3 ^a	2.4 ^b	0.8 ^c

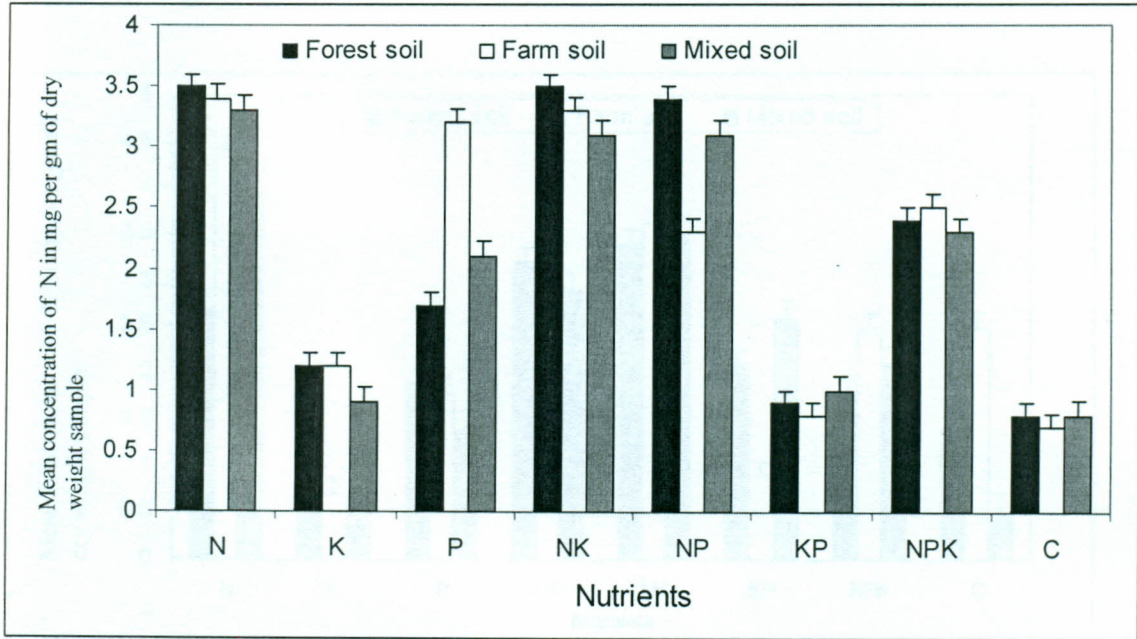


Fig. 4.35: Mean total nitrogen concentration in plant tissues of *Markhamia lutea* grown in different nutrient combinations (vertical bars represent + 1 SE)

Total nitrogen concentration in *Olea capensis* ranged from 0.27 to 2.17 mg per gram of dry sample weight. The highest concentration was also recorded in the combination of nitrogen, phosphorus and potassium (Fig. 4.27). However, a two way ANOVA showed that the differences were not significant ($P = 0.06$, $df = 6$). The differences in concentration among the different soils were also not significant ($P = 0.61$, $df = 1$) (Table 4.26). Student's t-test revealed no significant difference in concentration between the samples harvested after 70 days and those harvested after 210 days for the three species (Table 4.28).

Table 4.26: ANOVA results for nitrogen analysis in *Olea capensis*

SOURCE OF VARIATION	SS	df	MS	F	P-value
Soil	0.130179	1	0.130179	0.282376	0.614236
Nutrients	10.74464	6	1.790774	3.884442	0.061618

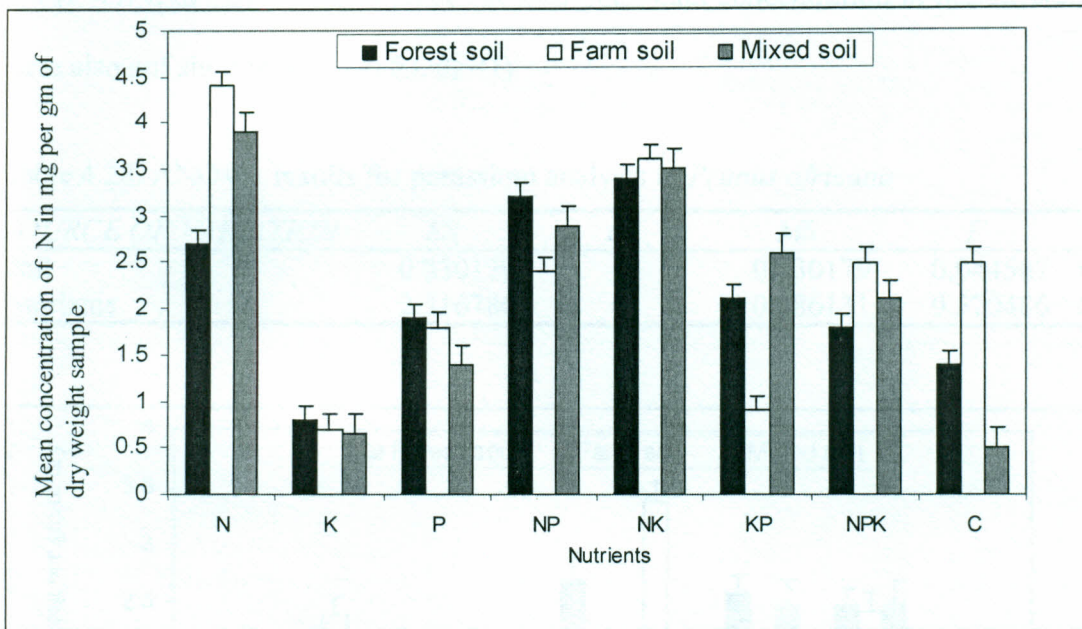
Fig. 4.36: Mean total nitrogen concentration in plant tissues of *Olea capensis* grown in different nutrient combinations (vertical bars represent +1 SE)

Table 4.27: Results of t- test to compare mean values of total nitrogen concentration in plant tissues of the three species

Species	Mean 70 days	Mean 210 days	t-value	df	p
<i>Prunus africana</i>	0.76	1.1	2.08	48	0.052
<i>Markhamia lutea</i>	1	1	0.136	48	0.089
<i>Olea capensis</i>	1.1	1	0.089	48	0.929

4.3.3 Potassium

The concentration of total potassium in *Prunus africana* ranged from 0.47 to 1.75 mg per gram of dry sample weight. The differences in concentration were no significant among the seedlings grown in soil amended with different fertilizer combinations as revealed by a two way ANOVA test ($P=0.74$, $df=6$). The differences in total potassium concentration in the different soils there were also not significant ($P=0.83$, $df=1$).

Table 4.28: ANOVA results for potassium analysis in *Prunus africana*

SOURCE OF VARIATION	SS	df	MS	F	P-value
Soil	0.030179	1	0.030179	0.044587	0.839754 ns
Nutrients	2.316786	6	0.386131	0.570486	0.743899 ns

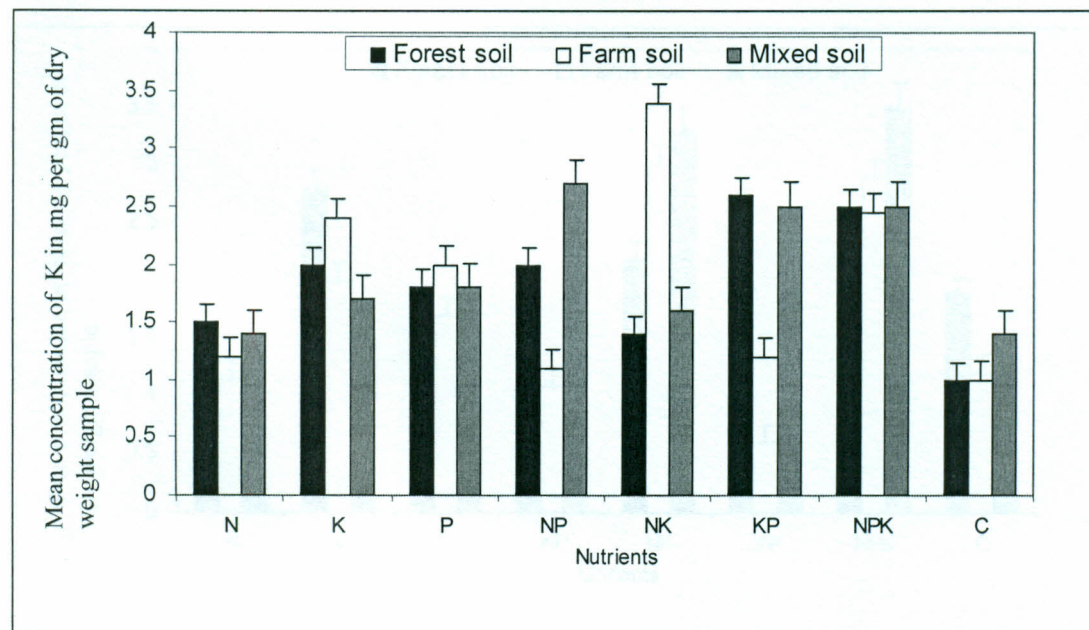


Fig. 1.37: Mean total potassium concentration in plant tissues of *Prunus africana* grown in different nutrient combinations (vertical bars represent +1 SE)

The concentration of total; potassium ranged from 0.27 to 1.8 mg per gram of dry sample weight in *Markhamia lutea* seedlings. The differences in total potassium concentration were found to be significant after conducting a two-way ANOVA test ($P=0.003$, $df=6$). The highest concentration

was recorded in seedlings grown in a combination of nitrogen, phosphorus and potassium and a combination of nitrogen and potassium (Table 4.30). However, there were no significant differences between potassium concentrations in the three soil types ($P=0.70$, $df=1$).

Table 4.29: ANOVA results for potassium analysis in *Markhamia lutea*

SOURCE OF VARIATION	SS	df	MS	F	P-value
Soil	0.025714	1	0.025714	0.155172	0.707259 ns
Nutrients	12.93429	6	2.155714	13.00862	0.003259**

Table 4.30: LSD test results for potassium analysis in *Markhamia lutea* (Letters in superscript denotes significant differences)

<i>N</i>	<i>P</i>	<i>K</i>	<i>NK</i>	<i>KP</i>	<i>NP</i>	<i>NPK</i>	<i>C</i>
1 ^b	0.9 ^b	2.1 ^a	2.8 ^a	1.4 ^b	0.9 ^b	2.3 ^a	1.5 ^b

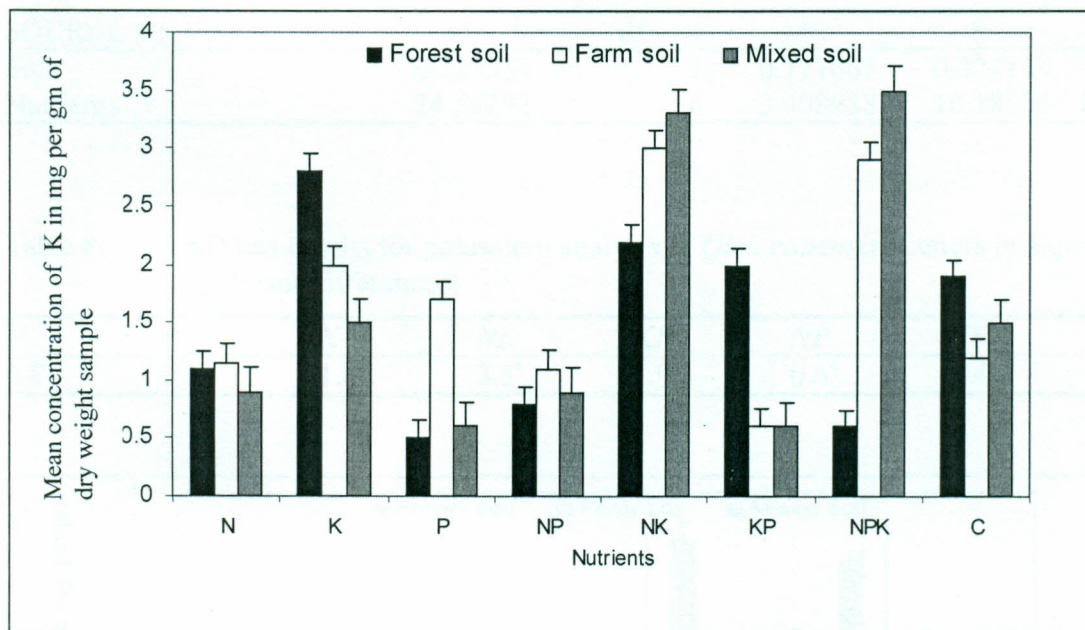


Fig. 4.38: Mean total potassium concentration in plant tissues of *Markhamia lutea* grown in different nutrient combinations

Concentration of total potassium in *Olea capensis* ranged from 0.32 to 1.9 mg per gram of dry sample weight. The differences in total potassium concentration were found to be significant after conducting a two way ANOVA test ($P=0.0001$, $df=6$). The highest concentration was also recorded in the combination of nitrogen, phosphorus and potassium (Table 4.32). There were no significant differences in concentration among the different soil types ($P=0.70$, $df=1$). There was no significant difference in concentration between the samples harvested after 70 days and those harvested after 210 days for the three species (Table 4.33) as revealed by student's t- test. The average concentration of total phosphorus and potassium was highest in *Olea capensis* and lowest in *Prunus africana* while the nitrogen concentration was highest in *Markhamia lutea*.

Table 4.31: ANOVA results for potassium analysis in *Olea capensis*

SOURCE OF VARIATION	SS	df	MS	F	P-
Soil	0.223333	1	0.111667	0.324119	0.728448 ns
Nutrients	24.56292	6	3.508988	10.18504	0.000147***

Table 8: LSD test results for potassium analysis in *Olea capensis* (Letters in superscript denotes significant differences)

N	P	K	NK	KP	NP	NPK	C
0.8 ^c	1 ^c	1.8 ^b	3.5 ^a	1.9 ^b	0.6 ^c	3.4 ^a	1.2 ^c

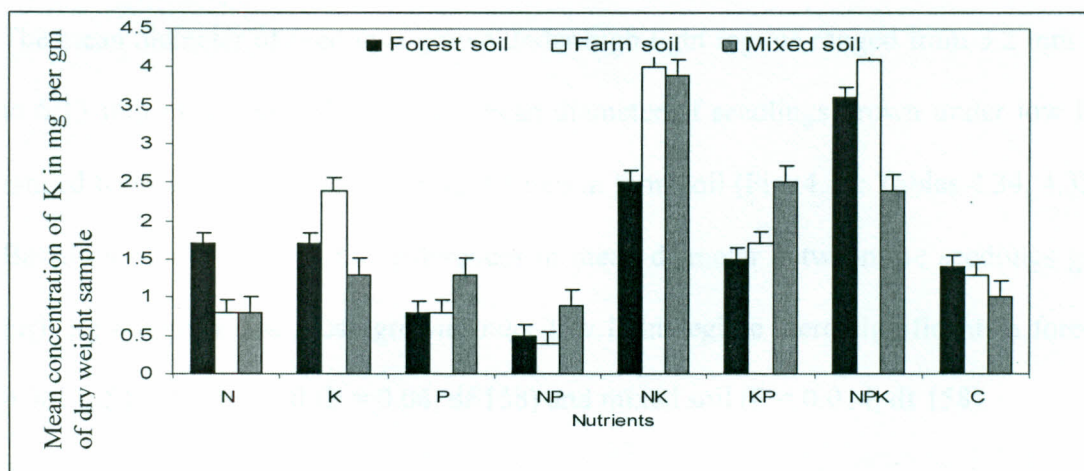


Fig. 4.39: Mean total potassium concentration in plant tissues of *Olea capensis* grown in different nutrient combinations (vertical bars represent +1 SE)

Table 4.33: Results of t- test to compare mean values of potassium concentration in plant tissues of the three species

SPECIES	Mean 70 days	Mean 210 days	t-value	df	P- value
<i>Prunus africana</i>	0.7	0.94	1.11	48	0.27
<i>Markhamia lutea</i>	0.74	0.76	1.17	48	0.24
<i>Olea capensis</i>	0.85	1.02	0.822	32	0.40

4.4 The effect of light on *Prunus africana*

The mean height of seedlings grown under high light regime ranged from 25 cm in mixed soil to 27.1 cm in forest soil while the mean height of those seedlings grown under low light regime ranged between 18.6 cm in mixed soil to 22.7 cm in farm soil (Fig. 4.40; Tables 4.34, 4.35 and 4.36). Based on Student's t-test the differences in seedlings mean height between the seedlings grown under high light regime and those grown under low light regime were significant in forest soil, ($t=2.5$, $df=158$, $P=0.013$) and in mixed soil, ($t=2.4$, $df=158$, $P=0.017$). However, the mean height was not significantly different in farm soil ($t=0.52$, $df=158$, $P=0.049$).

The mean diameter of seedlings grown under high light regime ranged from 3.2 mm in farm soil to 6.13 mm in mixed soil while the mean diameter of seedlings grown under low light regime ranged from 2.3 mm in mixed soil to 2.7 mm in farm soil (Fig. 4.41; Tables 4.34, 4.35 and 4.36). Based on Student's t-test the differences in mean diameter between the seedlings grown under high light regime and those grown under low light regime were significant in forest soil ($P < 0.001$, $df=158$), farm soil ($P=0.04$, $df=158$) and mixed soil ($P=0.014$, $df=158$).

Mean leaf number for seedlings grown under high light regime ranged from 11.5 in farm soil to 14.7 in forest soil while mean number of leaves of those seedlings grown under low light regime ranged between 10.2 in farm soil to 13.8 in forest soil (Fig. 4.42; Tables 4.34, 4.35 and 4.36). However, the differences in the mean number of leaves between the seedlings grown under high light and those grown under low light regime were not significant as revealed by Student's t-test, in forest soil, ($P = 0.7$, $df = 158$) in farm soil, ($P = 0.2$, $df = 158$), and in mixed soil ($P = 0.4$, $df = 158$).

The mean shoot: root ratio for the seedlings grown under high light regime ranged from 2.4 in both the farm soil and mixed soil to 3.5 in forest soil while the mean shoot: root ratio of those seedlings grown under low light regime ranged from 3.6 in both farm soil and forest soil to 4.4 in mixed soil (Fig. 4.43; Tables 4.34, 4.35 and 4.36). Student's t-test revealed that the differences in mean shoot: root ratio between the seedlings grown under high light and those grown under low light regime were significant in farm soil, ($P = 0.001$, $df = 158$) and mixed soil ($P = 0.02$, $df = 158$) but not significant in forest soil ($P = 0.30$, $df = 158$).

The mean leaf area of seedlings grown under high light regime ranged from 141.2 cm² in farm soil to 148.4 cm² in forest soil while the mean leaf area of those seedlings grown under low light regime ranged between 138.4 cm² in farm soil to 142.7 cm² in mixed soil (Fig. 4.44; Tables 4.34, 4.35 and 4.36). However, Student's t-test showed that the differences in mean leaf area between the seedlings grown under high light and those grown under low light regime were not significant in forest soil ($P = 0.6$, $df = 158$), farm soil, ($P = 0.89$, $df = 158$) and mixed soil ($P = 0.8$, $df = 158$).

The proportion of leaves infected ranged from 0.22 in mixed soil to 0.26 for the seedlings grown under high light regime in forest soil while in seedlings grown under low light regime, the proportion of infected leaves ranged between 0.48 in forest soil to 0.57 in farm soil (Fig. 4.45; Table 4.34, 4.35 and 4.37). Student's t-test revealed that the differences in proportion of leaves infected between the seedlings grown under high light and those grown under low light regime were significant in forest soil, ($P < 0.001$, $df = 158$), in farm soil ($P < 0.001$, $df = 158$) and in mixed soil ($P < 0.001$, $df = 158$). Hence the seedling grown under low light regime had significantly higher proportion of leaves infected than the seedlings grown under high light regime in forest soil, farm soil and mixed soil.

Table 9: Results of t- tests comparing mean values of growth properties of *Prunus africana* grown under low light regime and high light regimes in forest soil (mean CONT=low light regime, EXP = high light regime, ns=not significant, * = $P < 0.05$, **= $P < 0.01$, $P < 0.001$)

PARAMETER	MEAN EXP	MEAN CONT	t-VALUE	df	P-VALUE
Mean height	27.152	22.391	2.504	158	0.013286*
Mean diameter	4.294	2.660	3.524	158	0.000555***
Mean number of leaves	14.777	13.805	0.356	158	0.721697 ns
Mean shoot: root ratio	3.593	3.667	1.039	158	0.299953 ns
Mean leaf area	148.450	139.910	0.480	158	0.631412 ns
Proportion of leaves infected	0.288	0.484	4.207	158	0.000043***

Table 4.35: Results of t- tests comparing mean values of growth properties of *Prunus africana* grown under low light regime and high light regimes in farm soil (mean CONT=low light regime, EXP = high light regime, ns=not significant, * = $P < 0.05$, **= $P < 0.01$, $P < 0.001$)

PARAMETER	MEAN EXP	MEAN CONT	t-TEST	df	P-VALUE
Mean height	25.105	22.781	0.526	158	0.049919
Mean diameter	3.225	2.7279	2.0646	158	0.040577*
Mean number of leaves	11.512	10.234	1.2152	158	0.226067 ns
Mean shoot: root ratio	2.491	3.6339	3.243	158	0.001442***
Mean leaf area	141.260	138.488	0.136	158	0.89161 ns
Proportion of leaves infected	0.2625	0.5716	5.067	158	0.000001***

Table 4.36: Results of t- tests comparing mean values of growth properties of *Prunus africana* grown under low light and high light regimes in the mixture of forest and farm soil. (mean CONT=low light regime, EXP = high light regime, ns=not significant, * = $P < 0.05$, **= $P < 0.01$, $P < 0.001$)

PARAMETER	MEAN EXP	MEAN CONT	t-VALUE	df	P-VALUE
Mean height	25.092	18.616	2.402	158	0.017464 *
Mean diameter	6.130	2.348	1.587	158	0.014383 *
Mean number of leaves	13.487	11.884	0.843	158	0.400061 ns
Mean shoot: root ratio	2.495	4.477	1.287	158	0.019992*
Mean leaf area	147.825	142.738	0.241	158	0.809748 ns
Proportion of leaves infected	0.229	0.535	6.845	158	0.0001***

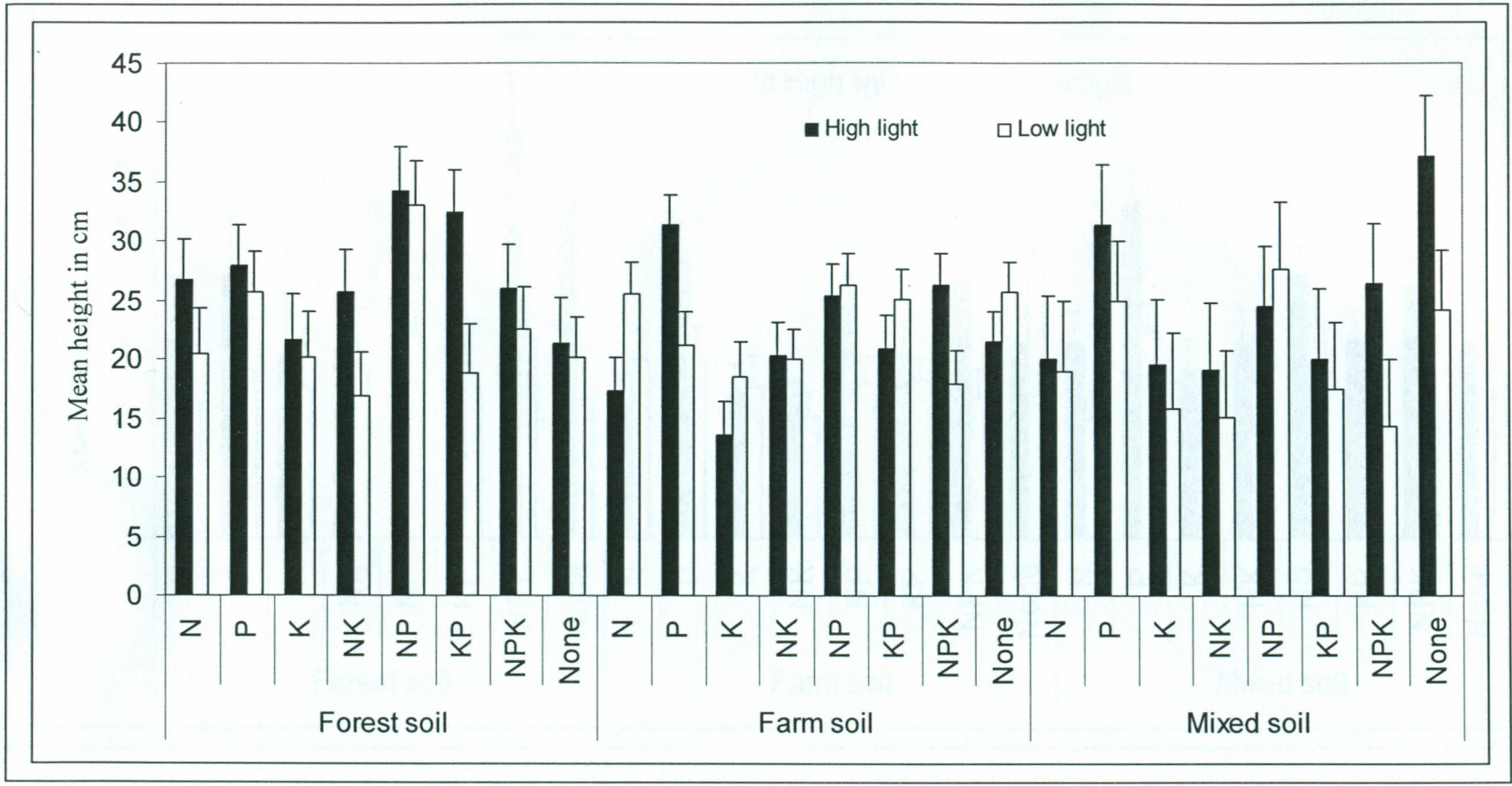


Fig. 4.40: Mean height of *Prunus africana* seedlings in three soil types amended with various fertilizers (vertical bars represent + 1 SE)

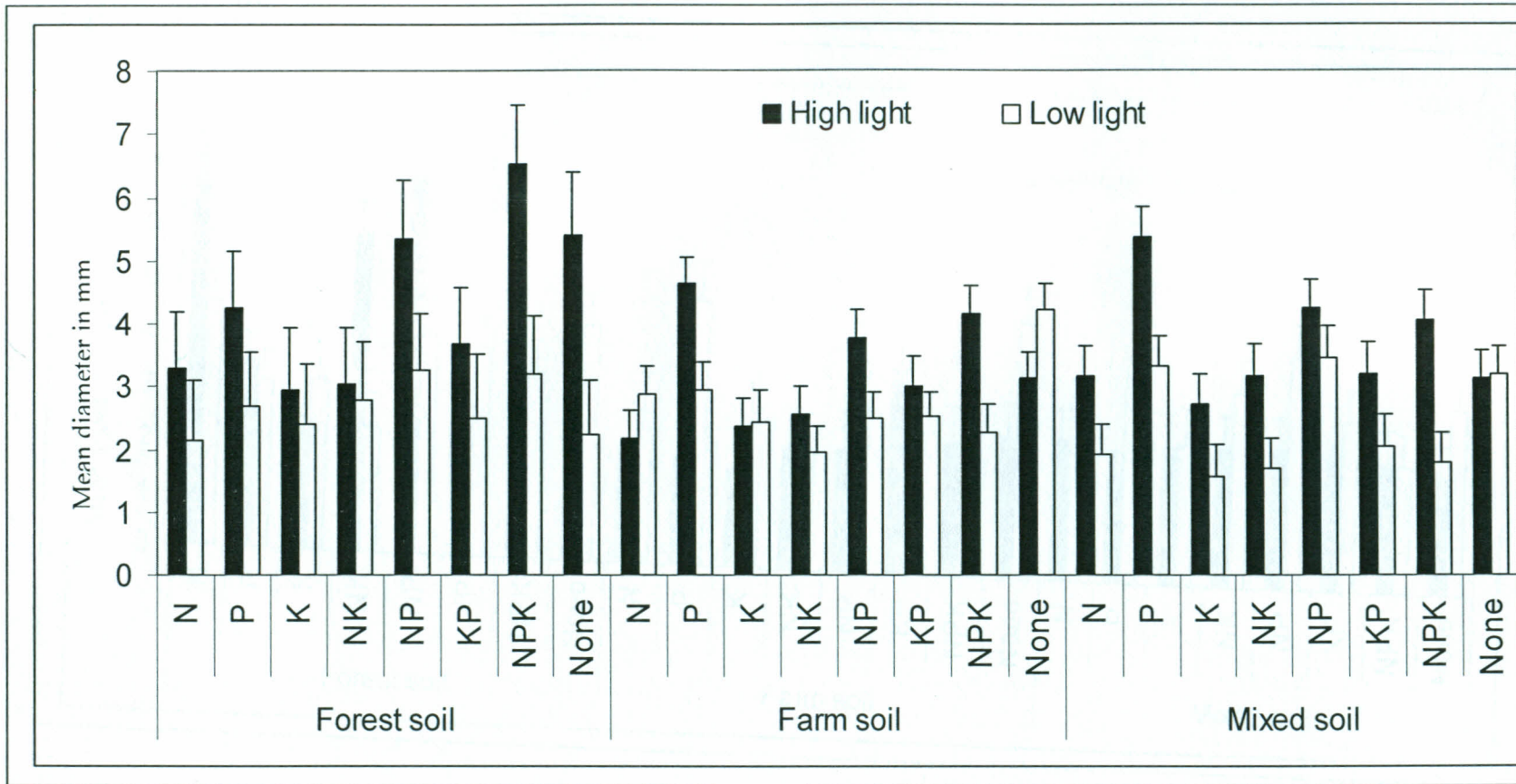


Fig. 4.41: Mean diameter of *Prunus africana* seedlings in three soil types amended with various fertilizers (vertical bars represent +1 SE)

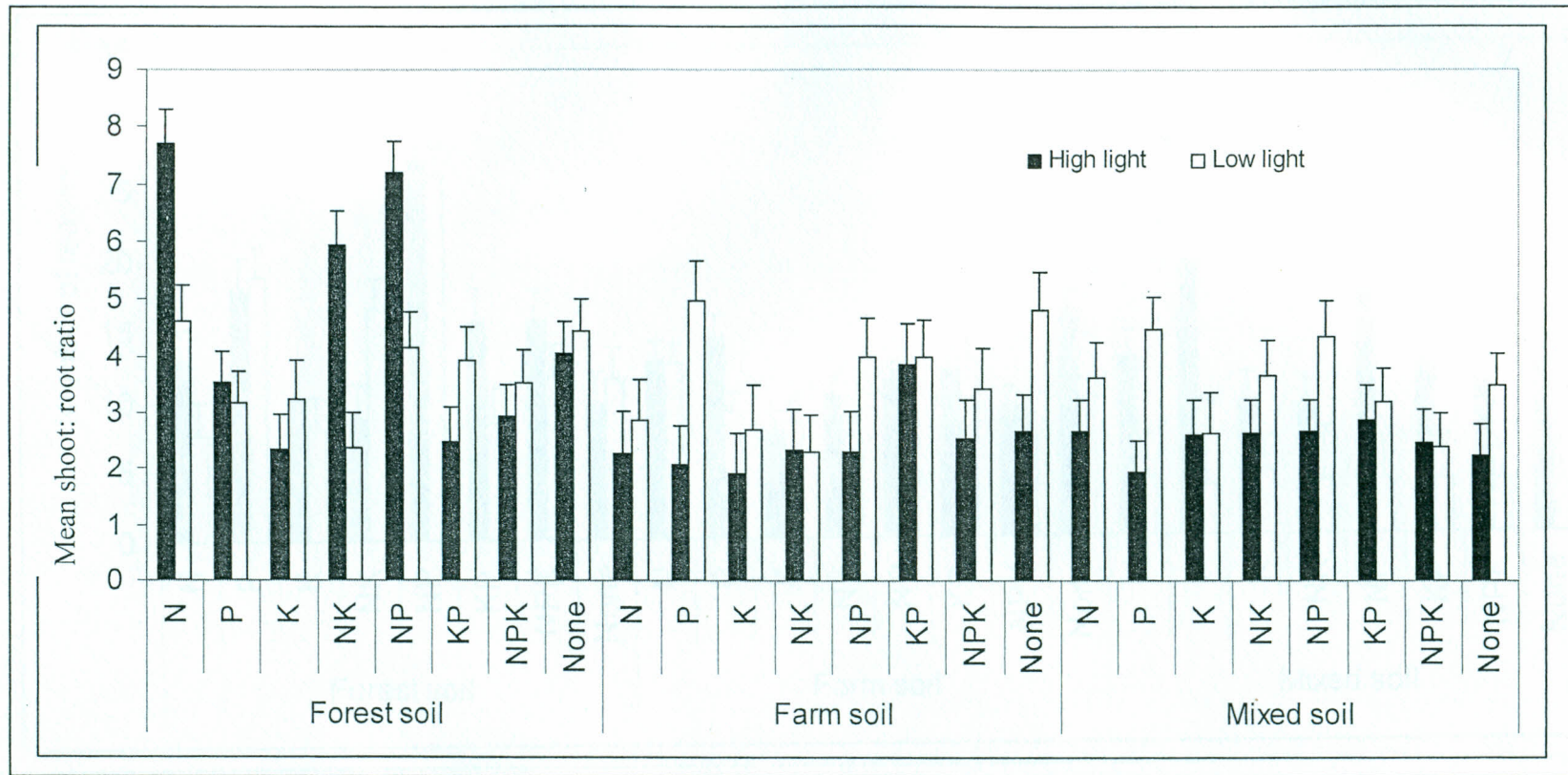


Fig 4.42: Mean shoot: root ratio of *Prunus africana* seedlings in three soil types amended with various fertilizers (vertical bars represent + 1 SE)

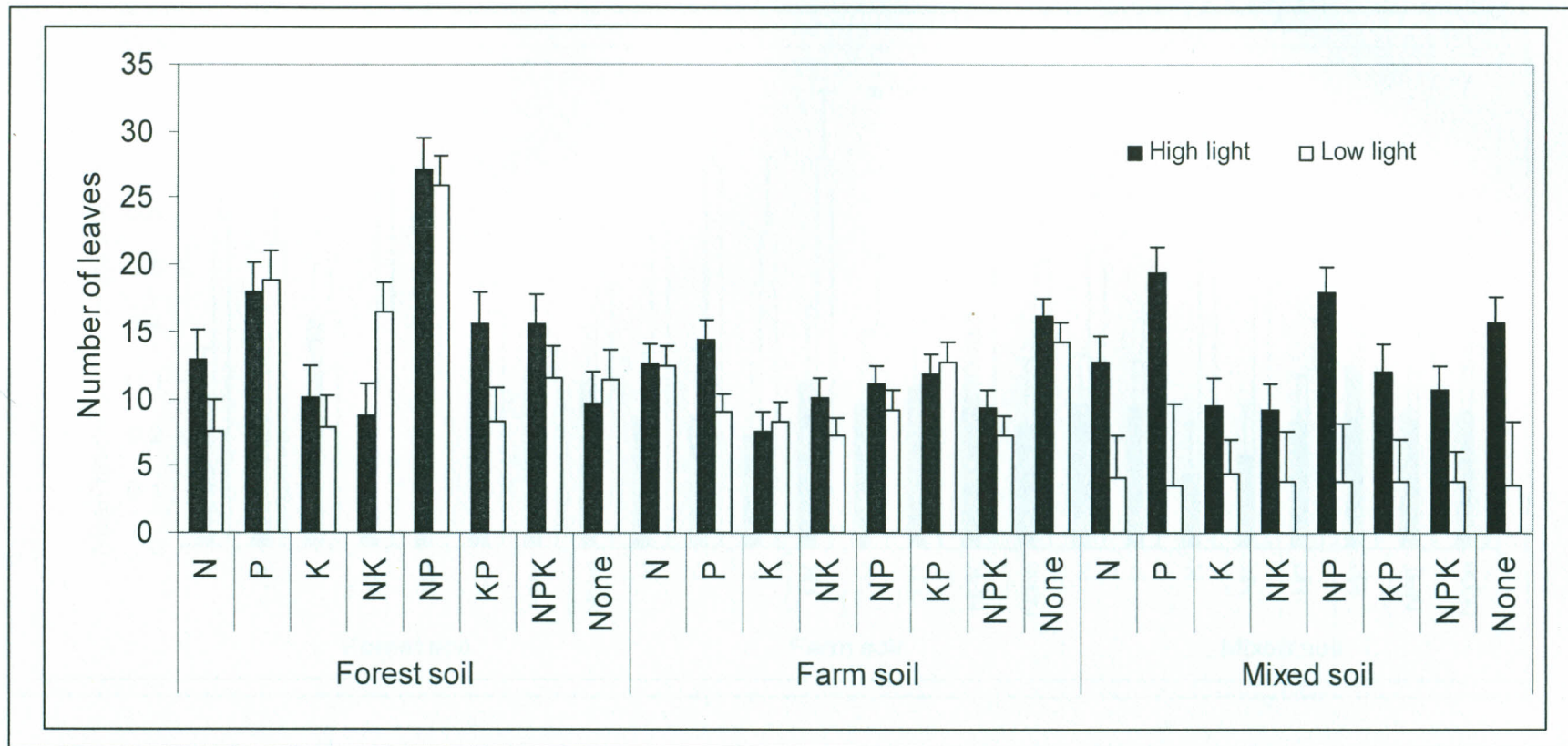


Fig. 4.43: Mean number of leaves of *Prunus africana* seedlings in three soil types amended with various fertilizers (vertical bars represent + 1 SE)

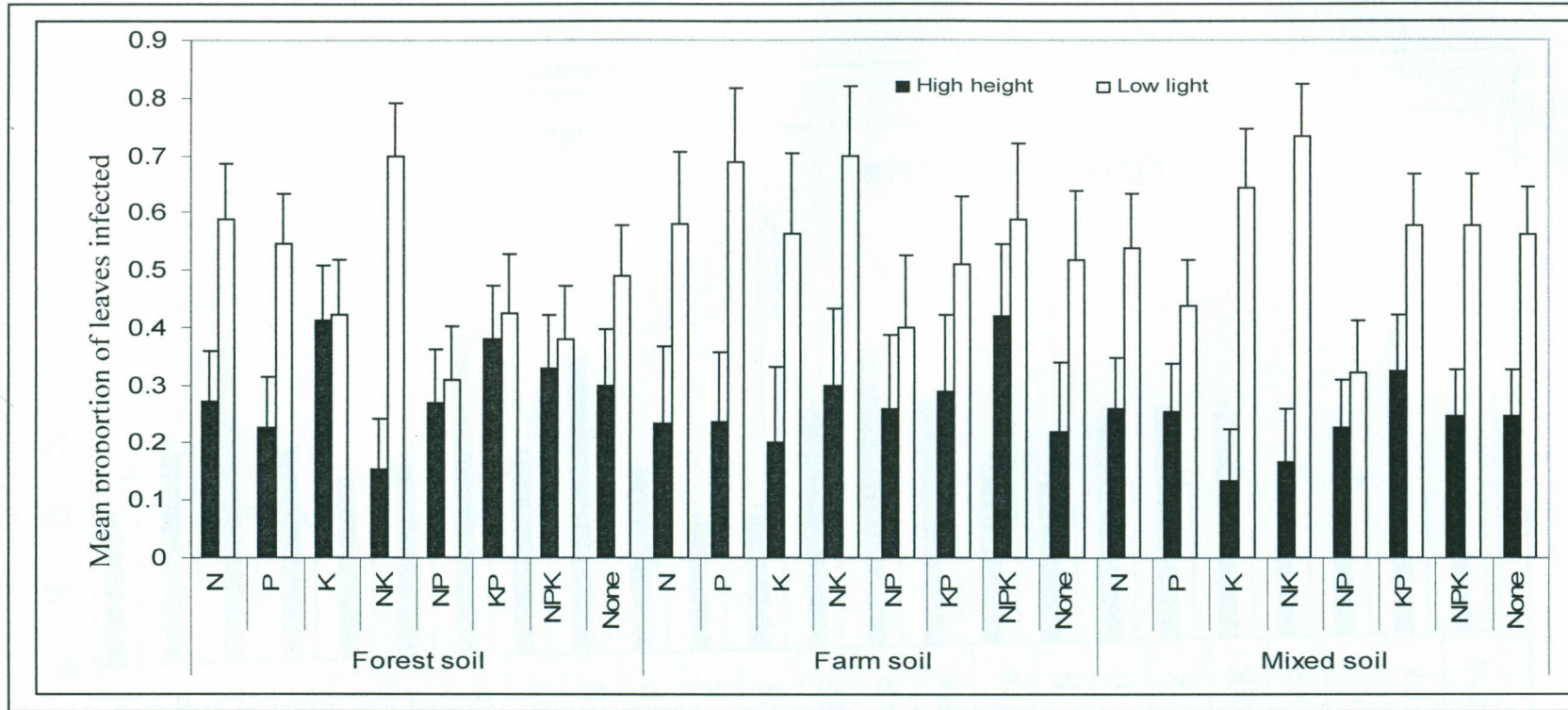


Fig. 4.44: Mean proportion of leaves infected of *Prunus africana* seedlings in three soil types amended with various fertilizers (vertical bars represent + 1

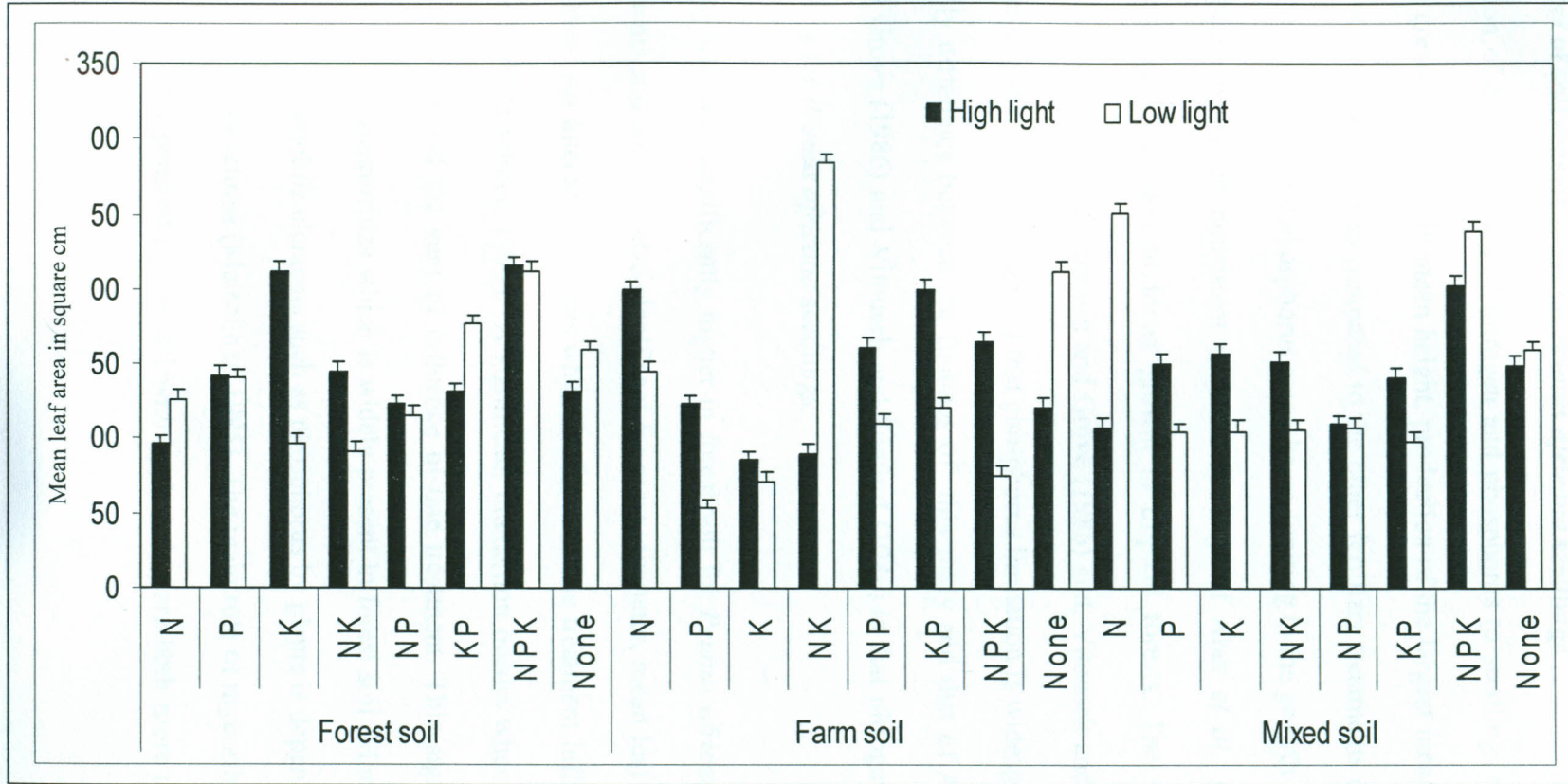


Fig. 4.45: Mean leaf area of *Prunus africana* seedlings in three soil types amended with various fertilizers (vertical bars represent + 1 SE)

CHAPTER 5- DISCUSSION

5.1 Effects of soil amendments on seedlings

5.1.1 Effect of soil amendments on *Prunus africana* seedlings

The application of a combination of nitrogen and phosphorus to seedlings of *Prunus africana* results in the greatest increase in mean height, production of the largest mean number of leaves and the largest mean leaf area as compared to the other fertilizer treatments (Table 4.2). This is an indication that nitrogen and phosphorus could be co-limiting to the growth of *Prunus africana* seedlings. These results are consistent with the findings of Aber *et al.*, (1995) who found widespread nitrogen limitation to forest growth in tropical forests. The results are also in agreement with the findings of Lathwell and Grove (1986) and, Vitousek and Sunford (1986) in an agricultural experiment that suggested that phosphorus limitation is widespread in old tropical soils. The only difference between the findings of this study and that of Aber *et al.*, (1995), Lathwell and Grove (1986) and Vitousek and Sunford (1986) is that nitrogen and phosphorus are both limiting for *Prunus africana* seedlings.

The mean leaf area was significantly higher in forest soil for *Prunus africana*. The interaction between nutrients and soil was also significant for mean diameter, mean leaf area and the mean number of leaves. An interaction occurs when the level of one treatment influences the level of another treatment (Marschner, 1995). A significant interaction occurs when the influence of a combined practice exceed the sum of influence of one treatment. This significant interaction could be as a result of mycorrhiza which is widely present in forest soil (Marschner, 1995). The uptake of relatively immobile elements such as phosphorus by plants is dependent on the surface area of the absorbing structures (Marschner, 1995). The main role of mycorrhizal associations is to acquire nutrients by penetrating the soil with hyphae that are both more receptive and more

extensive than the roots themselves (Harley, 1989). This makes it possible for the plants to effectively absorb the nutrients in the soil. Nitrogen and phosphorus promote mycorrhizal associations (Marschner, 1995). This may explain why the forest soil amended with a combination of nitrogen and phosphorus gave higher values for mean diameter, mean leaf area and the mean number of leaves.

5.1.2 Effect of soil amendments on *Markhamia lutea* seedlings

The soil amended with a combination of nitrogen, phosphorus and potassium promoted growth of *Markhamia lutea* seedlings resulting in the greatest mean height, mean diameter, largest mean number of leaves, largest mean shoot: root ratio and the greatest mean leaf area (Table 4.5). This is an indication that nitrogen, phosphorus and potassium are all limiting to growth of *Markhamia lutea* seedlings. This response was probably because of the strongly weathered nature of Kakamega forest soils as is characteristic of old tropical soils resulting in low nitrogen and phosphorus levels (Musila, 2007; Vitousek and Sanford, 1986).

The seedlings growing in soils rich in nitrogen and phosphorus do not allocate a lot of resources to formation of root clusters (Dinkelaker, *et al.*, 1995). The root clusters are important in production of organic exudates that promote solubility of chelated phosphorus. Earlier theories also related the formation of root clusters to increase in the surface area for uptake of nutrients (Jeffrey, 1967). The soils deficient in phosphorus are therefore characterized by the formation of cluster roots to aid in absorption of chelated phosphorus. This is supported by the fact that the seedlings that were grown in un-amended soil had a significantly smaller mean shoot: root ratio compared to soils amended with a combination of nitrogen, phosphorus and potassium.

Seedlings growing in un-amended soil could have invested more in production of root clusters to aid absorption of the scarce soil resources at the expense of above ground biomass (Table 5.5).

Other research findings relate increase in nitrogen status of the soil to less development of root clusters (Racette *et al.*, 1990). Root clusters contribute to an increase in below ground biomass and therefore a small shoot to root ratio as observed in this study. This means that under conditions of an abundant supply of phosphorus and nitrogen, the above ground biomass is likely to be larger than the below ground biomass therefore leading to a larger shoot to root ratio.

Low pH in Kakamega forest soils, which ranges from 4.5 to 6.5 (Musila, 2007) could explain why phosphorus and nitrogen are limiting nutrients. Low pH usually leads to high concentration of aluminum ions in the soil. These ions bind with orthophosphate ions to form insoluble compounds resulting in low levels of extractable phosphorus (Pearce and Summer, 1997). As a result, phosphorus is less available for uptake in acidic soils.

Potassium appears to be a limiting nutrient for growth of *Markhamia lutea* seedlings in addition to nitrogen and phosphorus (Table 4.5). These findings are consistent with the findings of Musila (2007) who observed that most disturbed sites of Kakamega forest, which includes the surrounding farmlands, are generally more acidic and have lower water extractable potassium and calcium.

5.1.3 Effect of soil amendments on *Olea capensis* seedlings

Olea capensis had the greatest mean height in soils amended with a combination of nitrogen and phosphorus and in soil amended with potassium only (Table 4.7). The greatest seedling mean height in soils amended with potassium suggests that potassium is likely to be the most limiting

nutrient to growth of *Olea capensis* in Kakamega. A significant difference in seedling mean height, mean number of leaves and mean leaf areas between the soil sources with greater values in seedlings grown in forest soil as compared to the seedlings grown in farm soil suggests greater nutrient limitation in farm soil. Since potassium had the greatest impact on seedling mean height, this nutrient is most likely to be limiting in farm soil as compared to forest soil. Potassium is a basic cation, which forms soluble salts that are easily leached. It is probable that more nutrient leaching occurs in on open farm soil as compared to forest soil. The acidity of the soil is also known to affect potassium uptake by plants where pH results to loss of potassium from the roots (Uehara and Gilman, 1981).

5.2 Effect of competition on seedlings

5.2.1 *Prunus africana*

The mean height and mean number of leaves of the seedlings was highest in seedlings grown in the absence of competition. The mean leaf area was highest in seedlings grown under interspecific competition. An abundance of resources in the absence of competition possibly led to a greater increase in seedling mean height. Since there was no competition for space, the seedlings grown in absence of competition produced more leaves. However, the seedlings that were grown under competition increased their mean leaf area possibly to compete for light with the competing individuals of other species. This is in agreement with the findings of Morgan and Smith (1981) who concluded that a reduction in the amount of light reaching the seedlings brings about changes in above ground biomass allocated to leaves, reduced branching, greater specific mean leaf area and changes in the shape of the leaves. In this case the seedlings grown under competition responded by increasing their mean leaf area. Reduced mean number of leaves in the competing seedlings could be as a result of the reduced branching seedlings.

The response of *Prunus africana* was such that the differences in the mean shoot: root ratios were not significant though the seedlings grown under competition had a slightly larger mean shoot: root ratio. This was highly pronounced in the seedlings grown in forest soil amended with phosphorus alone (Fig. 4.19). Seedlings grown in soil where phosphorus is limiting usually invest more on root and therefore when phosphorus is applied, the investment in the roots is minimal hence a large shoot: root ratio (Dinkelaker, *et al.*, 1995). This was despite the fact that the average allocation to the aboveground biomass was larger for the seedlings grown without competition than in those seedlings growing in both intraspecific and interspecific competition. It would have been expected that the seedlings in competition would have a smaller mean shoot: root ratio. Given that the seedlings grown under competition were planted in a limited space in one tube, the seedlings were likely to experience competition for both soil resources and the above ground resource which is light. The results of this study show that competition for light influenced biomass allocation perhaps more than the soil resources for these test species. This perhaps opens another debate on which resource is more important in determining the outcome of competition between light and soil resources.

5.2.2 *Markhamia lutea*

Markhamia lutea seedlings gave a similar response to *Prunus africana* in respect of seedling mean height and mean diameter. Seedlings grown in the absence of competition responded by increasing their mean height and mean diameter compared to those grown under competition. *Markhamia lutea* seedlings grown in interspecific competition showed a larger mean shoot: root ratio than those grown in absence of competition. This means that resource allocation to below ground structures in interspecific competition was less than in seedlings grown in absence of competition. Similar to the case of *Prunus africana* seedlings, it would have been expected that

the seedlings in competition would have a smaller mean shoot: root ratio compared to the seedlings grown in absence of competition. Given that the seedlings grown under competition were planted in a limited space in one tube, *Markhamia lutea* seedlings were also likely to experience competition for both soil resources and the above ground resource which is light hence more investment in above ground biomass as compared to below ground biomass.

5.2.3 *Olea capensis*

The seedlings grown in absence of competition increased in the parameters that account for the above ground biomass. Mean height and mean diameter as in the case of *Prunus africana* and *Markhamia lutea* were significantly larger compared to that of the seedlings under interspecific competition. Similarly, the mean number of leaves for the seedlings grown in the absence of competition was significantly more than for seedlings grown under competition as was the case for *Prunus africana* seedlings. Mean leaf area was also significantly higher for seeds grown in the absence of competition as observed in the case of *Markhamia lutea*. However, the seedlings grown in a combination of the three nutrients in interspecific competition had larger mean leaf area compared to the rest (28.4). This is possibly because when all the three limiting nutrients are supplied, then the seedlings are more likely to compete for light than nutrients hence a large leaf area to maximize absorption of light. These findings concur with the findings of a study by Gersani *et al*, (2001) who observed that plants sharing a resource supply with other plants produce less shoot biomass than plants grown alone with access to as much as half the resources.

5.3 Nutrient analysis

The results of this study shows significant increase in above ground nutrient concentrations of the respective elements analyzed for the samples harvested after 70 days and those harvested

after 210 days. The results also suggest a synergistic effect of nutrient on uptake of other nutrients. For example, nitrogen and potassium addition stimulated a greater phosphorus uptake than in the case of the application of phosphorus alone (Fig. 4.31, 4.32 and 4.33). This observation was also true for potassium where the application of a combination of potassium, phosphorus and nitrogen stimulated the uptake of potassium (Fig. 4.38 and 4.39). This suggests that the various nutrients interact to influence plant growth, physiology and allocation patterns (Drenovsky and Richards, 2004). Many factors are important to the uptake of soil nutrients by the plant roots. Root density is particularly important especially in uptake of nutrients such as phosphorus and nitrogen, especially where these nutrient levels are low. Plants growing in relatively nutrient poor soils have low capacities for nutrients uptake than plants growing in nutrient rich soils (Jackson and Caldwell, 1989). This explains why the seedlings grown in soil amended with a combination of nitrogen, phosphorus and potassium had a higher nutrient uptake compared to cases where any one of the nutrients was applied individually in this study. The nutrient uptake capacity is also influenced by the tissue concentration of a given nutrient. As a result, the presence of a high tissue concentration of a particular nutrient in a plant often leads to more uptake of the nutrient by plant roots (Jackson and Caldwell, 1989). The addition of limiting nutrients therefore favors the species with high concentration of those nutrients in their tissues (Momolos and Veresoglou, 2000).

5.4 Response of *Prunus africana* to different light regimes

The seedlings that were grown in low light regime had a larger mean shoot: root ratio and a larger mean leaf area compared to the seedlings that were grown in higher light regime in farm soil and mixed soil (Tables 4.35 and 4.36). This means that *Prunus africana* seedlings in low light regime responded to low light by allocating more to their aboveground biomass than to

their below ground biomass compared to the seedlings grown in higher light regime hence a larger mean shoot: root ratio. Reduced amount of light probably leads to this phenomenon as the seedlings invested more on the above ground biomass in order to access the limited amount of light.

Different species have often been observed to respond differently to different light regimes. Montgomery and Chazdon (2002) have reported a higher growth rate in biomass, stem mean diameter and stem length in higher light levels but lower survival at lower light levels for *Dipteryx panamensis* as compared to *Virola koschnyi*. Other studies have revealed completely different seedling responses to light for other species. Bloor and Grubb (2003) have for instance reported an absence of a relationship between high light, growth rate and low light survival across 15 different species in tropical lowland forest. Morgan and Smith (1981) concluded that a reduction in the amount of light reaching the seedlings makes them to respond by changing the amount of the above ground biomass allocated to leaves, reduced branching, greater specific mean leaf area and changes in the shape of the leaves. The results of this study tend to concur with the observation of Montgomery and Chazdon (2002) as far as the increase in stem length and mean diameter for seedlings grown in higher light regime is concerned. This is because the *Prunus africana* seedlings grown in higher light regime in forest soil, farm soil and in the mixture of the two soils had significantly larger mean diameter and mean height compared to the seedlings grown in low light regime with an exception of the mean height in seedlings grown in farm soil where the differences were not significant (Table 4.34, 4.35 and 4.36).

The proportion of leaves with fungal infections for the seedlings in low light regime was nearly twice as high as that of the seedlings in higher light regime in forest soil, farm soil and in the

mixture of the two soils (Fig. 4.44). The fungal infection of leaves leads to drying of leaves and eventually the seedlings die (Franklin *et al.*, 1987). This possibly explains why the seedlings of *Prunus africana* appear to require large light gaps in the canopy to survive to the pole stage (Kiama and Kiyiapi, 2001; Nzilani, 2002; Tsingalia, 1989). Furthermore, the dense undergrowth layer of Acanthaceae in Kakamega forest, believed to be a by-product of the selective logging of the 1940's may play a role in inhibiting *Prunus africana* sapling survival (Fashing and Gathua, 2004).

Light-dependent increase in growth is mainly caused by an increase in assimilation rate (Poorter, 2001). Light-demanding species have a high photosynthetic plasticity, and therefore they may show a stronger growth response to light than the shade-tolerant species (Poorter, 1999 and Rose, 2000). Other studies have lead to a conclusion that seedlings growth is positively related with mean leaf area (Oberbauer *et al.*, 1988; Poorter, 2001 and Zagt, 1997). This indicates that seedlings growth is limited by the amount of light interception, and that leaf loss due to herbivory or leaf shedding due to attack by diseases or other factors might have important repercussions for plant growth (Anten and Ackerly, 2001).

Besides light, several other factors are likely to influence regeneration of *Prunus africana* in Kakamega. These include disease (Franklin *et al.*, 1987; Waring, 1987), insect attack (Cunningham *et al.*, 2002; Nair *et al.*, 1996), nutrient deficiency (Gerrish *et al.*, 1988; Hunter, 1993), and climatic fluctuation (Evenson, 1983; Lwanga, 2003). The actual contribution of these factors require further investigations.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The results of this study lead to rejection of the null hypotheses and the following conclusions were made:

- Soil amendment with nitrogen, phosphorus and potassium has a positive effect on *Prunus africana*, *Markhamia lutea* and *Olea capensis* seedlings development in soils from Kakamega farmlands and Kakamega forest.
- Interspecific and intraspecific competition negatively effect on *Prunus africana*, *Markhamia lutea* and *Olea capensis* seedlings development.
- Low and high light regimes differ in their effect on the growth of *Prunus africana* seedlings

It was further concluded that;

- Soil amendment with nitrogen, phosphorus and potassium had varied effects on the growth and development of seedlings of *Prunus africana*, *Markhamia lutea* and *Olea capensis* in soils from Kakamega farmlands and Kakamega forest. *Prunus africana* seedlings grown in a combination of nitrogen and phosphorus significantly increased in mean height and mean leaf area. All growth measurements in *Markhamia lutea* seedlings grown in a combination of the three nutrients responded positively to soil amendment with the combination of the three nutrients. In the case of *Olea capensis*, only seedlings grown in soils amended with potassium showed a significant increased in mean height. Hence, the growth of three test species in Kakamega forest and farm soils may be nutrient limited.

- In general, both intra-specific and inter-specific competition adversely affected seedling growth in Kakamega Forest and farmland soils. Seedlings grown in the absence of competition had significantly greater above ground biomass as expressed by seedling mean height, mean diameter and leaf numbers. However, *Markhamia lutea* and *Olea capensis* seedlings grown under competition had a significantly larger mean shoot: root ratio compared to seedlings grown in absence of competition, a feature possibly resulting from increased light competition in seedlings planted in one pot.
- Light is an important factor in the growth of *Prunus africana* seedlings. The seedlings grown under a high light intensity regime recorded significantly greater values of the growth properties investigated (mean height, mean diameter and mean leaf area) as compared to the seedlings grown in a low light regime.

6.2 Recommendations

The following recommendations should be passed on farmers and other stakeholders interested in the growing of the test species:

- Kakamega forest soils need amendment especially with nitrogen and phosphorus for the growth of *Prunus africana*, while a combination of the three nutrients is necessary for *Markhamia lutea*. *Olea capensis* seedlings require potassium for proper growth of the seedlings.
- Fertilizers with liming effect should be used to amend Kakamega soils to raise the pH for improvement in availability of nitrogen and phosphorus by the plants.

- *Prunus africana*, *Markhamia lutea* and *Olea capensis* seedlings are negatively affected by competition hence proper spacing might be crucial to reduce competition among the seedlings.
- Fungal infection on the leaves of *Prunus africana* seedlings can be significantly reduced by growing the seedlings in open areas rather than growing them in shaded areas.

Owing to the varied responses of the test species to soil amendments with nutrients and competition, the following recommendations for further research are proposed:

- Further studies in more controlled environment need to be carried out to determine why some growth properties in *Prunus africana* and *Olea capensis* seedlings responded positively to nutrient amendments while some were not affected significantly.
- More studies need to be carried out with seedlings of other indigenous tree species in order to compare and document their response to soil amendment with nutrients.
- Studies using other growth parameters not covered in this study like carbon uptake should be carried out to determine the influence of soil amendment on such growth parameters.

More studies should be carried out to determine why the mean shoot: root ratio for seedlings grown in the absence of competition was greater compared to competing seedlings.

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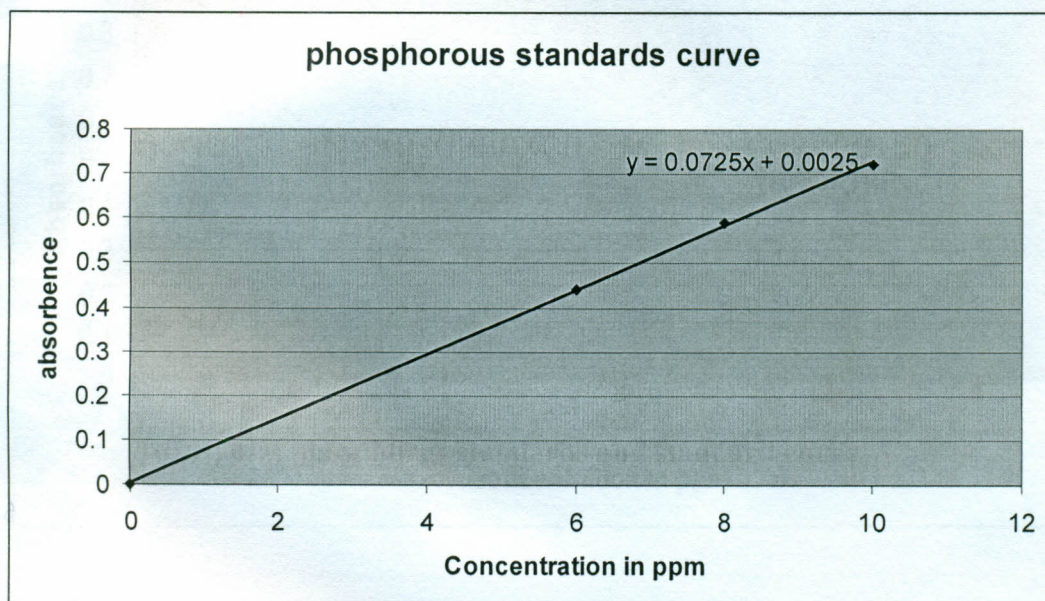
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APPENDICES

Appendix 1(a): Total phosphorus standards and standard table

CONCENTRATION IN ppm	ABSORBENCE	CORRECTED ABSORBENCE
0	0.9	0
6	1.34	0.44
8	1.49	0.59
10	1.62	0.72

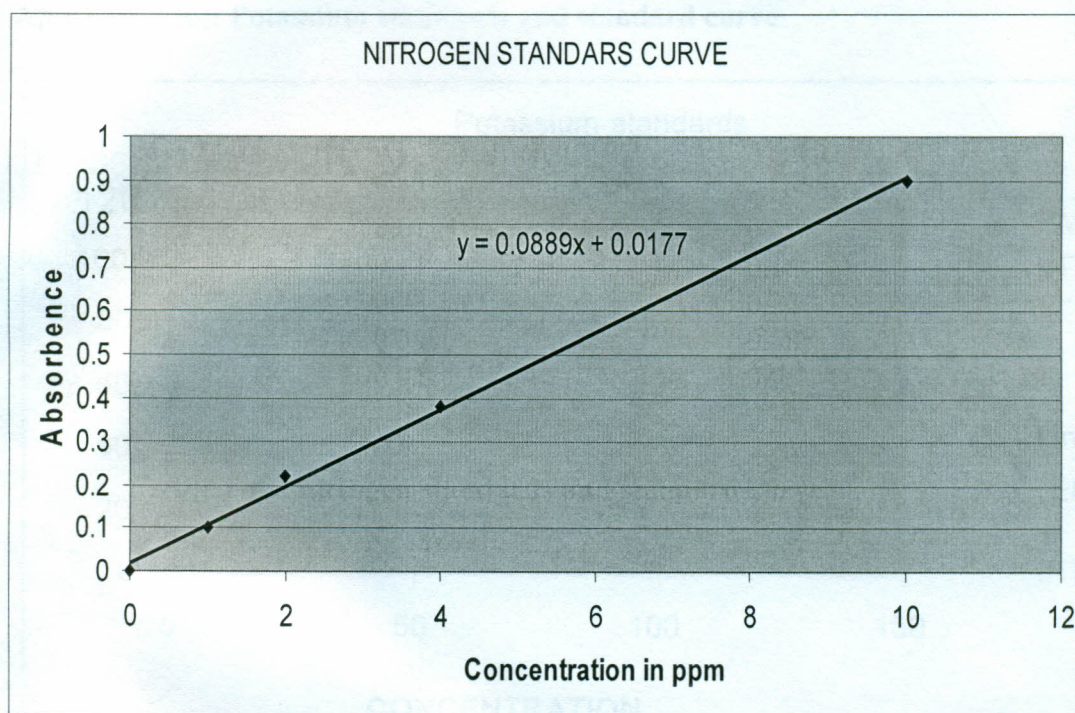
Appendix 1(b): Total phosphorus standards and standard curve



Appendix 2 (a). NITROGEN STANDARDS TABLE

CONCENTRATION IN ppm	ABSORBENCE	CORRECTION FOR ABSORBENCE
0	0.01	0
1	0.11	0.1
2	0.23	0.22
4	0.39	0.38
10	0.91	0.9

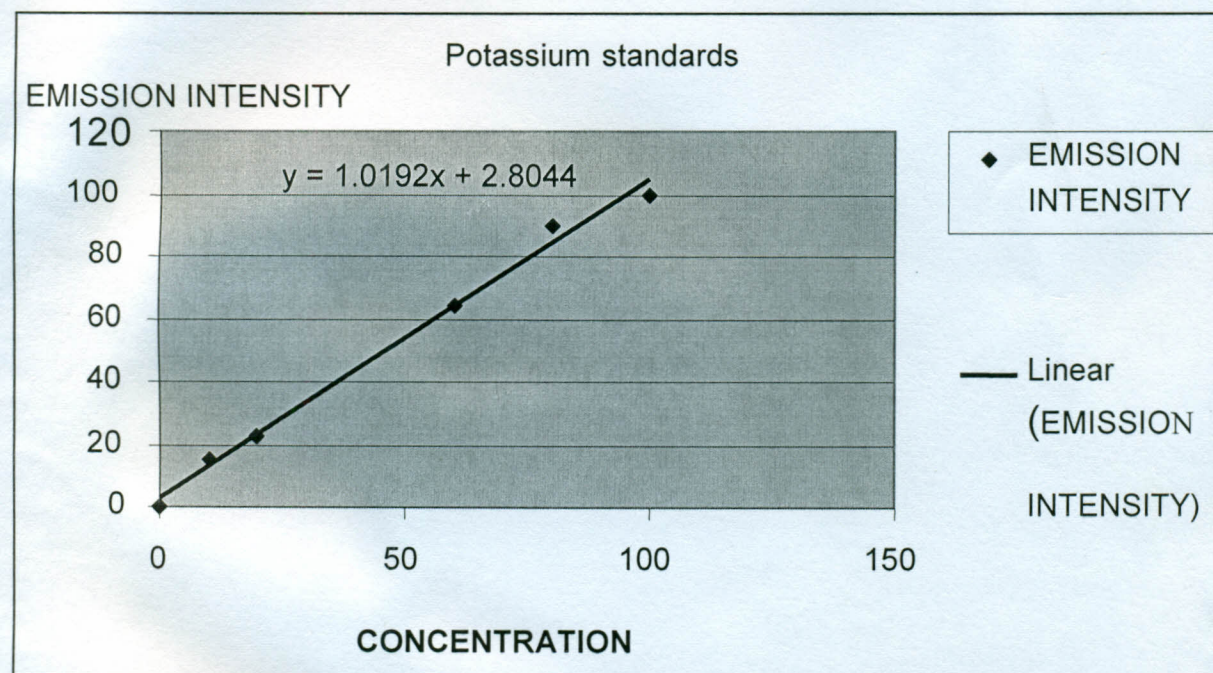
Appendix 2 (b): Total nitrogen standards and standard curve



Appendix 3 (a): Potassium standards table

CONCENTRATION	EMISSION INTENSITY
0	0
10	15
20	23
60	64
80	90
100	100

Appendix 3 (b): Potassium standards and standard curve



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