"The Effects of *Prosopis julifora* (DC) Hyne and *Acacia tortilis* (Forsk) Trees on Understorey Plant Species and Soil Properties on Njemps Flats, Baringo District, Kenya."

by

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Declaration

I, Henry Chore Kahi, hereby declare that this thesis is my original work and has not been presented for a degree in any other University.

Signature---------------------- Date-15th Jan 2004

This thesis has been submitted with our approval as University Supervisors

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Dedication

To my late Father Rev. Jamin Kahi Sahani who, though not highly educated, supported my education fully. Fondly remembered and sadly missed by family members, relatives and friends.

Acknowledgement

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Abstract

The effects of *Prosopis juliflora* (exotic species) and *Acacia tortilis* (indigenous species) trees on soil properties and understorey herbaceous plant species production were investigated on the Njemps flats, Baringo district, Kenya. The objective was to compare the effects of an invasive and indigenous tree species on soil physical and chemical properties, the occurrence and production of the understorey plants under their canopies relative to the adjacent open areas.

Five mature *P. juliflora* and *A. tortilis* trees of similar canopy size and structure, without shrubs or termite mounds under their canopies were systematically selected. Samples of soil and herbaceous plant species were obtained at 1m, 2m and 3m from the tree trunk within the canopy and at 4m, 5m and 6m from the edge of the tree canopy. Soil samples were collected 0-5cm, 15-20cm and 40-45 cm depths at the above-mentioned points along four cardinal directions of the tree trunk. Soil samples under each experimental unit, from all the three distances and depths, were composited into a single sample before carrying out the analyses.

Standing biomass, frequency and cover of understorey plant species were significantly ($p<0.05$) higher in the open area, than under the tree canopies. Biomass was 3 and 5 times higher in open areas than under *A tortilis* and *P. juliflora* canopies, respectively. Cover for herbaceous plant species was 63% under *P. juliflora*, 82% under *A. tortilis* and 90% in open areas. All forbs occurred

under the shade indicating that they are more adapted to the microenvironment found under the shade than grasses.

Soils under the tree canopies had significantly ($P<0.05$) higher organic carbon and total nitrogen than those in adjacent open areas. Organic carbon and total nitrogen concentration in soils under *P. juliflora* were 13% and 45% higher than in the open areas, respectively; and 25% and 153% higher under *A. tortilis* than in the open areas respectively. Soils under *A. tortilis* had significantly ($P<0.05$) higher organic carbon and total nitrogen than soils from under *P. juliflora*. Soils were slightly more acidic under the tree canopies than in the open areas. Bulk soil density was significantly ($P<0.05$) higher in the open area than under the canopies, suggesting that tree canopies protect the soil from compaction.

The results suggest that *A. tortilis* trees are more beneficial to soil physical and chemical properties than *P. juliflora* trees. Therefore, the common practice of clearing woody trees indiscriminately for crop cultivation or to improve grassland for livestock production should be reconsidered. The practice also removes beneficial effects of trees such as *A. tortilis,* on soils, such as the provision of shade for grazing animals, habitats for birds and wildlife, and as source of protein in the dry season when the grasses are in short supply.

Based on the result of this study, *P. juliflora* tree species should not be encouraged to grow in rangelands as it inhibits the development of herbaceous plants species under its canopy. In areas where the tree is already established, research should be conducted to determine the best methods of eradicating them.

CHAPTER ONE

INTRODUCTION

1.1 Background information

Globally, two main plant life forms exist: grasses and woody plants. These two have different requirements and frequently occupy distinct niches (Medina 1982). In Africa, savannas are characterised by the presence of a continuous graminoid stratum and a discontinuous woody stratum that forms the upper canopy of the vegetation (Menault *et al.* 1985). Shrubs and trees take water from deep soils, which is beneficial to the herbaceous plants especially in the dry seasons. Thus, removal of trees from the savanna ecosystems, which usually have alternating wet and dry season and often support large numbers of grazers, could endanger the survival of the shallow rooted herbaceous plants during the dry periods as they are unable to access water from the deep soil horizon.

Trees and shrubs also play an important role in terrestrial ecosystem, hence the need to understand their ecological role, especially in arid and semi-arid areas where they are an important component of the vegetation (Barth and Klemmedson 1982). They are of major importance to the biodiversity of these areas. Large trees, for instance, attract mammals and birds by providing shade, perch, nest and roost site (Belsky 1994). The scattered trees increase the structural heterogeneity of arid and semi-arid areas. The nutrient-enriched soils beneath their canopies support distinctive herbaceous vegetation (Belsky *et al.* 1989, Jeltsch *et al.*1996). In addition, trees and shrubs in the dry regions have the potential to increase grass production (silvopastoralism), increase crop production (agroforestry), and hold or reverse desertification (Steppler and Nair 1987, Young 1997).

In arid and semi-arid areas, trees generally have a favourable impact not only on micro-environmental factors, but also on diversity, phenology and productivity of grasses. Benhard-Reversat (1982) concluded that trees are an important ecological component that maintains soil fertility as a result of nitrogen fixation and accumulation of organic matter through litter fall. Therefore, for proper management of the rangeland, an understanding of the interactions between herbaceous and woody plant species is necessary.

Although there are some doubts as to whether trees at low density improve or degrade the condition of rangelands, some studies have shown that forage production is often reduced by trees that compete with the understorey plant species for water, nutrients and light (Burrows 1990). Smith and Rechenthin (1964) noted that brush cover is frequently cited as the primary limitation to effective management of rangeland for livestock production. Consequently, trees are cleared from rangeland by expensive mechanical and chemical techniques without considering the effect of such practice on the fragile arid and semi-arid ecosystem. Burrows (1993) argue that such decisions have been made without consideration of the beneficial contributions of woody species to the fragile savanna ecosystems, especially where trees are spatially distributed within the grasslands.

Recently, the effects of trees on their understorey environments have received attention as range scientists investigate the effects of the interaction of woody plant species and herbaceous plants in rangelands. These studies have been conducted in a wide variety of ecosystems, with various tree and herbaceous plant species, often with different results. Belsky *et al.* (1989), working in Tsavo National Park, Kenya, noted that in areas of low tree densities, moderate or high soil fertility, and low rainfall, trees might increase forage production. Young (1989) found substantially higher organic matter under canopies of *Adansonia digitata* (Linn.) and *Acacia tortilis* (Forsk) than in the adjacent open area in the semi-arid areas of Tsavo National Park, Kenya. Tiedmann and Klemmedson (1973) reported that soils under canopies of mesquite trees *(Prosopis* spp*)* were more fertile than those in the open areas. In contrast, Ellison and Houston (1958) noted an inverse relationship between the tree canopy and herbaceous understorey production. Similar results were observed by Engel *et al.* (1987) who reported a substantial reduction in herbage production under and around *Juniperus virginiana* L. in north-central Oklahoma. The foregoing results are relatively area and plant-specific.

Different herbaceous plant species will respond differently to different types of tree canopies (Jetsch *et al.* 1996). The effects of trees on associated understorey herbaceous productivity varies with the species and environment (Burrows 1993). Jetsch *et al.* (1996) further argued that the function of savannah trees might vary with the population density and distribution. The few studies on tree/understorey parameters and dynamics so far conducted in southern and central Kenya rangelands have only involved a few tree species. These rangelands support wide variety of trees and grasses. It is apparent results from one area with specific tree species cannot be extrapolated to other areas with different tree and herbaceous plant species. Therefore, research findings cannot be generalised for all sites with different grass and tree species, soil type and climates. For research findings to furnish a better base for future decision making on the use and management of rangeland resources, there is need to carry out more research in different environments to gain a better understanding of the tree canopy/herbaceous layer interactions.

Based on the few studies so far published and the little quantitative information available on the woody plant species of tropical arid and semi-arid areas, and their effects on understorey plants, it is apparent that the interaction between trees and their understorey herbaceous plants is far from being fully understood. *Prosopis juliflora* is a native of the American continent, while *A. tortilis* is native in the African continent. *Prosopis juliflora i*s a prolific seeder and grows vigorously near water sources and it has become a formidable invader of other land use systems along rivers, around lakes, swamps, farmlands and ponds in this area. The local communities feel that the species has presented a number of social, ecological and economic concerns that need to be investigated and quantified. An example of the problems presented by the rapid spread of *P. juliflora* is the diminishing of good grazing lands due to loss of good pasture. This study was therefore, conducted to evaluate the effects of *Prosopis juliflora* (an exotic) and *Acacia tortilis (*a native tree species) trees on herbaceous plant species and soil properties in the lowlands of Njemps flats, Baringo District, Kenya.

The objectives of the study were to determine the effect of *Prosopis juliflora* and *Acacia tortilis* canopies on:-

i. aboveground net primary production (AGNPP), cover, and composition of herbaceous plant species within and outside the canopy.

ii. total soil nitrogen, organic carbon, available phosphorus, bulk soil density, and pH within and outside the canopy.

1.3 Hypotheses

i. *Prosopis juliflora* and *A. tortilis* canopies have no significant effect on above ground net primary production, percent cover, and species composition within and outside the canopy.

ii. *Prosopis juliflora* and *A. tortilis* canopies have no significant effect on total soil nitrogen, organic carbon, available phosphorus, soil bulk density, and pH within and outside the canopy.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Although shrubs and trees are the most visible forms of plant life in arid lands, they have been neglected in most scientific research (Mckell 1975) and land management policies (Le Houerou 1989). Motivated by the desire to increase livestock forage and reduce the density of unpalatable shrubs, numerous research efforts have been directed towards methods of shrub eradication or control (Scifres *et al.* 1973). The magnitudes of these efforts have inclined many students, researchers and managers towards the biased view that most, if not all, shrubs are of low value and only by conversion of shrubland to grassland, can productivity be increased (Meckell 1980).

A number of range specialists and agronomists look at trees as competitors for nutrients, water and light, which should be available to grasses. However, trees and shrubs have been recognized for their role in maintaining favorable climate, prevention or reduction of wind and water erosion, creation of favorable conditions for recycling of soil nutrients and addition of humus and nitrogen to the soil (Kellman 1979). In addition to providing important food resources for livestock and people, tree shades reduce heat loads on both human and animals and reduce potential evapo-transpiration rates, thereby reducing the potential moisture stress for the sub-canopy herbaceous plants (Coughenour *et al.* 1990). Shrubs and trees therefore, play an important role in terrestrial ecosystems, hence the need to understand their ecological importance (Barth and Klemmedson 1982). This is particularly important in the arid and semi-arid areas where shrubs and trees are an important component of the vegetation.

To increase livestock production on rangelands with high shrub and tree densities, it is necessary to manipulate the present woody vegetation density by mechanical, chemical and biological means (Carlton *et al.* 1983). The aim of such practices is to play around with the woody: herbaceous species plant density ratio. The justifications for these practices have been that bush clearing enhances livestock production through increased forage production (Kinyua 1996).

2.2 Relationships of overstorey and understorey plant species

Woody plants are an important component of all arid and semi-arid lands throughout the world. Their desirable qualities are dependent, to a considerable extent, on the presence of a fair percentage of perennial grasses. The amount of rainfall in rangelands is insufficient to maintain these grasses if they have to compete with woody vegetation, which is better adapted to withstand an arid climate (Whysong and Bailey 1975). Grasses are however, more efficient than trees in extracting water from the upper layers of the soil, while below the grass root zone (sub-soil), the woody vegetation has nearly exclusive access to the water that exists there. Moore (1960), further observed that co-existing herbaceous and shrub species competed for soil moisture supplies and at the same time shared the favourable effects arising from the joint microclimatic modification.

Pressland (1973) working in Australia recorded a six-fold increase in the amount of water trapped in the sub-soil below a tree canopy, compared to that trapped in the area outside the canopy. He attributed these differences to the canopy that intercepts the rain and funnels it down into the soil at the tree base, facilitating rapid percolation of water into the sub-soil before the topsoil is at field capacity. In contrast, Kelly and Walker (1976) demonstrated that the rate and amount of infiltration in a loamy savanna soil is about ten times greater under a grass cover and litter than on a bare soil surface. Based on the results of the study by Walker and Noy-Meir (1982), herbaceous biomass is a critical factor in determining the rate and amount of water that percolates into the soil. Therefore, there is need for high herbaceous cover to enhance higher infiltration of water into deeper soil layers.

Trees and shrubs adversely affect the performance of herbaceous plant species growing under them. Heady (1960) and Thomas and Pratt (1967) reported that, heavy bush thickets reduce herbaceous forage production and that most forage produced in dense thickets is invariably inaccessible to livestock. Smoliak (1956) noted that potential understorey biomass yields might be reduced by the effect of associated shrubs and trees. Such findings have led to a general negative attitude towards all woody plants in rangeland that has provided an impetus for intensive research on brush control methods. The presence of woody plants on rangelands has, therefore, been of concern to land managers interested in increasing forage production (Belsky *et al.* 1989). This approach to the complex and often beneficial interaction between woody and herbaceous plants is largely fallacious and overly simplistic (Wenner 1981, Rattiff *et al.* 1991). Woody species not only have important contribution to the society such as animal fodder, firewood, charcoal, fibre and construction materials, but also play an important role in creating the necessary micro-environment conducive to the productivity of herbaceous plant species. Tiedmann and Klemmedson (1973) observed that some understorey plants were adapted to shades beneath mesquite canopies while others were shade intolerant. Brock *et al.* (1978) working in north-central Texas, noted that cool-season grass species which are normally found in the canopy zones decreased following mesquite removal.

Angus (1958) reported that trees, by virtue of their height, attract more due than grasses, which grow below them. He used an artificial shrub on a uniform surface and found that the shrubs collected 40% more dew than its equivalent horizontally projected area of grass cover. This observation suggests that removal of shrubs may increase aridity by eliminating or reducing moisture availability in form of dew and by eliminating or reducing the transfer of water from the moist lower soil horizons to drier surface layer.

The possibility of a beneficial association between herbaceous plants and deep-rooted shrubs or trees is demonstrated by the work of Breazeale and Crider (1934). These investigators showed that tomato plants rooted in moist soils could be induced to root above the ground level by clamping collars containing soil around the stems. The tomato plant transferred sufficient water from the lower moist pot to keep wheat seedlings alive in soils initially below the wilting point in the top container. It was argued from this experiment that plants could take water from deep layers of soil with low moisture tensions and exude it from their shallower roots into the drier upper layers. Therefore, there is a possibility that shrubs and trees transfer water from lower soil zones to the upper horizons where it is accessible to the herbaceous plants, especially in the dry seasons. Thus, careless removal of trees could endanger the survival of the shallow rooted herbaceous plants during the dry periods in arid and semi-arid areas.

The canopy of the woody plants has been viewed as critical factor in the evolution of herbaceous layer characteristics (Lee 1978, Pieper 1990). The canopy has been shown to modify the understorey microenvironment either favourably or unfavourably. Lee (1978) pointed out that a dense forest canopy drastically modifies the climate of the underneath, especially net radiation, wind speed and amount of precipitation. He found that on average, rainfall deficits under mature hard wood canopies may vary from less than 10% during the leafless period, to more than 20% during the growing season, while the relative humidity under the canopy exceeds that of the area immediately outside the canopy.

Different tree or shrub densities with their associated canopy cover, have variable effects on herbaceous plant cover and production, with the amount of available forage being reduced by competition as density increases (Gachanja 1996). Arnold

(1964) found less total herbaceous biomass productivity within the canopy zone than outside the canopy. Therefore, trees may adversely affect the growth of herbaceous plants under their canopies. Clearing of forests increases herbaceous biomass yield. Because of competition for light, water and nutrients, and possible negative chemical effects including allelopathy, the inverse relationship between the effect of tree canopies and herbaceous plant species productivity is possible and has often been reported in the literature (Cable and Tschirley 1961, Johnston *et al.* 1988).

Some researchers have reported more species abundance and higher cover beneath tree canopies than outside them (Kinyua 1996). Wenner (1981) reported that areas under the canopies of *P. juliflora* trees had a dense stand of perennial grass cover (24 % more than areas outside the canopies). The study was carried out in areas with annual rainfall of 330 mm, which is typical of the more arid rangeland of Kenya. Georgiadis (1989) reported that the variation in grass cover and height with distance from *Sericomopsis pallida* was highly significant. The grass cover and height was higher in open areas than beneath the shrub. Belsky *et al.* (1989) detected domination of the area(s) under the canopy by stoloniferous perennial grasses such as *Cynodon nlemfluensis* with the change in species composition from under the tree canopy to the open grassland occurring abruptly at the edge of the canopy. The foregoing literature shows that different tree and herbaceous plant species interact differently in different localities with some herbaceous plant species being physiologically better adapted to canopies of certain woody plant species. Need therefore, arises for more studies to be

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2.3 Effect of tree canopies on productivity of herbaceous plant species

Woody plants are normally considered detrimental to the understorey herbaceous vegetation productivity (Whysong and Bailey 1975). Walker *et al.* (1981) reported that if herbaceous plant biomass is maintained at a low level for a sufficiently long time, for instance, through several years of sustained intensive grazing, then the soil surface changes in terms of degree of compaction and encrustment, leading to reduced infiltration rate. The combined effect is that the woody vegetation has more water available to it, resulting in an increase of the woody vegetation biomass. These two factors, (reduced infiltration and/or greater woody biomass) suppress re-establishment of grasses even when the grazing pressure is reduced. Pase (1958) noted that grass and forb biomass increased with decrease in the density of the canopy cover. Martin and Tschirley (1961), Martin (1975), Cable (1976), Kinyua (1996) and Wasonga (2001) arrived at the same conclusion.

Although most of these studies arrived at almost the same conclusions in principle, there are fundamental differences in the cause-effects relationships between different plant species. Pase (1958) working with pines reported that different understorey species reacted differently to fluctuations in canopy density, with graminoids showing the greatest change in terms of weight per unit area to reduction in canopy diameter. He found that some herbaceous plant species virtually disappeared at maximum canopy density. Cooper (1959) predicted that no herbaceous vegetation would be found at canopy densities above 75%. The reasons ascribed to the reduction in understorey biomass productivity with increase in canopy density are many and varied, but the most important one is the competitive interaction between the woody species and herbaceous plants species. The woody vegetation has an extensive root system, often accompanied by a deep taproot, high sprouting ability, and reduced palatability. These characteristics provide competitive advantage to trees over grasses and forbs for drought survival (Jacoby 1986).

Trees and shrubs may also affect the associated herbaceous vegetation by altering the species composition, density and vigour. For instance, Wasonga (2001) found less herbaceous vegetation production under the canopy of *Balanites glabra* than in the zone outside the canopy. Tiedmann and Klemmedson (1977) observed that elimination of mesquite shade and roots resulted in increased foliar cover of understorey vegetation in the canopy zone from 19% with intact mesquite trees to 24% in the open areas. Competition for light, soil moisture and nutrients are the contributing factors to the reduced herbaceous plant productivity under the tree canopy (Wood *et al.* 1984). Competition for resources and shading effects, therefore, seem to be the principle factors responsible for reduced production beneath the canopy.

Different types of canopies affect the understorey layer differently, principally through the shading effects, with closed canopies producing less herbaceous biomass than the more open canopies (Rattiff *et al.* 1991). These types of canopies influence production in a contrasting manner during dry and wet periods with the closed canopies being more beneficial to the understorey species during the dry season than the open canopies. Large tree/shrub canopies reduce light intensity and evaporation from the microenvironment under them. The soil moisture and the prevailing ambient temperatures of the surrounding microenvironment are also reduced. Raindrops are intercepted by tree canopies, reducing their impact, and therefore, influencing infiltration rate, amount of runoff and total soil moisture storage (Pressland 1976, Maranga *et al.* 1983, Maranga, 1986).

Areas with different production potentials also respond differently to the canopy cover in terms of productivity. This is important in management because rangelands are inherently heterogeneous comprising a mosaic of different range sites (Pratt and Gwynne 1977). Rattiff *et al.* (1991), working in a run-in site with alluvial type of soils observed that there was a higher biomass production of herbaceous plant species in the open area than under the tree canopies. This suggests that areas outside the canopy benefit more from energy flux from the sun than areas under the canopy.

The productivity of herbaceous plant species under tree canopies in the tropics may be higher than in adjacent open area (Georgiadis 1989, Belsky *et al.* 1989).

The higher herbaceous biomass production under the canopy has been partially attributed to the ameliorating influences of the tree canopy particularly under the hot and dry conditions of arid and semi-arid areas.

Several studies in the tropics have reported an overall lower productivity from understorey herbaceous layer, a phenomenon which is attributed to reduced rainfall under the canopy (drought effect) and other interactions between trees and the understorey plants. Most studies on the canopy/understorey plant interactions have been conducted in temperate environments with only a handful conducted in the tropics. There is need to distinguish results obtained from these two regions. In the temperate regions, where only one growth period is experienced per year, energy flux from the sun is more important in terms of plant development. In contrast, production in the tropics can take place throughout the year (Cox and Waithaka 1989) and is normally limited by precipitation (Kinyamario and Macharia 1992, Boutton *et al.* 1988) and low soil moisture. From the foregoing literature review, it appears that the effects of the canopy depend on the balance between the shading and the inhibitory effects of the canopy on one hand, and its ameliorating effects, canopy on the other hand.

2.4 Effects of tree and shrub canopies on soil fertility

One of the advantages commonly associated with tree canopy/herbaceous layer interaction is the improvement of soil fertility through addition of nitrogen and organic matter (Kellman 1979). Tiedmann and Klemmedson (1973) reported that perennial plants, particularly shrubs, tend to accumulate soil nutrients beneath their canopies. This phenomenon results from three main nutrient recycling processes. First, absorption of nutrients by roots from areas outside the canopy of the plant and lower soil substratum and concentration of these nutrients under the tree canopies. Secondly, fixation of nitrogen in the soil by leguminous plants with the associated symbiotic organisms, and thirdly, importation of nutrients by fauna that use the trees for nesting, resting, roosting or feeding. The accumulation of nutrients under the tree canopies can also be as a result of wind or water movements that tend to concentrate litter around the tree trunk. The litter decomposes, releasing nutrient beneath the trees. Kellman (1979) concluded that the gradual accumulation of minerals by trees and the incorporation of these into the plant-litter-soil nutrient cycle, was the key mechanism responsible for the increase in soil fertility beneath the tree canopies.

Aggarwal (1980) reported that soils under *Prosopis cineraria* had higher organic matter, nitrogen and micronutrients than soil in the open areas. Dregne (1992) further observed that trees utilize deep water tables, improve soil physical conditions, reduce raindrop splash effect and ground level wind speed, and hence, the overall ecosystem productivity. In addition, Garcia-Moya and Mckell (1970) asserted that shrubs play an important role of maintaining a pool of soil nutrients in desert ecosystems by creating islands of fertility beneath their canopies through accumulation of organic matter.

Other known avenues through which nutrients are added to the sub-canopy zone of trees include litter-fall,-dead leaves, fruits and branches (Brimson *et al.* 1980) and dead roots. Nye (1961) reported that under moist tropical forests, the net annual contribution of dead roots was approximately at 2,600Kg ha^{-1}. Apart from the direct contribution of the woody species to the soil nutrients around the canopy, spatial transfer of nutrients is considerable even under normal grazing practices. Belsky *et al.* (1989) suggested that the higher mineral nutrient concentration under the tree canopies than in the open areas, could be due to the nutrients brought from the surrounding areas by the extensive root systems.

Rattiff *et al.* (1991) found that soils under blue oak had more humus, better water holding capacity and better nutrients status than the nearby open areas. Georgiadis (1989) noted that, sub-canopy soil had five times more nitrogen and twice the amount of carbon than in areas immediately outside canopy. He also observed that soils under the tree canopies had higher pH than those in the nearby open area. Belsky *et al.* (1989) reported higher soil organic and extractable phosphorus, potassium and calcium under the canopies of *A. tortilis* and *Adansonia digitata*, than in areas immediately outside the canopy zone. There is a general consensus that soil fertility is relatively higher beneath the canopy than in the nearby open areas. The higher soil fertility under tree canopies than the adjacent open area might be responsible for better performance of herbaceous plant species observed in some of the studies despite any anticipated competition between the woody and herbaceous plant species.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the study site

This study was conducted between February and May 2001 on the Njemps flats, Baringo district, Kenya, situated 15 kilometers East of Marigat trading centre along Marigat-Logumukum road (Figure 1). The area falls within eco-climatic zone IV, classified as semi-arid (Pratt and Gwynne 1977). Total annual rainfall range is 600-900mm described as low, unreliable and highly localized (Ekaya *et al.* 2001) with a bimodal distribution (Appendix 2). Annual evapo-transpiration potential is 1600-2300mm indicating 1000-1400mm moisture deficit. The mean annual minimum and maximum temperatures are 28°C and 38°C, respectively.

The main soil type is fluvial-lacustrine characterised by poor general structure, high erodability and low infiltration rate (Jaetzold and Schmidt 1983). *Prosopis juliflora* and *A. tortilis* are the dominant woody plant species. *Acacia tortilis* is indigenous while *P. juliflora* was recently introduced into the area as part of a rangeland rehabilitation programme and has since then invaded most lowlands. Other woody plant species in this area include *Acacia seyal* and *Balanites aegyptiaca. Cynodon dactylon* is the dominant perennial grass species. Other grass species include *Setaria verticilata* and *Eriochloa meyerianum.* According to local people, before the introduction of *P. juliflora*, the main vegetation type was *Indigofera-Cynodon* grassland with scattered or clumped *Acacia tortilis* trees.

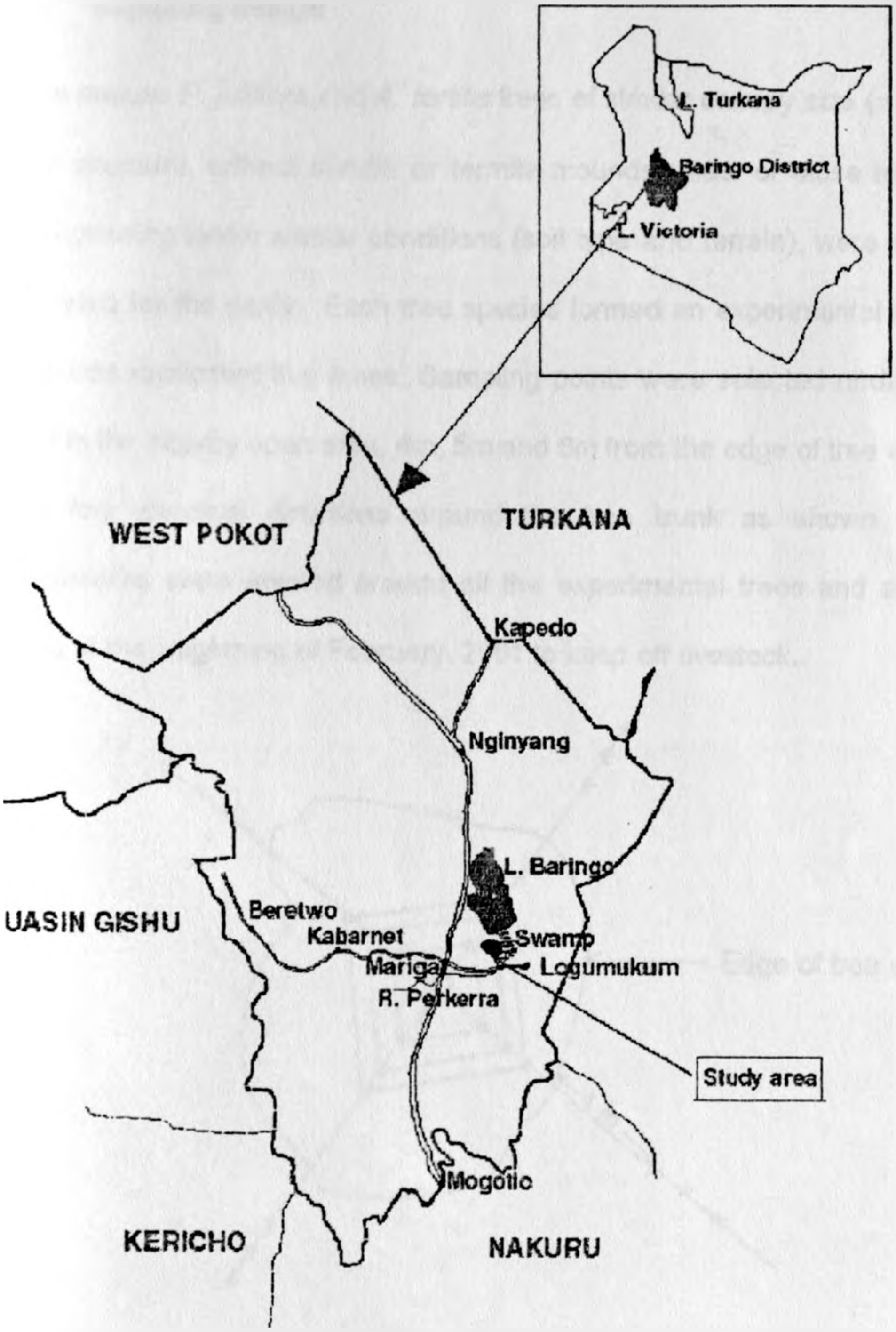
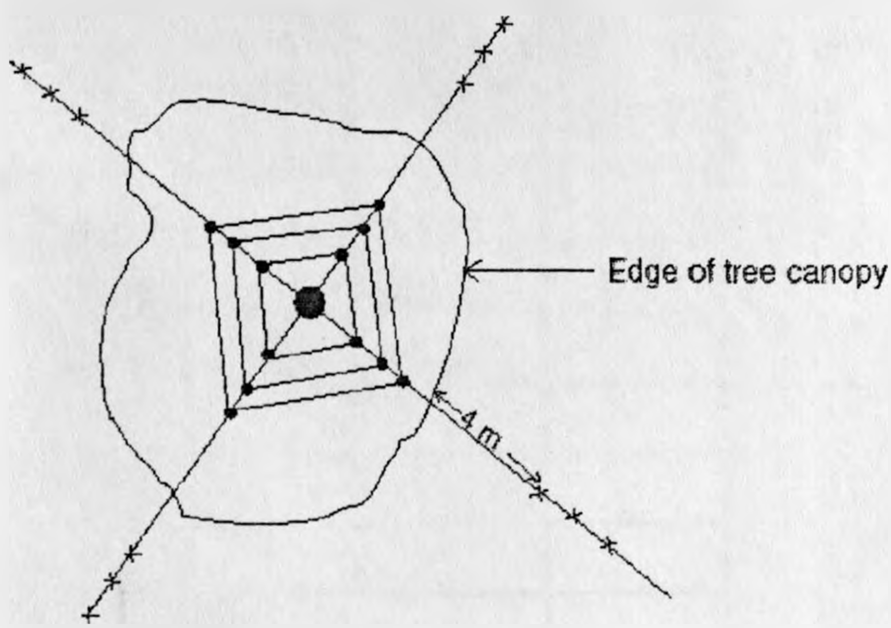


Figure 1: Location of study area

3.2 Sampling design

Five mature *P. juliflora* and *A. tortilis* trees of similar canopy size (≅ 8m diameter) and structure, without shrubs or termite mounds under or close to their canopy and growing under similar conditions (soil type and terrain), were systematically selected for the study. Each tree species formed an experimental unit and each unit was replicated five times. Sampling points were selected under the canopy and in the nearby open area, 4m, 5m and 6m from the edge of tree canopy, along the four cardinal directions around the tree trunk as shown in Figure 2. Exclosures were erected around all the experimental trees and adjacent open area at the beginning of February. 2001 to keep off livestock.



Key:

● Tree trunk of either *P. juliflora* or *A. tortilis*.

• • • Sampling points under the tree canopies

x x x Sampling points in open area

FIGURE 2: Experimental layout showing the sampling points

Plant and soil samples were collected at 1m, 2m and 3m from the tree trunk under the canopy, and at 4m, 5m and 6m from the edge of tree canopy along the four cardinal directions.

3.3 Soil sampling and analysis

Soil samples were also obtained at 0-5cm, 15-20cm and 40-45cm depths along each of the four cardinal directions of the tree trunk as shown in Figure 2. Thus a total of thirty-six samples were collected beneath the canopy of each tree and another thirty-six samples outside the tree canopy. For each tree or experimental unit, soil samples at the three depths and distances were composited into one sample. For each *P. juliflora* tree there was an adjacent *A. tortilis* tree that was 20-30m away. The two tree species formed a pair.

For each pair of *P. juliflora* and *A. tortilis* trees, soil samples from the open areas were further composited into one sample as the area was uniform in terms of slope, soil type and ground cover. The composite soil samples were stored in labeled polythene bags for subsequent analyses. All the soil samples were oven dried at 70^0C for 24 hours, ground using a mortar and pestle, then sifted over a sieve over a 0.5mm sieve grade. The samples were analyzed for organic carbon, total nitrogen, available phosphorus and pH.

Organic carbon was determined using the Walkley-Black method as outlined by Black *et al.* (1965). Total nitrogen was determined by the wet digestion method of

Bremner (1965), while available soil phosphorus was determined using the double acid method described by Mehlich (1962). Soil pH was determined using the method described by Peech (1965). Aluminium cylinders (5cm diameter) were used to extract undisturbed soil core samples for soil bulk density determination. Core rings were hammered into the soil and carefully removed. The soil cores were oven dried at 105^{0}C for 24 hours, weighed and bulk density calculated as follows:

$$\text{Bulk density } (\text{g cm}^{-3}) = \frac{\text{Weight of oven dry soil (g)}}{\text{Volume of core ring (cm}^3)} \text{X} 100$$

3.4 Aboveground standing crop biomass of herbaceous plant species within and outside the canopy

Sampling of herbaceous plants was conducted in May 2001, two and half months after onset of the long rains when the plants had gained substantial growth. Above ground herbaceous biomass production within and outside the canopies of the two tree species was determined using a 0.25m^2 quadrat. The quadrat was placed at 0-1m, 1-2m and 2-3m intervals from the tree trunk along the four cardinal directions around the tree trunk under the tree canopy (Figure 2). The same procedure was repeated in the open area. The herbaceous vegetation within the quadrat was clipped at 2cm above the ground level to avoid soil contamination. The fresh plant materials were stored in labeled paper bags and later oven dried to a constant weight at 70^{0}C for 48 hours. Aboveground biomass yield was expressed in ton.ha^{-1} on dry matter basis using the formular shown below:

$$\text{Biomass production } (t\ ha^{-1}) = \frac{\text{Weight (kg) X } 10{,}000m^2}{0.25m^2}$$

Basal cover was estimated by the ten-pin point frame method described by Levy and Madden (1933). The frame was placed at each of the three sampling points under the canopy and in the open area (Figure 2). Nine plots were sampled under each tree and in the open area along the established radii. The mean basal cover from four plots within and outside the canopy, at each of the designated points along the four cardinal directions, was determined. For each pair of *A. tortilis* tree and *P. juliflora* tree, an average of twenty-four sampling points outside the canopies of two trees was calculated. Samples of herbaceous plant species from open areas of each pair of the tree species were pooled. The samples were pooled because the study site was uniform in terms of land terrain and vegetation cover and that each pair of the tree species was 20-30m a way from each other. Percent plant cover was computed as follows:

$$\text{Total cover (\%)} = \frac{\text{Total number of intercepts}}{\text{Total number of pins}} \text{X} 100$$

Percent frequency of herbaceous plants was also determined by means of a point-frame with ten pins. The number of intercepts on a given plant species was recorded. The percent frequency of each herbaceous plant species was calculated as follows:

$$\text{Frequency (\%)} = \frac{\text{Number of intercepts of a given species}}{\text{Total number of intercepts of all species present}} \text{X100}$$

3.5 Statistical analysis

Data on percent herbaceous biomass, cover, species frequency, soil carbon, total nitrogen, available phosphorus, pH and soil bulk density were subjected to analysis of variance (ANOVA) (Steel and Torrie 1980). Sources of variation in the analysis were the tree species, tree canopies and the open area. Where significant differences were detected, means were separated using least significance difference (LSD) according to Steel and Torrie (1980). The model used in the analysis was:

$$\mathbf{Y_{ij} = U + T_{i\,(1,2,and3)} + E_{ij}}$$

Where U= underlying constant common to all records of Y (overall mean)

i_1= mean of samples obtained below the canopy of *p. juliflora.*

i_2=mean of samples obtained below the canopy of *A. tortilis.*

i_3=mean of samples obtained in the open area.

E_l = residual error with (μ=0; e=lδ^2)

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Aboveground net primary production, cover and frequency of herbaceous plant species within and outside tree canopies

Table 1 presents average net primary production, cover and relative frequency of herbaceous plant species within and outside the canopies of the two trees. The results showed a significant ($P<0.05$) difference in biomass production between the open and shaded areas for both trees, with the higher biomass yield being found in the former than the latter area for both trees. Mean biomass yield was 5 times higher in open areas than under the *P. juliflora* canopy and 3 times more in open areas than under the *A. tortilis* canopy. The average herbaceous biomass yield was more than twice under *A. tortilis* canopies than under the canopies of *P. juliflora.* The ground cover of herbaceous plant species was significantly ($P<0.05$) higher in the open area than under the shade of the two trees. Ground cover in the open areas was 43% and 30% more than under the *P. juliflora* and *A. tortilis* respectively. The lowest herbaceous plant species cover was recorded under *P. juliflora* canopy (Table 1).

Cynodon dactylon was the most dominant grass species both within and outside the canopy (97.2% in open area, 69% under *P. juliflora* canopy and 50% under *A. tortilis* canopy). Results in Table 1 indicate that there was a high concentration of herbaceous plant species under the canopy than in the open areas. The dominant herbaceous plant species under *P. juliflora* canopy were *C. dactylon* (69%), *Setaria verticilata* (9.4%), and *Cyperus rotundus* (9.4%), while under *A. tortilis* these were *C. dactylon* (50%), *Eriochloa meyrianum* (18%) *Setaria verticilata* (15%), and *C. rotundus* (12%). There were more herbaceous plant species under *P. juliflora* canopy than under *A. tortilis* canopy. Frequency data showed that there were more grass species under the *A. tortilis* canopy than under *P. juliflora* canopy. *Acantherspermum hispidum* and *Amaranthus spinosa* forbs were present under the canopies of the two trees but not in adjacent open areas while *Mormodica foetida* and *Polygonum setbsum* forbs occurred under *P. juliflora.*

Table 1. Mean biomass production (ton ha^{-1}), ground cover (%) and relative frequency (%) of herbaceous plant species within and outside *P. juliflora.* and *A. tortilis* canopies

Parameter	*Prosopis juliflora*	*Acacia tortilis*	Open area
Cover (%)	63^c	82^b	90^a
Biomass production(t ha^{-1})	0.65^c	1.33^b	3.3^a
Relative frequency (%)			
Grasses			
Cynodon dactylon	68.9^b	49.6^c	97.2^a
Setaria verticilata,	9.4^b	14.6^a	0.0^c
Eriochloa meyerianum	0.0^b	18.3^a	0.0^b
Forbs			
Acantherspermum hispidum	3.1^a	2.6^a	0.0^b
Amaranthus spinosa,	3.1^a	2.6^a	0.0^b
Polygonum setbsum	3.1^a	0.0^b	0.0^b
Mormodica foetida	3.1^a	0.0^b	0.0^b
Sedges			
Cyperus rotundus	9.4^b	12.3^a	2.8^c
Total	**100**	**100**	**100**

Means on the same row with different letter superscript are significantly different ($P<0.05$)

The lower total biomass production under the tree shades than in open areas shows canopies inhibit production of understorey plant species with the former having more negative effects than the later. Visual inspection of the two tree species canopies shows a distinct difference in physical structure. *Acacia tortilis* crowns are shallower and more hemispherical in shape while *P. juliflora* crowns are deeper and more globular, giving rise to a higher shade intensity that reduces the photosynthetic rates of the understorey herbaceous plants, resulting in lower biomass production. Therefore, the architectural and allometric differences between the canopies of the two tree species are important factors as far as light transmission to the understorey plant species is concerned.

Other researchers (Frost and Edinger 1991, Belsky *et al.* (1993) have reported lower biomass production from herbaceous plant species under tree canopies than in the open areas. Galt *et al.* (1982) observed that *P. juliflora*-free pasture produced 1.2 tons ha^{-1} of herbaceous biomass compared to 0.8 tons ha^{-1} from pastures with 17% *P. juliflora*. Carlton *et al.* (1983) noted that as *P. juliflora* becomes established, the herbaceous vegetation cover within the canopy decreases, which he attributed to the rooting pattern and the shading effect of this tree. Tiedmann and Klemmedson (1977) further noted that roots of *Prosopis* spp. extend downward and laterally and affect the soil moisture regime under the canopy. Further more, the extensive lateral root systems of *P. juliflora* occupy the same soil horizon as the grasses. Cable (1976) reported that water is extracted rapidly from the upper part of the root zone close to the tree trunk. The assumption is that the roots of *Prosopis spp* exert a stronger "pull" on the soil water than the grasses. This could also explain the low biomass of herbaceous plant species observed under *P. juliflora* than *A. tortilis* canopy.

McGinnes and Arnold (1939), Parker and Martin (1952), and Fisher *et al.* (1973) noted that when *P. juliflora* becomes established, its lateral roots grow in all directions and take up soil moisture that could be used by herbaceous vegetation. This enables trees to have a competitive edge over herbaceous plants, which could partially account for these differences in herbaceous biomass between areas under and outside the canopies. Cable and Tschirley (1961) and Paulsen (1975) observed an increase in average soil moisture content in areas where *Prosopis* trees had been removed compared to areas where the trees were still intact. They argued that herbage yield was higher in areas where the trees had been removed due to an increase in moisture availability. Frost (1990) also noted that the shading effect of the evergreen woody species, such as *P. juliflora*, might limit herbage production. Further, Weltzin and Coughenour (1990) observed that shading by tree canopies might be the most important factor affecting understorey herbage production and composition in African savanna.

The results of this study showed that areas outside the canopy had higher grass cover than areas within the canopy. The shading and litter cover did not influence the open areas. The lower herbaceous plant species production under both canopies than in the open areas could be attributed to the canopy geometry, which influences the intensity and duration of light received by the understorey plant species.

In this study, grasses were less abundant under the canopy than in open areas. In contrast, forbs were more abundant within than outside the canopies. This indicates that forbs require a modified microclimate of lower temperature and lower light intensities – such as is found under tree canopies. There seems to be a more enhanced plant biodiversity under the canopy of *P. juliflora* than that of *A. tortilis*, although most of these species are annuals that have little limited grazing value. Tiedmann and Klemmedson (1973) noted that in some situations, particularly on ranges that have had poor grazing management, as is the case in the current study area, perennial grasses might not be abundant under the tree canopy. He noted that cattle seek out the more palatable herbaceous plant species under tree canopies on the desert grassland, where if the level of use is not controlled, the perennials lose viguor rapidly and eventually they die. This could explain to some extent why there is suppressed herbaceous biomass production under the *P. juliflora* and *A. tortilis* canopies. Sen and Sachwan (1970) stated that *P. juliflora* trees inhibit growth of understorey plant species due to phytotoxic effects of their leaves. The observation by Sankhla *et al.* (1965) that *A. tortilis* and *P. juliflora* are alellopathic in nature may also partly explain the relatively low biomass production of herbaceous plant species obtained under the tree canopies.

In New south Wales, Australia, Harrington and John (1990) observed that herbaceous biomass production was negatively correlated with canopy density of *Eucalyptus* species. He attributed this phenomenon to the combined effects of shading and chemicals contained in leaves of *Eucalyptus* trees on the understorey herbaceous plant species. Jacoby *et al.* (1982) reported higher herbage production away from *Prosopis glandulosa* Torr. trunk than near it in Texas rangelands. They attributed their findings to the competition between the trees and associated grasses for moisture. Pieper (1990) and Walker *et al.* (1981) argued that apart from reduced light intensity at higher canopy densities, competitive interactions for water and nutrients between trees and herbaceous plant species, could partly account for the low biomass production. Therefore, selective grazing, phytotoxic effects of leaves, shading and competition for soil moisture are some of the most important factors that contributed to the low frequency of grass species under the canopies of *P. juliflora* and *A. tortilis.* Therefore *P. juliflora* should not be introduced or encouraged to grow in arid and semi-arid areas because it has more negative effects to herbaceous plant s species below its canopy compared to *A. tortilis.*

The difference in relative percent frequency of herbaceous plant species within and outside the canopy observed in this study may be attributed to differences in soil properties such as soil reaction (pH), which tended to be more acidic under the tree canopies than outside. Although competition for moisture between woody plant species and the herbaceous plant species was not investigated, it could also partially account for the difference in percent species frequency. Results of this study agree with those of Harrington and John (1990), Belsky *et al* (1993) and Kinyamario *et al.* (1995) who noted that the understorey plant species composition was generally different from that of the area immediately outside the canopy. The authors attributed the differences in herbaceous species composition and frequency to differences in shade density, water stress, and grazing tolerance among the herbaceous species. Wasonga (2001) working in south-central Kenya reported a higher frequency (68%) of herbaceous plant species in the open areas than under the canopy of *Balanites glabra* Mildbr & Schlecht (29%). Kinyamario *et al.* (1995) attributed the differences in herbaceous plant species composition between the canopy zones and adjacent open grassland to differences in carbon assimilation rates and water use efficiencies among the herbaceous species.

4.2 Soil organic carbon, total nitrogen, available phosphorus, pH and bulk density within and outside the canopy

Soil organic carbon, total nitrogen, available phosphorus, pH and bulk density data is presented in Table 2. Organic carbon content was significantly (P< 0.05) higher under canopies of both trees than outside the canopy. Under *P. juliflora* and *A. tortilis* canopies organic carbon contents were 13% and 26% respectively higher than the soils in the adjacent open areas. On the other hand, soils under *A. tortilis* had 11% more organic carbon than those under *P. juliflora*. For both trees, total soil nitrogen content was significantly (P< 0.05) higher under the canopy than in adjacent open areas. However, soils under *A. tortilis* canopy had twice as much total nitrogen as the soils in the adjacent open areas and more than one and half times than soils under *P. juliflora*.

Our results also showed that available phosphorus was significantly (P<0.05) higher in the open areas than under the canopies of both trees. Soils under *A. tortilis* and *P. juliflora* canopies had significantly (P<0.05) higher available phosphorus content, with soils under the former having 2.2% more phosphorus than those in the latter.

There was a significant (P<0.05) difference in pH between the soils within and outside the canopies of both trees, with a higher pH being found in the open than in the shaded areas. Soil pH under the canopies of the two tree species was not significantly (P<0.05) different.

The results of this study also showed a significant (P<0.05) difference in soil bulk density between areas under the canopy and those outside the canopy within 0-5 cm depth but not within 0-45cm depth. The soil bulk density in the open areas was 10% higher than that under the shade. The bulk densities of soils within the canopies of *P. juliflora and A. tortilis* were not different. The low bulk density under the tree canopies was probably due to the rooting pattern of the trees that loosens the soil and the protection of the soil from direct impact of raindrops.

Table 2. Mean organic carbon (%), total nitrogen (%), available phosphorus (%), pH, and bulk density (g cm^{-3}) within and outside tree canopies and in open areas

Attribute	*Prosopis juliflora*	*Acacia tortilis*	Open area
Percent organic carbon	1.23^{a}	1.37^{b}	1.09^{c}
Percent total nitrogen	0.08^{b}	0.13^{a}	0.06^{c}
AvailabblePhosphorus (ppm)	664^{c}	675^{b}	722^{a}
Soil pH	7.08^{b}	7.16^{b}	7.48^{a}
Bulk density (gcm^{-3}) 0-45cm soil depth	1.20^{a}	1.20^{a}	1.22^{a}
Bulk density (gcm^{-3}) 0-5cm soil depth	1.16^{b}	1.18^{b}	1.28^{a}

Means on the same row with different letter superscript are significantly different (P<0.05)

The results of this study showed an accumulation of organic carbon and total nitrogen below the tree canopies. This may be partly due to the earlier seasonality of litter fall and reduced leaching under the tree canopy. The residential herbivores and birds could also be responsible for the higher organic carbon and total nitrogen observed under the tree canopies. The lower organic carbon content in open areas could also be attributed to the fact that the main source of organic matter is grass. Jones (1971) indicated that in grass-dominated savanna soils, residues from the natural vegetation, are usually poor in nitrogen and seem likely to initiate a period of soil nitrogen immobilization when returned to the soil as the grass residues are low in nitrogen:carbon ratio. This may also explain the low total nitrogen obtained in the open areas.

The higher organic carbon and total nitrogen level under *A. tortilis* canopy could be attributed to the deciduous nature of the species compared to *P. juliflora*, which is an evergreen tree. Higher concentration of carbon and nitrogen in the soils within the canopy than in soils in the adjacent open areas has been reported in other studies (Belsky *et al.* 1989, Kinyua 1996 and Wasonga 2001). These results also corroborate with those of Felker (1978) who reported 50-100% higher organic carbon under the tree canopies. Young (1989) reported substantially higher organic carbon under the canopies of *Adonsonia digitata* Linn. and *A. tortilis* (Forsk) than in the adjacent open areas in Tsavo National Park, Kenya. The results concur with those of Garcia-Moya and Mckell (1970) and Dregne (1992) who observed a similar pattern of enrichment of soils under canopies of desert trees. They attributed this enrichment of carbon and nitrogen to organic matter accumulation and reduced leaching under the tree canopies. The high nitrogen and organic carbon of soils *A. tortilis* canopies was attributed to the semi-deciduous nature of the species and the strong symbiotic relationship with the native soil microbes. The results of this study indicate that *P. juliflora* is not more efficient in improving soil fertility than *A. tortilis*. Thus, *P. juliflora* should not be encouraged to grow in arid and semi arid areas at the expense of native tree species like *A. tortilis.*

Tiedemann and Klemmedson (1973), Kellman (1979), Georgiadis (1989), Grouzis and Akpo (1997) noted that the improved soil fertility beneath the tree canopies could be due to accumulation of "top fertile" soil that has been eroded from open areas. Sharma (1985) was of the opinion that the most important source of organic matter and a substantial proportion of the currently available nutrients in the soil is the annual litter falling from the trees. Other exogeneous sources include spatial transfer of nutrients, which may be considerable even under normal grazing practices. Miyazaki *et al.* (1987) for example, reported that under temperature of around 27°C, 44-53% of urination and 26-29% of defecation by herbivores, particularly cattle, occur in the shade.

Trees also act as windbreaks resulting in loose organic debris swept from areas between trees being trapped and retained beneath the tree canopies. The enhanced soil fertility under the two tree species can be accounted partially by the decomposition of these materials. Menault, *et al.* (1985) argued that root turn-over is probably more important than litter accumulation in improving the soil fertility status within the canopy zone. Therefore, the higher amount of soil nutrients found under tree canopies may as a result of litter and roots decomposition, biological processes such as nitrogen fixation and dung deposition from mammals.

The lower available phosphorus content under both tree canopies in this study could be attributed to biological processes that are continuously taking place between the Rhizobium bacteria and the tree roots, as both tree species are leguminous. Rhizobium bacteria are utilize the phosphorus in synthesising their proteins and hence the low level of it under the canopies. The results of this study are consistent with those of Young (1989) who also observed low phosphprusin sub-canopy zones and attributed it to being utilized in biological nitrogen fixation by the Rhizobium bacteria.

Soils under the canopy tended to be more acidic than soils in open areas. The slight acidity of the soil within the canopy zone could be attributed to leaches and exudes from litter fall and roots. The findings of this study are in agreement with those of Bhatia *et al.* (1998) who observed a significant reduction in the soil reaction (pH) under the canopies of *P. juliflora*, but inconsistence with the findings of Dunham (1991) reported that soils were less acidic within than outside the canopies.

The lower soil bulk density observed under the tree canopies than in the adjacent open areas could be attributed to tree canopies that protect the soil from the force of raindrops. The high bulk density in the adjacent open area could be attributed to increased soil compaction as result of animal activities or raindrop effect (Garg and Jain 1996). *Prosopis juliflora* and *A. tortilis* trees have lateral roots, some running close to the surface. *Prosopis juliflora* is evergreen, which ensure that the soil is protected from the action of raindrop at any given time. Other studies have reported lower soil bulk density beneath tree canopies than in adjacent open areas (Tiedemann and klemmedson 1973, Haworth and Mcpherson 1995). The lower bulk density within the canopy could be due to improved macroporosity (Joffre and Rambal 1988). Conversely, higher bulk densities could be as a result of trampling by large animals seeking shade or forage (Federer *et al.* 1959 and Warren *et al.* 1986)

There is an indication that *P. Juliflora* and *A tortilis* trees are the causal agents of the pattern observed in the soil analysis and that they function to improve the soil physical and chemical properties beneath their canopies at the expense of soil between the trees with the later being more efficient than the former. Therefore, *A. tortilis* trees should be allowed to grow in pasture for improved livestock production.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

This study has demonstrated that *P. juliflora* and *A. tortilis* trees inhibit herbaceous plant growth under their canopies. Inhibition is more pronounced under *P. juliflora* canopy than *A. tortilis* canopy. The rapid spread of *P. juliflora* through natural propagation combined with its inhibition effect on herbaceous plants has resulted in diminished grazing pasture.

The results also suggest that forbs are more suited to shaded environment than grass species. Similarly, the canopy zone seemed to hosts a richer species composition than open areas but majority of these species were annuals that have low significance in the management of the arid and semi arid areas for livestock production. There were more plant species under *P. juliflora* canopy than *A. tortilis* canopy.

The results of this study have indicated that *P. juliflora* and *A. tortilis* improve the soil organic carbon, total nitrogen and bulk density beneath their canopies. However, *P. juliflora* trees are not more efficient at increasing soil fertility than some indigenous tree species like *A. tortilis*. Although the improvements in physical and chemical properties of soils under the canopies might have resulted from the combined inputs of trees and grass litter, the external sources of the nutrients that enrich the soil seem not to be known. The nutrients enriching the canopy-zone soils were likely to have been brought into the zone by the trees, which extract nutrients and water with their roots from deeper and in areas beyond the tree canopies and by birds and large mammals, which transport nutrients from the grassland to the canopy zone in their food and nest materials.

With higher soil total nitrogen and organic carbon under the tree canopies, it would have been expected that there would be improved soil water relations, which could have favoured herbaceous plant species production. However, nutrients are less likely to have been a limiting factor in production of herbaceous plant species under the canopy. Therefore, it is probably competition between the woody plants and herbaceous plant species for soil moisture and sunlight, which resulted in low production of the later within the tree canopy. It is necessary to consider appropriate tree density, and in case of high tree canopy density, thinning of some trees with occasional lopping of others should be encouraged. This will reduce the density of the tree canopies thereby facilitating light and rainfall penetration into the understorey layer.

Apart from shading and competition for nutrients and moisture by trees and grass roots, other factors such as allelopathic effects from litter and livestock seeking more fresh and nutritious grass species could have influenced the grass cover and production of biomass within the canopy zone than in the nearby open areas. Additional research therefore, is needed to isolate and separate different factors influencing herbaceous biomass production within the canopy zone.

Though high biomass production was obtained in open areas than under tree canopies, positive effects of woody plant species justify the need to leave some trees and shrubs in pasture. The common practice of clearing all woody plants in order to establish farms and improve rangelands does not only remove the beneficial effects on soil fertility, but also removes other beneficial effects such as the provision of shade for grazing animals, habitat for birds and wildlife and browse for livestock. Therefore, trees that have beneficial effects to the ecosystem like *A. tortilis* must be taken into consideration in managing Kenyan rangelands as their loss could have a negative impact on soil physical and chemical properties.

Based on the results of this study, *P. juliflora* trees have more negative effects to the arid and semi arid ecosystem than *A. tortilis* trees. Therefore *P. juliflora* should not be allowed to grow in rangelands and in areas where this tree is already occupying large track of land, it should be eradicated through mechanical, use of chemicals, biological control or combination of these methods. However, research should be conducted to determine which control methods are more efficient and economical. There is need also to conduct more research in different areas with different trees and herbaceous plant species for a longer period of study. These data will generate adequate information necessary for comprehensive conclusions and recommendations to be made as concerns woody-herbaceous plant interactions.

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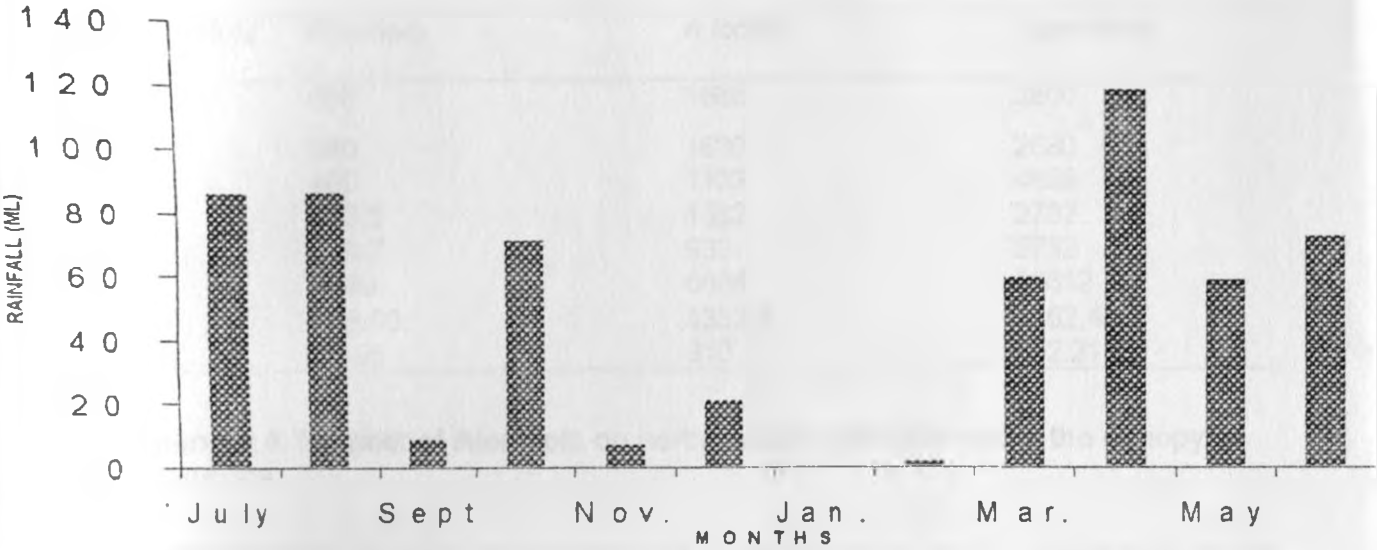
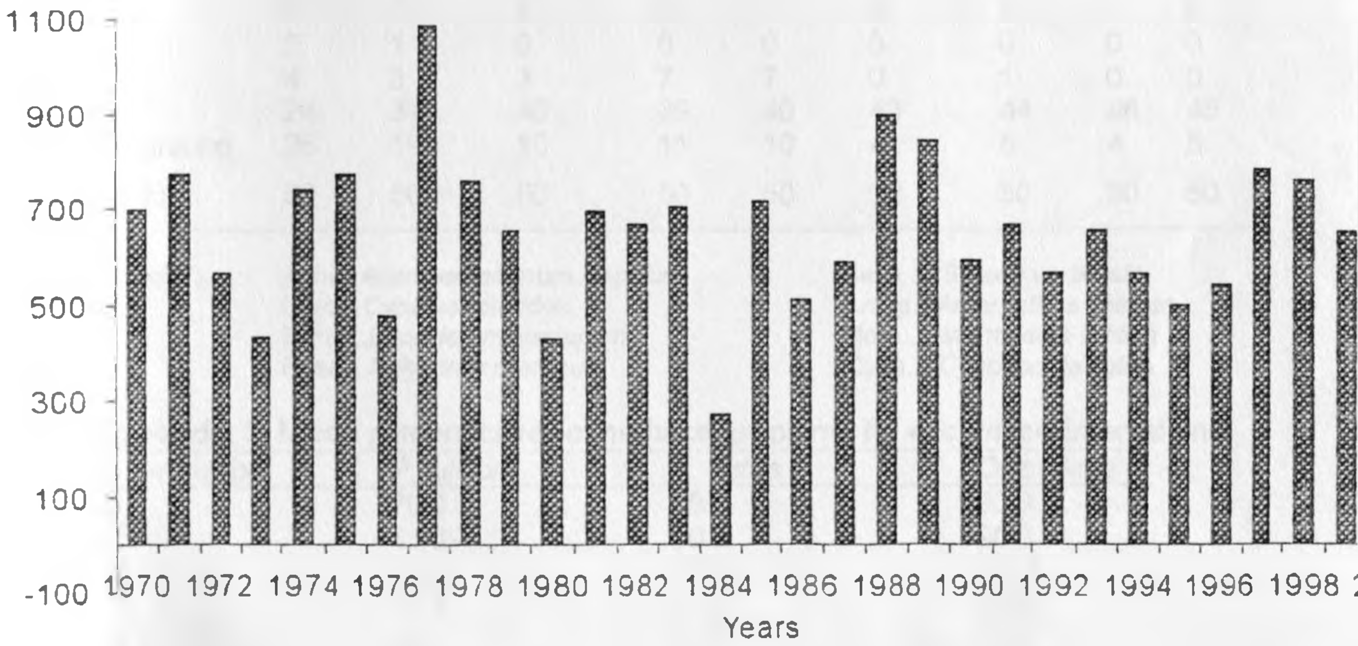
Appendices



Appendix1. Monthly rainfall of Njemps flats Baringo district during the period the study (july 2000-june 2001



Appendix 2. Total annual rainfall of Njemps flats Baringo district, Kenya, for 31 years (1970-2000)

Appendix 3. Mean biomass production per experimental unit (kg ha^{-1})

Tree number.	*P.juliflora*	*A.tortilis*	Open Area
1	600	1668	3800
2	960	1600	2680
3	480	1132	4868
4	573.3	1332	2732
5	626 7	932	2732
Σ	3240	6664	16812
Mean	648.00	1332.8	3362.4
S.E.D	17.96	310	962.21

Appendix 4. Number of intercepts on herbaceous vegetation under the canopy and outside

Species	*P.juliflora*			*A.tortilis*			Open Area		
	1m	2m	3m	1m	2m	3m	4m	5m	6m
Cydon	13	24	30	14	17	25	41	45	42
Seve	0	3	5	10	10	7	0	0	0
Erme	0	0	0	8	5	8	0	0	0
Achi	1	0	0	0	0	1	0	0	0
Amsp	2	0	2	0	1	1	2	1	3
Pose	2	0	0	0	0	0	0	0	0
Mofo	2	1	0	0	0	0	0	0	0
Cyro	4	3	3	7	7	0	1	0	0
Total	24	31	40	39	40	43	44	46	45
Bare ground	26	19	10	11	10	4	6	4	5
Total hits	50	50	50	50	50	50	50	50	50

KEY:
Achi...*Acantherspermum hispidum*
Cyro...*Cyperus rotundus*
Erme...*Eriochloa meyerianum*
Pose...*Polygonum setbsum*
Seve.....*Setaria verticilata,*
Amsp...*Amaranthus spinosa,*
.Mofo.....*Mormodica foetida*
Cyda....*Cynodon dactylon*

Appendix 5. Mean percent cover of herbaceous plants for each experimental unit

Tree number	*P. juliflora*	*A. tortilis*	Open Area
1	70.0	90.0	93.3
2	81.6	90.0	90.0
3	50.0	80.0	9 3.3
4	53.3	83.3	9303
5	66.7	73.3	90.0
Σ	321.6	416.6	459.9
MEAN	**64.3**	**83.3**	**91.98**
S.E.M	12.87	7.08	1.81

Appendix-6. Percent frequency of *cynodon dactylon* per experimental unit

Tree number	*P. juliflora*	*A.tortilis*	Open Area
1	42.3	0.0	93.3
2	43.3	23.3	90.0
3	50.0	56.7	90.0
4	33.3	50.0	66.7
5	33.3	56.7	86.5
Mean	**40.4**	**43.7**	**85.34**

Appendix 7. Analysis of variance on soil organic carbon

Source of Variation	Df	s.s	m.s	v.r	Fpr.
Treat	2	0.19	0.952E-01	1.06E+04	<0.001***
Residual	12	.0108E-03	0.897-05		
Total	14	0.191			

Key :-*** *Highly significant*

Appendix 8. Analysis of variance on soil total nitrogen

Source of Variation	d.f	s.s	m.s	v.r	Fpr
Treat.	2	0.164E-01	0.822E-2	2.7E+04	<0.001***
Residual	12	0.36-05	0.3E-06		
Total	14	0.164E-01			

Appendix 9. Analysis of variance on available soil phosphorus

Souce of Variation	Df	s.s	m.s	v.r	Fpr.
Treat.	2	9979.456	4989.728	1.52E+04	<.001***
Residual	12	3.94	0.328		
Total	14	9983.396			

Appendix 10. Analysis of variance on soil ph

Source of Variation	d.f	s.s	m.s	v.r	Fpr.
Treat.	2	0.422	02108	196.40***	<.001
Residual	12	0.013	0.0011		
Total	14	0.435			

Appendix 11. Analysis of variance on soil bulk density

Source of Variation	d.f	s.s	m.s	v.r	Fpr.
Treat.	2	0.0023	0.00114	2.09	0.167 n.s
Residual	12	0.0066	0.00055		
Total	14	0.0088			

n.s-not significant

Appendix 12. Analysis of variance on soil bulk density

(0-5cm soil horizon)

Source of Variation	d.f	s.s	m.s	v.r	Fpr.
Treat.	2	0.048	0.0240	7.01	0.01**
Residual	12	0.041	0.0034		
Total	14	0.089			

Appendix 13. Analysis of variance on percent frequency for *cynodon dactylon*

Source of Variation	d.f	s.s	m.s	v.r	Fpr.
Treat.	2	7216.0	3608.0	13.69	<0.001***
Residual	12	3162.4	263.0		
Total	14	10378.4			

Appendix 14. Analysis of variance on percent ground cover of herbaceous plants species

Source of Variation	d.f	s.s	m.s	v.r	Fpr.
Treat.	2	2001.79	1000.89	13.7	<0.001***
Residual	12	876.76	73.06		
Total	14	2878.55			

Appendix 15. Analysis of variance on above ground standing biomass of herbaceous plants.

Source of Variation	d.f	s.s	m.s	v.r	Fpr.
Treat	2	1930399	9651998	28.05	<0.001***
Residual	12	412873	344061		
Total	14	2343272			