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THE BIOLOGY AND USE OF THE CACTUS (*Opuntia exaltata*) AS A GAME DEFENSE BARRIER

by

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DECLARATION

The work presented in this thesis is the result of my own investigations and has not been presented for a degree in another university. All sources of information have been specifically acknowledged by means of references.

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DEDICATION

This thesis is dedicated to my parents whose encouragement and support during the study was of immense value.

ABSTRACT

Human-wildlife conflicts result as a competition for resources between man and wildlife. This thesis describes the use of traditional and conventional game barriers in managing wildlife populations and the use of cholla cactus (*Opuntia exaltata*) as a live fence in two main areas of Kenya and the problems facing the suitable growth and establishment of this live fence.

Traditional methods of deterring wildlife such as noise, lighting fires, constructing thorny barriers and extermination are widely used. Conventional barriers such as moats, stone walls, wire fences, high tensile fences and electric fences are expensive to construct, have high recurrent costs and are only marginally effective.

The cholla cactus (*Opuntia exaltata*) was introduced from South America and provides a "hard edge" barrier with its thick spiny stand and is used by ranches and small scale farmers in controlling wildlife depredation. The cholla cactus (*Opuntia exaltata*) is distributed in a total of seven districts but its use is concentrated in Nakuru and Laikipia districts. The growth of *Opuntia exaltata* as a managed fence was more successful in Nakuru then Laikipia district. To be an effective wildlife barrier it has to attain a height of at least 2-3 m and be 1-2 m wide.

However in some cases gaps and uneven height resulted in poor growth leading to an unsuitable barrier. This poor growth was caused by the physical conditions present in the soil such as compaction, shallow soil depth and poor moisture retention. The levels of nutrients in the different areas of growth were not significantly different and did not affect

the growth. The presence of partial shade from neighboring trees at a minimum level of $1500\ \mu E\ m^{-2}\ s^{-1}$ and the presence of leaf litter from the overhead canopy of the trees resulted in better growth of the *Opuntia exaltata* fences.

The limiting physical factors can be removed by excavating a trench and filling it with loose soil and manure to create a suitable matrix for root development and moisture retention. In areas with poor physical soil conditions and low rainfall this method would be suitable for growing a cholla fence.

The cholla cactus (*Opuntia exaltata*) can provide a cheap, cost effective barrier for reducing human wildlife conflicts and its xerophytic properties can allow it to be used in semi-arid and arid areas.

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CHAPTER 1

1. INTRODUCTION & LITERATURE REVIEW

In Kenya the majority of wildlife is found outside protected areas and is mainly concentrated in semi-arid habitats. This wildlife is responsible for human-wildlife conflicts which involves depredation of crops, livestock and humans (Bell and McShane-Caluzi, 1984). Encroachment of wildlife habitats by expanding human settlements is resulting in the range compression of wildlife populations resulting in human-wildlife conflicts at this interface.

Several types of barriers have been used both traditional and conventional types. The earliest methods involved making loud noise (Allaway, 1979, Mackinon *et al.*, 1986 and Teare, 1938), using fire (Ngure, 1992), sentries (Allaway, 1979), scarecrows (Kamweya, 1986), exterminating wildlife (Teare, 1938) and bush barriers (Madany, 1991).

The large scale farmers use more conventional methods such as moats, stone walls, wire fences, high tensile fences and electric fences. These barriers have found to be ineffective mainly due to high construction and recurrent costs and the ability of wildlife species to breach these high cost barriers.

Small scale farmers use vegetative barriers (live fences) because they are found to be cheap and easily manageable. The cholla cactus (*Opuntia exaltata*) is a barrier that is commonly used as a live fence. There has been no study conducted on the problems associated with the growth of a good continuos stand of cholla cactus in Kenya.

In order to gain a better understanding of the growth and use of the cholla cactus as a wildlife barrier an investigation was conducted in three areas namely Nakuru, Laikipia and Taita Taveta districts. The study was conducted with the following objectives:-

1. To conduct a survey in Nakuru, Laikipia and Taita Taveta districts to determine the methods of planting, problems and use of cholla cactus as a live barrier.

2. To investigate the physical and chemical characteristics of soil on the growth and height of the cholla cactus in two main areas Naivasha (Nakuru district) and Laikipia district.

3. To determine the viability and germination of cholla seeds.

1.1 HISTORY OF WILDLIFE BARRIERS

During the first half of the century crop raiding animals were controlled by shooting, poisoning and game drives. In the forested areas of Mt. Kenya and Aberdares elephant (*Loxodonta africana*), buffalo (*Syncerus caffer*), black rhino (*Diceros bicornis*), waterbuck (*Kobus ellipsiprymnus*), bushbuck (*Tragelaphus scriptus*), bush pig (*Potmochoerus porcus*) and baboons (*Papio anubis*) posed a serious threat to forest plantations and cultivated plots of maize belonging to forest employees and squatters. This problem in the forests was so acute that an elephant control officer had to be employed (Forest Dept. Ann. Rep., 1934).

During this same period the game department engaged in control shooting and poisoning of problem animals which was the main avenue of control. The idea of rough fences for buffalo was also suggested (Game Dept. Ann. Rep., 1926). Between the period 1950 and 1970 the use of game barriers was considered to arrest the problem of human-wildlife conflicts. Ranches and farms that were utilizing stout wire fences were not experiencing the same degree of problems with buffalo than farms which had no protection.

In the forests of Mt. Kenya and Aberdares, before the Mau Mau emergency (1953-56), game was controlled by shooting. During the emergency the game sought shelter in the security of the plantations because of the military operations in the forest. During 1957-58 the game was driven back into the forests by control shooting (Holloway, 1960).

The initial barriers utilized in the forest were moats or ditches with fence combinations. The ditches were constructed 1.8 m wide and 0.6 m deep and covered with branches and the plantation side had an electric fence. The covered ditch simulated a pit trap as the game could not see the bottom of the ditch. This method worked successfully with buffalo but was not effective against elephants. The elephants removed the branches and easily breached the ditch system and pulled up the posts holding the live wires (Forest Dept. Ann. Rep., 1957-58).

The "Burma Ditch" was also discontinued by the Forest Department in 1958. This was a ditch whose walls were lined with sharpened stakes and this was considered dangerous to soft-skinned animals (Holloway, 1960).

Two types of fences were tried in the forest, the post/rail and post/log fence. Since most damage in forests is caused by migrating animals, game corridors were provided which were bordered with moats and covered with branches (Holloway, 1960). These two types of fences mentioned were effective against buffalo but not elephant. The gaps caused by elephants had to be periodically maintained (Behrens, 1947 & Forest Dept. Ann. Rep., 1961). A system of post/log barriers was considered effective against elephant and buffalo in forested areas but was supplemented with regular patrolling and the use of thunder flashes (Game Dept. Ann. Rep., 1961).

During the 1950's the Royal National Parks realized the importance of barriers. Various types of fencing with electrification were tried but the cost of fencing was a major constraint. Live fencing was considered an option as the cost factor would be less. The variations in soil structure and presence of rocks made a continuous hedge difficult to establish. A *Euphorbia* fence established as a trial in Nairobi National Park was destroyed by zebra while solitary *Euphorbia* plants remained untouched (Royal Nat. Parks, 1952).

During the 1960's a moat was constructed around the Salient in the Aberdare National Park to curtail the activities of crop raiding animals (Woodley, 1965). Wire fences were extensively erected around the Nairobi National Park and the adjacent Ngong Hills Area to curtail the movements of animals. A chain link fence along a section of the Nairobi National Park was constructed on a raised bund. The Ngong Hills fence was also constructed during this time and funding was obtained from the West German branch of the World Wildlife Fund (Brown, 1968). The cost of wire fences was the main constraint and cheaper alternatives that could function as wildlife barriers needed to be investigated.

The 1970's and 1980's saw increased construction of moats, especially in the forested areas of Kenya around the Aberdare National Parks, Mt. Elgon, Kijabe and Muranga. High tensile steel fences were also constructed along the Meru National Park and the Loita wheat farming area north of the Masai Mara Game Reserve. The Meru fence was not subjected to a lot of pressure as the majority of elephants had been exterminated by poachers. The Loita fence also lost its usefulness as the sprawling wheat farms spread on either side of the fence (Thouless, 1993). In the mid 1980's electric fences were constructed around Lake Nakuru National Park, Tsavo West National Park and in parts of Laikipia and adjoining Meru district to secure rhino sanctuaries (Corfield, 1993).

1.2 TYPES OF WILDLIFE BARRIERS

1.2.1 TRADITIONAL METHODS

1.2.1.1 NOISE

This is used to scare away crop raiding wildlife and is produced by shouting, beating tins or banging hollow logs with sticks (Teare, 1938; Allaway, 1979 and Mackinon *et al.*, 1986). Crop raiding elephants in Cameroon were driven away by villagers chanting, shouting and beating drums (The Standard Newspaper, September, 29th. 1993, pg.8).

Cultivated plots in forests are usually guarded at night and noise is produced by banging tins and throwing thunder flashes at offensive animals. This method is effective against buffalo and rhino but more dangerous and less effective against elephants (Holloway, 1960).

1.2.1.2 FIRE

This has extensively been used as a deterrent against wildlife since time immemorial. Crop raiders are challenged by lighting fires on the perimeters of cultivated plots. Burning wood missiles, which are simply burning pieces of wood are flung at crop raiders (Ngure, 1992). In the Tana River area, burning nuts of the Doum palm (*Hyphaene compressa*) are projected with hand slings at elephants and low dense foliage of the Phoenix palm (*Phoenix reclinata*) which serves as a hiding place for buffalo is regularly burned down (Alloway, 1979).

1.2.1.3 SENTRIES AND SCARECROWS

Cultivated areas are also guarded by sentries located at strategic points. To maintain a clear view and protection from the sun, elevated platforms and simple huts are constructed (Allaway, 1979). Farms adjacent to Lake Nakuru National Park are raided by baboons during the day and children are used as sentries to guard cultivated plots.

Scarecrows are used widely to deter crop raiding animals including pest birds such as the *Quelea* species from raiding farms. In the Sayabei area of Narok district, human scarecrow models in fields of maize and wheat have been observed. These models usually have plastic strips that move in the wind depicting movement. The effectiveness of scarecrows is doubtful as *Quelea* have been observed perching on scarecrow models (Kamweya, 1986). In Taveta guards use dogs to protect maize fields from baboons and bush pigs, though dogs on their own are usually killed by baboons.

1.2.1.4 EXTERMINATION

This method involves killing of problem animals either by poisoning or through the use of traditional weapons. Baboons, bush pigs and porcupines (*Atherurus africanus*) can be poisoned with arsenite which is carefully put in maize cobs, sweet potatoes or bananas. Leopards (*Panthera pardus*), hyaena (*Hyaena* spp.) or mongoose (*Mungos* spp.) can be poisoned with strychnine placed in dead chickens or pieces of meat (Teare, 1938). Ranchers are known to use either herbicides or insecticides to lace maize cobs for exterminating baboons and bush pigs.

When baboons become a nuisance they can be killed in a wholesale manner by trapping the entire troop with nets. The roosting tree of the baboons is encircled with nets suspended on poles and as they try to climb over they are clubbed to death (Teare, 1938). Traditional weapons including spears can be used to drive away crop raiding animals such as elephants (Allaway, 1979).

1.2.1.5 BUSH BARRIERS

Traditionally bush barriers have been constructed around homesteads, cultivated plots and cattle bomas. This barrier is still in wide use today and branches of the thorny

Acacia provide material for this barrier. This method is not suitable as it results in deforestation and the deadwood is readily consumed by termites (Madany, 1991).

1.3 CONVENTIONAL METHODS

1.3.1 BUSH FENCES

During 1941 a bush fence was constructed in Tanganyika to limit the spread of rinderpest. It consisted of pairs of poles with logs placed in between that were lashed together with bark strips. It was fairly effective in containing plains game but was not effective against elephants, who simply pushed it over or unstacked the logs (Behrens, 1947). The post/log barriers constructed in the Mt. Kenya and Aberdare forests were based on a similar concept. Gaps caused by elephants had to be regularly repaired (Holloway, 1960).

The bush fence also serves as a non-transparent fence as animals will generally not "jump blind". An interesting comment was passed by a Dr. Austin Robert's during a game inquiry commission in the Transvaal Province when he said that *no fence would stop a Kudu if it could see green pastures on the other side of the fence* (Behrens, 1947). Palm leaf and vine fences are also used to protect cultivated plots. These are extensively used in the Tana River area by small holders to protect their farms from crop raiding animals (Allaway, 1979).

The disadvantage of the bush fences is that it encourages deforestation as the material for the fence comes from the surrounding vegetation. The life of a "dead fence" barrier is short because of natural decomposition and consumption by termites (Madany, 1991).

1.3.2 MOATS

These have evolved from game pits and traps that have been used since early times (Game Dept. Ann. Report, 1931). Moats or ditches have been extensively used especially in forested areas to protect forest plantations and farming activities (Brown, 1968; Clark, 1968; Bell and McShane-Caluzi, 1984; Seidensticker, 1984; Pertet, 1985 and Mackinon *et al.*, 1986).

Moats can be supplemented with fences, canals, sharpened stakes or covered with branches to simulate pit traps. Fences have proved useful in preventing rhino outbreaks and human intrusions in the Royal Chitawan National Park in Nepal (Mackinon *et al.*, 1986). Fences and moats have also been used with some success in the Salient area of the Aberdare National Park, Kenya (Woodley, 1965). Vegetation cover on moats is only feasible on shorter ditch systems. It is difficult to maintain a vegetation cover on longer ditch systems (Woodley, 1965).

Moats are effective against heavy, non-jumping animals such as buffaloes (Forest Dept. Ann. Rep., 1961). Elephants are notorious for breaching moats. They collapse the moat using their feet and tusks and will also push over trees to cover the moat (Seidensticker, 1984). In the forested reserves of Mt. Kenya elephants have been known to uncover branches covering moats and pull down electric fences used to back up moats (Holloway, 1960).

In the Padang Sugihon wildlife reserve in Sumatra, Indonesia, canals are effectively used as barriers in swampy terrain (Mackinon *et al.*, 1986). Ditch systems are highly susceptible to erosion, especially in tropical areas with heavy rainfall (Seidensticker, 1984). They also silt up in flat or lower areas (Behrens, 1947).

1.3.3 STONE WALLS

These are used in areas with abundant supplies of surface stones. Stonewalls are used on ranches in Laikipia as wildlife and boundary barriers. Stone walls act as physical barriers for heavy, non-jumping species. These are constructed by placing stones on top of each other without any binding agent such as cement. The base is kept wider then the top to increase strength and stability.

In the Laikipia area stone walls are used as barriers against elephants. They are usually effective against family groups as the young find it difficult to cross over and the females will not leave their young behind. Solitary males or rogue bulls will cross over with ease. Elephants push over the stone wall with their chest knocking it over. A contractor in Laikipia building stone walls complained how every night elephants knocked over stone walls, built the previous day, to raid crops in surrounding farms.

Stone walls can also be strengthened by applying a layer of concrete with wire mesh to strengthen the top or have a 'hot' wire running across the top but this may raise the cost significantly.

1.3.4 WIRE FENCES

These are extensively used to demarcate boundaries and act as barriers for livestock and wildlife. Wire fences are suspended on posts made of wood, metal or concrete. Live trees can also be used as posts to suspend the wires (Budowski, 1987).

Wire fences consist of a five to ten strand barbed or plain galvanized wire suspended on treated wooden posts. According to Behrens (1947), Robinson (1984) and Mackinon *et al.*, (1986) simple wire fences are not suitable as wildlife barriers. Large antelopes simply jump over while the smaller species simply crawl through. In Botswana roaming herds of zebra (*Hippotigris burchelli*) and wildebeest (*Connochaetes taurinus*) destroyed fencing on cattle ranches and some animals had to be shot as a control measure (Robinson, 1984).

Animals can also become entangled in wire fences and barbed wire is not recommended as it can cause death and injury to wildlife and is weaker in strength (Wildlife Protection Soc. of S.A., 1960). In some cases barbed wire fences have been used to act as a deterrent rather than as a barrier. In the Tana River area locals use tins suspended on barbed wire fences to serve as an alarm when challenged by elephant and buffalo (Allaway, 1979). Zebras were observed near Lake Elementeita crawling under wire fences and leaving a depression under the fence (pers. observ.).

1.3.5 HIGH TENSILE FENCING

These are constructed to act as a physical barrier rather than a psychological barrier such as electric fences or covered moats. The posts are either old railway sleepers or wooden, metal or concrete posts. Wooden posts are only recommended for small and medium species (KWS, Annex 6, 1990). Fire breaks have to be maintained as high tensile wire becomes brittle if exposed to fire, causing it to break easily when challenged by wildlife. Chain link is added to the bottom to provide protection against burrowers such as bushpigs and porcupines. These tunnels can provide entry or exit points for undesirable species (Bothma, 1989).

In Kenya, high tensile fences have been constructed in the Meru National Park and in the Loita wheat farming area north of the Masai Mara Game Reserve. The fence along the Meru National Park faces little pressure from elephants because of poaching activities that have reduced their numbers significantly. The Loita fence has become obsolete because wheat farms have spread on both sides of the fence (Thouless, 1993).

A high tensile fence constructed in the Kruger National Park was considered ineffective (Wild Life Protection Soc. of S.A., 1960). This fence was to act as a barrier for preventing the transmission of foot and mouth disease. The antelopes were not contained as they easily went through or over the fence. Numerous breaks were noticed probably as a result of large herbivores crashing in to the fence at high speed. This fence was also considered unsuitable for megaherbivores such as elephants that would simply break through the barrier during times of drought.

Veterinary cordon fences in Botswana have taken their toll on wildlife by blocking their migration routes and sources of water during drought. These fences have caused a massive decline in Kalahari wildlife populations (Williamson & Williamson, 1984). The fence in the Kruger National Park was also constructed across an ecological unit rather than along the boundary and this is one of the reasons it was considered a failure (Wild Life Protection Soc. of S. A., 1960). High-tensile fences in Kenya have also failed due to poor planning and location of these fences.

Elephant-proof fences were constructed in South Africa in the Addo and Kruger National Park. These consist of old railway lines embedded in concrete and thick mine cable substituting for wire. These fences cost up to $ 20,000 per kilometer and require a high level of maintenance and are occasionally broken by elephants (Bell & McShane-Caluzi, 1984).

1.3.6 ELECTRIC FENCES

These are similar to wire fences but have electrified wires that provide a short, safe electric shock when touched. Electric fences work more as a psychological barrier than a physical barrier (Vesey-Fritzgerald, 1968).

According to the Gallagher, 9th International Power Fence Manual (1992) the main components of an electric fence are the power source, energizer, wire and insulators. The two main types of electric fences are the all-live wire system and the earth-return wire system.

The all-live wire system is used in areas with high rainfall, presence of green vegetation or in areas with highly conductive soils. This system is cheaper to construct and maintain, but is not suitable for arid places like Africa. The wires on the post are all live and when an animal touches the wire the electrons flow through the animal into the damp soil. These electrons move to the earthing system, completing the circuit and delivering a shock. This system could be modified by growing a line of cholla cactus (*Opuntia exaltata*) and having a single live wire running six-eight feet above the cactus. The cactus would provide a suitable medium for transmitting the electrons to an earthing system (pers. comm., Dr. Thouless).

The earth-return wire system is commonly used in arid areas such as Africa. This system has a disadvantage because it is expensive to construct and requires a high standard of maintenance. The wires on the posts are both live and neutral. The animal has to touch both the wires to complete the circuit and get a shock. In this system droppers are used to keep the wires from touching each other to prevent earthing faults.

Electric fences are susceptible to a variety of problems. According to Hoare (1992 a) these problems can arise from:-

a). SOLAR PANEL

It has to be cleaned regularly to maintain its charging efficiency.

b). BATTERY

The battery has to be maintained by topping up with distilled water and cleaning corroded terminals. In some cases, electric fences lose their power because batteries are "borrowed" for other purposes (Hoare, 1992 b).

c). EARTH

The earthing system can perform poorly due to poor connections, corrosion and dry soil. In a survey conducted by Gallagher Power Fence Systems, it showed that 80% of fence systems suffer from faults resulting from poor earthing systems.

d). WIRE

The wire is susceptible to corrosion and tension. Weak tension can cause shorting due to sagging and touching of wires.

e). POSTS

These can be broken by elephants (Appendix 1, photograph 1) or can be attacked by termites and fungi.

f). VEGETATION

When live wires are touched by vegetation, earthing results and this causes unnecessary power drain. Vegetation is controlled manually by trimming under the fence or by applying herbicides. The use of herbicides is discouraged as it pollutes the environment.

g). INSULATORS

They suffer from cracks that reduce their life span and cause earthing faults that reduce the effectiveness of the fence.

h).THEFT

The above components are expensive as they have to be imported using valuable foreign exchange. This results in theft as they have a high resale value. The solar panels, batteries and energizers have to be housed in a small shed and this also raises the cost of construction.

Electric fences are generally expensive to construct and maintain. Construction designs vary and are based on the target species for which the fence is being designed. Elephant specific fences have live wires placed high enough to allow other species to pass underneath. Fences can have wires all the way from the bottom to the top and these are designed for a wider variety of animals. Fences can have up to 23 strands and these are used to protect rhino sanctuaries and are equipped with alarms that detect breaks and failures in the electrification system.

The performance of electric fences in elephant control have met with limited success. Thouless (1993) reports that elephants have been able to breach all types of electric fences constructed in the Laikipia area. Various innovative designs were tried, but fence breaks occurred in all types of fences. In forested areas electric fences have had little success (Holloway, 1960).

During 1982 a 162 km trans-Laikipia electric fence was proposed that was to run from Baringo in the west to the Mukogodo Hills in the east. This project failed to materialize due to lack of funds and the high cost of maintenance that would be involved.

Fence posts are also pushed over by elephants using their feet or their tusks and removing the wires with their insulated tusks (Thouless, 1993 & Vesey-Fritzgerald, 1968). Detusking of elephants has also been tried but was found to be unsuccessful. On the Ol Airo Nyiro ranch detusked elephants were responsible for breaking through electric fences. Elephants are ready to accept a 7 kv shock for the price of maize or other crops across an electrified fence (Thouless, 1993).

There are cases of electric fence projects never being fully completed. This results in an inefficient fence that does not operate properly and is plagued with maintenance problems. An example is the electric fence at Lake Nakuru National Park which was never fully completed and still requires droppers half-way between the posts

(Contractors, pers.comm). Fences maintained by private ranches and game lodges are usually more successful. In small holder situations and settlement schemes crops are spread out and of a lower unit value and the erection of costly game barriers does not justify the cost of protecting these crops (Bell & McShane-Caluzi, 1984).

1.4 LIVE FENCES

This is the use of suitable plant species which are grown to act as barriers. Live fences can be used to demarcate boundaries, restrict human and livestock movement and provide protection against wildlife (Budowski, 1987 & Rocheleau *et al.*, 1988). Live fences also produce fuel wood, fodder and act as windbreaks (Budowski, 1987).

In Africa, live fences have been used since ancient times and in Cameroon during the 14th century the Kipsiki people used *Euphorbia* fortifications fortified with stones. During the 18th century the Midjiving people in Cameroon used an outer line of *Commiphora africana* with a dense inner row of *Adenium obesam*. These fortifications were virtually impenetrable (Rocheleau *et al.*, 1988).

In the forest reserves of Mt. Kenya and Aberdares, live fences of *Eucalyptus* are used to protect plantations. The *Eucalyptus* is backed with an artificial barrier. After the *Eucalyptus* has established it takes over the protective function from the artificial barrier and there is no future maintenance cost (Holloway, 1960).

Along the western part of Lake Nakuru National Park there is intense crop raiding by baboons, bush pigs and porcupines. These species easily breach the electric fence surrounding the national park. The baboons have learned which wires are live and neutral and they easily climb over 'hot' electric fences. Bush pigs and porcupines easily breach the fence by burrowing underneath the fence.

The farmers have been encouraged to grow Mauritius Thorn (*Caesalpinia decapetala*) as a living barrier against these crop raiding wildlife species. The Mauritius thorn is allowed to grow dense and it has sharp recurved spines that prevent the crop raiders from passing through the fence. In some cases the fence was pruned to about 1 m high and this allowed the baboons to jump over as they can see the maize plantation. Along the fence some farmers have not planted Mauritius thorn and this serves as an entry point for the crop raiders who can then raid adjacent plots. When the animals are cornered they will charge through the Mauritius thorn to escape if their point of entry is blocked.

The Mauritius thorn is commonly used as a live fence in the Kericho area and it requires high rainfall for optimal growth. The disadvantage of Mauritius thorn is that a lot of dead material collects at the base of the plant and in the event of a bush fire the fence can easily be destroyed (Ivens, 1968).

Live fencing, involving the use of plain or barbed wire attached to living trees, is also widely used (Budowski, 1987). This technique is also used in the Tana River area where barbed wire is attached to posts or living trees (Allaway, 1979).

"Dead Fences" comprise of plant material that is harvested and used as a fence. This material can consist of millet stalks (Quangroua, 1988) or the use of palm leaf or vine fences (Allaway, 1979). These fences do not usually last long, as they are consumed by termites (Madany, 1991).

According to Rocheleau *et al.*, (1988) live fences need planning before they are planted. The location of a fence along a boundary affects two or more people who share the boundary. There should be a consensus on harvesting and maintenance. During the initial 2-5 years, live fences require maintenance, after they are established very little maintenance is required. In arid areas microcatchments are constructed to aid in water collection. In some places trenches are excavated to keep livestock from destroying young fences.

The Cactaceae is an American family that has spread to other parts of the world and have become widely naturalized. The two genus that are found in East Africa are the epiphytic *Ripsalis* and *Opuntia* species.

The naturalized Opuntia species found in East Africa are:-

1). *Opuntia exaltata* otherwise known as cholla, Jerusalem Thorn or Congoreva,

2). *Opuntia vulgaris*

3). *Opuntia ficus-indica* otherwise known as prickly pear.

4). *Opuntia cochenillifera*

5). *Opuntia* species A- this is an unknown species collected in Naivasha in 1958 and is possibly *Opuntia streptacantha* or *Opuntia megacantha* (Hunt, 1968).

The cactus (*Opuntia exaltata*), otherwise known as cholla pronounced "choya" is widely used as a living barrier (Appendix 1, Photograph 2). The genus *Opuntia* consists of 250 species and there are about 900 local names in the literature. The genus *Opuntia* extends from Massachusetts to British Colombia in North America, through South America to the Straits of Magellan. The range of the cactus (*Opuntia exaltata*) extends from Bolivia, through the Andes in Peru and to Equador. In South America it is used to form tall live fences and is usually found between 2600-3700 m above sea-level (Britton & Rose, 1963).

The vernacular names for this cactus are *pp'ata quisca*, *chachanqui*, *kacila*, *pp'ta-chachanqui* and *espino*. It forms live fences in Cuzco, Peru and occurs at an altitude of 2600 m to 3700 m. Fruits fall off the plant and litter the base of the plant and in some cases they will undergo decomposition and a few will put out shoots and roots which in some cases appear after 15 months (Marin, 1992).

The stems are approximately 2-5 m high with a definite trunk that is approximately 5-30 cm in diameter. The joints are fleshy and are easily detached and leaves are fleshy and 1-7 cm long. The spines on the joints are 1-5 in number and their length is from 5-13 cm long. Flowers including ovaries are 7 cm long and the flowers are brick red. The fruit is green and pear shaped with usually sterile seeds which are irregularly shaped and are approximately 10 mm broad (Britton & Rose, 1963).

This cactus normally propagates through vegetative reproduction and to a lesser extent through seeds. The fruit of the cactus is not eaten by man or animals since it is hard and unpalatable and is not an important method for distribution (De Beer, 1986).

The cactuses are capable of Crassulacean Acid Metabolism (C.A.M.) which occurs in plants that are found in arid areas. In this process the cactus assimilate carbon-dioxide in the dark when transpiration would be lower. During the light period the stomata would be closed when increased temperatures and low humidity would result in rapid transpiration and subsequent water loss (Bonner & Verner, 1976).

The cholla cactus, in conjunction with dry stone walls, has been recommended as a barrier for restricting elephant movements in the Mwatate-Bura area of Kenya. This barrier would be simple, cost effective and easily maintained by small holders (Tucker, 1990).

1.5 DISTRIBUTION OF CHOLLA IN KENYA

According to Hunt (1968) this species was introduced into Kenya from South America and planted as an ornamental plant in Nairobi. It is recorded growing in Naivasha since 1961. The distribution of cholla in Kenya is shown in figure 1.

1.5.1 NAKURU DISTRICT

Cholla was probably planted as an ornamental in a rock-garden with other species of Cactaceae and *Euphorbias*. The value of this species to form a spiny barrier led to it being planted as a living barrier. The A.D.C. (Agricultural Development Corporation) complex at Ndabibi formerly belonged to Colville, who used it as a live fence and the first fences were planted around this complex and then at Manera near Naivasha town. Farms and ranches around this area have utilized the Ndabibi fence as a source of cholla for planting around their respective properties. These fences are found all along the southern and eastern shores of Lake Naivasha. The cholla at the Delamere Estate at Soysambu was brought from Manera farm at Naivasha.

1.5.2 LAIKIPIA DISTRICT

The Colville Estate in Laikipia which is now known as Ol Morani and Sipili settlement schemes has cholla growing in abundance. The cholla in Laikipia is known as congoreva and this name is a corruption of the Congreve farm in the Delamere Estate at Soysambu. The initial cuttings of cholla were probably collected here and taken to Laikipia and thus became known as congoreva.

In Laikipia cholla is found growing on various ranches such as Ol Airo Nyiro Ranch (Laikipia Ranching Ltd.), Ol Jogi, Mpala Ranch, Ol Morani (ex-Colville Estate), Lewa Downs and the Ngare Ndare area. Cholla is also found within Nanyuki town, along the Nanyuki Don-Dol road and at Isiolo in neighboring Meru district.

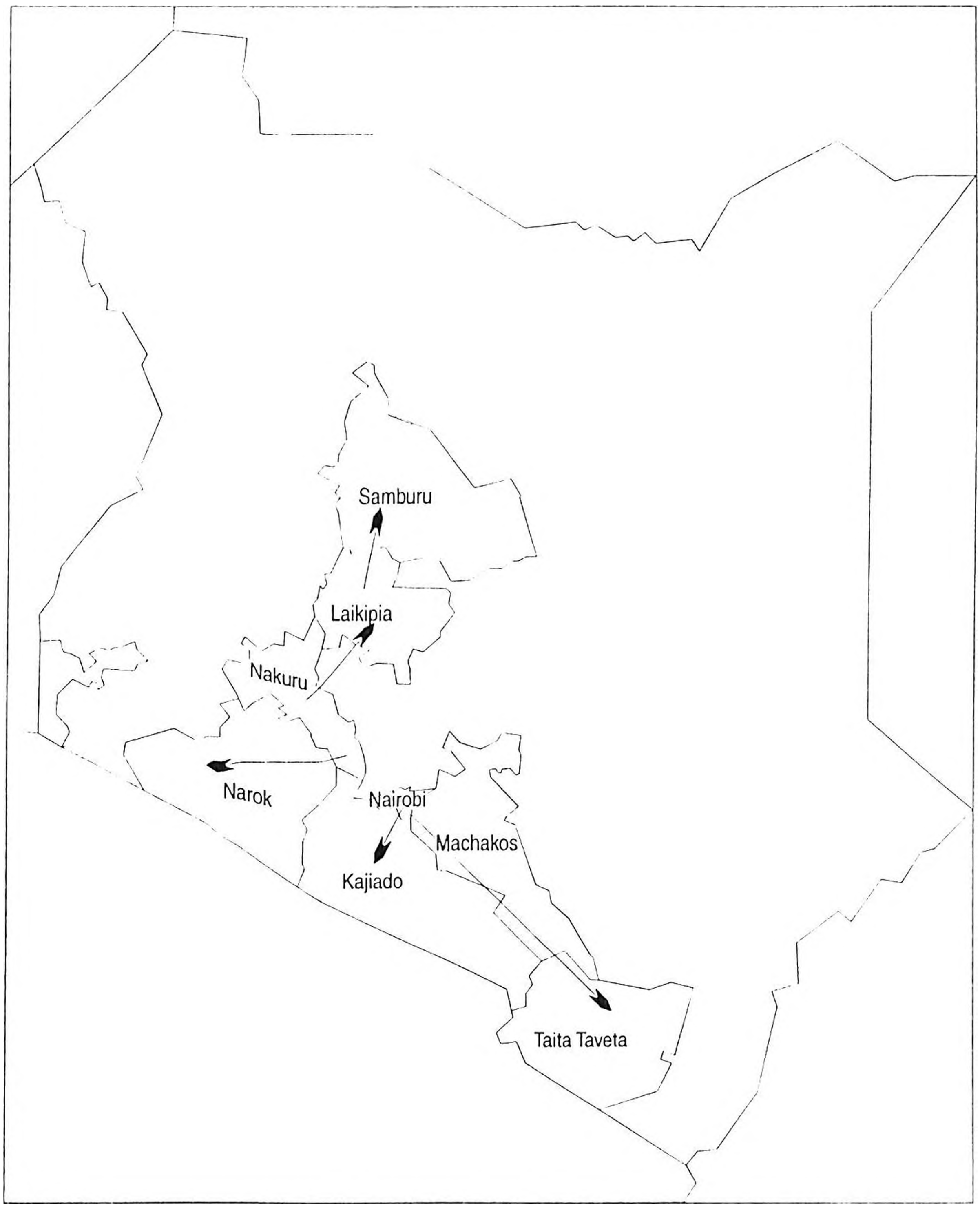
1.5.3 SAMBURU DISTRICT

A cholla fence was observed growing near Maralal town. The material for planting this fence is from the neighboring Laikipia district to the south.

1.5.4 NAIROBI, KAJIADO AND MACHAKOS DISTRICTS

Cholla is found growing extensively around Nairobi in rock gardens. It is also planted as a fence at the A.S.K. (Agricultural Society of Kenya) Jamhuri Park show ground. It

Figure 1. Distribution of cholla cactus in Kenya



is also found planted in the Kitengela area, Athi River area and at Isinya in Kajiado district where it is naturalized.

Fences of cholla occur in the Kitengela area and next to Isinya township where there is a large wild patch growing next to a seasonal river. In the Isinya area it has also been used as a cattle boma and old disused bomas are evident.

1.5.5 TAITA TAVETA DISTRICT

Cholla was found growing in an old neglected rock garden in Taveta township and at Grogan's Castle near Taveta town. In both these cases the cholla is part of a rock garden. The Lake Jipe Safari Lodge recently collected some cholla from Grogan's Castle and have planted it as a fence and ornamental within the lodge premises.

1.5.6 NAROK DISTRICT

Cholla fences were found in the Sayabei area and within Narok township. The dispersal method in this area followed the Naivasha-Mai Mahiu-Suswa-Sayabei-Narok town. The xerophytic properties of cholla make it an ideal candidate for rock gardens in dry areas. It has mainly spread through people transporting cuttings from one place to another. Its virtue as a barrier has been recognized and it has become a multi-purpose plant serving both as an ornamental and living barrier.

CHAPTER 2

2. STUDY AREA

There were three main study areas Nakuru, Laikipia and Taita Taveta districts. Their locations are shown in figure 2.

2.1 NAKURU DISTRICT

2.1.1 LOCATION

This district lies between latitude 35° 28' and 36° and 35' East and 0° and 13' North and 1° and 10' South. Nakuru district is bordered by the western wall of the Rift Valley to the West and the Mau Escarpment to the south. This district covers an approximate area of 7,200 km² and is over 1800 m above sea-level (Nakuru Dist. Dev. Plan, 1989-93).

The major lines of communication run in a south-east-south-west direction connecting Nairobi-Naivasha-Nakuru-Eldoret. There are other minor branches that connect smaller towns such as Nyahururu and Gilgil with other areas in the district.

2.1.2 CLIMATE AND RAINFALL

The study area lies in an area with rainfall less then 760 mm/annum, these are the semi-arid areas around Naivasha, Longonot, Gilgil and Rongai. Rainfall figures for two stations in Nakuru district are shown in figure 3. Temperatures in the district average from a low of 10° Celsius to a maximum of 29° Celsius. It is generally cooler in the higher areas then in the lower areas.

2.1.3 VEGETATION

The area around Lake Naivasha is bounded by stands of Yellow Fever tees (*Acacia xanthophloea*) and the lake shore is covered by extensive papyrus swamps. The area away from the lake is a typical savannah with Acacia trees dominating and Leleshwa (*Tarchonanthus comphoratus*) on areas where excessive grazing occurs.

2.1.4 GEOLOGY

This district lies predominantly in the Great Rift Valley. This valley can be defined as two long parallel cracks averaging approximately 100 kilometers apart which appeared roughly one million years ago. The Rift Valley is about 6,400 kilometers long with two branches, the Western and the Eastern rift. The western arm of the Rift Valley peters out around Lake Albert in Uganda. The Eastern rift stretches from Beira in Mozambique to the Dead Sea in the Western Jordan area in the Middle East.

There are two theories regarding the formation of the Rift Valley. One theory states that there was cracking and fracturing in the earth's crust causing the central crust to sink between the cracks. The other theory states that the scarp sides of the valley were forced upwards by tensions arising in the crust and these slowly weathered away to expose the sloping edges present today (Pritchard, 1967).

According to Thompson and Dodson (1963), the geology of the rocks of the Naivasha-Nakuru region around the study area is as follows:-

2.1.4.1 VOLCANIC ROCKS

There are numerous volcanic cones, craters, scarps and lakes present along the Rift Valley floor. There is also recent evidence of lava flows like on the slopes of Mt. Longonot which has erupted within the last hundred years. These volcanic rocks mainly consist of tephrites, trachytes, phonolites, ashes, tufts, agglomerates and the acid lava's rhyolite, comendite and obsidian.

2.1.4.2 THE LAKE DEPOSITS

These cover large areas but are nowhere deposited in thick layers. The configuration of the Lake deposit is closely allied to the Gambian Lake that stretched between Mt. Longonot and the Menegai crater (Thompson and Dodson, 1963). The outflow of the lake was through the present day Njorowa Gorge or Hells Gate. The lake Naivasha basin and the Elementeita/Nakuru basin were only linked during the maximum of the Gambian Pluvial. The Gambian Lake deposits in addition to clays, silts and a few bands of diatomite also contain volcanic material in the form of ashes.

2.1.5 SOILS

Soil groups that are important to this study are those found on the lacustrine plains. There are two main types of soils and these are:-

a) soils developed on sediments from volcanic ashes and other sources. These soils are imperfectly drained to poorly drained, very deep, dark greyish brown to dark brown, firm to very firm, slightly to moderately calcareous, slightly to moderately saline, but strongly to moderately sodic, silt loam to clay, often with humic topsoil. These types are found on the subrecent lake sides of the Rift Valley and are classified as SOLONETZ, undifferentiated saline phase.

b) Soils developed on sediments which are mainly derived from volcanic ashes (the Gambian Lake of the Rift Valley). These soils are a complex of two different types:-

- well drained, moderately deep to deep, dark brown, friable and slightly smeary, fine gravely, sandy clay loam to sandy clay with humic topsoil. These soils can be classified as ando-haplic PHAEOZEMS.
- Imperfectly drained, moderately deep to deep, strong brown, mottled, firm and brittle, sandy clay to clay. These soils can be classified as gleyic CAMBISOLS, fragipan phase.

2.1.6 LAND USE NAIVASHA: NAKURU DISTRICT

Cholla is widely grown within Nakuru district in the Rift Valley province of Kenya. The main areas where cholla is used as a barrier are around Lake Naivasha and Elementeita. Cholla hedges are widely used around the northern, eastern and southern shores of Lake Naivasha.

There are two main national parks in this area namely Hells Gate National Park and Mt. Longonot National Park which are located to the south-east and east of Lake Naivasha respectively. There is abundant wildlife present in these two national parks and in the surrounding ranches such as Kedong , Kongoni, Akira, Oserian Development Company and the A.D.C. Ndabibi complex.

According to the Hells Gate/Mt. Longonot Management Plan (1992) the area around the south and eastern part of Lake Naivasha was used as a grazing ground by European ranchers. This land was then purchased by the Brooke Bond company and this caused the European ranchers to move away and their place was taken over by Masai pastoralists who moved in from the Suswa area, after land subdivision commenced in the adjoining Narok district.

The wildlife species in this area are predominantly plains game such as buffalo, zebra, grants gazelle (*Gazella granti*), Thomsons gazelle (*Gazella thomsoni*), Cokes Hartebeest (*Alcelaphus buselaphus*) also known as "Kongoni" and Masai giraffe (*Giraffa cameleopardalis*). These animals move between Hells Gate National Park and Mt. Longonot National Park via the Kedong ranch. There are also large numbers of these species in the above ranches.

The wildlife in this region is suffering from range compression as the traditional dispersal areas such as Karai, Nyamathi and Kinungi locations are now under human settlement. The area to the east of Mt. Longonot has also been intensively settled by small scale farmers. The lake shore is also inaccessible due to the mushrooming of horticulture and floriculture operations. The lake was a valuable resource in times of drought and provided water when the waterholes in the adjoining areas dried up during the dry season. Drinking troughs are provided for the wildlife in Hells Gate National Park and in the adjoining ranches the wildlife competes with livestock for water resources. The larger ranches have started planting wheat and this will lead to a reduced toleration of wildlife on these ranches.

Figure 2. Location of the three main study areas: Nakuru, Laikipia and Taita Taveta districts

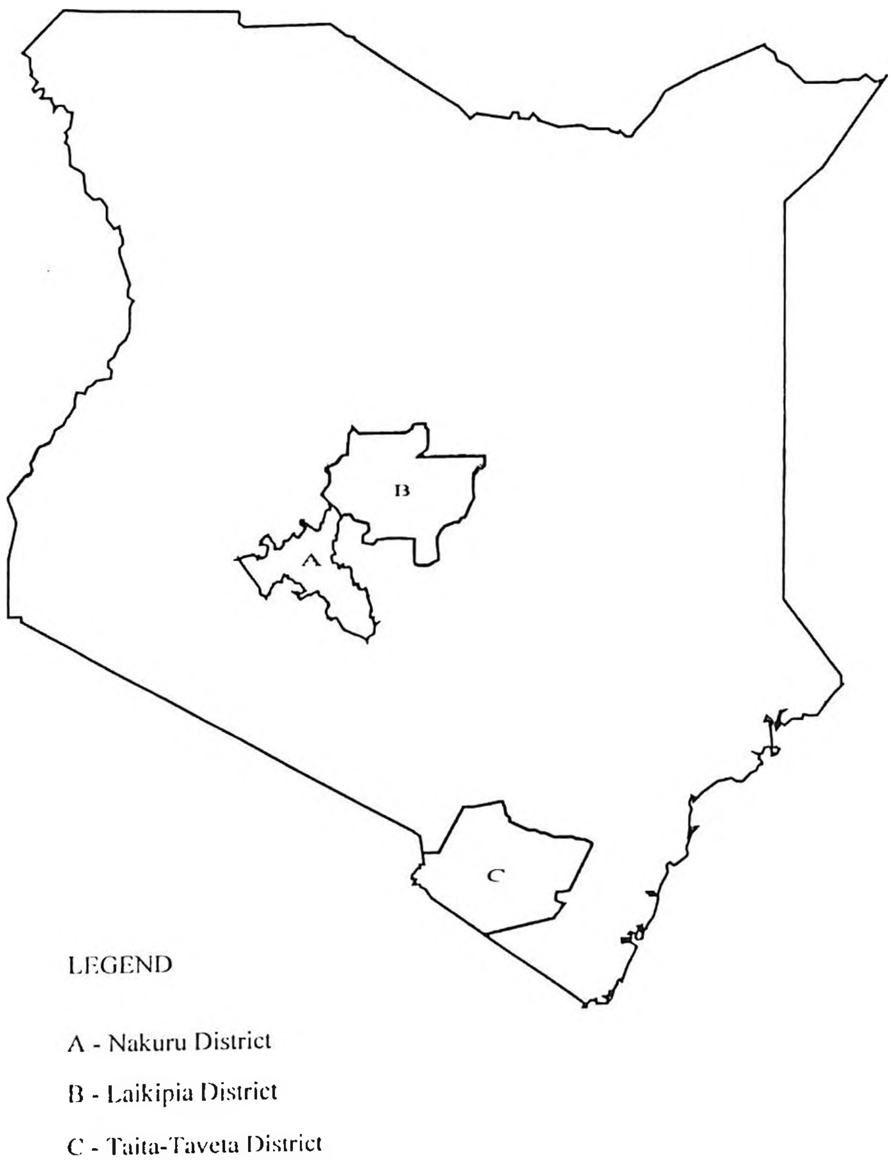
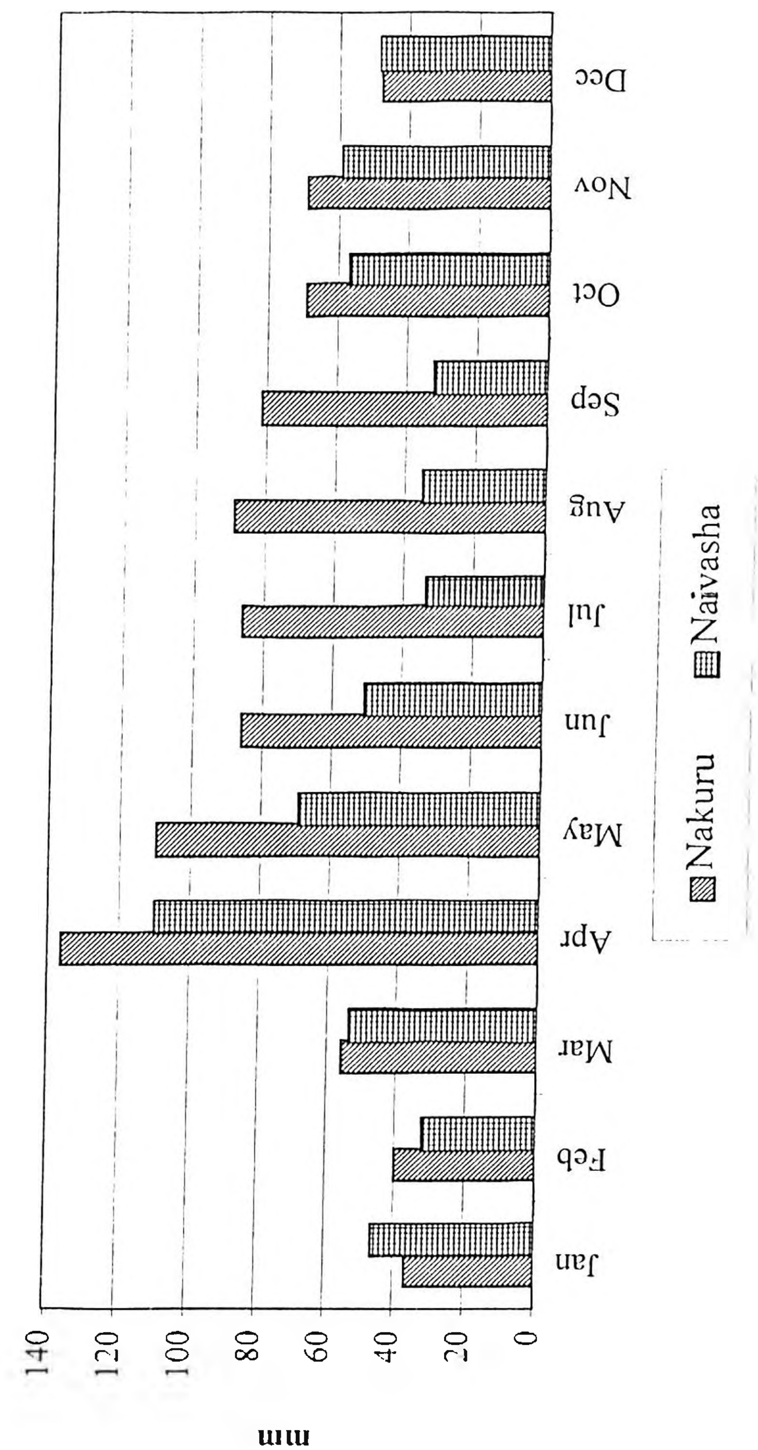


Figure 3. Rainfall for two stations in Nakuru district



There are problems with hippopotami (*Hippopotamus amphibius*) which are present in the lake and are responsible for crop raiding and trampling flower plantations adjacent to the lake. A press report in the Daily Nation newspaper dated 21/9/93 reports that 290,000 stems of flowers worth KShs 1,500,000/= on a floriculture farm along the eastern shores of lake Naivasha were destroyed by marauding hippopotami.
In Naivasha cholla is used both by small holders and large scale ranches. The initial cholla fences were planted over 30 years ago at the ADC Ndabibi complex by Colville. The use of this cholla has now spread around the lake.

2.2 LAIKIPIA DISTRICT

2.2.1 LOCATION

This district lies within the Rift Valley province of Kenya and is situated between latitudes 36° 10°-37° and 3' East and longitudes 0° 17'-0° and 45' North. The Laikipia plateau lies at an altitude of 1800-2000 m above sea-level. The plateau lies between Mt. Kenya in the east and the Aberdare mountains in the south and covers an area of approximately 9,275 km^2. The area is served by major roads like the Nyahururu-Rumuruti-Maralal and the Nanyuki-Timau Isiolo/Meru road. There are various other minor roads within the district.

2.2.2 CLIMATE AND RAINFALL

The average annual rainfall in the district is between 400 and 800 mm/annum. A bimodal pattern in the study area with rainfall predominating between April-May and November-December.

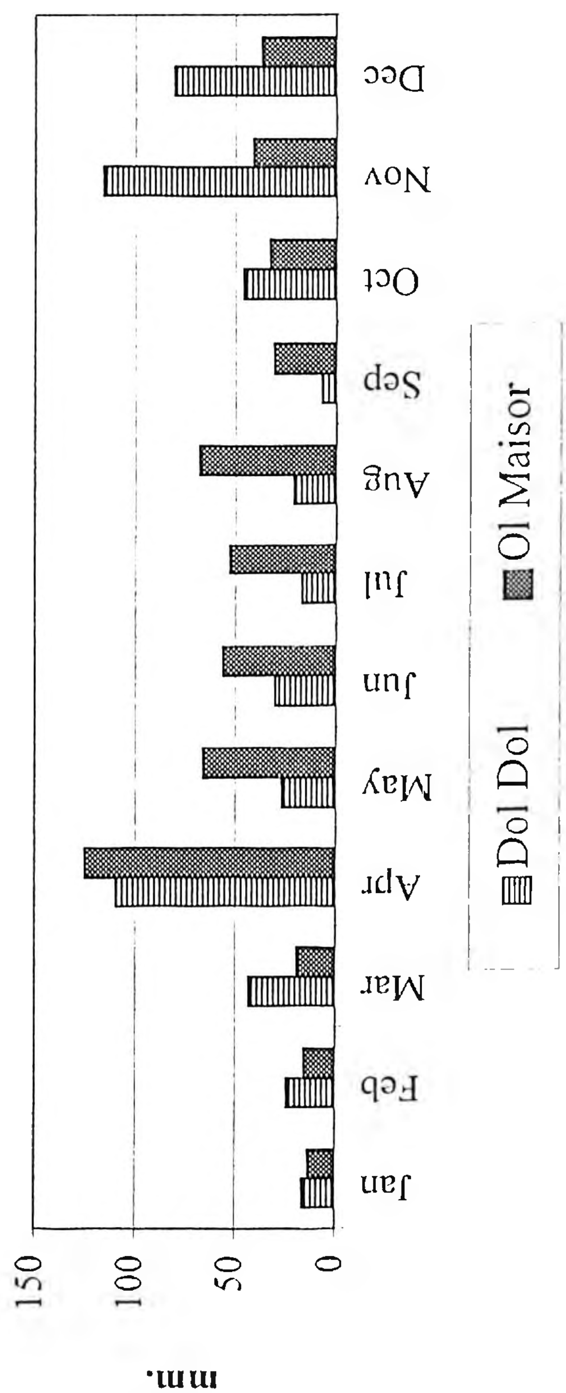
The erratic and low rainfall pattern of the Laikipia Plateau places the majority of this district in agroclimatic zone V which has Et (Evapo-Transpiration) over 'r', ratio percentage Et/r of approximately 25-80%. The Laikipia Plateau which is relatively dry is situated in the rain-shadow of Mt. Kenya. The winds that carry moisture from the Indian Ocean, deposit much of it as rain on the eastern slopes of Mt. Kenya and much less on the western side (Ahn & Geiger, 1987). The rainfall for two stations is shown in figure 4. The mean temperatures of the district average at 17° Celsius and the annual extremes lie between 12°-24° Celsius.

2.2.3 VEGETATION

According to Taiti (1992) the vegetation of Laikipia district can be divided into the following types. In the Ol Ngarua division in the west of the Laikipia plateau the vegetation is dominated by stands of *Tarchonanthus* in association with *Combretum molle* and *Hyparrhenia* grass are found in areas where the upland forest has been removed. The characteristic species is *Tarchonanthus camphoratus* (Leleshwa) with *Combretum* and genera of small savanna trees that are fire resistant. This *Combretum-Tarchonanthus-Hyparrhenia* association occupy sites between the Upland forest belt in the mountains and the *Acacia* dominated types in the lowlands.

Along the central parts of the district in the areas of Ol Jogi, Kisima and Borana ranches and along the Ngare Ndare escarpment the *Acacia drepanolobium* bushland is dominant. This small thorny shrub is found on poorly drained, heavy vertisol type soils in flat or slightly depressed areas.

Figure 4. Rainfall for two stations in Laikipia district



2.2.4 GEOLOGY

According to Ahn and Geiger (1987), the geology of the area can be divided into basement rocks and volcanic formations:

2.2.4.1 BASEMENT ROCKS

This area is covered by metamorphic basement system rocks of Pre-Cambrian origin. These rocks are exposed on the surface and form the Mukogodo and Loldaiga Hills in the east of the district.

2.2.4.2 OVERLYING VOLCANIC FORMATIONS

The majority of the district is covered by two different types of volcanic formations. These formations are lava sheets of phonolitic composition, which chemically weather to form soils dominated by a clay texture and the volcanic sediments of the Nanyuki formation give rise to vertisols.

2.2.5 SOILS

These soils are developed mainly from phonolite and basalt lavas in the district. The soils in the study area were of two main types. The first type is dominated by clays that crack when dry and expand when wet and are commonly known as vertisols. The second type is dominated by clay loam to clay subsoils and are deep dark brown to reddish brown.

2.2.6 LAND USE: LAIKIPIA DISTRICT

The Laikipia plateau has the highest concentration of wildlife outside protected areas in Kenya (Waweru, 1993). This concentration of wildlife comes into conflict with the rising human population in the district.

During the 1800's the Laikipia plateau was mainly used by the Masai as a dry season grazing area. The Masai were prompted to leave the area by the arrival of the British during the early 1900's. The plateau was settled by European ranchers and there was prolific ranching activity between the 1960's and 1970's.

The rainfall between the 1960's and 1970's in this area was above average and after 1962 the decreasing rainfall was felt by the remaining European settlers and the incoming small scale farmers. After independence, there was rapid Africanisation of the European owned farms. These ranches were either bought up by land buying companies, cooperatives or government settlement schemes and subdivided into smaller land units.

The land in Laikipia can be divided into three broad categories namely, large scale ranches, small scale holdings and forest reserves. According to the map prepared by Kohler (1986) the large scale ranches lie along the middle of the district in a north-east to north-west line. The area south of this line is the region of intense small holder activity which is gradually moving north. A similar area of intense small holder activity lies between Nanyuki and Timau in the south-east of the district. The Mukogodo pastoralist area lies in the extreme north-east and is mainly designated as a grazing area. There are also nine forest reserves and the prominent ones are Mukogodo, Marmanet and Rumruti.

Laikipia district can be divided into Ngarua, Rumruti, Central and Mukogodo divisions. Ngarua division has the highest population density within the district. In the Central and Rumruti division the population is sparse with large scale ranches occupying a major portion of the land in each of the two divisions. The Mukogodo division has the lowest population composed mainly of scattered pastoralists.

Scarcity of suitable land in other parts of Kenya has resulted in migration of small holders into Laikipia district. The larger ranches which are mainly owned by Europeans have been bought by cooperatives or land buying companies and demarcated in to small plots averaging 2-10 acres which are then sold to small holders (Laikipia Dist. Dev. Plan, 1989-93).

Former ranches that have been subdivided for small holders lie in areas adjacent to or are surrounded by large scale ranches. These ranches such as Ol Jogi, Ol Pajeta, Ol Airo Nyiro and Lewa Downs amongst others practice game ranching and offer tourist facilities besides ranching and other farming activities. The wildlife that is present on these ranches is responsible for most of the cases involving human-wildlife conflicts. The movement of small holders north into Laikipia district will result in increased human-wildlife conflicts.

2.3 TAITA TAVETA DISTRICT

2.3.1 LOCATION

This district lies in the south-west part of Kenya's Coast province and is situated between 2° and 4° South and 37°30' and 39°30' East. The district covers an approximate area of 10,500 km² out of which 62% is a national park and reserve. The altitude ranges from 300 m-2,150 m above sea-level (Taita Taveta Dist. Dev. Plan, 1988).

The mountainous areas in the district are the Taita Hills, Sagalla and Kasigau ranges. The area is served by major roads such as the Nairobi-Mombasa highway which passes through Voi. There is a minor road which connects Voi to Taveta which is situated on the Kenya-Tanzania border (Taita Taveta Dist. Dev. Plan, 1988).

2.3.2 CLIMATE AND RAINFALL

The average annual rainfall is between 250 mm in the lowlands to over 600 mm in the mountanious areas. Rainfall for two stations is shown in figure 5. The mean temperature is in the region of 24.9 ° C. The rainfall in the district follows a bimodal pattern with rainfall peaking in March-April and November-December.

2.3.3 VEGETATION

The vegetation of the district is predominantly an open woody canopy with a varying degree of cover. The majority of the area is dominated by small-leaved deciduous woody species of the *Bursaceae* and *Mimosaceae* with grasses represented by the tribes *Stipaeae* and *Chloridae*. The poorly drained alkaline/saline soils are dominated by *Acacia* species and *Capparidaceae* which are the dominant woody species. In areas with well-drained acid soils the *Bursaceae* and *Lannea* species are dominant (Wijngaarden, 1981).

2.3.4 GEOLOGY

The geology of this district is dominated by extensive planation levels of both erosional and sedimentary origin. Erosional surfaces are represented by the base of the Chyulu Hills and the Yatta Plateau which are of the Nyika level of end-Tertiary age. The sedimentary plains are developed on Plio-Pleistocene deposits of unconsolidated clays of saline nature. Inselbergs also occur which consist of a quartzitic type of basement rock which makes them more resistant to weathering and erosion (Wijngaarden, 1981).

2.3.5 SOILS

According to Wijngaarden (1981) the soils in Taita Taveta district show a wide range of variation in depth, color, drainage, structure, chemical and physical properties. The main soil types are:-

- Soils of the footslopes which are very deep, well-drained, dark red soils with a sandy-clay-loam to sandy-clay texture. These are highly weathered, acidic and have low mineral reserves.
- Soils of the erosional plain and uplands on the basement system rocks which are formed directly from underlying rocks. The basement rocks are ferro-magnesium

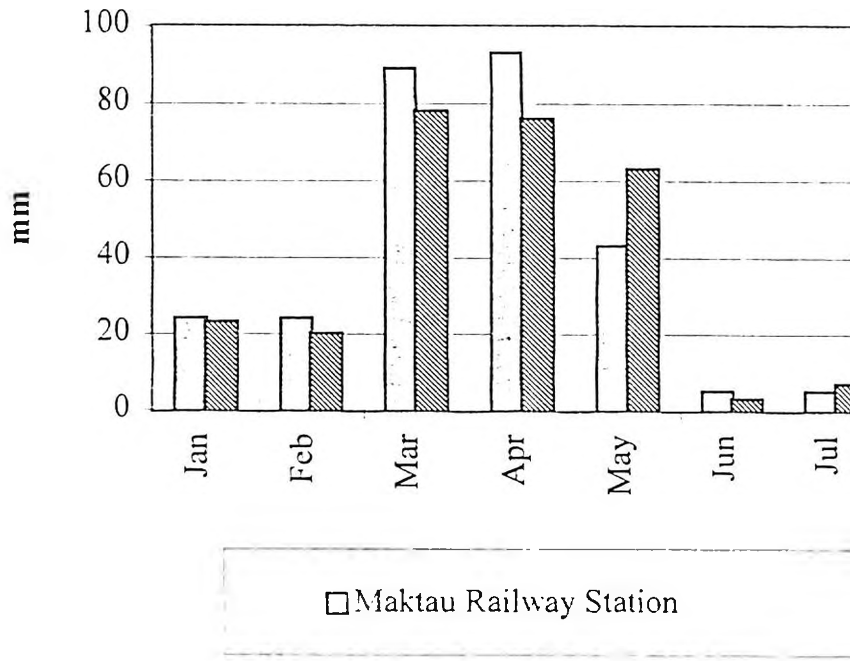
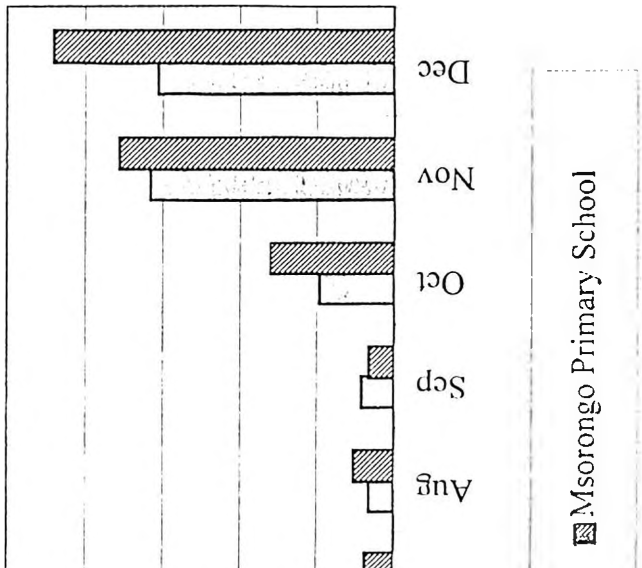

mm
100
80
60
40
20
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Maktau Railway Station

Figure 5. Rainfall for two stations in Taita Taveta District



rich genesis which results in fertile soils. These soils are referred to as "red sandy soils".

- Soils of the volcanic hills, plains and lava flows which have developed on recent volcanic rocks and are always well-drained, loamy and gravelly. They are generally very fertile.

2.3.6 LAND USE: TAITA TAVETA DISTRICT

The hilly areas of Taita and Sagalla Hills are the districts main agricultural areas and have the highest population density. The other areas are marginal to semi-arid and can only be used to grow drought resistant crops. The population density is not as high as the hilly areas. The remaining 80% of the district is a national park and game reserve comprising of a typical savannah habitat with a very low human population (Taita Taveta Dist. Dev. Plan, 1988).

CHAPTER 3

3. MATERIALS AND METHODS

3.1 SURVEY

This was carried out in three main areas namely Nakuru, Laikipia and Taita Taveta districts. The survey was conducted using a pick-up truck and involved visiting ranches and farms that were known to use cholla.

The data was collected using a specially designed questionnaire which had sixteen separate sections (Appendix 2, Sample questionnaire sheet). The first seven sections had questions regarding the name of observer, date, sheet number, person interviewed and address, occupation of respondent, grid reference and name of ranch/farm. This information was necessary in case of future correspondence with an individual ranch/farm.

The next two sections were on the form and use of cholla cactus and on the distance covered by the cholla cactus barrier. In the first section the questions focused on the exact use of the cholla barrier, for example wildlife barrier, fire break, protecting crops and other uses. The second question was on the distance covered by the cholla cactus on the ranch/farm. In this section the information was estimated from a map or a rough estimate was used. The majority of ranches/farms did not keep detailed information.

The next three sections covered questions on the specific animals against which cholla cactus is used, the success and specific problems associated with the cholla cactus. In the first question, specific wild and domestic animals were named against which the cholla cactus was planted. The respondent was asked to rate the success of the barrier against three responses, namely excellent, good and poor. Specific problems affecting the use of the cholla cactus as a successful barrier was the final question in this section.

The next four sections were on the growth rates of cholla cactus, the original source for planting, method of planting and remarks. In the first section growth rates were recorded after data regarding dates of first planting and present height were obtained. The height of the cholla cactus was measured using a graduated metal pole demarcated in metres. The original source of cholla cactus for planting, assisted in locating new areas where cholla was being used as a barrier. The method of planting yielded information on the different methods used in planting cholla cactus. The last section covered any remarks the respondent wanted to add as additional information.

3.2 GROWTH RATES OF CHOLLA CACTUS

To investigate the growth rates, two plots were planted one at Naivasha and the other at Taveta in Taita Taveta district.

3.2.1 NAIVASHA

This plot is located along the boundary fence of Sher Agencies Ltd. a floriculture operation along the southern shores of Lake Naivasha. The farm management had agreed to grow cholla as it would serve as a cost effective barrier. A neglected cholla fence adjacent to the planting site was chosen as a source for collecting cholla cuttings. The cholla was transported with a tractor-trailer to the planting site. A planting bed 185 m x 1 m wide was prepared by digging the soil up to 0.40 m and incorporating vegetation matter into the soil. The cholla cactus joints were laid on this bed and lightly covered with soil. There were two replicates in the open and two were shaded by *Acacia xanthophloea* trees. This plot was planted on 18th January, 1993.

3.2.2 TAVETA

A plot was planted at Taveta sisal estate near Taveta Town on 29th January, 1993. Cholla cuttings were harvested from the same Naivasha site and transported to Taveta in a pick-up truck for planting.

3.2.3 SURVEY

The growth rates of existing fences was measured in the study areas and figures are presented.

3.3 SOIL PHYSICAL AND CHEMICAL CHARACTERISTICS

These investigations were carried out in Naivasha, Nakuru district and at Ol Airo Nyiro Ranch, Laikipia district.

3.3.1 NAIVASHA: NAKURU DISTRICT

Along the eastern shores of lake Naivasha cholla is extensively planted as a live barrier to protect ranches and farms. A pattern was noted along established cholla fences growing under trees where a positive growth in height was observed under the tree canopy as compared to outside the canopy (see figure 6). A site was chosen where a fence line running in an east-west direction displayed the pattern shown in figure 6. Three Yellow Fever trees (*Acacia xanthophloea*) were chosen where the cholla fence showed this pattern along a fence planted as a boundary fence.

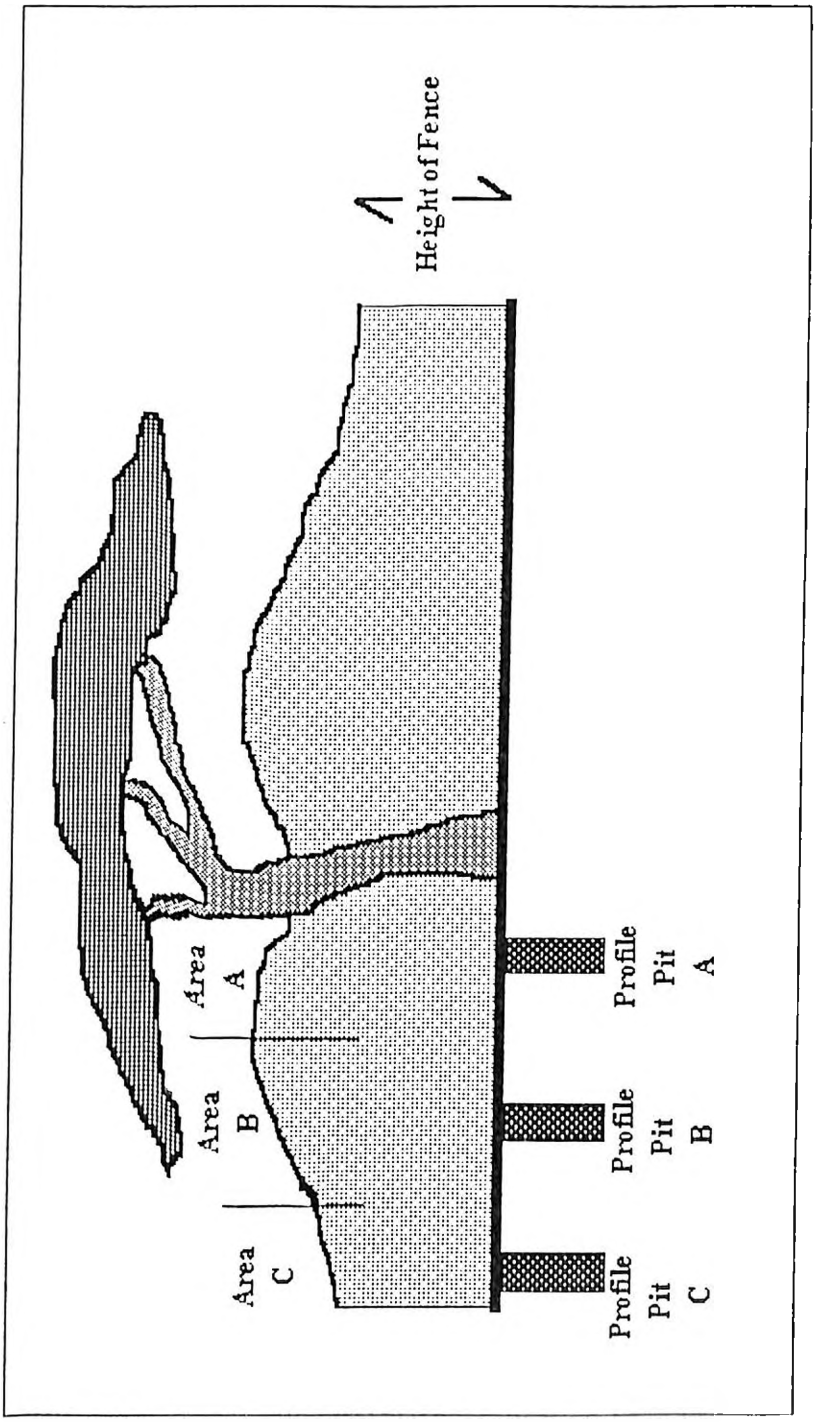
3.3.1.1 SOIL ANALYSIS

To investigate this pattern, soil analysis were conducted to measure the nutrient levels and physical structure of the soil. To investigate the physical structure and nutrient levels a total of nine soil profile pits were excavated. A total of three pits were excavated per tree in the three areas A, B and C and these were replicated three times along the fence line. These pits were marked as under canopy (area-A), intermediate canopy (area-B) and outside the canopy (area-C).

The profile pits were excavated to over 1 m deep and were approximately 0.80 m wide. These pits were excavated so that the open face was directly under the cholla fence. A part of the fence was destroyed as the open surface had to be directly under the cholla fence to represent the soil conditions existing under the fence.

These profile pits were described using Soil Profile Description forms and these forms are divided into two parts. In the first part, general site information is recorded and in the second part profile characteristics are recorded. Profile characteristics such as naturally occurring horizons, soil color, soil structure, presence of cutans, texture, consistency, presence of concretions amongst other details were recorded.

Figure 6. Location of soil profile pits along a cholla fence growing under a Yellow fever tree at Naivasha, Nakuru District.



In each of the nine soil pits, soil samples were collected from naturally occurring horizons A and B for pH and macro nutrient analysis. The organic carbon was determined by the Walkley and Black method and total nitrogen was determined using the wet oxidizing procedure of Kjeldahl (Bremmer, 1965). The pH was measured using a glass electrode on an electronic pH meter. The soil sample was suspended in distilled water and the suspensions stirred several times and then measured (Peach, 1965). Calcium was measured by versanate titration and phosphorus was determined by the Olsen method (Olsen, 1962). These results were statistically analyzed for differences in nutrient levels between the three zones A, B & C using analysis of variance (ANOVA).

3.3.1.2 SOLAR RADIATION

There is a shade effect on the cholla fence growing underneath the tree. The shade levels were measured for each of the three areas A, B and C using a Steady State Porometer manufactured by Li-Cor. Inc., U.S.A.. The solar radiation is measured in quantum ($\mu E\ m^{-2}\ sec^{-1}$). The results were plotted on a graph and an ANOVA test done to test for any significant difference in shade levels.

3.3.1.3 MOISTURE RETENTION

A final test was done to check the moisture retention characteristics of the soil where root penetration was present. Core ring samples were collected from transect I from all the areas A, B and C. These samples were collected from horizon A and B in zone A, horizon A and B in zone B and horizon A in zone C. These samples were analyzed at the Kenya Agricultural Research Institute (KARI) laboratory in Nairobi for moisture retention at pF 0 (saturation), pF 2.3 (field capacity) and pF 4.2 (permanent wilting point).

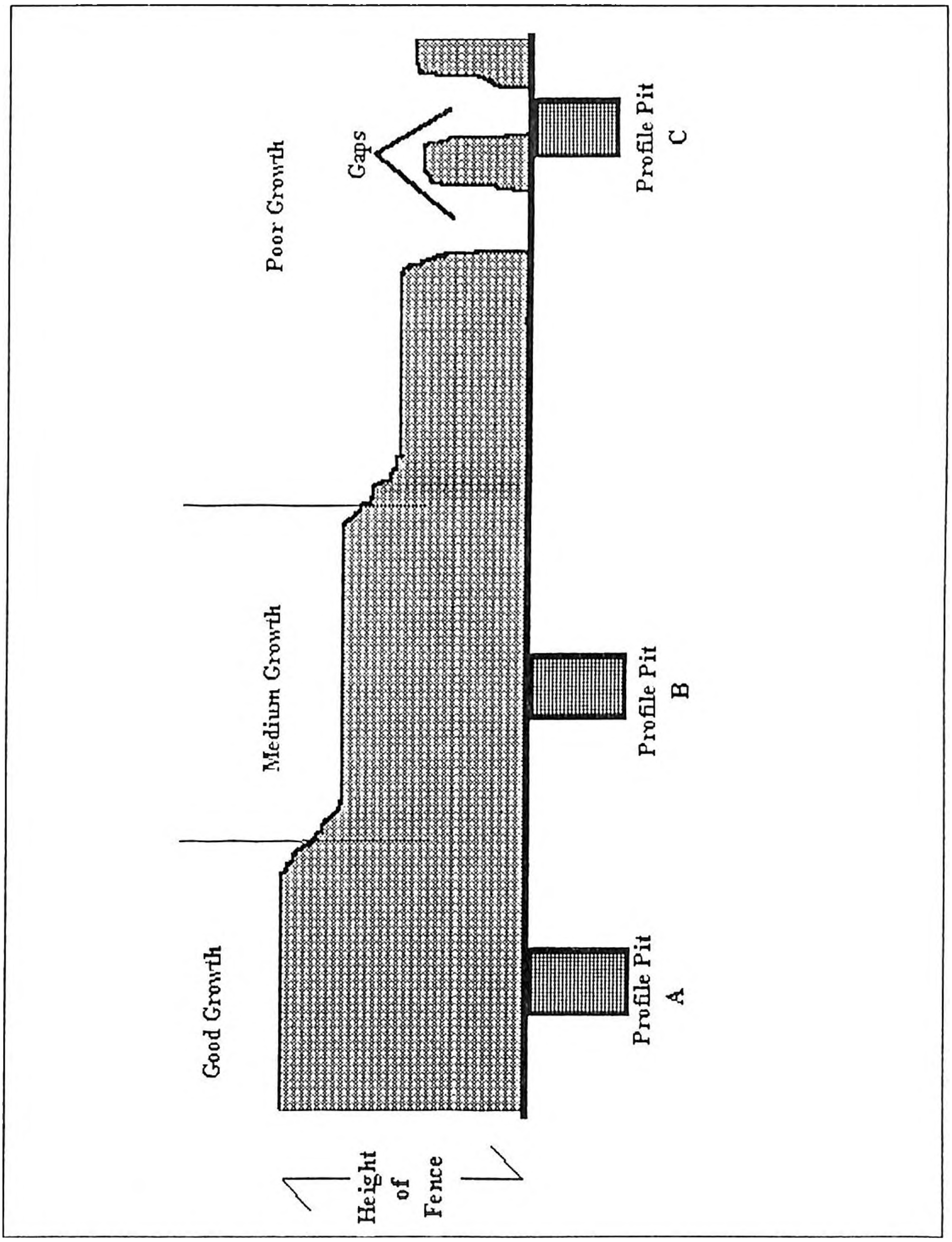
3.3.2 OL AIRO NYIRO RANCH: LAIKIPIA DISTRICT

3.3.2.1 SOIL ANALYSIS

Along the eastern boundary of the Ol Airo Nyiro ranch in Ngarua division of Laikipia district a cholla fence was planted as a wildlife and boundary fence in 1988. The fence runs in a north-east to south-east direction and a decrease in height and efficacy over a distance of 2-3 kilometers is evident. This decrease in height results in an inefficient barrier that can be easily breached by wildlife (figure 7).

Along transect 1, three areas were chosen that represent areas of good, medium and poor growth. A total of nine soil profile pits were excavated with three in each of the good, medium and poor growth areas. The profile pits were described using Soil Profile Description forms and soil samples for nutrient analysis were collected from naturally occurring horizons A and B and were analyzed according to the methods described for nutrient analysis in the Naivasha area (section 3.3.1.1). The results were analyzed using ANOVA statistical tests.

Figure 7. Location of soil profile pits along a cholla fence at Ol Airo Nyiro Ranch, Laikipia District



3.3.2.2 MOISTURE RETENTION

To investigate the moisture retention characteristics core ring samples were collected and analyzed according to the method described in the Naivasha section (3.3.1.3). The core ring samples were collected from an area of good and medium growth.

3.4 GERMINATION OF CHOLLA CACTUS SEEDS

The cholla cactus reproduces through vegetative reproduction and to a lesser extent through the germination of seeds. The fruit of the cholla is hard and unpalatable and is not eaten by man or animals (De Beer, 1986). The plant gives rise to a bright yellow-red flower and the seeds are enclosed in a fruit with a sticky mucous layer. The seeds of cholla are generally sterile and fertile seeds are only found in cholla growing around Cuzco in Peru and this may be the place from where cholla originated (Britton & Rose, 1963).

To determine whether cholla seeds are fertile and capable of germination, cholla fruits were collected for gathering seeds. The fruits were split open to expose the seed mass. These seeds were separated with a lot of difficulty as they are strongly bound together and covered with a sticky mucous layer.

According to Shurley (1959) cacti seeds require moisture, warmth and darkness to germinate. The seeds of the cholla were dried of the mucous layer and then subjected to the following treatments for testing germination.

A total of six petri dishes with ten seeds in each were divided into three groups. One group was placed in a dark cupboard and the other on a shelf in naturally illuminated room.

GROUP A

In these two petri dishes the seeds were placed between tissue paper and water added with a syringe three times a week to maintain moist conditions.*

GROUP B

In these two petri dishes the seeds were rubbed with and paper to break the seed coat or testa to allow moisture penetration. They were then treated similar to group A.*

GROUP C

In these two petri dishes no treatment was done and this group acted as a control.*

*-This experiment was carried out for a total of five months.

CHAPTER 4

4. RESULTS AND DISCUSSION

4.1 SURVEY

4.1.1 FORM AND USE OF CHOLLA CACTUS

4.1.1.1 NAIVASHA AND ELEMENTEITA: NAKURU DISTRICT

In Naivasha and Elementeita, 45% of cholla fences are used for wildlife barriers, 32% for security reasons, 18% for preventing illegal grazing or straying of livestock and 5% as a fire break (figure 8). The versatility of cholla fences allow them to be used for a variety of purposes.

The Delamere Estate at Soysambu uses cholla on a large scale to keep resident wildlife species within their ranch boundaries. The economic activities of this ranch are livestock ranching, game ranching and an up-market tourist camp. The surrounding ranches have been split up and there is intense small-holder activity in the surrounding areas (Ahn & Geiger, 1987). A livestock and game census conducted in January 1993 showed large numbers of plains game present within the ranch (Chira, 1993). This ranch also experiences problems with cattle rustling and regular theft of fencing wire. These problems have prompted the ranch management to plant cholla around their ranch boundary. The total distance of cholla, planted by the Delamere Estate at Soysambu and Elementeita is 140 kilometres.

In the Naivasha and Elementeita area there are large numbers of Masai pastoralists, who graze their cattle and in some cases trespass into private property, to locate suitable pastures for their cattle. Cholla is the barrier of choice, as wire fences can easily be cut and traversed and are expensive to maintain and replace.

The Delamere Estate at Soysambu has a thick cholla fence which is over 9 m wide and this hedge successfully halted a bush fire that would have swept through the ranch with dire consequences. The hedge was burned halfway through but the presence of a large amount of moisture in the stems was responsible for stopping and extinguishing the fire. Cactus fences have thick juicy stems that store moisture and unlike other species that may have the presence of deadwood which can result in the hedge being destroyed in the case of a fire. Species such as the Mauritius thorn can be easily destroyed by fire and this is the prescribed method of control for this species (Ivens, 1968).

4.1.1.2 LAIKIPIA DISTRICT

The three main uses of cholla are 50% use it as a wildlife barrier, 37.5% use it to protect crops and 12.5% to protect dam walls (figure 9). The majority of ranches use cholla as a boundary fence. This fence is used either to contain or keep out wildlife, as some of the larger ranches border settlement schemes that have small holders as neighbors. The ranches that use cholla as a boundary fence to contain wildlife within the ranch boundaries are Ol Airo Nyiro, Ol Jogi, Ol Maisor and Lewa Downs. The main reason for adopting cholla is that it is cheap and cost effective to plant and maintain. Wire fences are regularly vandalized and the wire is either sold or used to make snares. The Ol Maisor ranch near Rumuruti has had serious problems with theft

Figure 8 and 9. **Form and use of the cholla cactus in Nakuru and Laikipia districts**

Figure 8 - Nakuru District

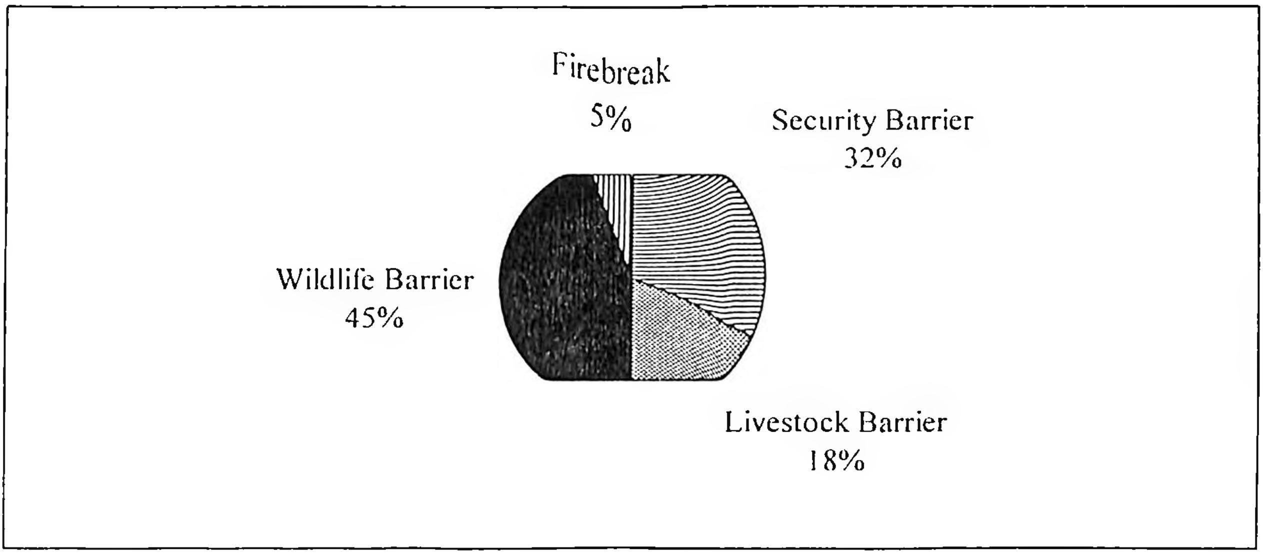
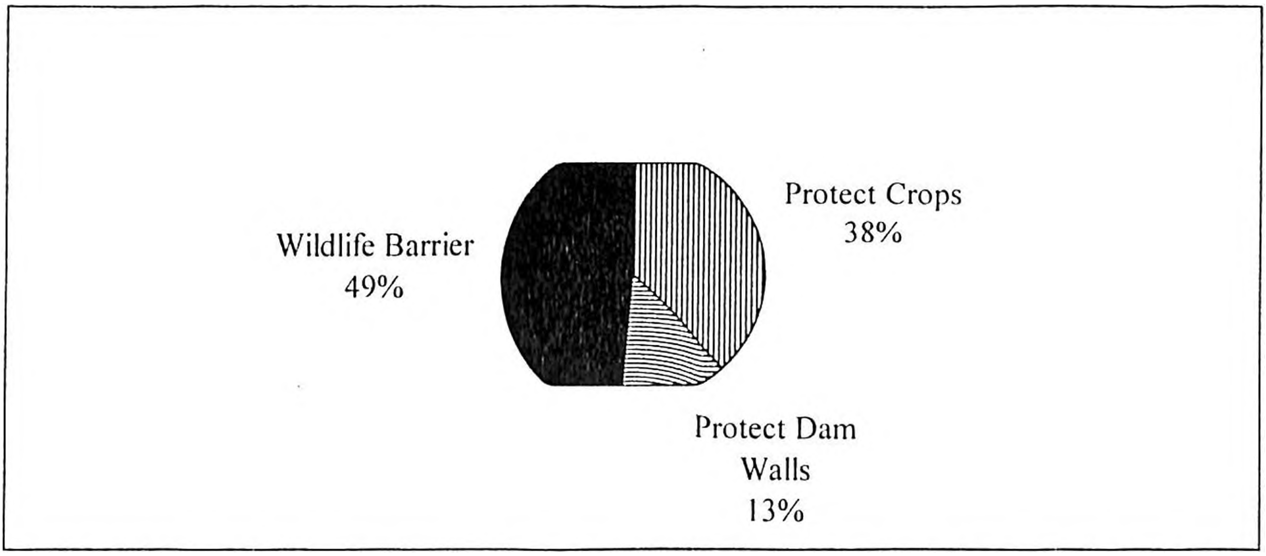


Figure 9 - Laikipia District



of wires and they have now planted approximately 38.4 kilometers of cholla as a boundary fence.

The Kisima-Rumuruti ranch uses cholla as a barrier to protect a 100 acre irrigated field in which maize and oranges are grown. This field is constantly challenged by crop raiding wildlife from the surrounding areas. The cholla is grown as the basic barrier and is supplemented by a moat and a single "hot" wire which encircles this field. The "hot" wire is used to electrify the gates which provide easy access to primates and can be pushed over by elephants.

The Mpala ranch whose main activity is ranching, has problems with elephants destroying dam walls. This ranch has large earthen dams located in depressions to hold water which collects during the rainy season. These dams provide watering points for wildlife besides the livestock on the ranch. On inspecting these dams large amounts of wildlife such as giraffe, buffalo, kongoni and Impala were observed watering at the dams.

Elephants destroy these dam walls by moving over the walls and creating a path that continuously erodes to weaken the dam walls. They also slide and wallow in the water weakening the base which finally leads to the dam wall breaching. The first measure that was employed to keep elephants off the dam walls was to place stones all over the wall. This method did not prove very effective as the elephants easily pushed the stones away with their feet. The next step was to plant cholla along the dam wall by spreading cuttings along the exposed wall. This cholla was harvested from the main ranch house where it is used to fence an orchard.

The cholla is planted along two dam walls which are approximately 100 meters in length. One particular dam which is known as the Lulwa dam is heavily used by elephants as a watering point. The dam wall is still intact as it is heavily planted with cholla and the elephant now avoid using the walls to approach the dam. On this ranch, a similar dam not planted thick enough with cholla, is heavily damaged and there are heavily eroded game trails leading to the water.

4.1.2 WILDLIFE BARRIER

4.1.2.1 NAIVASHA AND ELEMENTEITA: NAKURU DISTRICT

This present study shows that cholla is used as a wildlife barrier and that 73% of the respondents use it against plains game, 20% against hippopotamus and waterbuck and 7% against livestock mainly cattle (figure 10). According to the data for the plains game buffalo and zebra were the most problematic animals. Giraffe, eland (*Tragelaphus oryx*), Thompson's gazelle and kongoni accounted as moderately problematic species. Kongoni and bushpigs accounted for the least problematic species. Cattle were blamed for illegal grazing and cholla barriers are used to keep them at bay.

About 20% of the cholla fences are erected to keep off hippopotamus and waterbuck. These two species occupy the extensive papyrus swamps that line the lake shore. Falling lake levels have resulted in extensive papyrus belts which are utilized by these two species. Hippopotami are more responsible for causing damage when compared to water bucks which are tolerated. Hippopotami can enter cultivated areas through adjacent plots or approach directly from the lake. They are also known to travel great distances in search of suitable grazing.

Cholla hedges are challenged in various ways by different wildlife species. Cholla barriers function as opaque barriers that wildlife cannot see through. This is an important aspect as most animals will not jump across a barrier they cannot see through. When this barrier is challenged it presents sharp spines that can puncture the skin of the animal and cause pain that will cause it to back away. Cholla hedges normally have joints that have fallen off and these can cause spines to penetrate the hooves of wildlife causing them intense discomfort.

In Naivasha the jumping species of wildlife such as zebra, eland, waterbuck, impala and Thompson's gazelle can be controlled by planting the fence across a wide strip approximately 2-8 m wide. This fence does not have to attain a tall height to be effective as the fence over a wider area presents a challenge to the jumping species.

A remark by a ranch manager sums the effectiveness of cholla as a wildlife barrier," *I am not aware of anything that can penetrate cholla above ground*".

4.1.2.2 LAIKIPIA DISTRICT

Ranches and farms that use cholla in Laikipia district are Ol Airo Nyiro Ranch, Ol Maisor and Kisima-Rumuruti in the western part of the district. In the central part of the district, Ol Jogi and Mpala Ranch use cholla and in the western part the Lewa Downs ranch and small holders at Ngare Ndare. It is also used within Nanyuki

Figure 10 and 11. The use of cholla cactus as a wildlife barrier in Nakuru and Laikipia Districts

Figure 10 - Nakuru District

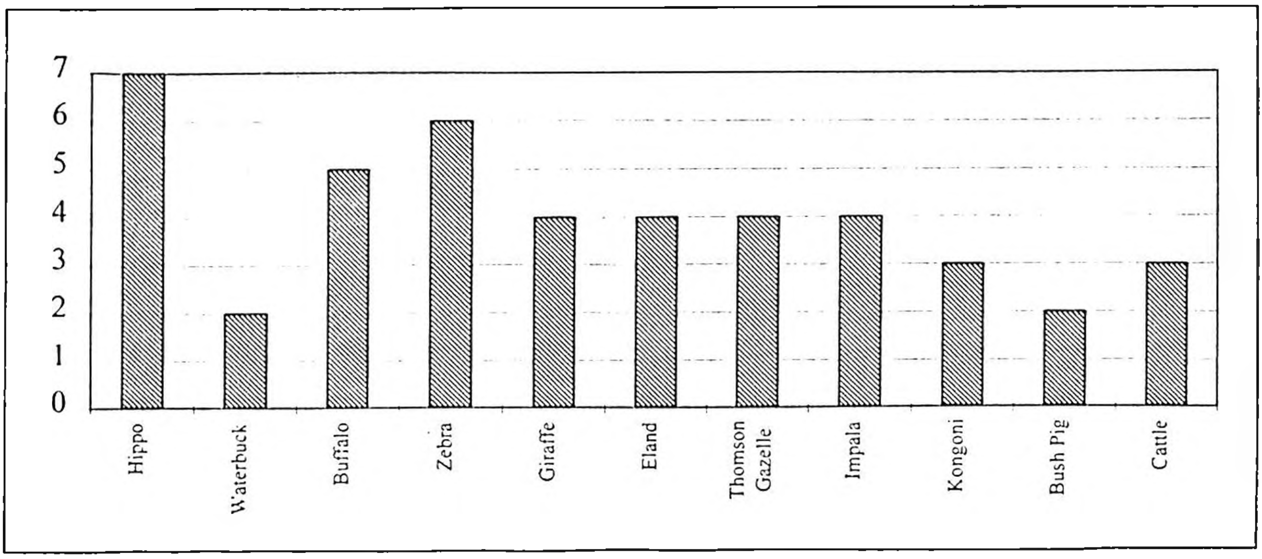
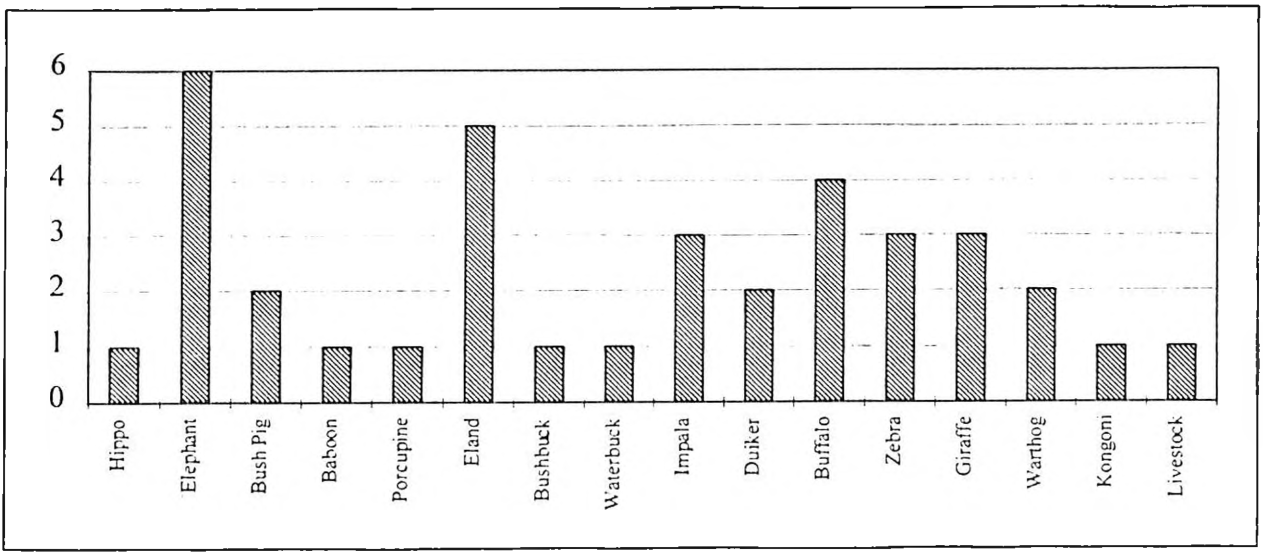


Figure 11 - Laikipia District



township and in some places along the Nanyuki-Don Dol road but not as a managed fence.

The wildlife species against which cholla is used as a barrier are mainly plains game species including baboons 75.7%, species living near or close to water such as hippopotamus and waterbuck 5.4% and livestock 2.7% (figure 11). The main problematic species on ranches and farms where cholla is used are the elephant, buffalo, eland, zebra, giraffe and impala. The other species of wildlife against which cholla is used are bushpigs, porcupines, bushbuck, waterbuck, duiker (*Cephalophus* spp.) and kongoni. Cholla is also used to prevent livestock from straying into private ranches and farms.

Laikipia district harbors a large population of elephants and a total aerial count conducted in 1990 estimated the population at 2,500 individuals. This population is resident on the Laikipia plateau due to safety from poaching pressure in Samburu and availability of water in the numerous dams present on ranches. This population has come into contact with the northward movement of small holders and has resulted in crop-raiding activities. The elephants seek refuge in the large ranches during the day and raid crops in the adjoining small holder settlements during the night. These elephants are also responsible for disrupting ranching operations by destroying fences, dam walls, water pipes and other related ranch infrastructure (Thouless & Dyer, 1992).

The conflict with small holders is often severe and press reports such as "Elephants eat farms bare" which appeared in the Daily Nation, 1st March 1994 shows how serious the problem is in Laikipia district. Incidents that have been reported to the Kenya Wildlife Service stations in Laikipia which are then relayed to the district headquarters in Nanyuki show that 59.6% of the reports belong to damage caused by elephants. The other serious offenders were buffalo, eland and lion followed by bush pig, leopard, hyena, zebra, giraffe, waterbuck and hippopotami.

The damages and incidents reported comprised of 53.5% crop damage, 16.8% killing livestock, 12.9% destroying fences, 12.9% death, injury and harassing people and 4.0% were wildlife species with visible snares. According to a study conducted in the Bura and Mwatate areas it was found that only 45% of the population reported wildlife related incidents to the authorities and at least 55% of the incidents went unreported (Ngure, 1992).

4.1.3 SUCCESS OF CHOLLA CACTUS AS A BARRIER

4.1.3.1 NAIVASHA AND ELEMENTEITA: NAKURU DISTRICT

The success of cholla as a barrier was measured as excellent, good and poor. The results show that 55% of the ranches and farms surveyed regarded cholla as an excellent barrier, 45% as a good barrier and no response for cholla as a poor barrier (figure 12).

The main reason cited for cholla being a suitable barrier is the cost effectiveness of establishing a fence. In most cases farms or ranches with established fences are eager to let people collect cuttings. This saves the farmers time and labor input in pruning the fence which may be necessary to control growth.

Figure 12 and 13. The success of cholla as a wildlife barrier in Nakuru and Laikipia districts

Figure 12 - Nakuru District

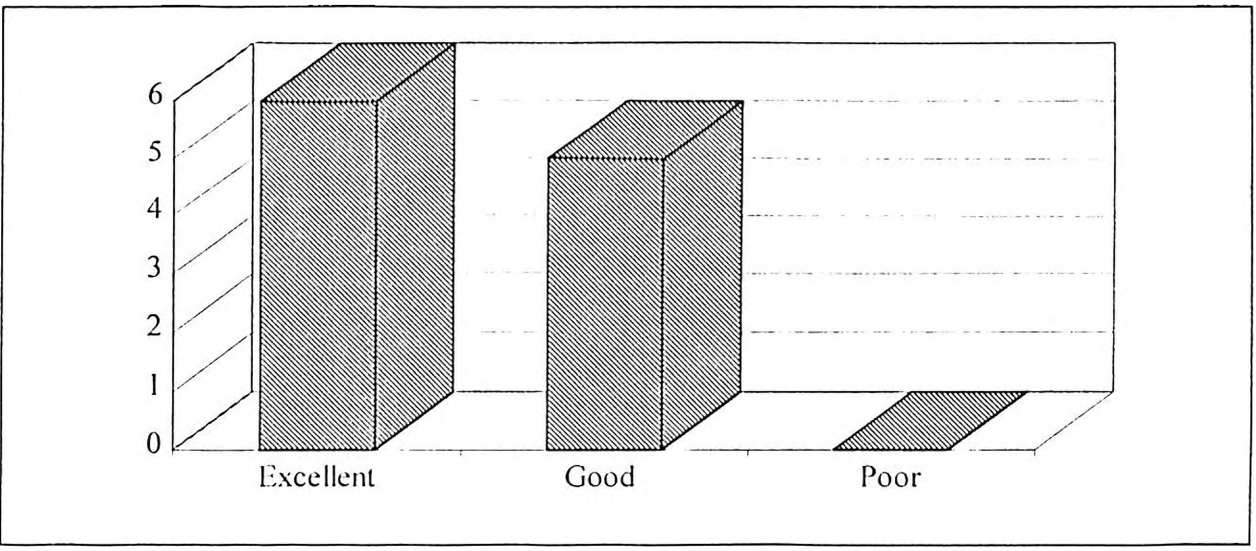
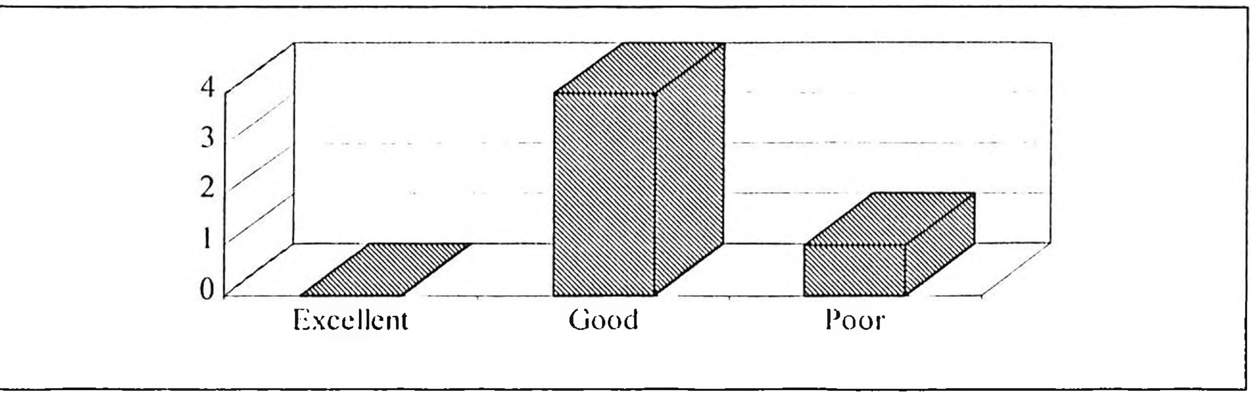


Figure 13 - Laikipia District



The cost of establishing alternative barriers may not be possible due to the cost involved. The theft of wire from fences is a serious issue and in Naivasha the wire from the K.W.S. training institute was stolen. The cost of establishing wire fences is also costly to most small holders who would rather choose a live fence option. The spread of cholla within the Naivasha area accounts for its success as a live fence that can be used as a wildlife, security and livestock barrier.

4.1.3.2 LAIKIPIA DISTRICT

To measure the success three responses were chosen namely excellent, good and poor. There was 0% response for excellent, 80% for good and 20% for poor (figure 13). There are various problems that face the establishment of suitable cholla fences in Laikipia. In most cases large distances of fence lines were planted such as a 2 kilometer fence line at Ol Jogi, 3.5 kilometer at Lewa Downs and 34.8 kilometers at Ol Maisor. The main problem observed was a lack of management during planting. In most cases people do not take fencing issues seriously enough and poor planting practices coupled with an arid climate and poor soil conditions lead to the establishment of poor fences.

4.1.4 METHOD OF PLANTING CHOLLA CACTUS

4.1.4.1 NAIVASHA AND ELEMENTEITA: NAKURU DISTRICT

Live fences of cholla are planted using cuttings from established cactus plants. These cuttings are harvested by chopping joints of cactus plants which are then transported to the planting site. Larger farms and ranches use tractors coupled to trailers for transporting cholla. When I established a fence at Naivasha the cholla was cut using "pangas" (machete) and grass slashers. The cut portions were then heaped together using garden rakes in piles approximately 1 m high. These cut portions were then loaded onto a trailer using a combination of hay forks, rakes and wide mouthed shovels.

There were three main methods of planting observed in Naivasha and the success rate of growth depended on these methods (figure 14). The survey showed that 50% of the farms and ranches simply threw cholla cuttings along a fence line. In this method the cholla cuttings are simply deposited in piles and then spread out using a rake or panga and there is no ground preparation and the cuttings have to compete with grass and weeds to establish themselves. This method is employed by farms or ranches that have to cover large distances, an example is the Oserian Development Company Ltd. that has a fence line measuring 7 Km.

The survey showed that 43% of farmers and ranches who planted cholla utilized some basic management during planting. Large scale farmers who have access to tractors and ploughs, make a harrow line and place the cuttings in the depression created by the harrow. The soil is then turned over and it partially covers the cholla cuttings.

Small scale farmers who do not have access to mechanized agricultural machinery normally dig a narrow trench and place the cholla cuttings in and half cover them with soil. The other method employed by small holders is to clear a patch approximately 1 m wide, till the soil over and place the cuttings on the soil and then lightly cover it with soil.

Figure 14 and 15. Methods of planting cholla in Nakuru and Laikipia districts

Figure 14 - Nakuru District

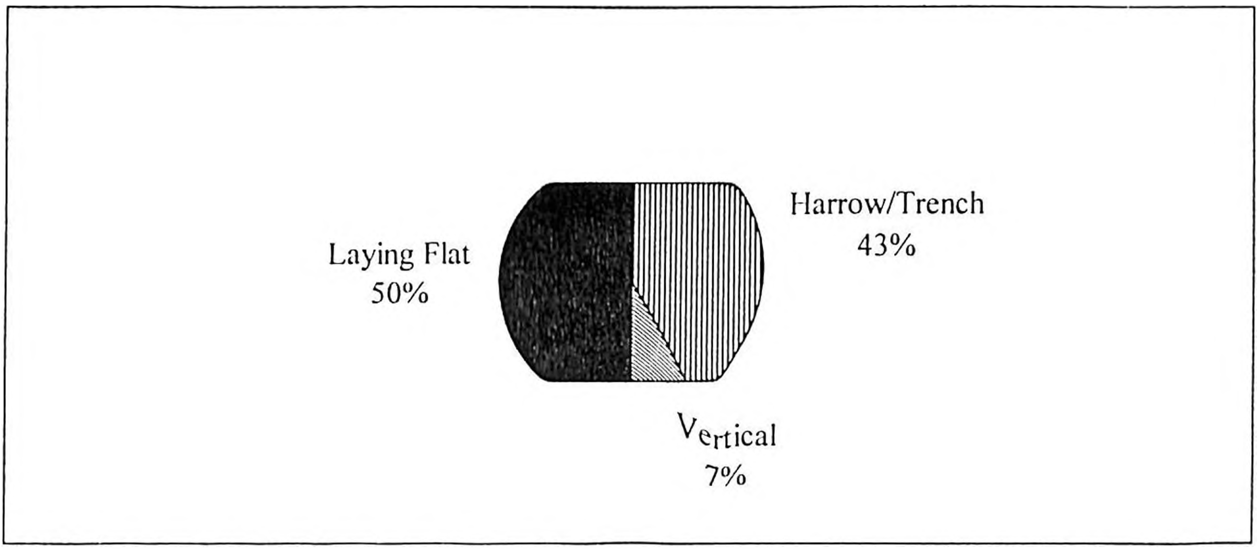
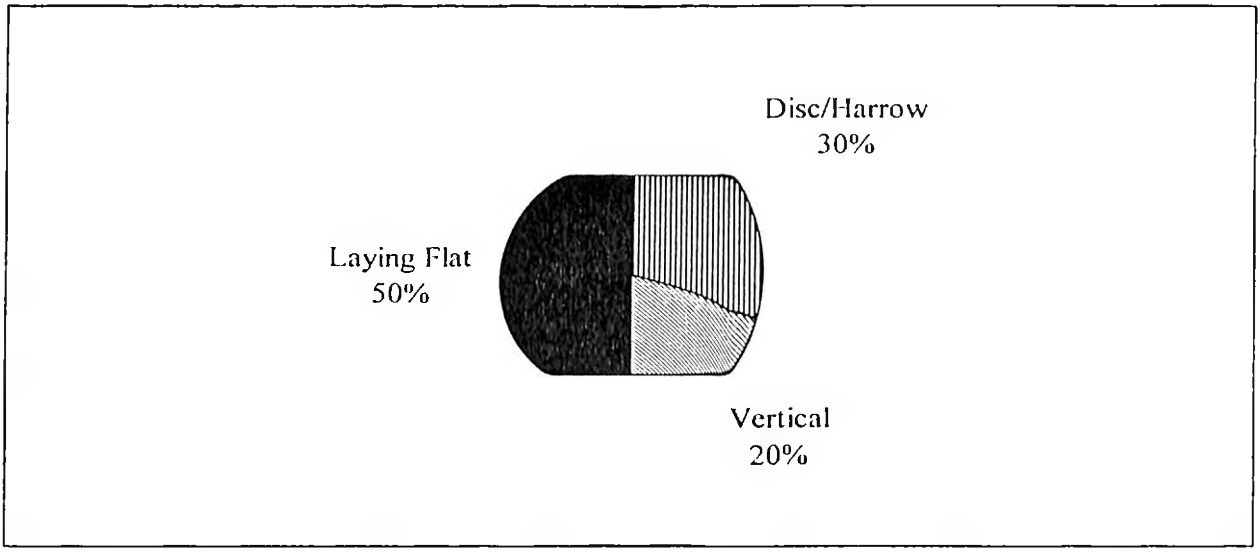


Figure 15 - Laikipia District



In 7% of the cases, cholla is planted vertically into the soil and this method is only used in special circumstances. In cattle bomas cholla is planted vertically, this method is more time consuming and results in handling difficulties because of the spines.

4.1.4.2 LAIKIPIA DISTRICT

There were three main methods of planting cholla that were observed within Laikipia district (figure 15). 50% of the ranches and farms using cholla laid it on the ground without any ground preparation. 30% used some ground preparation by either running a disc harrow or digging a shallow trench and then placing the cuttings and lightly covering them with soil. 20% planted cholla vertically by digging a hole and by placing each joint in the hole and leaving approximately 40-60% of the stem sticking out of the hole.

4.1.5 PROBLEMS ASSOCIATED WITH CHOLLA CACTUS

4.1.5.1 NAIVASHA AND ELEMENTEITA: NAKURU DISTRICT

The main problems associated with cholla fences in the Naivasha area are slow growth, invasiveness and injuries to wildlife and humans (figure 16). Invasiveness accounted for 64% of the problems associated with cholla fences. Invasiveness is caused by widening of the cholla fence as it grows which then uses up extra land. A cholla fence observed at the Delamere Estate at Soysambu was 12 m wide and was planted as a fence in 1965, thus it spread and widened at approximately 0.43 m/year. This was a neglected fence that could have been pruned every year to maintain a suitable width.

A fence planted at Manera farm during the late 1960's is 7.5 m wide and its rate of spreading would be about 0.3 m/year. The main method of controlling invasiveness in cholla fences is by pruning the fence. The larger ranches use a bulldozer or grader that moves parallel to the fence and pushes in any new growth into the fence. Small holders and farms without access to agricultural machinery use a labor intensive method of pruning with a panga or slasher. The fallen pieces are usually pushed back into the fence where they grow and create a thicker fence or are used to fill gaps.

Slow growth accounts for 14% of the response and this results in a fence that is not high and thick enough. The main reasons for slow growth and poor efficacy are soil compaction and poor moisture retention in the soil. The spines of the cholla are very damaging to both wildlife and humans, as the spines have microscopic barbs that give a secure hold once they are embedded in the skin.

4.1.5.2 LAIKIPIA DISTRICT

The problems associated with cholla in Laikipia district were gaps in the fence line, slow growth, invasiveness and handling (figure 17). Gaps in the fence accounted for 28.6% of the problems affiliated to cholla fences. These gaps can occur in well established fences and are normally caused by three main reasons:-

- Poor management during planting especially in the first two years of growth.
- Paths used by both people, livestock and wildlife.
- Newly planted fences that are disrupted by people, wildlife and especially baboons that feed on the succulent stems.

Figure 16 and 17. The problems associated with cholla in Nakuru and Laikipia districts

Figure 16 - Nakuru District

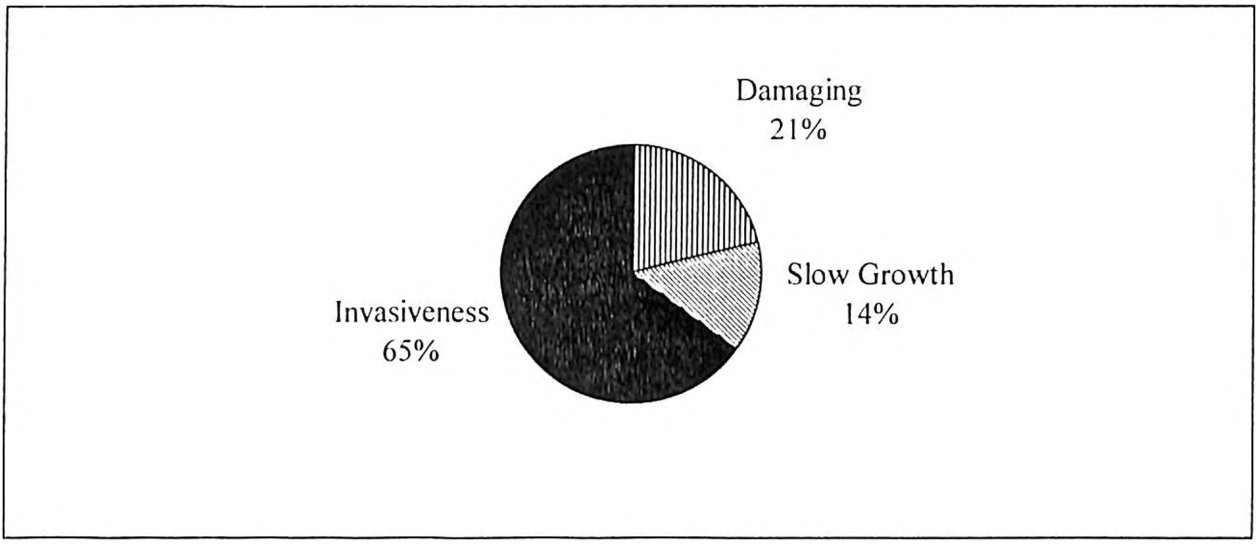
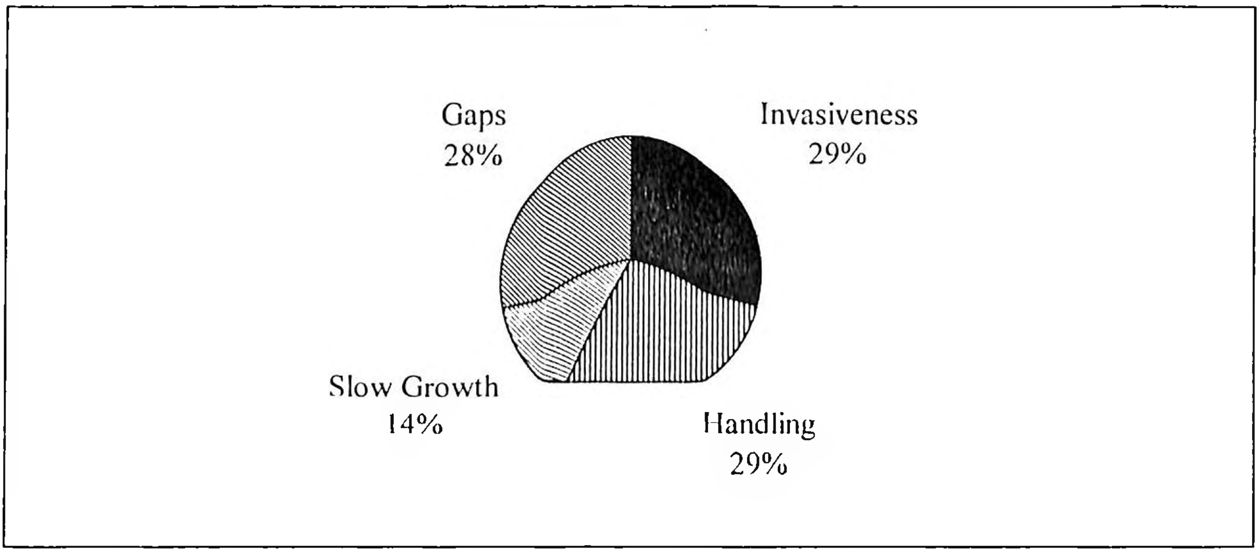


Figure 17 - Laikipia District



Cholla fences are usually planted by laying cuttings along a fence line. In some cases the cuttings may not be placed wide enough. Cuttings can be infected by fungus if planted during the wet season and if the lesions have not healed then no growth will result. In such cases the fence may develop gaps because there was no growth at a particular point. Cuttings should be placed where gaps are persistent to encourage new growth.

In most cases a fence line can be planted along a well used path or game trail and the growth can be disrupted along that point. A fence planted across a path should be allowed to grow normally as it is hard to stop a path or trail from being used. When the surrounding cholla has reached a suitable height the gap can be sealed with thorny branches and/or with wire and posts.

Gaps can also be caused by the presence of rocks or unsuitable soil types. The presence of rocks can cause a gap to form as the cholla will not be able to establish properly due to unfavorable conditions for root formation and moisture retention. Vertisols or black cotton soils are prone to cracking during the dry season and remain waterlogged during the wet season. In places where patches of black cotton soil occur, there is very little or no growth along a cholla fence line. The water logging properties of these soils are unsuitable for cholla.

In this study, slow growth accounted for 14.3% of the responses attributed to problems experienced with cholla. The two ranches that experienced this problem on a large scale were Kisima-Rumuruti and Lewa Downs. The Kisima-Rumuruti uses cholla to fence off an irrigated field, where maize and oranges are grown and as a boundary fence. The height of the cholla fence planted around the irrigated field was measured on 14th December 1993 and the average height was 1.2 m-1.8 m and it was planted in 1975. The height of cholla planted along the boundary in 1980 during had an average height of 0.76 m.

The slow growth rate of cholla necessitated the digging of a moat adjacent to the cholla fence as a supplementary barrier. Cuttings of cholla that had dropped into the trench showed a better growth then the original fence. This trench acts as a microcatchment collecting any available precipitation and was evident by improved growth and height.

The gaps in this fence never fill up as it is very hard to establish new cuttings in an arid situation. The lower efficacy of this cholla fence makes it easier for wildlife to breach the fence. In this case hippopotamus, bushpigs, baboons, Vervet monkeys (*Cercopithecus aethiops*) and porcupines easily breach the cholla fence. These animals can easily crawl or run through the gaps, making it even more difficult for new cuttings to establish themselves. The cholla fence is effective against eland, bushbuck, waterbuck, impala and duiker who find it difficult to jump over a fence they cannot see through.

The Lewa Downs ranch attempted to use cholla as a boundary fence over a distance of 3.5 kilometers but experienced problems associated with slow growth and gaps. The main problem observed was poor management during planting and the soil type which is dominated by vertisols. The method of planting involved throwing cuttings from a trailer along an intended fence line and this method resulted in patchy growth with the cholla growing in clumps instead of a straight line. In this area there were problems with recently planted cholla fences being disturbed by humans and wildlife and this can also lead to the formation of gaps. The establishment can be improved by placing cuttings along an existing fence line as this will decrease disturbance of the planted cholla cuttings.

Invasiveness accounted for 28.6% of the problems associated with cholla in Laikipia district. This invasiveness was perceived as a long term problem and was not seen as a major problem. The cholla that was initially planted at the Colville Estate (now Ol Morani Settlement Scheme) now consists of large stands of cholla and is used as a source for cuttings by neighboring ranches such as Ol Airo Nyiro, Kisima-Rumuruti and Ol Maisor. Invasiveness in Laikipia is not a major problem as compared to the 64% of the response shown in the Naivasha-Elementeita area.

In most of the cases cholla has not been seen to spread and the presence of roads, paths or game trails adjacent to fences restrict the movement of cholla. These paths, trails and roads represent areas of compacted soil that are not easily penetrated by cholla roots and serve as firebreaks.

4.1.6 THE SPREAD AND DISTRIBUTION OF CHOLLA

The survey provided information on the spread and distribution of cholla in Nakuru and Laikipia districts. This information was then used to prepare maps for the two districts.

4.1.6.1 NAKURU DISTRICT

In Nakuru district the use of cholla was initially centered around Lake Naivasha. The first cholla fences were planted at the A.D.C. Ndabibi complex which formerly belonged to a settler known as Colville. The fences at Ndabibi were used as a source of cuttings by farmers for establishing fences around Lake Naivasha and its environs. The fences at Delamere's Manera farm came from Colville's ranch.

The use of the cactus also spread to Delamere's Estate at Soysambu and past Nakuru to Rongai. The cactus from the Delamere Estate in Soysambu was also taken to Laikipia where fences were initially planted at Colville's Laikipia ranch which is now known as Ol Morani settlement scheme. The distribution and spread of cholla in Nakuru district is shown in figure 18.

4.1.6.2 LAIKIPIA DISTRICT

Cholla fences have been used in the north-west part of the district and its use has spread south-east towards Nanyuki town. The ranches in this area that use cholla are Ol Airo Nyiro, Ol Morani, Sipili, Kisima, Ol Maisor, Mpala and Ol Jogi. The use of cholla cactus has also spread northwards from Nanyuki to Ngare Ndare, Lewa Downs and Isiolo and the distribution is shown in figure 19.

Figure 18. The spread and distribution of cholla in Nakuru district

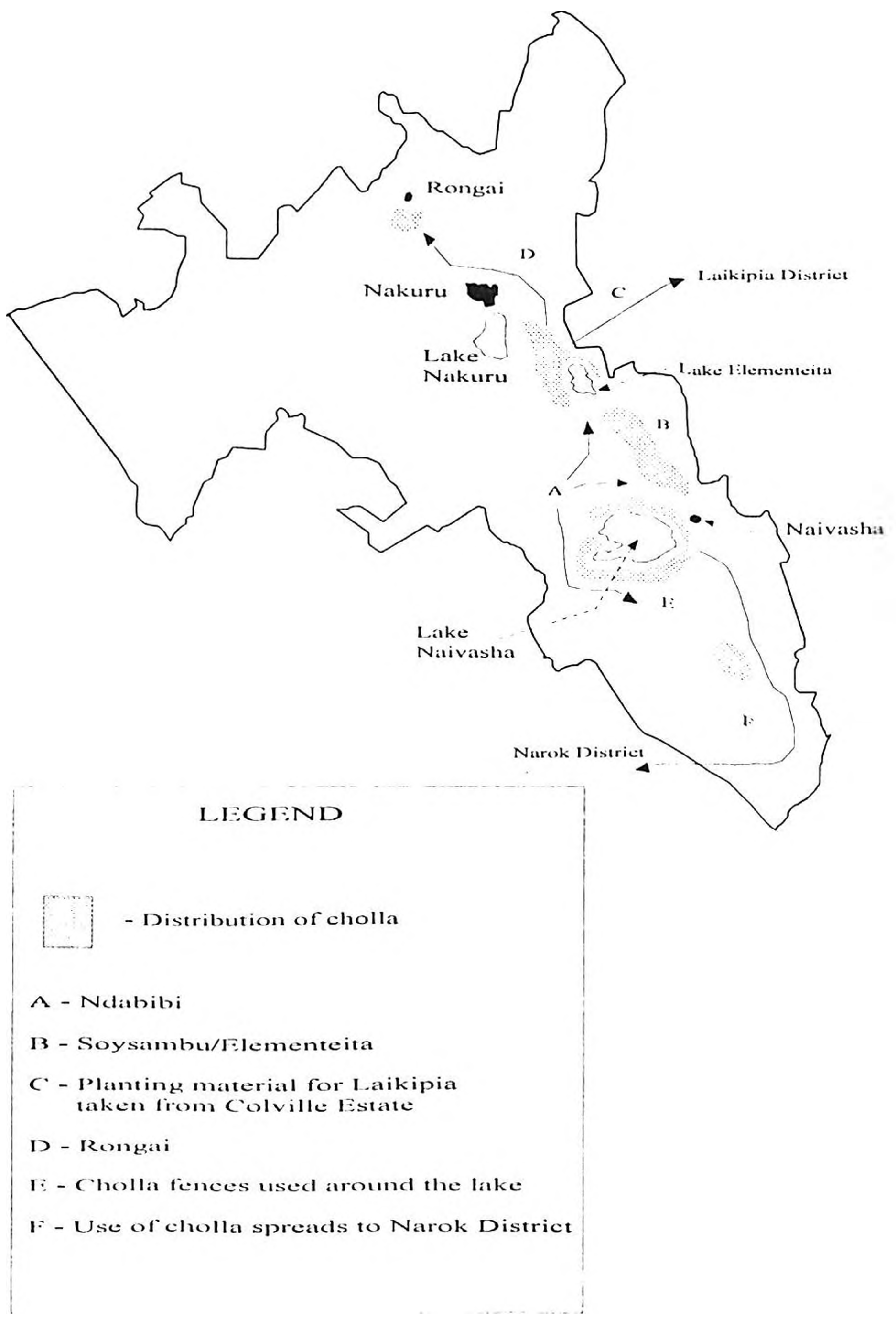
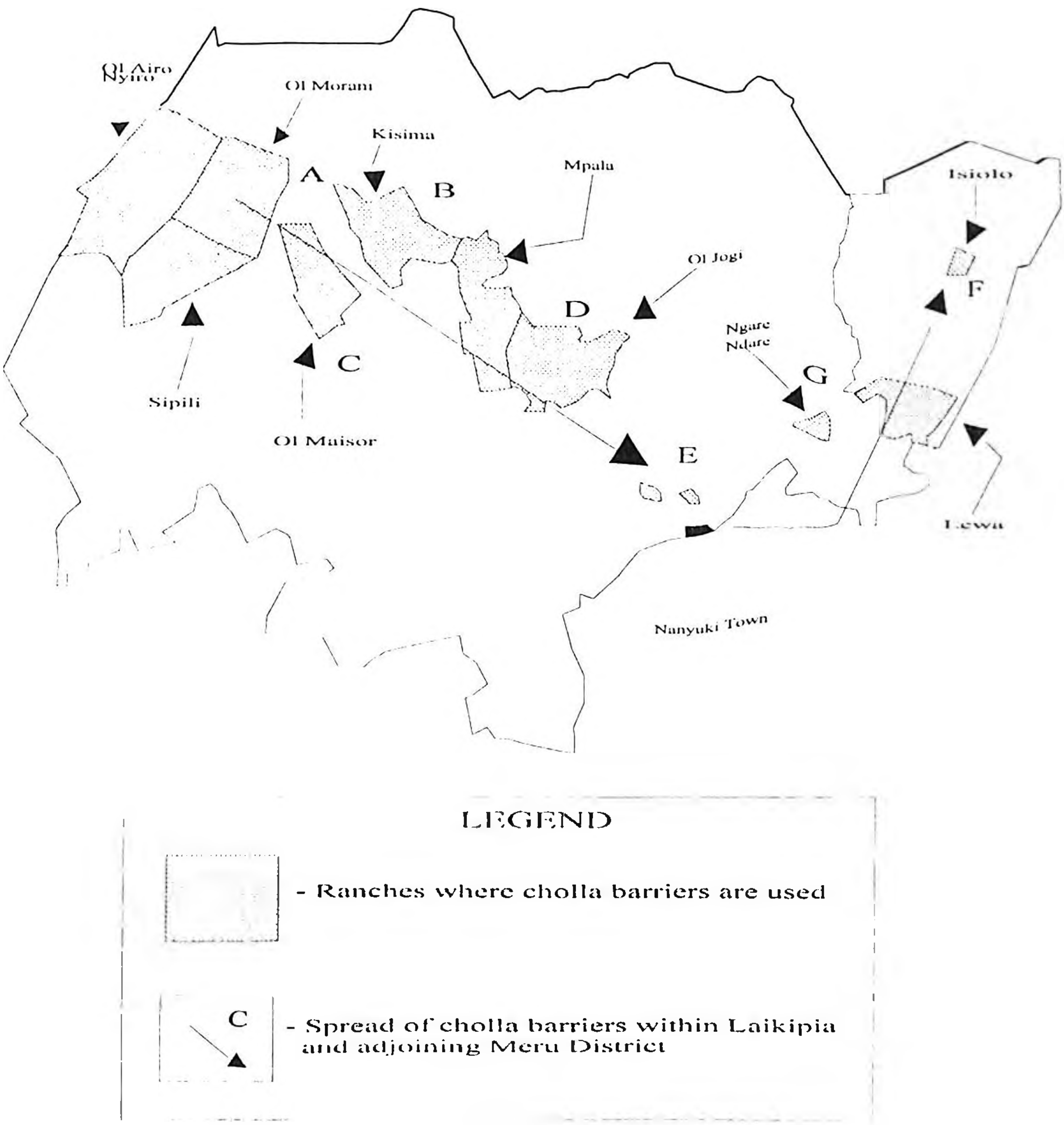


Figure 19. The spread and distribution of cholla in Laikipia district



4.2 GROWTH RATES OF CHOLLA CACTUS

4.2.1 NAIVASHA

The results at Naivasha are given for the shaded and unshaded plots. There were two replicates for the unshaded plot. The z value = - 0.01 for the two replicates shows no significant difference in growth rate at 0.05 level of significance

The two replicates for the shaded plot give a z value = 1.62 at 0.05 level of significance. This shows no significant difference in growth rates between the two replicate plots.

The pooled estimate of z = - 10.40 which is significantly different at 0.05 level of significance. Therefore there is a significant difference between the shaded and unshaded plots.

The experimental plot planted at Naivasha yielded a growth rate of 0.63 m/1 year 4 months in an unshaded plot and 0.82 m/1 year 4 months in a shaded plot. The growth under the shade was significantly higher (z= - 10.40 at 0.05 level of significance) than compared to the growth in the unshaded plot.

The cholla growing under the *Acacia xanthopholea* in the shaded plot had growth characteristics of reduced light intensity such as thin, spindly stalks as compared to the stouter stalks of the cholla growing in the unshaded plot.

4.2.2 TAVETA

The plot at Taveta was planted during the unseasonal heavy rains of 1993 and suffered from a fungus that destroyed over 80 % of the planted cholla. Ranches mainly plant cholla in the dry season and not during the wet season. When the cholla is harvested the cut lesions have to heal dry with a scab forming over the cut area. During moist weather the wet lesions are a perfect source for fungus infections. This infection resulted in a slimy brown exclusion from the cutting with decay setting in which finally destroyed the whole cutting. Therefore no growth rates were available from Taita Taveta.

4.2.3 GROWTH RATES FROM SURVEY

4.2.3.1 NAIVASHA

Growth rates were observed to be better in Naivasha than in Laikipia. At Manera farm the growth rate along a boundary fence was 0.38 m/8 months. Two farms along the eastern shore of Lake Naivasha recorded growth rates of 0.78 m/1 year, 0.74 m/2 years 9 months and 1.36 m/3 years 9 months. At Kongoni farm along the southern shores of Lake Naivasha a cholla fence planted by laying the cuttings flat on the ground gave a growth rate of 0.40 m/10 months. Cholla that was planted in a furrow gave a growth rate of 0.30 m/1 year 8 months.

In the Naivasha area the growth rates are very variable. The rainfall in Naivasha is very localized and erratic. Poor soil conditions in terms of compaction and rocky soil generally give a slower, patchier growth. Cholla planted in furrows had a slower growth rate but generally gave rise to a more continuos and efficacious fence.

4.2.3.2 LAIKIPIA

The cholla planted at Ol Jogi ranch was growing on murram and there was very little soil present. This resulted in a growth rate of 0.80 m/2 years. At Kisima Rumuruti the cholla fence growth was very poor with a growth rate along a boundary fence of 0.77 m/13 years. The growth rate around an irrigated plot was approximately 1.54 m/18 years. The Lewa Downs cholla fence had grown only 1 m/7 years, this is an area of vertisols and this makes establishment of cholla difficult. The Mpala ranch had growth rates of 0.36 m/6 months and 1.16 m/2 years 6 months.

4.3 SOIL PROPERTIES

4.3.1 NAIVASHA

4.3.1.1 NUTRIENT ANALYSIS & DESCRIPTION OF SOIL PROFILE PITS

Tables 1-a and 1-b show the chemical and nutrient analysis of the Naivasha area soils which were collected from area A (good growth), area B (medium growth) and C (poor growth). A control sample was also collected from a nearby adjoining area in a grassland which was devoid of cactus.

Comparing the nutrient levels of areas A, B and C, the pH in both horizons A and B is not significantly different between the three areas. The pH is neutral with an average of 6.0 in the surface horizon of the three areas.

Table 1-a and 1-b. Results of nutrient analysis at the Naivasha site

Table 1-a:

HORIZON A		AREA - A	AREA - B	AREA - C
	CONTROL	GOOD GROWTH	MEDIUM GROWTH	POOR GROWTH
pH	7.8	6.07	5.43	6.27
SODIUM m.e. %	1.8	1.31	0.95	1.14
POTASSIUM m.e. %	2.6	2.15	1.21	1.95
CALCIUM m.e.%	7.3	4.2	4.47	5.13
MAGNESIUM m.e.%	2.5	1.6	.87	1.07
MANGANESE m.e.%	0.6	0.54	0.45	0.47
PHOSPHORUS ppm	14	17.67	21.0	33.33
NITROGEN %	0.12	0.14	0.13	0.11
CARBON %	0.75	1.61	1.39	1.09

Table 1-b:

HORIZON B	AREA - A	AREA - B	AREA - C
pH	6.73	6.33	7.03
SODIUM m.e.%	1.85	1.49	1.55
POTASSIUM m.e.%	2.97	2.15	2.23
CALCIUM m.e.%	4.3	5.27	4.93
MAGNESIUM m.e.%	1.57	0.9	0.9
MANGANESE m.e.%	0.39	0.40	0.41
PHOSPHORUS ppm	28.0	31.67	23.0
NITROGEN %	0.06	0.13	0.10
CARBON %	1.06	0.33	0.10

Table 2. The results of Analysis of Variance (ANOVA) for horizon A and B at the Naivasha site

HORIZON - A

pH

SV	SS	DF	MS	F
TSS	1.8	8		
GSS	1.1	2	0.6	
ESS	0.7	6	0.1	5.1

Sodium

SV	SS	DF	MS	F
TSS	0.5	8		
GSS	0.2	2	0.1	
ESS	0.3	6	0.1	2

Potassium

SV	SS	DF	MS	F
TSS	2.9	8		
GSS	1.4	2	0.7	
ESS	1.4	6	0.2	3

Calcium

SV	SS	DF	MS	F
TSS	2	8		
GSS	1.4	2	0.7	
ESS	0.6	6	0.1	6.8

Magnesium

SV	SS	DF	MS	F
TSS	1.3	8		
GSS	1.1	2	0.5	
ESS	0.3	6	0	17.7

Manganese

SV	SS	DF	MS	F
TSS	0	8		
GSS	0	2	0	
ESS	0	6	0	0.8

Phosphorus

SV	SS	DF	MS	F
TSS	2444.4	8		
GSS	408.7	2	204.3	
ESS	2035.7	6	339.3	0.6

Nitrogen

SV	SS	DF	MS	F
TSS	0	8		
GSS	0	2	0	
ESS	0	6	0	2.5

Carbon

SV	SS	DF	MS	F
TSS	1	8		
GSS	0.4	2	0.2	
ESS	0.6	6	0.1	2

HORIZON - B

pH

SV	SS	DF	MS	F
TSS	1.9	8		
GSS	0.7	2	0.4	
ESS	1.1	6	0.2	2

Sodium

SV	SS	DF	MS	F
TSS	0.8	8		
GSS	0.2	2	0.1	
ESS	0.6	6	0.1	1.1

Potassium

SV	SS	DF	MS	F
TSS	1.6	8		
GSS	1.2	2	0.6	
ESS	0.4	6	0.1	8.7

Calcium

SV	SS	DF	MS	F
TSS	2.4	8		
GSS	1.4	2	0.7	
ESS	1	6	0.2	4.5

Magnesium

SV	SS	DF	MS	F
TSS	2.4	8		
GSS	0.9	2	0.4	
ESS	1.5	6	0.3	1.7

Manganese

SV	SS	DF	MS	F
TSS	0.1	8		
GSS	0	2	0	
ESS	0	6	0	0

Phosphorus

SV	SS	DF	MS	F
TSS	1074.2	8		
GSS	113.6	2	56.8	
ESS	960.7	6	160.1	0.4

Nitrogen

SV	SS	DF	MS	F
TSS	0	8		
GSS	0	2	0	
ESS	0	6	19	1.6

Carbon

SV	SS	DF	MS	F
TSS	2.7	8		
GSS	1.5	2	0.8	
ESS	1.1	6	0.2	4

LEGEND:-
SV - Source of Variation
TSS - Total
GSS - Group
ESS - Error

SS - Sum of Squares
DF - Degrees of Freedom
MS - Mean Squares
Critical Value - 5.1400

The basic nutrients sodium, potassium and manganese do not show any significant differences in the three areas in horizon A. There was a slight increase in calcium and magnesium levels in horizon A.

The organic carbon and nitrogen levels are higher in area A and decrease through area B and C. The levels of nitrogen are 0.14% in area A, 0.13% in area B and 0.11% in area C. The levels are not significantly different but they show a slight decrease in the three areas A, B and C. This change is probably related to the increase in organic litter layer present underneath the tree. The phosphorus levels are adequate within the three areas A, B and C and are not significantly different.

Compared to the adjoining control area, there was a decrease in the nutrient levels when compared to the control sample. However, the level of nutrients and the pH levels underneath the cactus fence did not significantly affect the three areas of growth. This is attributed to the adequate and balanced level of nutrients present. The ANOVA results are shown in table 2. The presence of a litter layer under the cactus fence, growing under the tree, acts as a mulch for retaining moisture and provides nutrient through decomposition.

The soil profile pits were described according to the areas A, B and C and the results are shown in table 3.

Table 3. The physical properties of the soil profile pits at Naivasha

TRANSECT	SITE	LITTER LAYER	COMPACTNESS AND DEPTH	PRESENCE OF GRAVELS	HEIGHT OF CACTUS
I	A(COVERED)	10 CM.	NONE	78 CM.	3.2 m.
	B(SEMI COVERED)	5- 7 CM.	++(14- 35cm.)	67 CM.	1.8 m.
	C (OPEN)	0- 2 CM.	+++(14- 35 cm.)	67 CM.	1.4 m.
II	F(COVERED)	13 CM.	0	NONE	2.8 m.
	E(SEMI- COVERED)	5 CM.	0	NONE	2.3 m.
	D(OPEN)	0- 1 CM.	+++(14- 39 cm.)	NONE	1.5 m.
III	I(COVERED)	11 CM.	+(11- 32 cm.)	113 CM.	2.5 m.
	H(SEMI- COVERED)	NONE	++(11- 35 cm.)	NONE	1.9 m.
	G(OPEN)	NONE	+++(0- 18 cm.)	NONE	1.0 m.

LEGEND:

Compactness and Depth = 0 - None, + - Slightly, ++ - Compacted & +++ - Very Compacted

AREA-A

The average height of the cactus in this area is 2.83 m. The growth is characterized by thin, long narrow stalks and a poor efficacy. There was no compaction of the soil in transect I and II and slight compaction in transact III in Horizon B (32 cm). Gravels are present in transects I and III at 76 and 113 cm respectively.

A litter layer was present with an average depth of 11.33 cm and was found piled under the undergrowth of the cholla fence. The litter layer is composed of leaves, pods and twigs from the overhead canopy of the *Acacia.* This litter piles up under the fence where it is blown and trapped by the wind.

AREA-B

The average height of cholla in this area is 2.0 m and the growth is characterized by an excellent efficacy. The growth in this region is thick and results in a strong barrier. In transects I and II there is slight compaction in Horizon B at 24 cm and 25 cm respectively. There was no compaction observed in transact III.

Gravels were present in transect I at 67 cm and none were present in transects I and II. A litter layer was present with an average depth of approximately 4 cm which is less when compared to zone A.

AREA-C

The average height of cholla in this area is 1.3 m and the growth is characterized by a shorter height but good efficacy. The compaction in all three transects was characterized as "very compacted". The compaction in transect I and II is in Horizon B at 10 cm and 15 cm respectively. In transect III the compaction is present in Horizon A at 8 cm. The average litter layer in this Horizon is approximately 0.5 cm.

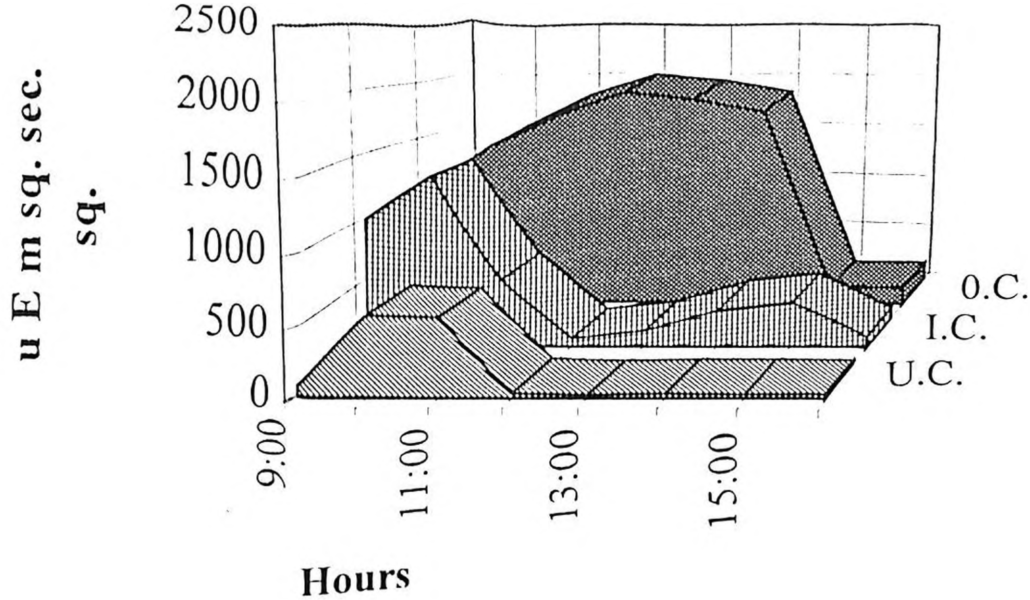
In Naivasha, compaction increases from zone A to B to C and this compacted layer makes it unfavorable for root development and penetration. The moisture retention properties also decrease across this gradient which results in low moisture availability away from the tree. The litter layer also decreased in depth from the base of the tree limiting its mulching effect.

4.3.1.2 SOLAR RADIATION LEVELS IN AREAS A, B & C.

The presence of the tree has a profound effect on the level of solar radiation reaching the cholla fence. The results of a two-way ANOVA, where solar radiation levels are tested against different times at the three canopy levels show a significant difference. The results are shown in figure 20.

In zone A, the heavy shade results in growth typical to low light intensity situations with thin, long spindly stems. The soil was not limiting in compactness and the moisture retention characteristics make it ideal for root development. On unearthing the litter layer a mass of cactus roots was observed intertwined within the humus layer. This litter layer would be an ideal source of moisture and nutrients and acts as a

Figure 20. Solar radiation levels in the three areas A, B and C under the Yellow Fever tree canopy at Naivasha.



LEGEND

U.C. - Solar radiation under canopy
I.C. - Solar radiation at Intermediate canopy
O.C. - Solar radiation outside the canopy

Results of ANOVA for testing differences in solar radiation levels:

SV	SSQ	DF	MS	F
Bet. Treat.	4.57 E -06	2	2.3 E -06	6.14
Bet. Blocks	2172173	7	313310.4	
Error	5.2	14	0.000037	
TOTAL	11956654	23		

F significant at .05; critical F=3.74

Therefore we can conclude that the levels of solar radiation amongst the three levels of canopy are significantly different.

mulch, which maintains a suitable soil structure, through the addition of organic matter.

In zone B the shade is intermediate and high light intensity is removed during the hottest time of the day from 10:00 hrs onwards. In this zone compaction is present but there is the presence of a litter layer and low light intensity when compared to the open zone. These factors result in a suitable moisture retention capacity and good growth.

In zone C full solar radiation from the sun is evident till 14:00 hrs after which it is significantly reduced. The cholla in zone C is subject to constant water stress due to a high level of soil compaction, poor moisture retention and the absence of a suitable litter layer. This makes growth possible only during periods of high moisture while in zone A and B the growing period will be extended over a longer period of time. This longer growing period is due to the availability of moisture stored in the litter layer. Evaporation is reduced through the mulching properties of the litter layer. The presence of shade also prevents the dehydrating effects of evaporation from the soil during the hottest period of the day.

4.3.1.3 MOISTURE RETENTION CHARACTERISTICS OF SOIL IN AREAS-A, B & C.

According to table 4 the results are as follows:

Table 4. Moisture retention characteristics of the three areas A, B and C at the Naivasha site

Values of available moisture storage in the soil profile for stored and available moisture for the Naivasha site, Nakuru district.

			AVAILABLE MOISTURE (pF 2.3 - pF 4.2)	
ZONES	SOIL DEPTH (cm.)	ROOTING DEPTH (cm.)	STORED (mm.)	AVAILABLE (mm.)
A	78	78	62.8	62.8
B	67	24	87.1	24.7
C	64	10	48.0	7.5

LEGEND:
Zone A - under canopy, Zone B - Intermediate canopy and Zone C - Outside canopy.

AREA-A

The available moisture storage in the soil profile A at 0-78 cm is 62.8 mm. The field investigations show that the cactus roots extend up to 78 cm. The moisture that is stored in this soil profile would be available to the cactus roots.

AREA-B

In this area the available moisture storage in the soil profile B at 0-67 cm is 87.1 mm. The cactus roots in this profile only extend up to 24 cm therefore only 24.7 mm of the moisture is stored in the rooted zone and is available to the cactus plants. The remaining 62.4 mm is beyond the reach of the cactus roots.

AREA-C

The available soil moisture storage in the soil profile C at 0-64 cm is 48 mm. The cactus roots in this profile only extend to 10 cm. Therefore only 7.5 mm of the moisture is stored in the rooting zone and is available to the cactus roots.

The results in table 4 show that the moisture retention capacity decreases from areas A-B-C. The cactus growing in areas A and B have 62.8 and 24.7 mm of available moisture in these profiles. Area C has only 7.5 mm of available moisture and this would limit growth as the water availability would be less when compared to areas A and B. This water stress would decrease the growth rate when compared to areas A and B which would benefit from a longer growing season when compared to the growth in area C.

The inoculation of *Opuntia* species with the nitrogen fixing bacterium *Azospirillum* results in nitrogen increase and promotes root development. This is very important as it can lead to an improved uptake of nutrients and improve the moisture status of the plant (Caballero-Mellado, 19??). This inoculation can improve the growth rate of the cactus and result in a fence that grows faster.

4.3.2 OL AIRO NYIRO RANCH, NGARUA DIVISION: LAIKIPIA DISTRICT

4.3.2.1 NUTRIENT ANALYSIS & DESCRIPTION OF SOIL PROFILE PITS

Tables 5-a and 5-b show the chemical and nutrient analysis of the Laikipia area soils collected from area A (good growth), area B (medium growth) and area C (poor growth). A control sample was taken from a nearby adjoining grassland that was devoid of cactus.

Table 5-a shows results of horizon A and table 5-b of horizon B. Comparing the pH levels in area A, B and C the levels are significantly different but do not show any pattern between the three areas of growth. The pH levels are acidic in area A and B when compared to area C which is less acidic than areas B and C.

The basic nutrients sodium, magnesium, manganese and phosphorus do not show any significant differences between the three areas A, B and C in both horizons A and B. The differences between A, B and C were slight but not significant. The organic carbon and nitrogen levels do not show any significant differences between the three areas of growth.

Table 5-a and 5-b. Results of nutrient analysis at the Laikipia site

Table 5-a:

HORIZON A	CONTROL	AREA - A GOOD GROWTH	AREA - B MEDIUM GROWTH	AREA - C POOR GROWTH
pH	6.9	5.03	4.80	5.13
SODIUM m.e.%	0.71	0.28	0.28	0.41
POTASSIUM m.e.%	1.36	0.34	0.27	0.65
CALCIUM m.e.%	1.73	1.27	1.43	1.73
MAGNESIUM m.e.%	3.4	0.77	0.43	1.03
MANGANESE m.e.%	2.47	2.3	2.02	2.22
PHOSPHORUS ppm	18.0	26.0	31.67	24.0
NITROGEN %	0.11	0.10	0.14	0.11
CARBON %	1.2	1.5	1.85	1.40

Table 5-b:

HORIZON B	AREA - A	AREA - B	AREA - C
pH	5.73	5.76	5.67
SODIUM m.e.%	0.32	0.45	0.37
POTASSIUM m.e.%	0.37	0.71	0.56
CALCIUM m.e.%	1.37	1.60	1.67
MAGNESIUM m.e.%	1.5	1.5	2.7
MANGANESE m.e.%	1.87	1.59	1.54
PHOSPHORUS ppm	12.67	26.0	34.67
NITROGEN %	0.08	0.14	0.10
CARBON %	1.05	1.46	1.03

Table 6. The results of the Analysis of Variance (ANOVA) for the three areas of growth at the Laikipia site

HORIZON - A

pH

SV	SS	DF	MS	F
TSS	0.2	8		
GSS	0.2	2	0.1	
ESS	0.1	6	0	6.9

Sodium

SV	SS	DF	MS	F
TSS	0.1	8		
GSS	0	2	0	
ESS	0.1	6	0	1.9

Potassium

SV	SS	DF	MS	F
TSS	0.3	8		
GSS	0.2	2	0.2	
ESS	0.1	6	0	11.6

Calcium

SV	SS	DF	MS	F
TSS	0.4	8		
GSS	0.3	2	0.2	
ESS	0	6	0	23

Magnesium

SV	SS	DF	MS	F
TSS	1	8		
GSS	0.6	2	0.3	
ESS	0.5	6	0.1	3.3

Manganese

SV	SS	DF	MS	F
TSS	0.5	8		
GSS	0.1	2	0.1	
ESS	0.3	6	0.1	1.2

Phosphorus

SV	SS	DF	MS	F
TSS	1519.6	8		
GSS	94.9	2	47.4	
ESS	1424.7	6	237.4	0.2

Nitrogen

SV	SS	DF	MS	F
TSS	0	8		
GSS	0	2	0	
ESS	0	6	0	3

Carbon

SV	SS	DF	MS	F
TSS	0.4	8		
GSS	0.3	2	0.2	
ESS	0.1	6	0	11.1

HORIZON - B

pH

SV	SS	DF	MS	F
TSS	0.9	8		
GSS	0	2	0	
ESS	0.8	6	0.1	0

Sodium

SV	SS	DF	MS	F
TSS	0.1	8		
GSS	0	2	0	
ESS	0.1	6	0	1.1

Potassium

SV	SS	DF	MS	F
TSS	0.4	8		
GSS	0.2	2	0.1	
ESS	0.2	6	0	2.3

Calcium

SV	SS	DF	MS	F
TSS	0.2	8		
GSS	0.1	2	0.1	
ESS	0.1	6	0	8

Magnesium

SV	SS	DF	MS	F
TSS	22.8	8		
GSS	2.9	2	1.4	
ESS	19.9	6	3.3	0.4

Manganese

SV	SS	DF	MS	F
TSS	1.1	8		
GSS	0.2	2	0.1	
ESS	0.9	6	0.1	0.6

Phosphorus

SV	SS	DF	MS	F
TSS	2718.2	8		
GSS	736.9	2	368.4	
ESS	1981.3	6	330.2	1.1

Nitrogen

SV	SS	DF	MS	F
TSS	0	8		
GSS	0	2	0	
ESS	0	6	0	1.1

Carbon

SV	SS	DF	MS	F
TSS	0	8		
GSS	0	2	0	
ESS	0	6	0	7

LEGEND:-
SV - Source of Variation
TSS - Total
GSS - Group
ESS - Error

SS - Sum of Squares
DF - Degrees of Freedom
MS - Mean Squares
Critical Value - 5.1400

The potassium and calcium levels show a significant difference between the three areas A, B and C. The calcium levels increase from A-B-C, with a level of 1.27 m.e.% in area A, 1.43 m.e.% in area B and 1.73 m.e.% in area C.

Comparing the control with areas A, B and C, the pH in the control (6.9) was alkaline when compared to the three areas with the cactus which was acidic (5.0). The level of nutrients was found to be adequate in the three areas A, B and C. Compared to the control sample from an adjoining area there was a decrease in nutrients underneath the cactus fence. However, the pH levels and nutrient levels did not significantly affect the growth of the cactus. This is evidently due to the adequate and balanced levels of nutrients available. The ANOVA results are shown in table 6.

4.3.2.2 SOIL PHYSICAL PROPERTIES

In transect I, a total of nine soil pits were excavated with three replicates each in the three zones of good, medium and poor growth. The results are shown in table 7.

GOOD GROWTH

The average height of the cactus in this zone is 2.17 m with an excellent efficacy and it forms an impenetrable barrier. The soil depth ranges of 0.70 m to 1.0 m and concretions are present at 47 cm and 70 cm respectively. These concretions are non-coherent and the slope is 3%.

The potassium and calcium levels show a significant difference between the three areas A, B and C. The calcium levels increase from A-B-C, with a level of 1.27 m.e.% in area A, 1.43 m.e.% in area B and 1.73 m.e.% in area C.

Comparing the control with areas A, B and C, the pH in the control (6.9) was alkaline when compared to the three areas with the cactus which was acidic (5.0). The level of nutrients was found to be adequate in the three areas A, B and C. Compared to the control sample from an adjoining area there was a decrease in nutrients underneath the cactus fence. However, the pH levels and nutrient levels did not significantly affect the growth of the cactus. This is evidently due to the adequate and balanced levels of nutrients available. The ANOVA results are shown in table 6.

4.3.2.2 SOIL PHYSICAL PROPERTIES

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GOOD GROWTH

The average height of the cactus in this zone is 2.17 m with an excellent efficacy and it forms an impenetrable barrier. The soil depth ranges of 0.70 m to 1.0 m and concretions are present at 47 cm and 70 cm respectively. These concretions are non-coherent and the slope is 3%.

Table 7. The physical properties of the soil profile pits at Laikipia

TRANSECT	GROWTH	SITE	SLOPE (%)	SOIL DEPTH (cm)	DEPTH OF CONCRETIONS (cm)	HEIGHT OF CACTUS (m)
I	GOOD	1-B	3 %	100 cm	47 cm (non-coherent)	2.5 m
	GOOD	1-C	3 %	100 cm	70 cm (non-coherent)	2.0 m
	GOOD	1-A	3 %	70 cm	none	2.0 m
	MEDIUM	2-D	2 %	63 cm	37 cm	1.8 m
	MEDIUM	2-E	2 %	63 cm	37 cm	1.6 m
	MEDIUM	2-F	2 %	63 cm	37 cm	1.6 m
	POOR	3-G	1 %	67 cm	21 cm	1.1 m
	POOR	3-H	1 %	67 cm	21 cm	1.1 m
	POOR	3-I	1 %	67 cm	21 cm	1.0 m
II	VERY POOR	4-J	4 %	5 cm	over hard rock	0.89 m
	VERY POOR	4-K	4 %	5 cm	over hard rock	0.45 m
	VERY POOR	4-M	6 %	17 cm	over hard rock	0.80 m
	VERY POOR	4-N	6 %	3 cm	over hard rock	0.57 m

MEDIUM GROWTH

The average height of the cholla fence is 1.67 m but it still has a good efficacy and forms a suitable barrier. The soil depth is in the region of 63 cm though concretions are present at 37 cm and the slope is 2%.

POOR GROWTH

The average height of the cholla fence is 1.07 m and the soil depth is 67 cm with concretions present at 21 cm. The cholla shows signs of necrosis and gaps are present in the fence and this zone would be unsuitable as a barrier. The slope is 1%.

TRANSECT II

Two sites were chosen along a ridge leading into a valley bottom and they were numbered site 4 and 5. In both these areas the cactus growth was very poor with heights ranging from 0.45 m, 0.57 m, 0.80 m and 0.89 m. The soil depth was shallow with depths ranging from 3 cm, 5 cm and 17 cm. This shallow soil was over a bed of continuous hard rock. The slope in zones 4 and 5 is 4% and 6% respectively.

In transect I in Laikipia the growth ranges from good, medium to poor. The presence of concretions and a shallow soil depth limit the depth of root penetration and development. The moisture retention characteristics of the soil profiles from the region of good to medium show that moisture retention is limiting. The cactus in the region of good growth will enjoy a longer growing season compared to the cactus in the medium and poor zones of growth.

In transect II very poor growth results from an extremely shallow soil depth of 3 cm, 5 cm and 17 cm and growth occurs only when moisture is readily available. In this area there would hardly be any moisture retention in the shallow soil and growth would be limited to the wet season only.

4.3.2.3 MOISTURE RETENTION CHARACTERISTICS OF SOIL IN AREAS OF GOOD AND MEDIUM GROWTH

After the nutrient and physical analysis of the soil profiles a further test was conducted to investigate the moisture retention properties of the soil. Moisture retention by the soil is important for the growth of a live fence as poor soil structure and moisture retention properties result in the cactus exhibiting xerophytic properties. According to table 8 the results are as follows:-

ZONE A

In the region of good growth the available moisture storage in the soil profile at 0-100 cm is 51.0 mm. The roots of the cactus fence extend up to 52 cm and only 26.5 mm is available to the cactus roots. The results are shown in table 8.

ZONE B

In the region of medium growth the available moisture storage in the soil profile at 0-63 cm is 30.9 mm. The cactus roots in this zone extend up to 30 cm and only 14.7 mm

Table 8. **Moisture retention characteristics of the Laikipia site for good and medium growth**

Values of available moisture storage in the soil profile for stored and available moisture for the Ol Airo Nyiro Ranch site, Laikipia district.

			AVAILABLE MOISTURE (pF 2.3 - pF 4.2)	
ZONES	**SOIL DEPTH (cm.)**	**ROOTING DEPTH (cm.)**	***STORED* (mm.)**	**AVAILABLE (mm.)**
A	63	30	30.9	14.7
B	100	52	51.0	26.5

LEGEND:
Zone A - Medium Growth / Zone B - Good Growth

of the moisture stored in the rooting zone is available to the cactus plants. The remaining 16.2 mm is beyond the reach of the cactus roots.

In areas where moisture and soil structure are limiting the cactus will only grow satisfactory when excess moisture is available otherwise it will be dormant during the dry periods.

4.4 GERMINATION OF CHOLLA SEEDS

According to the results shown in table 9 there was no germination of the cholla seeds kept for a period of over five months. The seeds that were placed in the moist treatments developed a fungus growth in both light and dark conditions.

It was evident from this experiment that seeds do not play an important role in reproduction of the cholla cactus. Unlike other species of cactus such as the prickly pear (*Opuntia ficus-indica*) that has fertile seeds and spreads as a pest. The fruit of the prickly pear is eaten by both man and animals and is responsible for dispersal through the feaces of animals.

The cholla fruit is not palatable and will remain on the plant for up to 5 years. The fruit will grow through normal vegetative reproduction if planted and the seeds play no role in germination. Cholla fences spread through pieces or joints falling of which take root and grow into a new plant. It is evident from various fences that were observed that cholla does not spread far and wide and is usually contained within an area.

Table 9. Germination of cholla seeds under various treatments

TREATMENTS CONDUCTED ON CHOLLA SEEDS TO DETERMINE THEIR GERMINATION:

THIS TEST WAS DONE IN DARK CONDITIONS		THIS TEST WAS DONE IN LIGHT CONDITIONS	
TREATMENT	**GERMINATION**	**TREATMENT**	**GERMINATION**
MOIST	NO	MOIST	NO
DRY (CONTROL)	NO	DRY (CONTROL)	NO
SAND PAPER	NO	SAND PAPER	NO

Note: a). Seeds that were placed in moist conditions developed a fungus growth in both the cases: light and dark.

5.0 GENERAL DISCUSSION, RECOMMENDATIONS AND CONCLUSIONS

5.1 GENERAL DISCUSSION

The African continent has lost approximately 65% of wildlife habitat out of a total of 33,275, 906 km^2. This loss has been through logging and conversion to agriculture (Kiss, 1990). This has resulted in range compression of Africa's wildlife and has resulted in increased human-wildlife conflicts as man encroaches remaining wildlife strongholds.

Kenya has an annual population growth rate of 3.3% which will increase from 23.4 million in 1991 to an estimated 35 million people by the year 2000 (UNFPA, 1991). This population increase and resulting conflict with wildlife will require increased management of the existing wildlife populations.

In Africa conventional methods of controlling wildlife have been the installation and erection of fences. These fences have been used to contain wildlife in parks, isolate livestock from wildlife and protect man's agricultural activities from the raiding activities of wildlife.

Traditional methods of erecting bush barriers are to be discouraged. These lead to increased deforestation of an area and result in degradation of the habitat through loss of vegetation cover. Conventional methods of fencing using wires, posts and electric fences are expensive to construct and have high recurrent costs. Wire fences can be detrimental to wildlife populations as the wire can be used to construct snares. In the

Chirisa Safari Area of Zimbabwe, 2000 snares were recovered in a period of 6 months in 1979 and they were made from wire stolen from a tsetse control game fence (Taylor & Martin, 1987).

The high cost of erecting wire fences was mentioned by the Director-General of the Royal National Parks of Kenya in 1952, that live fencing would be the only long-term solution to fencing wildlife areas (Royal Nat. Parks. Ann. Rep., 1952). During 1991/92 the main constraint for constructing fences was the lack of funds and this had a negative effect on support for wildlife conservation from the general populace (K.W.S. Ann. Rep., 1991/92).

In Kenya fencing is considered important on the following four issues:

a) Conservation

- To protect important ecosystems to maintain biodiversity and water catchment areas.

b) Agriculture

- To stop damage to farm and ranch infrastructures and prevent crop raiding to stabilize food production.

c) Research

- To be used as a management tool in wildlife conservation to protect important areas for research.

d) Social/Political Aspect

- Imposing wire fences are considered aesthetically unpleasant and impose as a barrier between the people and wildlife. This may result in negative attitudes towards wildlife in general (Munai, 1991).

According to the K.W.S. Annex 6 (1990), human-wildlife conflicts are to be controlled through fencing so that the wildlife assumes a positive role in the lives of rural communities. This will be through fencing of certain National Parks and forest reserves to control wildlife movements. The erection of wildlife barriers around private property with abundant wildlife will also be undertaken, such as in Laikipia district. In areas where fencing is found to be ineffective in halting crop raiding the animals responsible can be controlled through shooting, trapping or other deterrence.

Traditional game barriers have been used against wildlife over a long period of time and have given way to more conventional and sophisticated wildlife barriers. Traditional game barriers and methods of driving game are simple and ingenious. The conventional methods include stone walls, wire fences (*both plain and electrified*) and game ditches. Conventional methods of controlling wildlife have variable success rates and costs of construction and maintenance are generally high. These types of wildlife barriers require a high standard of construction and require skilled supervision and maintenance. In Kenya ambitious fencing projects are normally funded from overseas grants and loans. This reliance on foreign aid to control wildlife depredation is risky and more economical alternatives that can be managed by the affected populations can be beneficial in achieving self-sustainability in controlling wildlife depredations.

Live fencing can be effectively used as a wildlife barrier as it is cheaper to plant and maintain when compared to other methods. The cactus (*Opuntia exaltata*) otherwise known as cholla has proved to be a suitable 'hard- edge' live barrier in controlling wildlife depredations.

Live fences used as wildlife barriers are economical and cost-effective to plant and maintain. Live fencing is a useful agro-forestry technique that results in a fence that is opaque to wildlife and the success of the cholla fence is as good as the management that goes into planting and maintenance the fence.

Cholla was introduced into Naivasha, Kenya as a barrier and the use has spread throughout most of the Rift Valley province of Kenya. The excellent suitability of this cactus as a wildlife barrier has been the main reason for its dispersal within Kenya. The two main districts where cholla is extensively used as barriers are Nakuru and Laikipia.

To be an effective barrier, cholla has to grow quickly and attain a suitable height of over 1.5-2 m in the least possible time. The suitable growth of cholla is affected by a poor physical soil structure rather than the nutrient status of the soil. A poor soil structure is caused by compaction and the presence of plinthite which inhibit proper root formation and results in poor moisture retention. These factors will result in a slow growth with poor efficacy and hence an unsuitable wildlife barrier. The growth of cholla fences under trees with a minimum light level of approximately 1500 uE $m^{-1} sec^{-2}$ is considered beneficial for growth. The soil under the tree stores moisture for a longer duration as the litter layer acts as a mulch. Yellow fever trees (*Acacia xanthophloea)* provide a much deeper shade which results in poorer growth at the base of the tree.

The Savannah tree (*Maerua triphylla*) is a common tree attaining a height of 5-7.5 m with a compact canopy (Elfers *et al.*, 1964). In the Naivasha area of Nakuru district, this tree is common and existing cholla fences growing adjacent to this tree have a good efficacy and the shade is not as deep as the large Yellow Fever trees. This tree should be grown along intended cholla fence lines.

The *Opuntia* species are very versatile members of the Cactaceae family. They have normally been branded as pests responsible for consuming large tracts of land. The species *Opuntia ficus-indica* has many uses such as a livestock and wildlife feed, manufacture of jam and tuna fruit production. The species *Opuntia engelmannii* is used as an emergency livestock feed after the spines are burned off with a propane torch. The young tender regrowth is cooked as a vegetable with fish dishes during Lent (Gathaara, Felker & Land, 1989).

5.2 RECOMMENDATIONS

To erect or plant a wildlife barrier the following approach should be taken:

PLANNING

During the planning stage, the main reasons for planting a barrier are reviewed:

a) What specific use is the barrier being planted for ?

- To protect crops
- As a wildlife barrier.
- As a fire break barrier
- To protect dam walls from erosion by wildlife

b) If cholla is being used as a wildlife barrier:

- What species of wildlife will the cholla be used against?
- Is the barrier function going to be on a year-round or seasonal basis?

- There might be need for a temporary barrier until the cholla is established and what choices are available?
- Jumping species can be deterred by planting the cholla fence in a wide strip approximately 3-4 m wide.

c) The intended fence line may be along a common boundary and if so is there a consensus among neighbors on the planned fence line? In Laikipia district there was a boundary dispute between a ranch and the surrounding communities and this resulted in constant destruction of the cholla fence whenever it was planted.

d). The use of natural barriers such as escarpments and rivers can be used as they reduce cost of the initial barrier.

HARVESTING

a) A suitable site should be located where cholla exists and can be harvested to provide material for planting.

b) In areas where barriers are to be planted, cholla cuttings can be used to form nurseries which can provide planting stock.

c) During harvesting tractors with trailers are used to transport cuttings if distances are less then 55 km. If distances are greater then 55 km a tipper truck would be more useful in transporting cuttings. A tipper truck is more useful as cuttings can be easily off loaded in various places along the intended planting line.

d) Harvesting is done by using grass slashers and pangas to cut the joints off the main stems. These stems are raked into piles which are loaded onto a vehicle using wide-mouth shovels.

PLANTING

a) Planting should be done during the dry season as fungus infections can account for major losses of cuttings. Over 80% of an experimental plot planted at Taveta, Taita Taveta district was lost due to infections resulting from unseasonal rain during the planting period.

b) The main causes of poor fence development are due to prevailing soil and climatic conditions.

- Soil auger samples should be taken along the intended fence line to determine the soils physical structure. Soil profile pits can also be excavated as they can provide a true picture of the soil's physical characteristics. Ideally the soil depth should not be less then 75 cm and without the presence of gravel's or compacted layers.
- The main reasons for patchy growth in cactuses is due to varying soil conditions, failure of some stems to grow and the presence of trails or paths passing through a cholla fence. To create a suitable matrix for root development and formation, a variation of the Mazibuko 'fertility' trench can be used. In this method a trench is excavated 2 m wide and 1 m deep and filled with alternating layers of soil and organic wastes. The addition of organic matter results in a soil with an improved structure which acts as a sponge to retain moisture (Dalzell *et al.*, 1987).

This method can be adopted for planting cholla in arid areas such as Laikipia district where growth is slow due to inadequate moisture. In areas such as Naivasha, Nakuru District cholla planted along lucerne fields where overhead irrigation is practiced, results in a fence that grows with a luxurious efficacy due to water and fertilizer runoff. *Opuntia* species react favorably to manure and fertilizer treatments.

The application of nitrogen and phosphorus on experimental plots of Prickly Pear *Opuntia ficus-indica* in Texas, showed a 4-5 fold increase in biomass and nutritive value (Gonzalez & Everitt, 19??). *Opuntia* species have also been fertilized with goat manure to increase biomass and fruit productivity (Gathaara *et al.*, 1989).

c) The appropriate method of planting cholla should be as follows:

- Dig a trench approximately 75 cm deep and 1.5-2 m wide along the intended planting line. This method would be very important in areas with soils exhibiting vertisol properties e.g. black cotton soils where the performance of cholla is poor.
- This trench should be filled with a mixture of manure (cow, goat, sheep or camel), compost (vegetation cuttings, farm wastes) and the excavated soil. This will result in a soil with a suitable structure, nutrients and superior moisture retention capacity.
- The land surrounding this trench should be gently sloping towards the trench to act as a microcatchment and to channel any rainfall into the trench.
- The cuttings should then be laid horizontally on the surface of this prepared trench.

POST-PLANTING MANAGEMENT

The results from the study show that the following management plans are necessary to maintain a cholla barrier:

- After planting the cholla some control kept over weeds smothering the cholla. A dense growth of grasses and weeds can slow the growth rate considerably and these can be easily controlled by weeding during the first two years of growth. Weeding is carried out by large ranches who have fences over 2 km long as it influences the growth rate.

- During the first two years, cuttings of cholla should be added in places where they have failed to take root. This encourages more even growth and does not result in gaps forming in the fence. If gaps are persistently formed then the fence should be allowed to develop and after it has attained a suitable height the gap can be closed with posts and wire.
- The fence should be pruned once a year using a grass slasher to trim the sides and the joints can either be thrown back into the fence or used in other places to fill gaps. Larger ranches that have access to graders used in road construction, use the large blade to trim the fence and push in any new growth into the fence. The best way to get rid of unwanted cuttings is to dispose them in a large pit in which waste vegetation is regularly burned.
- Baboons (*Papio* species) are notorious for feeding off the stems of cholla joints. They will carefully pull off the thorns and eat the succulent stems. The planted beds of cholla can be covered by thorny bushes or alternative measures such as scaring or shooting can be used.

5.3 CONCLUSIONS

The following conclusions can be drawn from the results and discussions of this study:-

1. Wildlife barriers are used to restrict the movements of game animals and can be broadly divided into traditional and conventional methods. The traditional methods have evolved into more conventional types. The success of these barriers

is marginal and high construction and recurrent costs make them an expensive option.

2. The use of live fences especially the cholla cactus (*Opuntia exaltata*) which is grown mainly in Nakuru and Laikipia districts where its use is increasing. It is cost effective and requires little management once it is established. It has been found to be suitable for a variety of wildlife such as gazelle and antelope species, zebra, buffalo, warthog, kongoni, bush pigs, porcupines, hippopotami, waterbuck and elephants.

3. Gaps and poor growth of cholla fences are due to physical factors such as soil compaction, shallow depth and lack of available moisture. These limitations can be reduced by digging a trench and filling with a suitable matrix to provide an optimum environment for growth. In the early stages of growth, cholla cactus beds should be protected until they are established.

4. This cactus has potential as a wildlife barrier for semi-arid to arid national parks and reserves and can also provide a cost effective barrier when compared to high tensile and electric fences. It can also serve the needs of small scale farmers who are the main victims of human-wildlife conflicts.

REFERENCES:

Ahn, P.M. & Geiger, L.C. (1987) Soils of Laikipia District. Ministry of Agriculture. National Agricultural Laboratories. Kenya Soil Survey. Reconnaissance Soil Survey Report.

Allaway, J.D. (1979) Elephants and their Interactions with People in the Tana River Region of Kenya. Unpublished Ph.D. Thesis, Cornell University. 390 pages.

Behrens, H.P.H. (1947) Bush-Fence Barrier. AFRICAN WILD LIFE-Official Journal of the Wildlife Protection Society of South-Africa, Vol. 1, No. 2. Pg 15-19.

Bell, R.H.V. & McShane-Caluzi, E. & (1984) Conservation & Wildlife Management in Africa. The Proceedings of a Workshop Organized at Kasungu National Park, Malawi. Produced through Office of Training & Program Support Forestry & Natural Resources Sector, U.S. Peace Corps. 646 Pages.

Bothma, J. du P. (1989) Game Ranch Management. Published by J.L. van chaik (pty) Ltd., Pretoria, South-Africa and Printed by National Book Printers Goodwood, Cape, South-Africa. Pg 42-59.

Bonner, J. & Varner, J.E. (1976) Plant Biochemistry. Third Edition. Academic Press, New-York.

Bremner, J.M. (1965) Total Nitrogen: Methods of Soil Analysis. Ibid: 891-904.

Britton, N. L. & Rose, (1963) The Cactaceae: Descriptions and Illustrations of Plants of the Cactus Family. Vol. I & II. Dover publications, Inc., New-York. Pg 76-77.

Brown, D.W.J. (1968) Game Control in Kenya. East African Agriculture & Forestry Journal, Special Issue. Pg 209-212.

Budowski, G. (1987) Living Fences in Tropical America: A Widespread Agroforestry Practice. In H. l. Gholz, ed. Agroforestry: Realities, Possibilities and Potentials. Dordrecht, The Netherlands: Martinus Nijhoff, Pg 169-178.

Caballero-Mellado, J. (19??) Potential Use of the Bacteria Azospirillum in Association with Prickly Pear Cactus. Departamento de Investigaciones Microbiologicas, Instituto de Clencias; Universidad Autonoma de Peubla. Pg 14-20.

Chira, R.M. (1993) Soysambu Wildlife and Livestock Census, Scientific Service Research Station, Kenya Wildlife Service Headquarters, Nairobi,

Clark, K. (1968) The Reconciliation of Wildlife Conservation with Forestry. East African Agricultural & Forestry Journal. Special Issue. Pg 213-216.

Corfield, T. (1993) The Wilderness Guardian. Published by Longman Kenya and printed by Kul Graphics Ltd. Pg 626-633.

Dalzell, H.W., Biddlestone, A.J., Gray, K.R. & Thurairajaru, K. (1987) SOIL MANAGEMENT: Compost Production and Use in Tropical and Sub-tropical Environments. FAO Soils Bulletin No 56. Food & Agriculture Organization of the United Nations.

De Beer, H. (1986) Weeds: Farming in South- Africa. A- 14.

Elfers, J., Graham, R. A. & Dewolf, G. P. (1964) CAPPARACEAE: FLORA OF TROPICAL EAST AFRICA. Published under the authority of the Secretary for Technical Cooperation by the Crown Agents for Overseas Governments and Administrations. Pg 43-45.

Forest Department Annual Report (1934) Nairobi, Kenya.

Forest Department Annual Report (1957-58) Nairobi, Kenya.

Forest Department Annual Report (1961) Nairobi, Kenya.

Gallagher Power Fence Systems. (1992) 9th. International Power Fence Manual, New-Zealand.

Game Department Annual Report (1926) Nairobi, Kenya.

Game Department Annual Report (1931) Nairobi, Kenya.

Game Department Annual Report (1961) Nairobi, Kenya.

Gaathaara, G.N., Felker, P. & Land, M. (1989) Influence of Nitrogen and Phosphorus on *Opuntia engelmanii* tissue N and P concentrations, Biomass Production and fruit Yields. Journal of Arid Environments (16): 337-346.

Gonzalez, C.L. & Everitt, J.H. Fertilizer Effects on the Quality and Production of Prickly Pear Cactus and its Wildlife Value. USDA-ARS, Weslaco, Texas, U.S.A. Pg 3-10.

Hells Gate/Mt. Longonot Management Plan (1991-96). Kenya Wildlife Service, Planning Department. May, 1992.

Hoare, R.E. (1992 a) Wildlife Fencing as a Management Tool for Protected Areas in Africa. IUCN Parks 3(2): Pg 35-39.

Hoare, R.E. (1992 b) Fencing as a Management Tool in Zimbabwe's Wildlife Programmes. Proceedings of a Seminar-Department of National Parks and Wildlife Management. 61 pages.

Holloway, C.W. (1960) The Effect of Big Game on Forest Management. A.C.F. Kenya. Forest Department.

Hunt, M.A. (1968) Flora of Tropical East Africa: CACTACEAE. Published under the Authority of the Minister for Overseas Development by the Crown Agents for Overseas Governments and Administrations. Pg 1-3.

Ivens, G.W. (19??) East African Weeds and their Control. Oxford University Press. Nairobi, Lusaka, Addis Ababa.

Kamweya, A.M. (1986) Seasonal Changes in Bird Population Densities with Special Emphasis on Rice Depredation and the Side Effects of *Quelea* Control Measures on Non-Target Birds at Mwea Irrigation Scheme, Kenya. Unpublished MSc. Thesis, University of Nairobi.

Kenya Wildlife Service (1990) Policy Framework & Development Program. 1991-96. Annex 6. Community Conservation & Wildlife Management Outside Parks and Reserves. Pg 85-164.

Kenya Wildlife Service. Annual Report 1991/92.

Kiss, A. (1990) Living with Wildlife: Wildlife Resource Management with Local Participation in Africa. World Bank Technical Paper, Number 130. Africa Technical Department Series.

Kohler, T. (1986) Laikipia District Kenya: Land Use & Ownership Map, 1982. Institute of Geography, University of Berne, Switzerland.

Laikipia District Development Plan (1989-1993). Ministry of Planning & National Development. Republic of Kenya.

Mackinnon, J. & K., Child, G. & Thorsell, J. (1986) Managing Protected Areas in the Tropics. Published by IUCN, Gland, Switzerland & Cambridge, U.K. in collaboration with UNEP, Printed by Page Bros. (Norwich) Ltd. U.K. Pg 156-161.

Madany, M.H. (1991) Living Fences: Somali Farmers Adopt an Agroforestry Technology. *Agroforestry Today (January-March)*: Pg 4-7.

Marin, F. (1992) *Opuntia exaltata* Berger Propagacio'n Asexual. QUEPO. Vol. 6.

Munai, J.R.A. (1991) Community Wildlife Service, Report on the Workshop on Fencing In Relation to Community Conservation & Wildlife Management Outside Parks & Reserves. Naro Moru River Lodge. Naro Moru, 23-25th. October.

Nakuru District Development Plan (1989-1993). Ministry of Planning & National Development. Republic of Kenya.

Ngure, N. (1992) History and Present Status of Human-Elephant Conflicts in the Mwatate-Bura Area of Kenya. Unpublished MSc. Thesis. University of Nairobi. 162 Pages.

Olsen, R.V. (1962) Phosphorus: Methods of Soil Analysis, Amer. Soc. Agron. Madison

Peach, H. (1965) Hydrogen Ion Activity: Methods of Soil Analysis. American Society of Agronomy, 914-925, Madison.

Pertet, F. (1985) Wildlife/Livestock Interfaces on Rangelands: Depredation and Predation Problems. Proceedings of a Conference held at Taita Hills Lodge, Kenya, April 22-25. Edited by Susan MacMillan. Sponsored by Winrock International an the Kenya Government. Pg 41-46.

Pritchard, J.M. (1962) A Geography of East Africa. J.M. Dent & Sons Ltd. Pg 12-27.

Quangraoua, H. (1988) Protecting the Garden. IDRC Reports. 17(4):18-19

Robinson, W.L. & Rolan, G.G. (1984) Wildlife Ecology & Management. Published by Macmillan. Pg 308-315.

Rocheleau, D., Weber, F. & Field-Juma, A. (1988) Agroforestry in Dryland Africa. ICRAF. Ch. 6. Pg 163-179.

Royal National Parks of Kenya (1952) Annual Report. Printed by Zenith Printing Works Ltd., Nairobi, Kenya. Pg 9-11.

Shurley, E. (1959) Cacti. Printed in Great-Britain by Billing & Sons Ltd. U.K.

Siedensticker, J. (1984) Elephant Depredation In Agriculture & Forestry Projects. World Bank Technical Paper. Published by World Bank. Pg 18-31.

Taita Taveta District Development Plan 1984-1988 (1988) Ministry of Finance and Planning. Republic of Kenya. 35 pages.

Taiti, S.W. (1992) The Vegetation of Laikipia District: Kenya. Laikipia-Mt. Kenya Papers. B-2. Series B: Baseline Papers, LRP, Universities of Nairobi and Berne.

Taylor, R.D. & Martin, R.B. (1987) Effects of Veterinary Fences on Wildlife Conservation in Zimbabwe. Enviromental Management. Vol. 11(3) pp.327-334.

Teare, S.P. (1938) The Relation of Game to Agriculture. The East African Agricultural Journal. Printed and published by the Government Printer, Nairobi, Kenya Colony. Vol. IV, No.2. Pg 153-154.

Thouless, C. & Dyer, A. (1992) Radio- Tracking of Elephants in Laikipia District, Kenya. Pachyderm, No. 15. Pg 34-39.

Thouless, C. (1993) Laikipia Elephant Project: Final Report in collaboration with

Kenya Wildlife Service, Worldwide Fund for Nature (WWF), Zoological Society of London and Gallmann Memorial Foundation.

Thompson, A.D. & Dodson, R.G. (1963) Geology of the Naivasha Area. Ministry of Commerce & Industry, Geological Survey of Kenya, Report No. 55, Government Printers, Kenya.

Tucker, T. (1990) Barriers to Prevent Incursions by Elephants into the Bura and Mwatate Area of Taita Division. A Proposal. Pg 1-7.

United Nations Population Fund (1991) Kenya: Programme Review and Strategy Development Report

Vesey- Fritzgerald, D.F. (1968) An Experiment in Adapting an Electric Fence to Elephant Behavior. East African Agriculture and Forestry Journal, Special Issue. Pg 185-190.

Waweru, F.K. (1993) Basic Ecological Monitoring: Programs for Private Sanctuaries in Laikipia District. Mweiga Research Station, MRS-8, Kenya Wildlife Service, Department of Scientific Services.

Wijngaarden, W. (1981) Elephants-Trees-Grasses-Grazers. International Institute for Aerospace Survey and Earth Sciences (ITC): 159 pages.

Wildlife Protection Society of Southern Africa (1960) Fencing of the Kruger National Park. African Wildlife. Vol. 14. Pg 93-97.

Williamson, D. & J. (1984) Botswana's Fences and the Depletion of Kalahari Wildlife. Oryx Vol. 18(4). Pg 218-222.

Woodley, F.W. (1965) Game Defense Barriers. East African Wildlife Journal. Vol. 3. Pg 89-94.

APPENDIX 1

PHOTOGRAPH 1: An elephant specific electric fence, on the Laikipia plateau, damaged by elephants who broke the pole to gain access to the safety of a large-scale ranch after raiding crops in neighboring small-holder farms.

PHOTOGRAPH 2: Cholla fence growing along a ranch boundary in Laikipia district.

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PHOTOGRAPH 2: Cholla fence growing along a ranch boundary in Laikipia district.