ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES

BIOLOGICAL AND ECOLOGICAL STUDIES ON *ACACIA DREPANOLOBIUM* HARMS EX SJÖSTEDT IN BORANA ZONE OF OROMIYA REGIONAL STATE, ETHIOPIA

By
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DECLARATION

I, the under signed, declare that this dissertation is my own work and that all sources of material used for the thesis have been correctly acknowledged.

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Date June ,2003

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ABSTRACT

The biological and ecological studies of A. drepanolobium: the floristic composition in A. drepanolobium wooded grassland, soil properties, seed production, seed dispersal, soil seed bank, percent seed germination at different treatments, capacity of coppicing , and its interactions (symbiosis) with ants, insects and microbes were investigated in four A. drepanolobium wooded grassland sites in Negele Borana , Oromiya Regional State, S. Ethiopia.

The results indicated that in A. drepanolobium wooded grassland 114 plant species were identified. Of these 70.2 %, 23.7% and 6.1% were herbs, trees/shrubs and climbers respectively. More over, 33.3 % were forage species whereas 14.4% and 2.6% had socio-economic and medicinal importance respectively. Asteraceae, Fabaceae and Poaceae have constituted 36 % of the total number of species. *The number of species was found to be smaller than previous studies on non- A. drepanolobium wooded grassland of the study area. This may suggest the impact of bush encroachment by A. drepanolobium, which had a mean density* of *1798 plants/ hectare with a large number of individuals at the younger stage. The soils studied had higher proportion of clay (> 30 %) with properties that favor the growth of most plant species. An average of 2417 ± 23 (X ± SE) seed production per plant was encountered, and only 1 ± 0.4 (X ± SE) trees bore seeds in average per plot. Seeds are mainly dispersed by wind. 267 seeds (8.3 ± 2.6 seeds /m* ^{2}*) were found only at the litter layer and none in mineral soil layer. There was statistically significant difference in percent germination among treatments [*$F_{(5, 17)}$*, P < 0.05]. Fast rate and higher percent germination was achieved by scarification treatments whereas dry heat treatment (90* ^oC*) and moist heat (98* ^oC *for greater than 30 minutes) resulted in almost all mold outgrowths after a week's period. Tukey's HSD indicated that moist heat treatments didn't improve the percentage germination. High percent germination of a control experiment within week's time may suggest the absence of pronounced seed dormancy in the study species. There is no statistically significant difference among stumping treatments both in number and in height of coppice but the coppice number and height increased down to a tree height (soil surface).*

Four A. drepanolobium occupant ant species (3 Crematogaster and 1 Tetraponera species) were identified. However, a black cotton soil habitat hosted only 2 Crematogaster species. Although each tree was occupied by a single ant species, Crematogaster mimosae occupied the largest proportion (85%) of seed bearing trees. The mutualistic association of Crematogaster nigriceps is doubtful because this species sterilizes flower buds and new shoots. Two seed feeding bruchid beetles (Callosobruchus maculatus and Acanthoscelides obtectus) were identified and found to reduce the reproductive vigor of the study species by mass predation of its seeds. A. drepanolobium was found to be nodulated by slow growing rhizobia called Bradyrhizobium species. There was no statistically significant difference in nodulation status between two soils (t at 24 df = -1.22 and P=0.268). The mean nodule number and weight were
4.93 ± 0.6 and 0.00381 **±** 0.0008 *(X ± SE) in clay soils respectively. Reduction in nodulation may be due to 1) richness of clay soil in mineral elements including nitrogen 2) absence of adequate aeration 3) missing of some nutrients elements such as molybdenum and 4) Slowness of the fixer species.*

From the socio-economic view point, 50% of informants declared the importance of A. drepanolobium, and the rest expressed their hatred for its bush encroachment impacts on their surrounding. However, from the present study , it can be suggested that sterilization of flower buds and young shoots by Crematogaster nigriceps ants, low soil seed bank, seed predation by bruchid beetles and low recruitment being the limiting factors, further expansion of bush encroachment by A. drepanolobium can be managed through integrated bush management systems such as reducing cultivation of dry season grazing areas, encouraging traditional rangeland management systems and applying proper land use policy, reducing excess livestock, stumping late in rainy seasons and periodic burning though complete recovery of the previous range condition is a difficult task.

***Key words**: A. drepanolobium, bush encroachment, seed characteristics, Crematogaster, bruchid beetles.*

1. BACK GROUND AND JUSTIFICATION

Rangelands make up to 50-70 % of the world's landmass. Over 50% of the world's rangeland is arid or semi-arid (Rango *et al.,* 2002). Semi-arid ecosystems cover the majority of the land area in sub-Saharan Africa, and the majority of these areas are acacia savannas (Menault *et al*., 1985). These ecosystems have been used by people of traditional cultures for many centuries, and are currently under rapidly increasing pressure for both intensive livestock production and arid farming (Young *et al*., 1998).

Scoones (1995) classified rangeland environments into two: the one that shows classic feedback mechanisms normally assumed in mainstream range management as in equilibrium whereas, those that are highly dynamic ecosystems in which production potentials are dominated by rainfall or other external factors as non-equilibrium. Most arid and semi-arid grazing ecosystems in Africa in general, and in Ethiopia in particular, were reported not to follow equilibrium dynamics and they are characterized by high level of temporal and spatial variability in biomass production.

Overtimes, the vegetation structure of arid rangeland habitats around the world has changed dramatically; grass cover has declined and the density of woody shrubs has increased (Valone and Thornhill, 2001). The frequency and intensity of wild fire disturbances were greatly reduced over the past century; wild fires have been rapidly suppressed and domestic cattle have reduced fuel loads (Bahre, 1991; cited in Valone and Kelt, 1999). According to Herlocker (1999), fire is an important management tool for the rangelands in East Africa especially in consuming encroacher woody plant species and facilitating the growth of grasses. It was reported that fire suppression has favored the invasion of woody plants (encroachers); resulting in increased cover of community dominated by species like *Acacia drepanolobium* in Borana, thereby diminishing landscape biodiversity (Zerihun Woldu and Sileshi Nemomissa, 1998). Moreover, Drema and Havstad (2001) indicated that the fire free intervals of greater than 10 years have resulted in increased shrub establishment and growth and production of seeds, many of which are disseminated by livestock.

The driving factor behind such shift in vegetation (grassland into thick bush) is a subject of controversy (Moleele and Parkins, 1998). Elsewhere explanations for these changes are debated to be either natural or human induced, or a combination of both (Vertstratle, 1986; cited in Mollele and Parkins, 1998). For example, Pratt and Gwynne (1977) believed in the natural succession of East African rangeland to woody vegetation. On the other hand, Prins and Jeugd (1993) associated the shift with high cattle densities (anthropogenic). Similarly, most of the pastoral elders of Borana complained that the driving force for the bush encroachment to be fire ban, a man made factor (BLPDP, 1998).

According to Pickup (1996), the woody species on rangelands are problematic in that they degraded the rangeland productivity. Nevertheless, most of the woody species in the Borana rangelands are legumes such as *Acacia* species. These are well known for improving soil fertility, and have forage value (both their leaves and pods) mainly during dry periods. Nonetheless, whether the objective is to have highly productive range for livestock grazing or to enhance biodiversity, to improve ecosystem health, to sequester carbon, rangelands are extremely valuable and worth preserving in optimum condition (Rango *et al*., 2002). Thus, even to manage the range condition and the encroaching woody species like *A.*

drepanolobium, the causal mechanisms of the invasion should be addressed. This can be done when the ecology and biology of a species is well known (Cronk and Fuller, 1995).

1.1. Objectives of the Study

This study addresses the following general and specific objectives: the **general objective** is to study the biological and ecological characteristics of the encroaching bushy plant, *A. drepanolobium*, and its survival strategies in a semi-arid region of Borana, S. Ethiopia, that may serve as a source of information for decision makers to formulate possible control of bush encroachment in particular and ecosystem degradation in general.

The specific objectives of this work are to: -

- Provide the floristic list of the study area;
- Examine the effect of stumping heights and the coppicing ability of the species;
- Investigate environmental factors (some soil conditions) and to test nitrogen fixing ability of the species;
- Assess the fruit and seed production potential of *A. drepanolobium* per pod and also per tree, and population of pests on seeds if present;
- Analyze the soil seed bank of the species to provide information on its future regeneration potential;
- Test germination behavior of seeds;
- Study the symbiotic relationship between ants, insect and the plant;
- Gather information about socio-economic values of *A. drepanolobium* and examine the present status of this species and the attitude of local people towards *A. drepanolobium* and its impacts on the surrounding and

- Document relevant information that would be useful for the related researches in the future.

2. LITERATURE REVIEW

2.1. General Overview on Acacia Species Vis-à-vis Arid Regions

Acacia is a large genus of the family Leguminosae, the 3rd largest family of flowering plants, including 3 subfamilies, 630 genera and 18, 000 described species (Armstrong, 1999). Acacias are of mainly tropical and subtropical trees and shrubs (Lazier, 1985; Asfaw Hunde and Thulin, 1989), and occasionally the warm temperate regions, mostly in woodlands and wooded grasslands; a few in forests (Friis, 1992). The genus *Acacia* is distributed in Southern USA, central and southern America, through out Africa, Arabia, India, E. Asia and Southward to Australia (Armstrong, 1999). The majority of the species are distributed in Australia but about 130 occur in Africa (Asfaw Hunde and Thulin, 1989), which are restricted to dry savanna habitats where they often form the dominant vegetation and canopy cover (Coe and Beentji, 1991). Of the 130 species, 53 are limited to E. Africa while only four to SW Africa. In Ethiopia there are 49 native species (Lazier, 1985), which are almost always armed with prickles and stipular spines (Hunde and Thulin, 1989). However, about 10 exotic species are usually unarmed and they originate from Australia. The groups with phyllode (fused leaves) are also distributed throughout Australia and Pacific Islands while those with bipinnated compound leaves are distributed in Africa, America and Australia (Armstrong, 1999). Acacias grow from the sea level to 2600 m a.s.l. and adapted well to sandy dunes and protecting the environment (ILCA, 1981).

Acacia is an important genus for its many uses to man and his domestic animals. Most species produce nectars and pollen useful to honey bees, edible parts are browsed on by livestock and wild animals which provide high nitrogen although tissues of some species are toxic to animals (NAS, 1984), bark fibers are used as rope substitutes (Asfaw Hunde and Thulin, 1989), gums and resins may be used medically and eaten during drought e.g. *Acacia drepanolobium* (Coppock, 1994). The wood of many *Acacia* spp is hard and durable, and hence is used in making local ploughs, building houses and making the best grade charcoal while small branches provide firewood. These living plants are useful in stabilizing soil and improving soil fertility with their ability to fix nitrogen so that they become important trees in agroforesrtry and soil conservation (Coe and Beentji, 1991), and their attraction to animals as browse and shade (Asfaw Hunde and Thulin, 1989). Nonetheless, their palatability to livestock can vary due to changes in toxic or other compounds resulting from differences in climate, seasons or environment (NAS, 1984). For instance, in Borana goats and sheep prefer to feed on *Acacia drepanolobium* only in a cool dry season (July to September) (Coppock, 1994).

Generally, acacias are easily propagated by seeds and adapted well to cultivation. These leguminous trees are often among the first to colonize newly cleared land due to rapid growth that enable them to overcome potential competitors, adaptability to a wide range of sites and soil, and ability to coppice (NAS, 1984). According to Ryan and Bell (1989), coppicing ability after cutting has been consistent across many of the genera but varied widely within the acacias, ranging from complete failure to abundant regeneration through root suckering following cutting. For example, *A. saligna* coppices extremely well. *A. melanoxylon* is the most vigorous from one metre treatment, while others like *A. mearnsi* coppices when a 1 m cut with little or no response from the lower (Ryan and Bell, 1989). Ahmed Jemal and Florian

(1997) noted that *A. drepanolobium* decreases its coppicing ability at 0.5 m heights than the ground level. However, coppicing ability depends on age, season, felling and felling techniques (Ryan and Bell, 1989). Acacias are successful savannah vegetations because they produce substantial quantities of seeds in order to overcome the rate of infestation by pests like bruchid beetle (*Bruchidus sp.*) and many other environmental uncertainties because they accumulate large quantities of viable but dormant seeds in the soil (Sabitti and Wein, 1987).

Acacia species have two different ways of distributing their seeds, either they have thick walled, robust pods which don't split and have to be eaten by animals (mainly larger herbivorous mammals) to be spread, or they split and release their seeds so that agents like wind, water or ants can disperse the seeds (Coe and Beentji, 1989). Most seeds have hard seed coat but germinate well after simple treatments by heat or sulphuric acid (NAS, 1984), and others have soft seeds like *A. drepanolobium* (Tamene Yigezu, 1990; cited in Coppock, 1994). Dry land acacias grow in coarse, well drained soils (NAS, 1984) while others like *A. drepanolobium* often forms almost pure stands on poorly drained or water logged black vertisols (Haugen, 1992).

In much of Africa trees are disappearing as they are cut for fuel and the land is cleared for agriculture. This has spawned policies that prohibit unregulated use of land. In Ethiopia, one form of control has been a ban on burning grassland since 1970's. This is fine for degraded and densely populated areas of the country, but it has led to new resource management problem in semi-arid lowland areas by allowing populations of some undesirable trees to increase such as *Acacia drepanolobium* (Coppock, 1990). The vigor and ability of acacias to regenerate make them potential weeds. They may encroach on poorly managed pastures, becoming noxious pests (NAS, 1984). In Africa, the main encroacher species are thorn trees such as *Acacia mellifera, A. reficiens* and *Dichrostachys cinerea,* which tend to have high levels of phenolic compounds in their leaves that reduce their nutritional values.

In Borana, people once more densely occupied certain areas and livestock heavily grazed particular areas, and then were abandoned (Coppock, 1994). This resulted in rangeland degradation characterized by invasion of undesirable woody species, unpalatable forbs, and loss of grass layer and increased soil erosion (Oba, 1998). According to Ahmed Jemal and Florian (1997), the gradual invasion of shrubs and bushes/trees like *Acacia* sp. (e.g. *A. drepanolobium*) and *Commiphora spp.* into former grassy rangeland is termed as bush encroachment that reduces grazing area, and the thorny nature of encroacher species prohibits their access to livestock. The extent of encroachment by woody plants, and their effects on the herbaceous understory are extremely variable. The most dramatic increase in woody plants have occurred recently in sites with favorable soil water features such as low elevation of poorly drained-black soils of Sarite ranch predominated by *Acacia horrida* and black –vertisol depression and plains in the North central and Melbana regions of Borana where *A. drepanolobium* has increased (Coppock *et al.,* 1990).

According to the Federal Democratic Republic of Ethiopia (FDRE, 2002), increases in human and livestock populations have exerted pressure on rangeland resources resulting in bush encroachment, deforestation and soil erosion, and thus resulted in the vulnerability of pastoral community**.** These trees /shrubs may obstruct access and compete with grasses for light, water and nutrients, undermining other uses of land (Coppock, 1990). Thus, Borana elders ranked bush encroachment third, next to drought and over grazing, as a cause of range deterioration (Alemayehu Mengistu, 1998).

2.1.1. Vegetation Change and Impacts of Bush Encroachment

A number of biotic and abiotic factors as described by Skarpe (1992) can influence vegetation structure. The commonest problems in forest vegetation change are deforestation meant for agricultural expansion, logging, road construction, firewood, clearing for grazing (Garwood, 1989; Jill *et al.,* 1992), and climate (John *et al*., 1986). Similarly, climate, fire and heavy grazing have been suggested to cause changes in arid vegetations, particularly the physiognomic conversion of grasslands to woodlands (bush encroachment) (Skarpe, 1992). According to Skarpe (1996), much of the vegetation of semi-arid lands, worldwide that is managed for pastoral use has shown marked fluctuation in species composition year-to-year.

Guevara *et al*. (1999) indicated that bush encroachment and proliferation of aggressive woody plant species posed serious problems in several rangeland types of the world leading to a serious reduction in available plant species. Bush encroachment is also a process that might take place on time scale that exceeds the observation horizon of an individual rangeland expert (Dean and Macdonald, 1999). The suppressive effect of bush encroachment on existing plant species are suggested to be caused by a competition for soil water (Smith and Ruth man, 2000) such as *Acacia nilotica* (Carter, 1994) and *Prosopis glandulosa* (Gile *et al.,* 1997), and allelopathic effects that significantly retard rate of germination of seedling growth (Al-Humaid and Warrag, 1998). Copious seed production, long distance seed dispersal, formation of persistent soil seed bank (Bond *et al.,*1999) and capacity to sprout after damage (Oba, 1998) are some of the characteristics of encroacher woody species that facilitate their suppressive effect on other plants. Moreover, Ayana Angassa and Baars (2000) believed that high grazing pressure, water pond development and fire ban negatively influenced range condition in terms of botanical composition, bush encroachment, forage production and soil erosion

Thus, the presence of bushes/shrubs in arid rangeland may adversely affect the cover, frequency and richness of perennials and annuals, and results in reduction of biomass and inadequate forage production of poorer quality (Drema and Havstad, 2001). Generally, currently increase in woody plant species (bush encroachment) is threatening the biodiversity with extinction in arid regions (Cronk and Fuller, 1995).

2.2. *Acacia drepanolobium*

Acacia drepanolobium, also called black-galled acacia or whistling thorn (old thorns which have been evacuated by the ants make a whistling sound as a wind blows across the entrance hole, thus a name whistling thorn), is taxonomically classified under family Fabaceae, subfamily Mimosoideae (Dale, 1961). It is a shrub or a tree (Asfaw Hunde and Thulin, 1989), forming pure stands in seasonal swamps on poorly drained dark colored soils (vertisols) of valley bottoms, mainly at lower elevation (Dale, 1961; Haugen, 1992) whereas red rocky friable soils predominate on more sloping topographies (Young *et al.*,1998). At present, *A. drepanolobium* is seen spreading vigorously with large number of individuals in the red soils around Seminto Kebele in one of the study sites (Pers. observation).

A. drepanolobium wooded grassland in E. Africa appears as uniform, and a single tree species accounts for virtually the entire overstorey (Young *et al.,* 1997). This monoculture African myrmecophyte has L-shaped size structure (Young and Okello, 1998). It was reported that the mean density of *A. drepanolobium* to be 2263/ha with no herbivore treatment (Young *et al.*, 1998). According to the same authors, the five most abundant species, all grasses, accounted for 88% of the relative cover of understorey vegetations in Laikipia district, Kenya. The reported species were *Pennisetum stramineum, P. mezianum, Lintonia nutans, Themeda triandra and Brachiaria lanchnantha*. The woody plant species such as *Rhus sp., Balanite sp., Lippia sp.*, and *Acacia brevispica* were reported as co-occurring with *A. drepanolobium*, but at a low density.

The stipular spines are slender, straight, some basally swollen and enlarged to form small spherical galls that house ants (Hunde and Thulin, 1989). According to Young *et al.* (1997), spines are formed during periods of rainy season, which are fully lignified within few weeks and contain no living tissues. Four species of stinging ants live symbiotically in the galls of *A. drepanolobium*. However, the symbiotic relation between some of these ant species and their host acacia may not be equally beneficial to both partners (Armstrong, 1999). For instance, *Crematogaster nigriceps* (prunner ants) sterilize the trees and decimate their flower production in their ways to prevent trees from coming in contact with neighboring trees with other ant species (Stanton *et al.,* 1999).

A. drepanolobium often becomes gregarious over large areas of grassland, which is liable to flooding at altitude of 1000-1700 m. It is also found in Sudan, Somalia, Uganda, Kenya, Tanzania and E. Zaire and reported to be tolerant to alkaline soil (Asfaw Hunde and Thulin, 1989). Phenological reports indicated that *A. drepanolobium* produces fruits starting from October and November and seed fall occurs between January and April. Flowering takes place in February /March (Coppock, 1994; Pers. observation). Standing crops of fruits and seeds per tree ranged from around 500 fruits (with 3100 seeds) for trees 1 to 2 m tall in

December to over 30,000 fruits (and 18,000 seeds) for trees over 6 m tall in January (Coppock, 1994).

Some Borana elders thought that goats and camel could disperse seeds by their droppings (Ahmed Jemal and Florian, 1997**).** According to Keesing (1997), 80% of *A. drepanolobium* seeds germinate within one week. A recruitment rate of young plants is low as mortality occurs before and during the seedling stage. Within two months after a long rainy season there were 2-4 plants /m^2 which dropped to less than 1 plant/m^2 in a dry season. Once established, its seedlings grow faster (Coppock, 1994). The same author reported that a plant with a height of 4 m had a taproot of 5-6 m in length, which is less than that of *A. brevispica* that has an extensive lateral roots. Consequently, *A. drepanolobium* has significant understorey (herbaceous layer under its canopy than that of *A. brevispica*).

A. drepanolobium maintains the ecological balance in the *A. drepanolobium* dominated wooded grassland. It is browsed by mega herbivores (elephant and giraffe) and other wild life like Grant's gazelle, elands, stein buck and oryx though cattle do not feed it (Young and Okello, 1998). Small mammals like rodents consume its seeds (Keesing, 1997). Domestic animals (camels and goats) feed on it during drought (Coppock, 1994). A plant has got some socio-economic values such as charcoal production (Coppock, 1994; Ahmed and Florian, 1997), and the gum was used as a food during drought periods (Wilding, 1984; cited in Coppock, 1994), and commercial gum Arabic can be derived though it is of a low quality (Kananji, 1994**).** The galls are a great favorite of baboons in Tanzania and adjacent E. Africa, which causally bite off each gall, munch it to get at the ant (Lorus and Milne, 1967). *A. drepanolobium* was reported to have medicinal values. When chewed, the bark juice is used to treat sore throat, the liquid from the boiled root is mixed with tea or milk and used as a diuretic to women after birth, the root part is used as an insecticide against ticks or flea, and the boiled bark juice is used for delayed after birth (Kokwaro, 1976).

Regardless of aforementioned importance, *A. drepanolobium* is becoming one of the noxious encroacher woody species currently increasing in lowland areas of Borana, which may be due to large quantities of seed production during warm seasons and rapid germination depending on the rainfall (Coppock, 1994**)**. *A. drepanolobium* also sprouts easily from stumps (cuttings), which results in a bush like growth form that is more likely to be obstructive to livestock, harbor wild life such as hyenas, compete with grasses and thus degrading rangeland, and invading farmlands at depressions mainly in lowlands of Borana (Coppock, 1994). Large percentage of small individuals of *A. drepanolobium* is located on hillside, flat areas and depressions (bottomlands) of Borana, dominating the vertisols where seasonal water logging occurs (Coppock, 1994). A current assessment showed that about 82.8 % of total landmass of Boran is invaded by different bush species. Thus, the question of bush encroachment in general and bush encroachment by *A. drepanolobuim* in particular remains a hot issue at Zonal level among administrators, experts and pastoralists or agropastoralists in Borana (SORDU / Southern Range Development Unit, 2003). Thus, in order to manage such bush encroachment, it seems principal to investigate the biological and ecological aspects of the plant.

2.3. Seed Characteristics

2.3.1. Seed Dispersal

Seed dispersal is a process included in the dynamics of seed bank and closely related to fruit and seed production, seed storage and germination establishment (Harper, 1977). The placing of a seed on the ground some distance from the parent plant is important to the survival of seedling and the species as a whole (Vickery, 1984). The dynamics of a seed population depends upon the flux of seeds into an area by dispersal and the loss of seed through granivores and pathogens, senescence and germination. Seed dispersal evolved with environmental predictability in space (spatial) depends on whether the primary agency of dispersal is wind, water, or animal (Carey and Watkins, 1993).

Dispersal may be influenced by abiotic factors (gravity, wind, water, and structure and characteristics of soil) and biotic factors that include animals (Harper, 1977). For instance, pattern of wind dispersal depends on height from seed release, aerodynamic properties of seed and environmental factors including wind velocity (Carey and Watkins, 1993). For example, seeds of *Acacia senegal* were described as wind dispersed by Skagerlund (1999). Similarly, Lonsdale (1993) reported that seeds of *Mimosa pigra are* normally dispersed by floodwaters. Very nutritious seeds (large seeded fruits) are usually dispersed by few specialized frugivores while small seeded ones by less specialized and opportunistic frugivores (Fleming and Estrada, 1995). For dispersal, fruits need to be usually either ripen at once and eaten by a variety of seed dispersal agents or a few ripen every day over a long period (Vickery, 1984).

Seed survival, seed germination and seedling growth following pod consumption by large herbivores and seed chewing rodents of acacia have been described by Miller (1995). Of two seed pod types of *Acacia* species, in dehiscent pods, the majority of the seeds are dispersed by wind and gravity while in indehiscent ones the seeds remain inside the pods until removed by browsers and mechanical action (Miller and Coe, 1993). Consumption of *Acacia* pods, for example, *A. erioloba*, by elephant and other ungulates results in seed dispersal and facilitates seed germination by scarifying the seed coat (Barnes, 2001). Birds being the most common seed dispersal agents do disperse either seeds by spiting out before swallowing or passing out them undamaged via feaces (Vickery, 1984). This mechanism is best explained in *Acacia seyal* as mentioned by Skagerlund (1999). However, many animals other than birds are fruit eaters in tropics whereas rodents could also disperse seeds while collecting seeds and bury them for the future (Vickery, 1984). Further, other seeds are dispersed by animal furs. Yet, seeds of Acacia *species* like A. *verticellata* that are rich in fat body (elaiosome) are dispersed by ants (Armstrong, 1999).

Large herbivores (mammals) facilitate the dispersal of seeds of woody plants away from their conspecifics and improve the germination capacity (Milton and Dean, 2001). It seems that dispersal by animals emerges as the main and most important way through which the seeds can be released from the indehiscent and highly mechanically resistant pods (Baes *et al*., 2001). Thus, understanding endozoochoric (seed dispersal by animals internally) dispersal may be relevant for management of invasive plants on ranches as well as for restoration processes in rangelands (Milton and Dean, 2001).

The effectiveness of seed dispersal agents depends on the number and quality of seed dispersed (Barnes, 2001). That is to say, the effectiveness of animal disperser has both quantitative and qualitative components (Schupp 1993). The same author also explained that the quantity of seed dispersal depends on: the number of visits made to a plant and the number of seeds dispersed per visit. Similarly, the quality of seed dispersal depends on: the quality of treatment given a seed in mouth/ gut, and the quality of seed deposition.

Generally, dispersal is important for risk reduction (seed predation) as well as escaping the negative consequences of crowding that enable the seeds to colonize new microhabitat (Venable and Brown, 1993).

2.3.2. Soil Seed Bank

The viable seeds that occur on the surface and under the soil or associated with the soil litter comprise soil seed bank and form part of the species composition of the standing vegetation (Leck *et al.,* 1989). The occurrence of viable soil seed bank may be regarded as an insurance against local extinction of populations during unfavorable periods (Thompson, 1987). Seed bank in the soil represents reservoir of seeds of a number of species, produced at different time, and in different states of viability. It also stands for an ecological genotype, which is modified by the environment via its effects on germination and establishment produce the ecological phenotype (Thompson, 1984). According to Ghermandi (1997), up to a certain point, soil seed bank is a reflection of the vegetation community of the area. The knowledge about the dynamics of soil seed banks and seedling population provides clues about the *potential* of a plant community to regenerate after disturbance (Leck *et al*., 1989).

According to Thompson and Grime (1979), there are two major types of soil seed banks: 1) transient seed bank: i.e. one in which none of the seed output persists in the habitat in a viable condition for more than a year and 2) persistent seed bank: i.e., Some of the component of seeds are more than one year old, become buried in the soil, and the majority have small seed. Data on soil seed bank characteristics such as species number, seed quantity and depth distribution can provide insight into the regeneration ecology, and in particular will give an estimate of the regeneration potential after disturbance. Seed abundance in any particular microhabitat depends on the input of seeds during phase-I (i.e., movement of a seed from the parent to a surface), and phase-II (i.e., subsequent horizontal and vertical movement). The store of seeds buried in the soil is composed in part of seeds produced in the area and partly seeds blown in from elsewhere. Seeds are continuously added to the soil seed bank by the seed rain and thus seed bank represents a record of past as well as present vegetation growing on the area or near by. Seeds in a dormant state in the seed bank can be regarded as a "deposit account" whereas a " current account " is a temporary stage, in which the only hindrance to immediate germination is the absence of adequate moisture and a favorable temperature (Harper, 1977).

In lowland areas, wind, sheet flooding, seed eating animals, and soil surface micro-topography are major factors affecting seed dispersal and distribution (Reichman, 1987; cited in Guo *et al.,* 1998) though seed morphology seems to be important in patterning initial dispersal distance and distribution (Guo *et al.,* 1998). Seed distribution (both horizontal and vertical) and storage in soil are also related to soil conditions such as particle size, structure, and soil chemistry (Harper, 1977; Chambers and McMahon, 1994).

The seed bank of African acacias is mainly influenced by the following factors: annual seed production, dispersal, predation, germination and mortality. 1) Annual seed production: Depending on species and population, African acacias produce from a few 100 to several million seeds per large tree, e.g. Acacia *albida* (Tybirk *et al*., 1992). 2) Dispersal: Most of African acacias are dispersed either by wind or ungulates (Coe and Coe, 1987). 3) Predation: susceptibility to attacks by bruchid beetles, which are natural regulators of acacia species (Tybirk *et al.,* 1992). On the other hand, Miller (1995) reported that 92 % of seeds of *A. tortilis* and 76 % of those of A. *nilotica* were consumed by browsers and grazers. 4) Germination: fresh seeds of wind- dispersed species usually germinate readily after rain (Tybirk *et al.,* 1992). Fire also affects the soil seed bank by breaking seed coat and allowing seed germination (Sabiiti and Wein, 1987), for instance, that of *Acacia brevispica* (Coppock, 1994). 5) Mortality: due to aging and loss of viability or pathogens (Harper, 1977).

Thus, seed banks are dynamic entities, within put occurring through dispersal and loss occurring through germination and various sources of mortality. Therefore, the study of soil seed bank is principal for management purposes, especially, to find out if the preferred species are present in the local seed bank, and what the conditions for their successful germination and seedling establishment are (Ghermandi, 1997).

2.3.3. Seed Germination

The recommencement of active growth by the embryo resulting in rupture of the seed coat and emergence of a young plant is known as seed germination (Agrawal, 1986). In seed testing, however, the International Seed Testing Association (ISTA) defines germination in a laboratory test as the emergence from the seed embryo and development of those essential structures that indicate the ability of the seed type tested to develop into a normal plant under favorable conditions in the soil (Van Geffen, 1986). The regeneration of plant communities from seeds depends on seeds being in the right place at the right time, and phase of germination is often the most critical one in the life of plants (Van der Pijl, 1982). Germination is of two types: hypogeal, in which the cotyledon does not emerge above the soil surface e.g., maize and epigeal germination is the one in which the cotyledon emerges above the soil surface such as soybeans.

Water, oxygen, temperature, and light influence germination although the first three are classified as principal. Oxygen is essential for aerobic respiration, for the expenditure of energy. With regard to temperature different seeds germinate within different temperature ranges, usually including an optimal temperature for the highest and most regular germination in a short time (Van Geffen, 1986). Very low and very high temperatures prevent the germination of all seeds (Agrawal, 1986). Finally, the seeds of most cultivated plants usually germinate equally well in the dark or light. However, freshly harvested seeds of some species, for instance, lettuce showed enhanced germination in the light (Agrawal, 1986). On the other hand, large seeds and seeds of many grass species don't require light for germination, and thus may be able to germinate from deeper in the soil (Guo *et al.,* 1998).

Phytochrome, responsible for absorbing light energy in seeds during germination exists in two forms. a) the one which absorbs red light (pr, λ =660 nm) promotes germination, where as b) the other that absorbs far red (pfr**,** λ = 730 nm) inhibits germination (Agrawal, 1986). The state of inhibited seed growth resulting from various internal causes is known as dormancy (Agrawal, 1986). It is a seed characteristics, the degree of which defines what condition should be met to make the seed germination (Vleeshouwers *et al.,* 1995). Dormancy can be influenced by 1) the characteristics of the seed coat, which may be impermeable to water (many legumes), to oxygen, as in (*Xanthium*) or mechanically resistant (in pigweed) and 2) embryo character, where embryo can be either dormant (apple & peach) or can be rudimentary (Agrawal**,** 1986).

Further, fire and insect damage (Sabiiti and Wein, 1987), predation of pods by large herbivores immediately after seed fall (Miller, 1995), and germination inhibitors such as phenolic compounds (caffeic, ferulic and abscessic acid /ABA) are some of the factors that influence the germination of species (Agrawal, 1986). The position of seed on the soil surface may also affect seed germination establishment (Guo *et al*., 1998).

Seed dormancy can be broken by mechanical scarification, low temperature (5-8 ^{o}C), high temperature (40- 45 ^{o}C), light and chemicals such as GB3 (Gibberellic Acid) and sulphuric acids (Agrawal, 1986), and by dry storage (Van Geffen, 1986). Germination and dormancy mechanisms are of great adaptive importance to plants by ensuring that seedling emergence occurs at the most advantageous time and place (Fenner, 1985). Seeds of tropical species have been broadly categorized into two major groups " recalcitrant" and " orthodox " based on their features and germination characteristics (Swaine and Whitmore, 1988). Seeds that cannot resist desiccation, and which germinate immediately within a few days after dispersal are termed as recalcitrant e.g., seeds of fruit trees, and those seeds that can withstand desiccation are called Orthodox seeds (Garwood, 1989).

Total germination and germination rate influence dynamics of seedling populations in natural habitats. Various studies have related seed size to total germination and germination rate. For instance**,** within species, larger seeds often have greater germination probability than smaller ones (Huo and Romo, 1998). According to Whitmore (1990), seeds of many rapidly germinating species are large, non-dormant, with a high water content and very sensitive to dehydration; they loss their viability if they are dried or heated.

2.4. Coppicing of Stumped Trees

Coppice is defined as the natural regeneration of stump sprouts or root suckers, or other branch layering (Nyland, 1996). Sprouting from cut stumps is the most common means of regeneration after cutting whereby most neotropical trees produce new shoots from stems and roots in recovery following the cut (Uhl *et al*., 1981). Coppicing constitutes an intelligent artificial interruption of plant growth, which stimulates the coping mechanism previously developed by the plant in response to natural disturbances as fire, parasitism and adverse weather conditions (Giovannini *et al*., 1992).

Coppicing ability has been consistent across many of the plant genera but varied widely within the acacias, ranging from complete absence to plentiful regeneration following cutting. Variations were observed between *Acacia species* in response to cutting. For example, 1) some coppice extremely well at all height with little stumps mortality like *A. saligna* 2) others coppice over all treatments, but shoots were most vigor from 1 metre height treatment, e.g. *A. melonxylon*. 3) Species like *A. mearnsi* coppiced when a 1 m cut with little or no response from the lower cut height and so on. However, coppicing ability of some may decline noticeably withincreasing age (Giovannini *et al*., 1992).

Coppicing is used as a natural management tool of regular harvesting of material without having to replant, but its success may be influenced by 1) increasing age (due to decrease in number of dormant buds) and increasing stump diameter. 2) Season of felling since heavy frost may reduce shoot production (FAO, 1979; cited in Ryan and Bell, 1989). 3) Poor felling technique and 4) failure to clear branch materials (Ryan and Bell, 1989).

Ahmed Jemal and Florian (1997) reported that there was 40% regrowth of *A. drepanolobium*, each stump with 4 to 6 new shoots (sprouts) in average following cutting trees for charcoal production experiment. Giovannini *et al.* (1992) recorded that vigorous vegetative regeneration after coppicing in seed reproducing plants following cutting appears to be of a secondary importance. It represents adaptive mechanism of species in Mediterranean ecosystem. The capacity to spread (regenerate) by cutting, in some species may indicate their potential for bush encroachment. According to Coppock (1994), stumping caused *A. drepanolobium* resprout rapidly which creates bushy growth that could be obstructive to livestock grazing.

2.5. Symbiosis (Acacia and Animals Interactions)

2.5.1. Ant-*Acacia drepanolobium* Interactions

Plants manage to defend themselves against other animals by attracting ants; the myrmecophytes (ant-plants) provide either nest-site (Beattie, 1985) or food sources such as beltain body (protein and lipid rich material) in the new world acacias (Hölldoller and Winson, 1990) or extrafloral nectars in African acacias (Chan, 1998), excretion from plant sucking bugs (Beattie, 1985). Ants in turn, benefit the plant in the field of dispersal or myrecochory in such away that either ant colony eats the nutritious fat body and discard the seed unharmed or direct supply of nutrients through ant refuses to the plant (Beattie, 1985), and protect against their natural enemies (Vickery, 1984; Fonseca, 1994). Thus, protectionists believe in symbiosis to be mutualistic (Hölldobler and Winson, 1990). Various studies indicated that clipping entire thorn from the acacias made them more vulnerable to attack by their insect herbivores (Hölldobler and Winson, 1990), and other herbivores like goats. This provides support for the hypothesis that ant-acacia relation at least evolved partly in response to pressure from herbivores. That is why the plant makes an investment in both types of defenses, i.e., formation of swollen thorn and feeding ants at its expense (Stapley, 1998). Ant-acacia mutualism occurs worldwide throughout the tropics (Vickery, 1984; Jolivert, 1997) though the coexistence of ant-acacia interaction is poorly understood.

Tropical African acacias symbiosed with ant genera called *Cataulacus, Crematogaster* and *Tetraponera* while American acacias symbiosed with *pseudomyrmex* (Hölldobler and Wilson, 1990). *Acacia drepanolobium*, a familiar tree in dry and arid regions of E. Africa (Jolivert, 1997) that produces evergreen leaves, swollen thorn (also called domatia) and extrafloral nectars, and exhibits typical ant- acacia association (Jolivert, 1997). In Kenya, two genera consisting of 4 species of ants are known to inhabit *A. drepanolobium.* These are described as follows. 1) *Crematogaster nigriceps* Emery (Cn) has a black head and thorax and a red abdomen (Young *et al.,* 1997). This species is the only group feeding on auxiliary shoots that produce flowers, and is dispossessed more than other ants during ant fight (Stanton *et al*., 1999). 2) *Tetraponera penzigi* Mayr (Tp) is a long thin ant, entirely black and readily recognizable. T. *penzigi* is the only one which feeds on nectars and is the least reactive that is actively evicted by strong groups (Cm and Cs). 3) *C. mimosae* Santschi (Cm) has a red head and thorax and a black abdomen 4) *C. Sjostedti* Mayr (Cs) has a black head and abdomen and a reddish black thorax. Both *C. mimosae* & *C. Sjostedti* are known to tend sucking scale insects (Young *et al.,* 1997). According to Stanton *et al*. (1999), *C. Sjostedti* seems to inhibit shoot growth. It is also reported to be an occupant of *Acacia seyal*, which produces a white swollen thorn (Chan, 1998).

Although *A. drepanolobium* lacks beltain, ants benefit from nesting sites and a constant and readily available extra floral nectars at the leaf base (Stanton *et al*., 1999). These four species of ants are in a fierce competition and mutually exclusive, competing for individual tree by colonizing and antagonistic takeover. Interactions seem to be essentially unstable due to competition and parasitism because of the rare and unpredictable benefits of protective mutualism (Stanton *et al*., 1999).

C. nigriceps & T. Penzigi are found on shoots, damaging or consuming shoots while *C. mimosae* & *C. Sjostedti* are hardly found on the shoots. The former two with their more parasitic nature are inferior competitors (Chan, 1998). *C. nigriceps* prunes new growth and flowers of acacia (sterilizes), and makes the tree more compact and highly branched (Cockcroft, 2001). Studies revealed that banishing these ants (*C. nigriceps)* has reduced 25%

of tree branching from the control tree within seven months (Stanton *et al*., 1999). *C. nigriceps* alters the architecture of host tree canopies, and this unique pruning activity seems to prevent any invasion (competition) for the host trees (Stanton *et al.,* 1999).

2.5.2. Acacia-Bruchid Beetle Interaction

Bruchid beetles (Coleoptera: Bruchidae) are known to attack acacia seeds in many parts of the world (Ernst *et al*., 1990; Miller and Coe, 1993) that represents a typical bruchid beetle. The bruchids lay their eggs on or inside developing pods (primary infestation) 30- 60 days after fertilization of the flower. The larvae then enter the seed (secondary infestation) where it feeds on the seed contents and pupates (Pellew and Southgate, 1984). According to Miller and Coe (1993), the beetles initially attack fresh green acacia seed pods on the tree. The same authors have also noted that reinfestation following emergence may then occur on mature, dry seed pods on the tree and on the ground, and the attacks of bruchid on *Acacia* seeds can be massive. Ernst *et al*. (1990) reported that the rate of infestation of *Acacia* seeds by bruchids is ranging from 12 to 79 % in Botswana. Most bruchid beetles can have enormous impacts on acacia seed viability. For example, *Bruchid uberatus* can destroy 60% of the seed crops of *A. nilotica* and *Bruchid sahlbergi* could destroy about 96 % of the seed crop of *A. erioloba*, and most seeds attacked by bruchids are destroyed, but seeds may remain viable if only a small part of the seeds cotyledon has been consumed (Coe and Coe, 1987; Lamprey *et al.,* 1974; cited in Skagerlund, 1999).

Miller and Coe (1993) have stated that passage of acacia seeds through ungulate gut may 1) prevent damage of seeds by bruchid by increasing percent germination 2) kill small bruchid larvae within seeds at early stage of development and 3) selectively destroy Bruchid infested seeds and some seeds may escape bruchid re-infestation because of this apparent pre-treatment.

3. MATERIAL AND METHODS

3.1. The Study Site

The study area is situated in the extreme south of Ethiopia in Oromiya Regional State, Borana zone**.** The study was carried out at Liben Woreda particularly at Seminto and Meissa kebeles.

3.1.1. Location

The sites are located at 05^{O}11’07 N - 05^{O}20’07 N and 39^{O}37’12 E - 39^{O}41’22 E (5^{0}19’ N and 39^{O}38’ E), about 630 km South of Addis Ababa (Fig. 1). Except for the central mountain range and scattered volcanic cones and craters, the land escape is gently undulating across an elevation of 1000 m to 1600 m (Coppock, 1994).

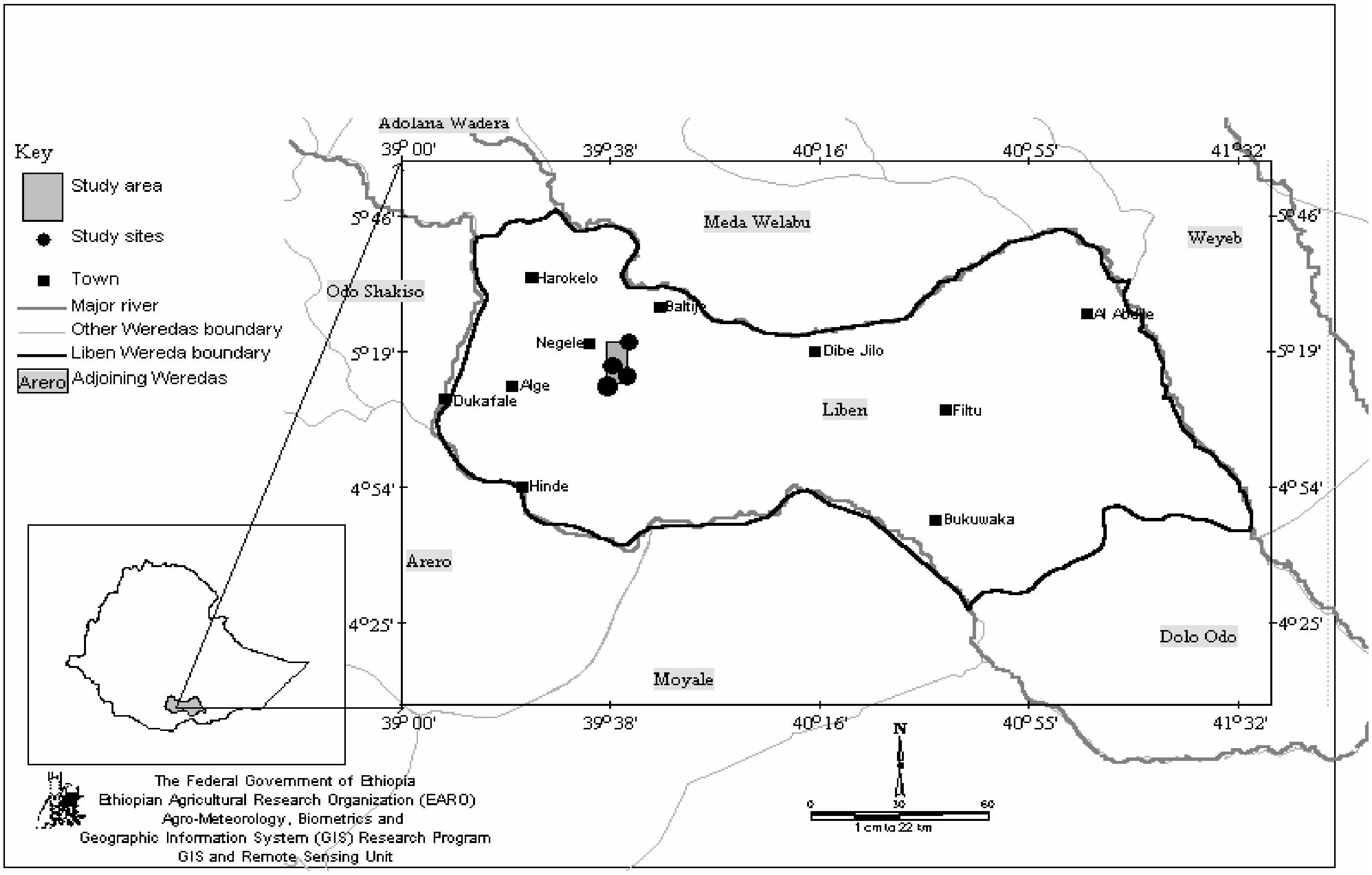


Figure 1: Map of the study area and sites (sources: orginal analogue map of Central Statistical Authority (1994), digitally transfered data from World Food Program , 1998)

3.1.2. Climate, Soil and Vegetations

Climate

Ethiopia can be divided into highlands which consist of 49 million ha (43.75%) and lowlands about 63 million ha (56.25%), using 1500 m elevations as a crude threshold (MOA, 2000).The highlands have climate conditions that vary from semi-arid to humid (sufficient moisture for 90 to 270 growing days).The lowlands, in contrast, are dominated by arid to semiarid climatic conditions (i.e. up to 180 growing days and 700 mm precipitation per year). The Borana area is dominated by semi-arid climates (Coppock, 1994). The annual mean temperatures vary from 19 ^{o}C to 24 ^{o}C with little seasonal variation and decreases 1 ^{o}C with each 200 m increase in elevation. Rainfall varies considerably with location, with an overall average of 700 mm rainfall, which increases by 64 mm for each 100 m rise in elevation. The rainfall pattern is bimodal (Coppock, 1994). The main rainy season (59% of annual precipitation) occurs from February/March to May/June or "gaana" (Haugen, 1992) and a minor or "hagaya" less reliable, rainy season (27%) occurs from September/ October to December (Ahmed Jemal and Florian, 1997). The short rains of "hagaya" are followed by long dry season "boona". The rain generally decreases with decrease in altitude (Haugen, 1992). The 30 years data of rainfall and temperature of the study area are given in Fig. 2.

Geology and Soils

Geologically the area is dominated by quaternary deposits (40%), basement complex formation at bottomlands (38%), volcanic (20%) and sedimentary deposits of 2% (Coppock, 1994). The soil is mainly red, ferruginous character in sloping areas and dark vertisols in the bottomland (Haugen, 1992) while the upland soils occurring elsewhere are well drained and usually have equitable proportion of sand (53%), clay (30%) and silts (17%). Vertisols are higher in organic

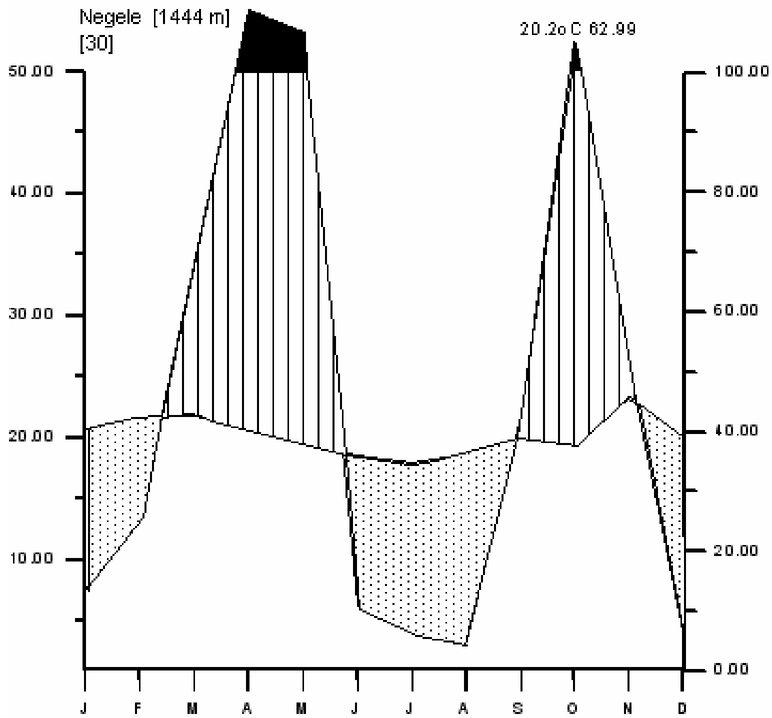


Figure 1 Climadiagram showing mean annual temperature and mean annual rainfall for the last 30 years (1970-2000) of the study area**.** Source: the original data obtained from National Meteorology Agency of Ethiopia; diagram constructed following Walter, 1973; cited in Lüttge (1997).

matter and have clay content over 60% (Coppock, 1994). Compared with those on the red soils, black cotton communities are relatively decreased in species for some but not all groups in N. Kenya. These types of soils support most of the productive rangelands in East Africa (Young *et al.*, 1997), and Coppock (1994) noted that the nutrient status is typical of tropical savanna.

Vegetations

The typical physiognomy of the vegetation is suggestive of tropical savanna (Pratt and Gwynne, 1977). The region is dominated by savannah vegetation containing mixtures of perennial herbaceous vegetation which include genera such as *Cenchrus, Cynodon, Pennisetum, Themeda, Enterpogon, Chloris, Aristida* and the main woody vegetations include genera like *Acacia* (major part*), Commiphora, Combretum, Terminalia, Grewia, Boswellia, Balanites* and *Juniperus* (Coppock, 1994*).* Zerihun Woldu and Sileshi Nemomissa (1998) classified vegetations of central Borana plateau in to seven vegetation types. Namely: *Tarconanrthus camphoratus* woodland, Commiphora woodland, *Chrysopogon plumulosus* grassland, *Barbeya oleoides-Combretum molle* woodland, *Clausena anisata-Panicum arundinacea* woodland, *Juniperus procera-Clausena anisata* forest and *Acacia drepanolobium- Acacia seyal* wooded land.

Several native species of grasses and other plants provide excellent forage for livestock upon which diverse groups of pastoral people depend on for their subsistence (Coppock, 1994). According to Ahmed Jemal and Florian (1997), compared to neighboring arid and semi-arid desert rangelands of Northern Kenya, the Borana rangelands are still resource rich. The study site represents an important region for the national livestock economy (Coppock, 1994). The major occupation of Borana people is pastoralism, and they have been living in the region before the 13 th century (Oba and Kotile, 2001). Their indigenous system of water technology, complete organization of the "gada" system and management attracted numerous researchers (Coppock, 1994). They keep cattle, camel, sheep, goats and some equines. There is a settled agricultural land near Negele.

3.2. The Study Species

Acacia drepanolobium is a shrub or a single stemmed tree, 1-5 (-7.5 m) long (Asfaw Hunde and Thulin, 1987) (Fig. 3A & C). There is a pair of straight sharp spines up to 6 cm (sometimes 10 cm) long at each node. About one node in five has a swollen, purplish-brown structure, up to 5 cm in diameter at the base of the spine pair called ant-gall that usually houses ants (Young and Okello, 1998) (Fig. 3B blacken balls).

Leaves are with 11-22 pairs of leaflets, 1.5-5.5 x 0.7-1.25 mm. The leaflets are glabrous or minutely ciliolate. Flowers are white or cream, in heads (Fig. 3 B). Punducles are glabrous or pubescent, with the involucre at or near the base. Calyx is 0.75-1.5 (-2.5 mm) long. Corolla, 3-4 mm long. Pods are falcate, mostly attenuated at both ends, dehiscent and brownish, 4-7 x 0.5-1cm long (Fig. 4B). Seeds are nearly elliptic, compressed, 10-12 x4.5- 5.5 mm long (Thulin and Asfaw Hunde, 1987) (Fig. 4D).

Fig. 3 (A) *Acacia drepanolobium* dominated rangeland; note the reduced herbaceous cover. Growth forms due to the 'symbiotic' ant species.: (B) *Crematogaster mimosae* ; profusely branching; (C) *Crematogaster nigricens ('pruning ant')*, suppression of lateral growths by the ants (black arrows). White arrows in B: upper = flowers; lower = point of contacts with the neighbouring individual plants. [All photos taken by Melesse Maryo]. Further explanation in the text.

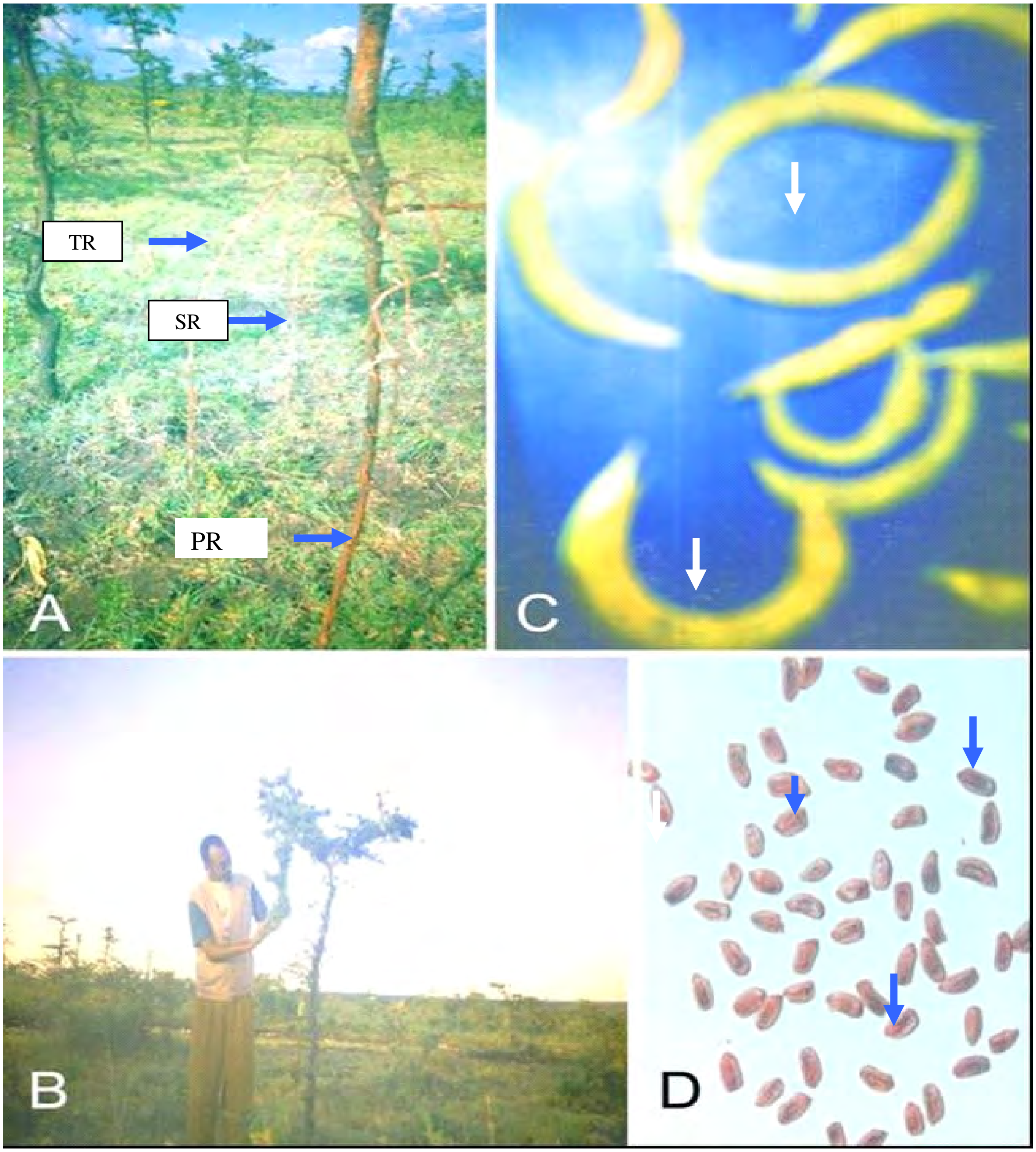


Fig. 4. *Acacia drepanolobium.* (A) Roots, note the arrows; (B) The researcher studying the symbiotic ant species; (C) Pods, note the magnitude of the curvature of mature pods (arrows); (D) Seeds, note the embryo (arrows). [All photostaken by Melesse Maryo]. Notes: PR = Primary Root; SR = Secondary Root; TR = Tertiary Root. Further explanation in the text.

3.3. Methods

3.3.1. Vegetation Sampling

Vegetation survey was carried out at four different *A. drepanolobium* wooded grassland sites. These sites are where *A. drepanolobium* was the single canopy tree. Floristic data was collected as described by Muller-Dombois and Ellenberg (1974) following systematic sampling in November 2002, i.e., two weeks after the short rainy season. The presence of all herbs, sedges, grasses, shrubs and trees was recorded in 40 quadrats laid along 4 transects. Transects 1 & 2 were from black cotton soil (Meissa and Seminto Kebeles) whereas 3 & 4 were from red soils (Seminto Kebele).

Voucher specimens were collected, pressed, dried and coded for identification at National Herbarium, AAU. Plant specimens were identified by comparing with the previously identified specimens in the Herbarium and with reference to the published volumes of Flora of Ethiopia and Eritrea and other relevant literatures.

Individuals of *A. drepanolobium* with a circumference greater than 5 cm were measured for dbh (diameter at breast height) to analyze the size distribution of the population, and individuals of the study species in each plot were counted to realize the extent of bush encroachment.

3.3.2. Soil Analysis

Soil samples were taken from a depth of 0-10 cm, from five points in such a way that four samples were taken from each corner and one from the center in each quadrat. Composite samples, each weighing about 1 kg, were taken for laboratory analysis. The soil samples were analyzed in the Ecology and Ecophysiology Lab. at the Department of Biology (AAU). The soil tests were carried out following the methods described by Juo (1978) and Sahlemedhin Sertsu and Taye Bekele (2000). The soil samples were air dried in glass house by spreading on plastic trays. Upon drying, they were grounded and sieved through a 2 mm mesh size for pH, Electric conductivity and Soil texture analyses. A brief description of each of these parameters is given below.

Moisture was determined by oven drying the soil sample at 105 ^{o}C for 24 hours. Percentage moisture was computed as follows. % Moisture = moist soil- oven dry soil / oven dry soil x100.

PH was determined in 1:2.5 soil/water ratio suspension following Sahlemedhin Sertsu and Taye Bekele (2000) using Jenway pH meter Mode 3071 EC (UK made).

Electric Conductivity (EC) which is a measure of soluble salts was determined in 1:2.5 soil/ water following Chopra and Kanwar (1976). The conductance at 20 ^{o}C of the filtrates was determined by YIS Model 5000 & 5100 (USA made) conductometer.

Texture (Particle size analysis**).** The textural classes of the soil samples were determined following Hydrometer method of mechanical analysis described by Sahlemadhin Sertsu and Taye Bekele (2000). The percentage of various soil separates was determined by the following formulae of Juo (1978).

% Sand= 100- (H1- 0.2 (T_2-68) –2) x 2

% Clay = H_2 = (T_2 -68-2) x 2

% Silt = 100- (% sand + % clay). Where H_1 and H_2 are first and second hydrometer readings, and T_1 and T_2 (in ^{O}F) are first and second temperature readings respectively. The percentage of soil separates was used to determine the textural classes of soil samples.

3.3.3. Seed Characteristics

I. Seed length, width and weight

Measurement of mean length (L), and width (W) of 25 randomly selected seeds in four replicates, from several trees, was made under binocular stereomicroscope following Lyaruu *et al*. (1998). The weight of thousand (1000) seeds was determined following the method described by ISTA (1985). Thus, number of seeds/ kg = number of seeds in a sample/ weight of a sample in kg x 1000 (ISTA, 1993).

Similarly, the length and width of pods were determined from samples of 25 pods in four replication following the method used by Kannan *et al.* (1996). The number of seeds per pod was determined from a sample of 25 pods in seven randomly selected trees in each of the four sites whereas the number of pods per tree was determined by directed counting of pods from the sample trees.

II. The status of seeds

Seven trees were randomly sampled from each of the four sites. A total of 700 pods (25 pods from each of 28 trees) were collected, from different branches and at different heights on each tree. After opening each pod, the seeds were counted and categorized following the method described by Skagerlund (1999).

1. Health seeds: seeds with no visible damage ;
2. Destroyed seeds: seeds with visible damage e.g. holes, softened and black ended seeds ;

3. Aborted seeds: small-undeveloped seeds or empty compartment in the pod and

4. Deformed seeds (not full seeds): seeds with an intact seed coat but with a clearly abnormal shape.

3.3.4. Seed Dispersal

To investigate the mechanisms of seed dispersal, pastoral elders were interviewed and field observation was carried out. Further, mature pods of *A. drepanolobium* were provided to a goat and a camel under controlled condition based on the results of interview to test whether these animals disperse the seeds or not, following the method described by Traveset *et al.* (2001). After feeding a goat for 4 days, its droppings were collected to recover seeds, if any.

3.3.5. Soil Seed Bank

At each of the four sites, 10 plots were selected at the end of November 2002 when very few trees produced seeds, to analyze the vertical distribution of the soil seed bank. The sample plots at each site were 30 m apart. At each plot, an area of 15 cm x 15 cm was marked following Demel Teketay (1996), and two separate soil layers (a total of 40 litter layer and 40 mineral layer, upper 6 cm of soil layer) were removed following Mekuria Argaw *et al.* (1999) using a sharp knife and a spoon and placed in polytene bags.

These samples were transported to AAU where samples were sieved in a glass house to recover the seeds using sieves with mesh size of 3 mm, 2 mm and 1 mm diameters. The recovered seeds were tested for viability.

3.3.6. Seed Germination

To investigate the germination of *A. drepanolobium* seeds, ripe pods were collected from several trees (28) from different branches, and sun dried. Intact and healthy seeds were selected randomly for different germination tests. Before incubation for germination, seeds were subjected to 22 different treatments. Four replications of 25 seeds per replicate were used for each treatment following Kannan *et al.* (1996) and Tilahun G/ Medhin and Legesse Negash (1999). The treatments are briefly described below.

1. **Control**: no pre-sowing treatment
2. **Mechanical scarification**: This treatment has involved the helium side of the seed and the side opposite to the helium where 2 mm of the seed coat were removed to facilitate imbibitions of water by the seed following Demel Teketay (1996) and Mekuria Argaw *et al*. (1999).
3. **Cold water**. Seeds were immersed in cold tap water for 24 hours and another batch of seeds for 48 hrs in 400 ml beaker.
4. **Boiling water**. Seeds enclosed in cotton were immersed in boiling water for 1, 5, 30 and 60 minutes, then removed immediately and allowed to cool down in each case before sowing following the method used by Demel Teketay (1996).
5. **Dry heat treatment**. Seeds placed in small trays of aluminum foil were exposed to a preheated oven at the range of two different temperatures (60 ^{o}C and 90 ^{o}C) for duration of 15, 30 and 45 minutes in each temperature gradient. Immediately after seeds were withdrawn from the incubator, they were allowed to cool before sowing following Demel Teketay (1998).

6. **Sulphuric acid (H_2SO_4 = 96 %).** Seeds were soaked for 5, 15, 30, 45, 60, 120, 180, 240 and 300 minutes in 400 ml beaker containing 96 % H_2SO_4 and stirred at regular intervals to ensure uniform treatment. Seeds were then washed with running tap water before sowing as described by Agrawal (1986) and van Geffen (1986).

Seeds were sown in 5.5 cm petridishes on filter paper, the latter was kept moist with distilled water, and placed on a table in the Lab. Seeds were considered germinated when a radicle penetrates the seed coat. Germinated seeds from all treatments and the control were counted every other day and removed at each assessment period to prevent double counting. The seeds were incubated for 21 days, after which ungerminarted seeds were cut open and assessed for damage by a bruchid beetle following Barnes (2001); some seeds which have remained dry were treated with concentrated sulphuric acid (96%) to analyze the status of seeds following Sabiiti and Wein (1987).

3.3.7. Stumping Height and Coppicing Ability

The experiment on the effect of stumping height on the coppicing ability of *A. drepanolobium* was conducted in November 19**,** 2002 in a randomized block design with replications on two different soil types (red and black cotton) from different sites following Uhl *et al.* (1981) and Mohammed (1997). Each block had an area of 450 m^2 (15 m x 30 m). Further each block has represented three different levels of stumping heights, viz., a) at 10 cm below ground; b) at ground level, and c) at 50 cm above ground. All the studied trees had only one stem, and the stumping was conducted carefully using an axe. The assessment of the experimental plots was carried out in February, 2003 (3 months after stumping of trees) in order to examine and record number of sprouts/ coppices per stumped trees and heights of coppices.

3.3.8. Symbiotic Interactions of Acacia

a) Ant- Acacia interactions

All individuals of *A. drepanolobium,* 0.5 m in height and above within randomly selected replicates of 10 m x 15 m quadrat, along 300 m transects of vegetation plots in each of the four different sites were investigated for occupant ant-species following Young *et al.* (1997). A total of 304 individual trees were surveyed. The relation between ant species and seed bearing trees was studied from 28 sampled trees.

b) Bruchid beetle- Acacia interactions

The seed feeding beetles were identified by Dr. Bekele Jembere in the Entomology Lab (AAU). The impact of the beetles on the germination of seeds of *A. drepanolobium* was assessed following Sabiiti and Wein (1987) and Miller (1995)**.**

c) Nitrogen fixation

To assess whether *A. drepanolobium* fixes nitrogen and if it does to evaluate the extent of nitrogen fixation, seeds were sown in a glass house in the red and black cotton soil samples taken from Borana. After finding that a plant can fix nitrogen, other seeds were sown and the young plants were allowed to grow for 3 months. To quantify nitrogen fixation, two parameters of nodulation were investigated. The mean number of nodules per seedling was determined, and the nodules were detached from the extracted roots, cleaned and oven-dried at 65 ^{o}C for 48 hrs. Following these procedures, the nodules were counted and weighed to obtain mean dry weight of nodules per seedling following Costa and Paulino (1997).

3.3.9. Root Depth

Due to the difficulty in digging up soils, the preliminary root excavation experiment was made only on three *A. drepanolobium* plants (two 1 m and the other 0.35 m height) at different sites to examine the depth of a root.

3.3.10. Community Perception on *A. drepanolobium*

Descriptive questions were posed to pastoral community elders on biological and ecological nature and the economic importance of *A. drepanolobium*, and solutions for its management through interviews (individual discussion) to realize their views to understand how they perceive *A. drepanolobium* and the indigenous knowledge associated to it.

3.4. Statistical Analysis

ANOVA was performed for environmental data, density of A. *drepanolobium*, coppice number and sprout height analysis using SPSS 10.00 soft ware and Microsoft Excel. Similarly, means of cumulative germination percentage, after transforming them to arcsine square root of the proportion following Zar (1984), and germination values were subjected to ANOVA. The statistical significance of the differences among means was tested using Turkey's test. The mean and percent values were used to analyze the seed characters and the effects of bruchids on seeds respectively, and the paired T-test was used to analyze the extent of nitrogen fixation in two different soils.

4. RESULTS

4.1. Floristic Composition and DBH Classes

4.1. a. Floristic Composition

In the present study 114 species of 96 genera distributed over 42 families of plants have been identified. Of these 70.2 %, 23.7% and 6.1% were herbs, trees/shrubs and climbers respectively. More over, 33.3 % were forage species whereas 14.9% and 2.6% had socio-economic and medicinal importance respectively. Three families, Asteraceae, Fabaceae and Poaceae have constituted 36 % of the total number of species. The complete list of plant species is presented in (Appendix III).

4.1. b. DBH Classes

A. drepanolobium formed L-or inverted J- shaped structure on the basis of dbh (diameter breast height) classes (Fig 5). About 70 % of individuals were found to be below 2 cm of dbh, i.e., many individuals were found at lower class which clearly indicates active regeneration of the species. The mean density of *A. drepanolobium* among sites in the study area was found to be 1798 individuals /ha (Appendix 4b). The result of Analysis of Variance showed highly significant difference in the density of *A. drepanolobium* among sites [$F_{(3, 36)} = 27.65$, $p<0.05$] (Appendix 4a). When Tukey's test was used to make comparison among means, site 4 indicated significance difference from all other sites at 0.05 level of significance (Appendix 4c). The density of the study species was used to qualify the condition of bush encroachment.

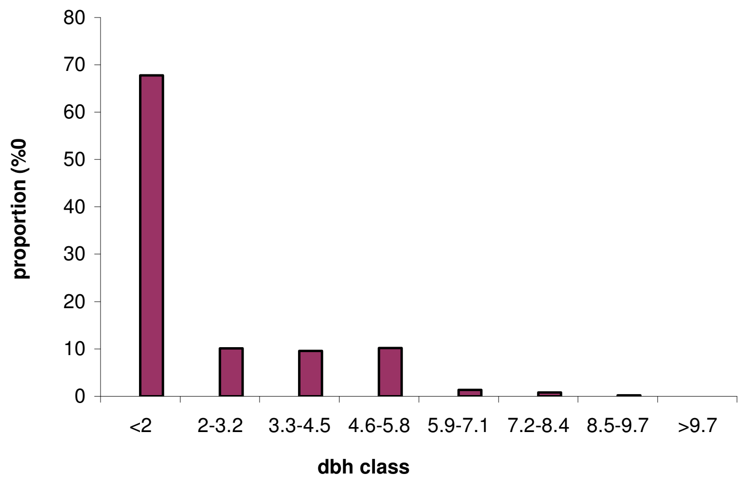


Figure 2 Distribution of individuals of *A. drepanolobium* in DBH classes.

4.2. Soil Properties

Moisture: In *A. drepanolobium* wooded grassland, the mean percentage moisture ranged from values 14.01 to 22.2 (Table 1). The percent moisture among the sites was highly significant [$F_{(3, 36)}$ =35.3, P<0.05] (Table 2) except the percent moisture of sites 3 & 4 when tested using Tukey's test of mean differences.

Table 1. Mean values of soil properties in 4 different sites with different variables**.**

Site	Moisture (%)	pH	EC (ms/cm)	Texture			Soil type
				Sand (%)	Clay (%)	Silt (%)	
1	22.2	8.3	0.299	31.1	46.4	22.5	Clay
2	18.8	8.14	0.248	25.1	49.4	25.5	Clay
3	14.09	6.78	0.084	31.6	33.2	35.2	Clay
4	14.01	6.78	0.008	28	42.2	29.8	Clay
Overall mean	17.275	7.5	0.15975	28.95	42.8	28.25	Clay

These latter sites represent the community with red soil habitat, relatively with gentle slope that had low percent moisture value.

Electrical Conductivity (EC): The mean values of EC were found between 0.08 and 0.299 ms/cm, which were the lowest and highest values respectively (Table 1). However, ANOVA result indicated that the values of EC are statistically significant [$F_{(3, 36)} = 60.2$, $P<0.05$] (Table 2). Tukey's test showed that sites 1 & 2, and 3 & 4 are not significantly different. It is to be noted that the former and the later correspond to black cotton and red soil habitats respectively. The mean values of these sites showed that the sites 1 & 2 that have relatively higher EC values are at bottomlands where floods are retained due to high clay content that possibly will hold more salts.

pH: The mean pH values have ranged from 6.78 to 8.30 (Table 2). There is statistically significant difference among study sites 1 to 4 [$F_{(3, 36)} =992$, $P < 0.05$] (Table 2). However, all sites have relatively high pH values probably due to topographic nature of the land. Tukey's test result is similar to that of EC, and the mean value of sites 3 & 4 (6.78) represents slightly acidic that supports the growth of many forage crops and grass species. It is to be noted that grasses such as *Sporobolus pellucidus, Panicum ruspoli,* and *Barleria quadrispina* dominated whereas sites 1 & 2, with mean values 8.30 and 8.14 represent medium alkaline soil respectively.

Table 2. Summary of ANOVA for Soil properties with different variables**.**

Treatments	Source of variation	Sum of squares	d.f	Mean of squares	F	Sig.
	Between groups	484.083	3	161.361		
	Within groups	164.687	36	4.576	35.273	.000
Moisture	Total	648.77	39			
	Between groups	20.714	3	6.905		
	Within groups	0.251	36	6.96	992.02	.000
pH	Total	20.965	39			
	Between groups	0.386	3	0.129		
	Within groups	7.69E-02	36	2.14E-03	60.193	.000
EC	Total	0.463	39			
	between groups	278.075	3	92.692		
	Within groups	642.9	36	17.858	5.19	0.04
Sand	Total	920.975	39			
	Between groups	1476.3	3	492.1		
	Within groups	835.2	36	23.2	21.211	.000
Clay	Total	2311.5	39			
	Between groups	948.475	3	316.158		
	Within groups	531.3	36	14.758	21.442	.000
Silt	Total	1479.775	39			

At significance level = 0.05

Soil Texture

Sand. The proportion of sand in the study area ranged from 25.1 to 31.6, which was statistically significant among sites [$F_{(3, 36)} = 5.19$, P= 0.04, Table 2]

Clay. The proportion of clay was the highest and has ranged from 33.2 to 49.4, and showed statistically high significant difference among sites.

Silt. Its values were highly significant among sites except for sites 1 & 2 as manifested by Tukey’s mean comparison test.

Generally, the soil particles among sites were significantly different. The overall mean values for sand, clay and silt were 28.95 %, 42.8 % and 28.25 % respectively.

4.3. Seed Characteristics

The result indicated that pod size, the length and width, of *A. drepanolobium* has ranged from (2.2 to 8.9 cm) and (0.4 to1 cm) with an average values of 6.1 ± 0.3 cm and 0.7 ± 0.02 cm (X ± SE) respectively. During the field study, it was observed that not all trees were seed bearing all at the same time though many were mature enough to produce seeds. The mean number of seed bearing trees per plot was 1 ± 0.4 (X ± SE) (cf. 4.8.1.). The number of pods counted has ranged from (44 to 2010) in the smallest and the largest trees respectively. Further, seed production has been noted to increase with height. It was found that an average value of pods per tree was 483.3 ± 226 (X ± SE). Similarly, seed number per pod ranged from 1 to 10 with an average value of 5 ± 0.1 (X ± SE), and the number of seeds per tree was 2417 ± 23 (X ± SE). Moreover, the mean measure of seed size and the calculated seed weight were 8.1 ± 0.3 x 4.1 ± 0.1 mm and 0.612 ± 0.01 mg respectively with 16,340 seeds/kg (Table3).

Table 3. Seed characteristics of *A. drepanolobium*

No	Seed characteristics	Mean value (X ± SE)
1	Number of pods per tree	483.3 ± 226
2	Pod size in (cm)	6.1± 0.3 x 0.7 ± 0.02
3	Number of seeds per pod	5 ± 0.1
4	Seed number /tree	2417 ± 23
5	Seed size (mm)	8.1 ± 0.3 x 4.1 ± 0.1
6	Seed weight (mg)	O.612 ± 0.08
7	Number of seeds /kg	16,340 ± 1.31
8	Seeded trees/ quadrat	1 ± 0.4
9	Soil seed bank (litter layer)	8.3 ± 2.6
10	Soil seed bank (mineral layer)	nil

4.4. Seed Dispersal

In the present study, 33 % of informants (Appendix II) have believed that *A. drepanolobium* is dispersed by animal droppings (goats and camels). In the attempt to test the suggestion of pastoral elders whether or not *A. drepanolobium* seeds are dispersed by goats and camels, no successful confirmation was attained. The absence of intact or damaged seeds from seed feeding experiment indicates that digestive process must have harmed the seeds. But a camel has refused to feed on collected pods under controlled experiment. Accordingly, no empirical data was collected regardless of the effort made in this study.

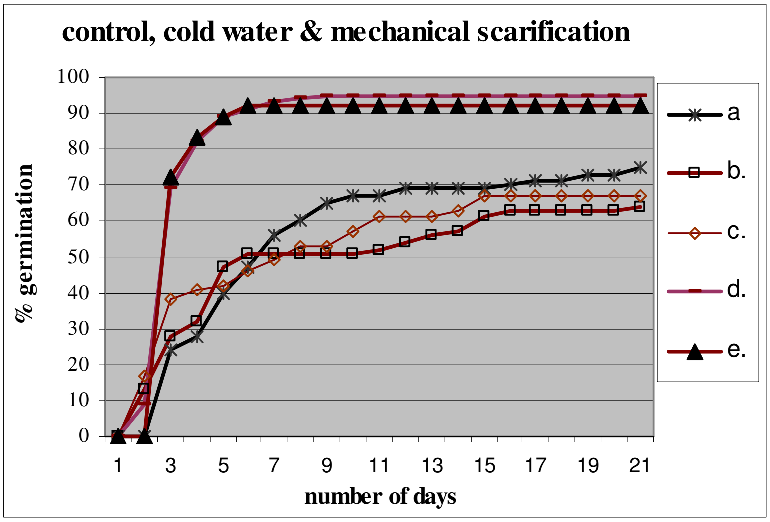
4.5. Soil Seed Bank

Only six *A. drepanolobium* seeds (2, 1, 3 & 0 from site 1, 2, 3 & 4 respectively) were found on the litter layer that accounted for a total of 267 seeds, with mean of 8.3 ± 2.6 (X ± SE) seeds/m^2. All seeds were viable except one being not full seed. In contrast, seeds were totally absent from the normal mineral soil layer (Table 3).

4.6. Seed Germination

The ANOVA result indicated that there was a significant difference among treatments [$F_{(5, 17)}$ =11.02, P<0.05]. Tukey's mean difference test demonstrated that mechanical scarification and hot water treatments, and acid and heat treatments (both dry heat and hot water) were significantly different.

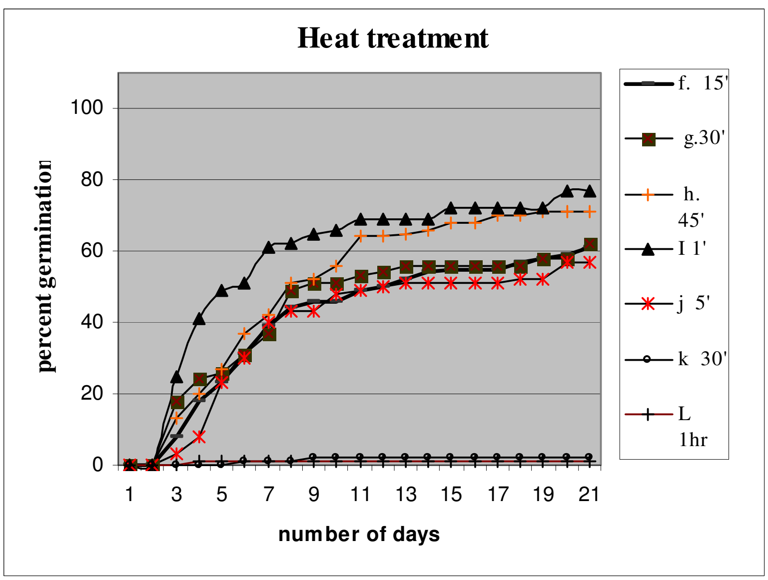
Although high percentage germination (75%) of *A. drepanolobium* was attained under control condition (Fig. 6 A), the highest percentage and rate of germination (greater than 90% within about 5 days) were achieved by scarification (mechanically by hilum side and acid especially for more than 30 minutes exposure), and the least percentage and rate was observed in those seeds treated in boiling water for > 30 minutes (Fig. 6 B). Heat treatments, both dry and moist heat (esp. hot water for more than 5 minutes) and cold water treatments did not improve the germination of the species (fig 6). But Tukey's HSD indicated that cod water, dry heat and control treatments were homogenous at 0.05 significance level. However, only hot water treatment didn't show germination improvement over the control experiment. On the other hand, complete failure of germination has been recorded following dry heat (90 ^oC) treatment, and it has resulted in an overgrowth of molds within 2 weeks.



Key

a. control
b. cold water 24hrs
c. cold water 48 hrs
d. scarification-hilum hilum side
e. scarification – hilum back side

Fig. 3A Germination result of *A. drepanolobium* under control, cold water and mechanical scarification treatments.

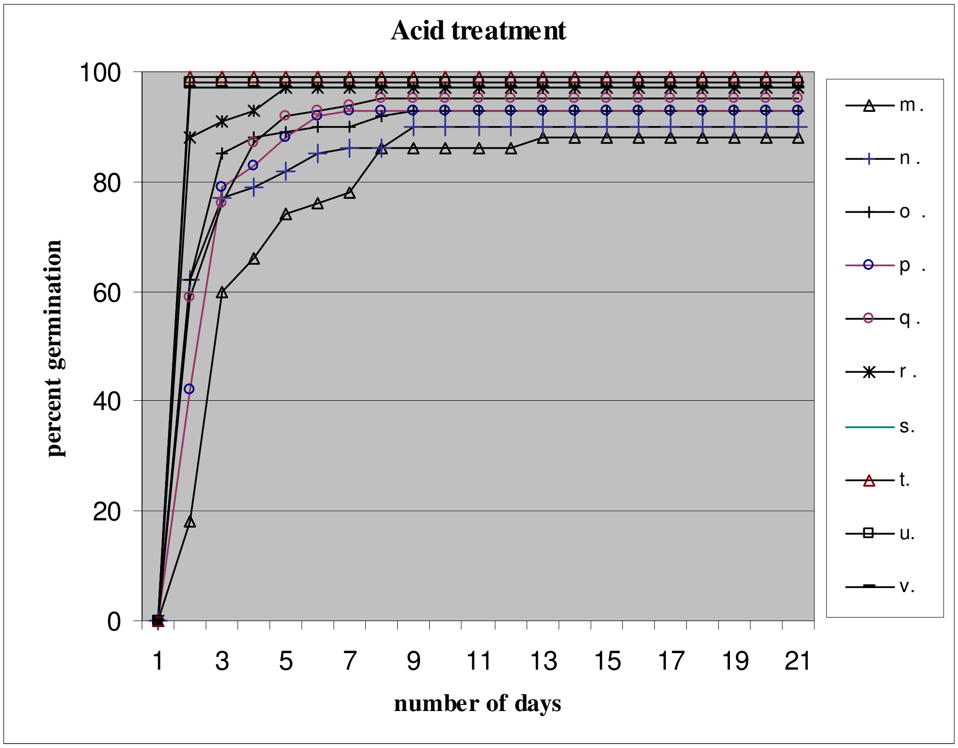


Key
Dry Heat (60 ^{0}C)
f. for 15'
g. for 30 '
h. for 45 '

Hot Water (98 ^{0}C)
i. for 1'
l. for 5'
k. for 30'

Figure 6B Germination of *A. drepanolobium* under dry heat and moist heat treatments.

Figure 6 Continued



Key

m. for 5 ‘
n. for 15 ‘
o. for 30 ‘
p. for 45 ‘
q. for 1 hr
r. for 2 hrs
s. for 2: 30 hrs
t. for 3 hrs
u. for 4 hrs
v. for 5 hrs

Figure 6C. Germination of *A. drepanolobium* under Sulphuric acid (96%) treatment for various periods.

Table 4. Mean cumulative percent germination of *A. drepanolobium* at different treatment showing Tukey HSD

Treatment	Mean cumulative percentage
Hot water (98 °C)	38.82a
Dry heat (60 °C)	53.60c
Cold water	45.00c
Control	60.00c
Mechanical scarification	75.24b
Sulphuric acid (96%)	76.76b

a. homogenous group 1 with p-value of 0.14
b. homogenous group 2 with p-value of 0.096
c. homogenous group 3 with p-value that belongs to both groups 1 and 2 at alpha = 0.05.

4.7. Stumping Height and Coppicing Ability

Analysis of Variance showed that there is no statistically significant difference both in coppice number and sprout height among the three treatments [F (2, 59) = 0.12 and 0.14, P > 0.05] respectively. The result of cutting stumps showed that there is a tendency to increase in both coppice number and sprout height down to the tree height. This may be because cells that are more juvenile are found down to the base and thus more coppices. Noteworthy is that 85 % of the variation in coppice height is accounted for by other factors rather than stump diameter (Fig. 7).

Table 5. Mean (X ± SE) number of coppice and mean height of *Acacia drepanolobium* under three different stump levels (50 cm above ground, ground level and 10 cm below ground).

Stem stump	Mean Number of coppices (X±SE)	Mean height of coppice (X± SE) cm	% of stumps coppiced
50 cm above ground	10.3 ± 2.3	7.8 ± 1.12	58.4
Ground level	10.8 ± 2.3	13.1± 3.1	76.9
10 cm below ground	12 ± 2.1	13.3± 1.1	62.5
Over all mean	11.19 ± 1.13	12.00 ± 1.12	65.93

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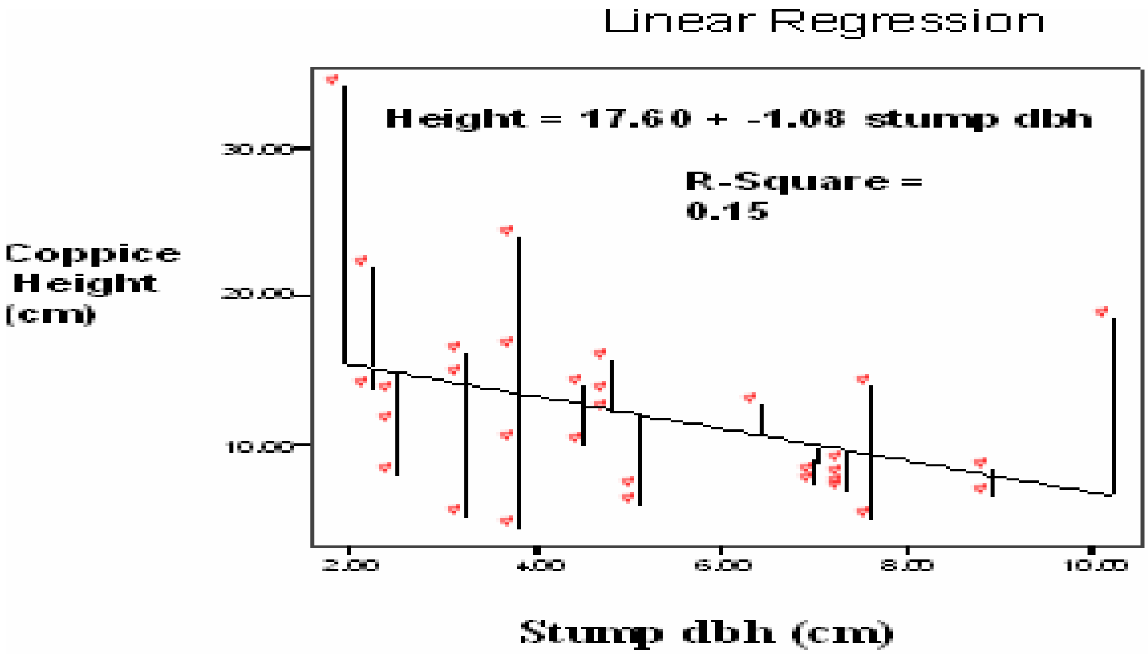

Figure 4. The relationship between original stump diameters and shoot coppice height in *A. drepanolobium*

4.8. Symbiotic Interactions of *A. drepanolobium*

4.8.1. Ant - *Acacia drepanolobium* Interactions

In the study area *A. drepanolobium* was found to host four ant species (3 *Crematogaster* and one *Tetraponera species*) particularly this was in red soil habitat. The largest *A. drepanolobium* occupant ant species in red soil habitat is *Crematogaster mimosae* (54.6%) (Table 6). Similarly, it was found inhabiting most of the sampled seed bearing trees (85%). The black cotton soil habitat hosted only two ant species, *Crematogaster nigriceps* with a slightly higher proportion than *Crematogaster mimosae*.

Table 6. Percentage distribution of occupant ant species on *A. drepanolobium* in two different habitats. Where Cn=*Crematogaster nigriceps*, Cm = *C. mimosae*, Cs= *C. sjostedti* & Tp=***Tetraponera penzigi.***

Occupant ants	**% in red soil**	**% in black soil**	**Percent of occupants in seed bearing trees**
Cn	23.1	56.9	11.7
Cm	54.6	43.1	85
Tp	15.7	0	1.3
Cs	6.6	0	2

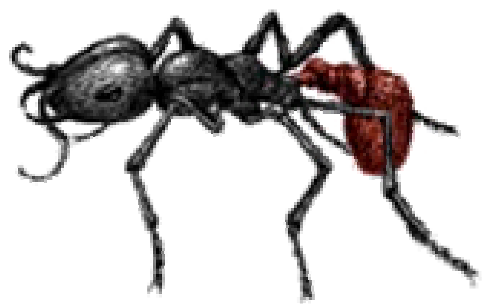

Figure 5. A typical *Crematogaster species* (*Crematogaster nigriceps)*

4.8.2. *Acacia drepanolobium*- Bruchid Beetle Interactions

Two *A. drepanolobium* seed feeding beetle species were identified. The larger species which has a brown colored body was identified as *Callosobruchus maculatus* (Fabricius) or cowpea beetle, (Coleoptera: Bruchidae) commonly known as bruchidand and the second rather small species was identified as *Acanthoscelides obtectus* (Say) or common bean weevil. It is small headed with short stout mandible (Fig. 9).

Table 7. The fraction of healthy, deformed, bruchid infested and aborted seeds (n= 700 pods) and percentage of ungerminated seeds (n= 22 treatments) due to bruchid infestation.

Condition of seeds	Percentage (%)
Healthy	77
Deformed	6
Destroyed	6.6
Aborted	10.4
Total	100
Ungerminated seeds due to bruchid damage	7.8

These two species challenge the reproductive capacity of the study species by destroying its seeds though the extent of damage by each species was not quantified in this study. Out of the seeds collected from mature pods (n = 700), 6.6 % was found to have been infested by bruchid larvae. On the other hand, 7.8 % of originally healthy looking seeds have failed to germinate (n=22 treatments) (Table 7). Such finding indicates that bruchids contribute to the reduction of percent germination of the seeds of *A. drepanolobium.*

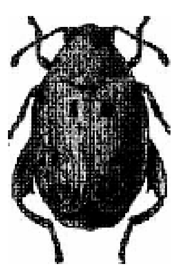

Figure 6. A representative Bruchid beetle (*Acanthoscelides obtectus*, a bean weevil)

4.8.3. Root Symbiosis

4.8.3. 1. Root Morphology

The preliminary root excavation experiment has indicated that *A. drepanolobium* has a very long taproot system (Table 8). The taproot is very long and associated with extensive lateral roots (Fig. 4A). Root symbiosis was mainly observed around the taproot (main root).

Table 8. Showing the length of root systems of *A. drepanolobium* of different aerial heights.

Plant aerial height	Taproot length	Lateral root length
0.35 m	1.65	1.4
1 m	2.1	2.32
1 m	1.8	2.19

4.8.3.2. Acacia drepanolobium *–Rhizobium Interactions*

Slow growing *Bradyrhizobium species* was isolated from root nodules of *A. drepanolobium* in this study. It was found nodulating mainly near or around the main tap root system. The mean number of nodules in 3 months aged seedlings of *A. drepanolobium* was 4.14 ± 1.01 and 5.8 ± 0.57 (X ± SE) in red and black cotton soils respectively. (Table 9). The calculated value of t at 24 df = -1.22 (P=0.268), which is less than the tabulated value of 2.06 at P = 0.05, showing that there is no significance difference in nodulation status of *A. drepanolobium* in the two soil types. But in both cases, the number of nodules is small and they are poorly developed.

Table 9. Mean number and mean weight of nodules in *A. drepanolobium* seedlings**.**

Soil type	**Number of nodules/plant (X ± SE)**	**Dry weight /plant (gm) (X ± SE)**
Red soil	4.14 ± 1.01	0.005586 ± 0.0021
Black cotton soil	5.8 ± 0.57	0.0026 ± 0.0005
Over all	4.9286 ± 0.5973	0.00381 ± 0.0008

4.9. Community Perception on *A. drepanolobium*

The result of interviewing (Appendix-I) pastoral community elders from different woredas (Appendix II) indicated that elders have attributed overgrazing (42 %, n = 5), climate change (25 %) and fire ban (25 %) as to the bush encroachment by *A. drepanolobium* since Dergue[1] regime. About 92 % (n =11) of them have stated that its seeds are dispersed by wind, and 50 % of the informants have expressed their hatred against its existence. Further, larger proportion (42 %) has agreed that bush fire could be a solution to manage bush encroachment of the study species.

[1] Former military government in Ethiopia

5. DISCUSSION

5.1. Floristic Composition, DBH and Bush encroachment

A. floristic Composition

In the study, although *Acacia drepanolobium* formed a virtual monoculture in the overstorey, investigation of floristic composition showed relatively considerable number of species in *A. drepanolobium* Wooded grassland. Several factors such as 1) the widely spaced nature and the reduced canopy crowns of *A. drepanolobium* that can provide sufficient light; 2) the nutrient enrichment by the deposition of cattle urine and feaces as described by Keesing (1997); 3) nitrogen fixing capacity of a tree and 4) a good soil condition might have contributed for the presence of considerable understorey species in *A. drepanolobium* woodland.

Coppock (1994) characterized *A. drepanolobium* with taproot, tall boles and elevated open crowns, which has either positive or neutral interaction among understorey herbaceous layer when compared with *A. brevispica*. A careful analysis of vegetation is a means of revealing important information about components of an ecosystem. Vegetation study could also help and promote to select and employ the appropriate conservation and management plans for sustainable use of ecosystem (Kershaw, 1980). So, floristic data are relevant for establishing the present situation for the environmental impact assessment and for monitoring changes in ecosystem quality in terms of changing species composition.

B. DBH

The present study showed the mean density (number of individuals on the total area of the sample plots) of *A. drepanolobium* was about 1798/ ha, which has represented size distribution with L-shape based on dbh classes. However, site 4 (a red soil habitat) constituted 3535 individuals /ha (Appendix 4 b) i.e., 49.1% of total density of *A. drepanolobium* in the study area. The density was found to increase significantly on red soil compared to black cotton soil perhaps the soil properties must have favored seed germination and establishment.

C. Bush Encroachment

The current study of floristic composition showed that relatively considerable number of species (114 species) has been recorded in *A. drepanolobium* wooded grassland (Appendix III). However, Zerihun Woldu and Sileshi Nemomissa (1998) have reported 221 species from non-*Acacia drepanolobium* wooded grassland in Borana. The reduced number of species count in vegetation composition in the present study may illustrate the effect of the invading woody plant, *Acacia drepanolobium*, on the species diversity.

Large shifts in floristic composition over one to several years can occur in response to unusually dry or wet weather condition. Concerning *A. drepanolobium* the fine textured soils with more water holding capacity, overgrazing following cultivation of earlier rangeland and concentration of a large number of livestock on the limited rangeland, drought, fire ban and natural succession of plants could be cited as possible factors facilitating *A. drepanolobium* encroachment over long period of times. Moreover, defence mechanism through its aggressive symbiotic ants and the thorny nature could be quoted as major factors for the extensive invasion of the rangelands by this species since these attributes have protected against browsing by herbivores.

Red soil habitats were found to be heavily infested by *A. drepanolobium.* This certainly could cause reduced grazing capacity due to low level of grass and growth of annuals of low forage value. The cumulative effect of this finding could threaten the sustainability and the livelihood of pastoralists, commercial livestock grazing and grassland biodiversity.

However, some challenges are fostering the reproductive biology of *A. drepanolobium*. For instance, the symbiotic ant species (*Crematogaster nigriceps*) that sterilizes the shoots and flowers (cf. 4.8.1.) results in reduced seed production. Moreover, its seeds are predated by bruchid beetles (cf. 4.8.2.). Likewise, A. *drepanolobium* hardly has persistent soil seed bank. Further more, no new seedlings were recorded during field study. However, many saplings about 5-30 cm height were found inconspicuous inside the grasses. Noteworthy is these sapling may be favored by grazing of grasses and drought since woody plants with a deep root system can extract water and nutrients from underground. Further, Coppock (1994) reported 10 % decrease in percent germination of this species at 3 cm soil depth, particularly in black cotton soils and the susceptibility of its seedlings to dry periods. Therefore, in view of invaders characteristics of encroacher woody legume species such as *Prosopis juliflora* (Hailu Shiferaw, 2002) and other *Acacia species* (Table 10), *A. drepanolobium* was found to be relatively unaggressive encroacher species. There fore, it may not invade new area over a short period of time.

Pratt (1987) reported that under favorable rainfall, natural succession would lead to a dominance of woody plants in most communities in Borana regardless of grazing. The same author has hypothesized that overall increase in woody plants appeared to be due to gradual thickening of the existing stands as a result of seed recruitment rather than expansion of plants in to new sites. Similarly, Young *et al.* (1998) suggested that increase in woody plants is from the old (thick stemmed) but very small and suppressed individuals already present in the area.

Table 10. Comparison of ecological characteristics for invisibility of 2 selected acacias with *A. drepanolobium.*

s. no	Factors	Acacia species		
		A. nilotica	*A. saligna*	*A.*
1	Native to	e.g. S. Africa	Australia	E.
2	seed production capacity	175000/tree/year	10,500 seeds/m^2/year	24
3	soil seed bank	persistent	persistent	sm
4	long seed dispersal	by animals/ flooding	poor but may be by birds, water and man ; fall to ground	m
5	growth rate of young seedling	fast	fast	fas
6	seedling and young protected by	thorn	thornless	th
7	climatic range of growth	wide	subtropical arid, flood plains	ari &
8	invasion facilitated by	treeless environment	open area	ov
9	Mechanisms to reduce seed predation	rapid consumption	not well established	ra
10	Tolerance	fire, drought & salinity	seeds tolerate fire ;tolerates different soil conditions	lo
11	Nitrogen fixation & vegetative reproduction by coppicing	yes	yes	ye
12	Other adaptations	long lived (30-60 years)	Short juvenile period	U
	source	Carter (1994)	Cronk and Fuller (1995)	Yc Cc

On the other hand, the increase in the sedentary life of pastoral community due to some developments activities such as water wells has led to an increase in the number of livestock and human population that perhaps has increased woody plant density (Coppock, 1994; SORDU, 2003). Moreover, fire ban played a key role with regard to extensive bush encroachment. According to Walker *et al*. (1981), proliferation of woody species under grazing pressure can be facilitated in fine textured soils, which can hold soil moisture.

It has been noted that every Boran is trying to cultivate bottomlands in Liben Woreda, which can degrade the rangeland quantity as well as quality which in turn will hasten overgrazing. Likewise, informant pastoral elders suggested over grazing, climate change and fire ban as causes for extensive encroachment of *A. drepanolobium* into the rangeland.

Nonetheless, multifactorial, multiyear as well as multisite studies are required for understanding the effects of different factors on species composition and diversity in grasslands, suggesting that a shorter or less extensive study might be inadequate to conclude.

5.2. Soil Properties

The proportion of soil particles can differ within sites that in turn could affect the productivity of an area. The overall mean values for sand, clay and silt were 28.95 %, 42.8 % and 28.25 % respectively. This is inconsistent with the reports from Coppock (1994) who indicated 53 %, 30 % and 17 % and 67 %, 17 % and 16 % for six upland range sites and 8 protected rangeland sites “Kalos[2]” respectively for the corresponding soil particles. The disparity among studies could be due to sites selected during the study periods. Nonetheless, in the present study the mean value for clay particles is > 30 %. This stands for high clay soil (Miller and Donahue, 1997). The high proportion of clay indicates the capacity of soil to store moisture and nutrient probably high N, P, and organic matter, which could increase the productivity of an area. On the other hand, high clay content may obstruct germination of buried seeds. In the current study, it was observed that black cotton soils affected the germination of *A. drepanolobium*. The presence of a very low level of seedling population of this species in the present study could be attributed partly to the compaction of black cotton soil.

Soil texture and structure have effects on seed germination and seedling emergence through their moisture holding capacity (Lawrence, 1957), soil aeration and by influencing contact between seeds and the substrata (Kennenni, 1990). The seed emergence from the greater depths is affected by soil thickness and compaction, which in turn can influence population dynamics of a particular plant (Lawrence, 1957). Soils with pronounced clay matrix impede germination of buried seeds (Benvenuti, 2003).

The high clay content particularly black cotton soil retains more moisture, which supports growth of forage plants, and agricultural crop species, which agropastoralists rely on. Thus, the higher density of *A. drepanolobium* seems to compete with many plant species, which inurn may upset the livelihood of agropastoral community.

Soils from all sites had the concentration of soluble salts less than 0.4 ms/cm (normal level). This could be due to the low level of soluble salts probably cations (Na^+, Ca^{2+}, Mg^{2+}) and

[2] Reserved grazing area

anions ($SO4^{2-}$ and Cl^{-}). It has been reported that such soils could support the growth of most plant species (Donahue et al., 1983). The present study may suggest that the recorded concentration of soluble salts of the soil from the study area may render *A. drepanolobium* a highly competitive position in comparison with other valuable forage species. The overall mean value of pH is 7.5 but the corresponding value reported by Coppock (1994) from seven rangeland sites was 7.1. This difference may be due to the sites sampled. According to Millot (1997), most plants grow well between pH 5.5 and 8.5, and also fair for the activity of beneficial microorganisms, which is consistent with the present study.

Generally, the study has indicated that though all the soil properties have shown significant differences among sites, 1) pH and EC were within the normal ranges that favor growth of most plant species, 2) the soils were rich in clay that contain more nutrients than soils with poor clay content and 3) soil could act as a water reservoir in dry periods where high density of *A. drepanolobium* competes with other valuable forage plant species.

5.3. Seed Characteristics

The largest number of pods or fruits counted from 7.25 m *A. drepanolobium* was 2010. This contrasts with Coppock (1994) who has reported 500 and over 30,000 pods for trees 1-2 m and over 6 m high respectively. This difference might have been generated due to differences in sampling and direct counting in the former and the current reports respectively.

The study species produced relatively high number of healthy seeds was perhaps meant to compensate challenges pertaining to both pre-dispersal and post-dispersal seed predation. Seeds contribute to the adult replacement and to increase in local population size and function as the means of dispersal to areas distant from the local population (Lounda, 1978). According to Harper (1977), total seed production of a plant is determined by the size of the plant, the proportion devoted to seeds and the mean seed weight. The number of flowers may control the number of fruit and seed produced by a plant (Lee and Bazzaz, 1982). The extent of seed production in *A. drepanolobium* was found to be large in number relative to its size. This may positively affect fitness of a plant by increasing efficiency of resource utilization, improving average quality of offspring, and increasing fitness of seed dispersal. Lee (1988) also suggested that pollen source, position of the inflorescence and pollination intensity are surely related to seed number. Seed number may also be determined by other factors such as number of ovules/ ovary.

A seed number per fruit was influenced by seed abortion. The abortion rate in *A. drepanolobium* was 10.4 %. Different abortion rates have been reported for various *Acacia species*, e.g., 4.6 % for *A. toritlis* (Tybirk, 1993), 3.8 % for *A. Senegal* and 6.4 % for *A. seyal* by Skagerlund (1999). As compared to these reports, the abortion rate in *A. drepanolobium* is higher than aforementioned species, which may contribute significantly to a reduced fitness value to its environment. Bruchid larvae and probably the nature of pollen might have imparted abortion in *A. drepanolobium*. However, further study is required to precisely figure out the factors contributing to such a high level of abortion in *Acacia drepanolobium*.

At the level of individual seed, abortion is related to the time of seed initiation, position within the fruit and pollen source such as lethal alleles (Wein, 1984; cited in Lee, 1988). Low pollen viability and predation on developing seeds by bruchid larvae were also suggested as causes for seed abortion in acacias (Tybirk, 1993).

According to Tolsma *et al.* (1987), the strong nutrient demand that causes high abortion rate among inflorescence and young pods is meant to regulate resource availability. Lee (1988) also suggested abortion as an adaptive in that it eliminates the inferior products of inbreeding, which provides an opportunity for selection among developing seeds (Guth and Weller, 1986).

The present study indicated that *Acacia drepanolobium* has relatively large seed size having more weight than some invader legumes such as *P. Juliflora* (Hailu Shiferaw, 2002). Thus, these seeds can influence the soil seed bank. Seed size is an important component of life history of a plant (Harper, 1970; cited in Wulff, 1986). According to Harper and Benton (1966), variability in seed size may affect seed germination, seed dispersal and seed-water relation, and ability to emerge from depth of sowing and affect seedling establishment. Harper (1977) stated that the smaller the seed, the later the seedling emergence from deeper sows because of less food store in the cotyledon.

Thompson and Grime (1979) indicated that small seeds form persistent soil seed bank, and easily enter the cracks and are incapable of germination following seed dispersal due to innate dormancy than large seeds. These authors also showed that a typical elongated seeds (greater than 0.5 mg) lack well-defined dormancy mechanisms after ripening. This seems consistent with *A. drepanolobium* (seed weight = 0.612 mg), indicating that it may lack pronounced seed dormancy. Keesing (1997) reported that 4/5 of *A. drepanolobium* seeds germinate rapidly within a week, which also might be associated with seed size and food reserve.

Generally, the study showed that *A. drepanolobium*, an indigenous invader, has relatively high seed production capacity perhaps to compensate seed predation, and relatively large seed size and weight that may limit soil seed bank.

5.4. Seed Dispersal

After feeding goat for 4 days and collecting its droppings, no intact or damaged seeds were found, indicating that the digestive process must have harmed the seeds. In the present study a camel refused to feed on pods under controlled experiment because of its behavioral pattern though large herbivores are expected to leave certain amount of unharmed seeds in their droppings (Hailu Shiferaw, 2002),

Acacia drepanolobium seeds are dispersed mainly by wind and floods. Informants believe that the dispersal of *A. drepanolobium* from the bottomlands to gentle sloppy areas by means of wind caused mass encroachment of the species. Moreover; floods normally carry seeds after stage I (dispersal from a tree to ground) to lower depressions depending on its intensity and frequency. From my observations, as pods dehisce seeds tend to lose their weight so that the probability of dispersal by wind increases. Note that most seeds remaining in their pods that are still on mother trees had holes, indicating that as seeds remain longer in the dehisced pods, they become susceptible to destruction by bruchid beetles.

In arid regions wind and sheet erosion were cited as one of the major factors affecting seed dispersal and distribution (Guo *et al*., 1998). According to Hobbs and Huenneke (1996), for invasion to take place available propagules of the species must disperse and land on suitable micro-site for germination and establishment. Dispersal offers the chance of eliminating competition among individual seeds (Thompson, 1984). Moreover, dispersal of seeds from the parent plant to its surrounding is often thought to decrease the risk of predation and pathogen attack (Harper, 1977). Coe and Coe (1987) reported that Acacia species are dispersed by cattle in Africa, and for a wide variety of species endozoochory (dispersal by animal internally) is suggested to be effective (Cronk and Fuller, 1995) particularly in indehiscent and mechanically resistant pods such as *A. nilotica* (Carter, 1994).

Coppock (1994) explained that both goats and camels feed on *A. drepanolobium* in the absence of preferable forage. It is also true that unless pods are dropped by other mechanical means, goats do not seem to afford ant attack in collecting ripe pods. Thus, due to the influence of ants and low preference of *A. drepanolobium* pods as a feed, these animals do not seem active dispersers. However, further exhaustive investigations are needed to find out the extent of the effectiveness of these animal dispersers.

5.5. Soil Seed Bank

In the present study except for the litter layer, no *A. drepanolobium* seeds were found in the mineral soil layer, showing that either the seed bank was small or non-existent. This result agrees with reports from Lyaruu *et al.* (1998) and Skagerlund (1999) who reported small or non-existence soil seed bank of other Acacia species. The absence of seed banks among most tropical trees has been attributed to predation (Thompson, 1987). Thompson and Grime (1979) also reported that large seeded herbs have evolved physiologies that favor rapid germination under a wide range of environmental conditions.

Different fates are exhibited in the history of seeds after dispersal. Some are predated (Miller, 1996), others can be destroyed by soil pathogens, and still others germinate (Thompson and Grime, 1979). Nonetheless, those seeds which don't germinate can be incorporated into the soil seed bank to stabilize population dynamics against local extinction of population under unpredictable environmental conditions (Thompson, 1987).

According to Leadem (1997), Acacia species belonging to “orthodox” seeds, and are suitable for long-term storage as soil seed bank. Sabiiti and Wein (1987) also affirmed that Acacia species accumulate large, viable but dormant seeds in the soil. Further, it was suggested that soils with pronounced clay matrix impede germination of buried seeds and accumulate an elevated persistent seed bank by inducing dormancy (Benvenuti, 2003).
Tybirk *et al*. (1992) reported greatly different variation in seed banks of tropical trees particularly acacias, within species and locations. Seed banks of African acacias are suggested to be influenced by annual seed production, dispersal, seed predation and germination. Further, prevailing environmental and soil conditions such as relatively high decay rate in arid regions were forwarded as another influences (Lyaruu *et al*., 1998).

High preference of seeds by rats was observed in the Laboratory. It also seems that some seeds can get deep into the cracks of black cotton vertisol during dry seasons. Moreover, fast germination rate of this species was found in this study. Coppock (1994) reported the occurrence of *A. drepanolobium* seeds near or on the soil surface. Conversely, about 80% of seed germination within one week was reported by Keesing (1997)**.** Also, Keesing (1997) indicated that predation of 70 % of seeds by rodents that were kept near the rodent mounds.

From the above perspectives, rapid seed germination under favorable conditions and predation appear to account a lot for the absence or small quantity of *A. drepanolobium* seed bank. This shows that *A. drepanolobium* may not depend on the soil seed bank for its regeneration. However, to reach at more accurate finding, samples should be taken several times in a year (for instance, immediately after seed dispersal or pre-germination), and over several years.

5.6. Seed Germination

The germination treatments indicated that *Acacia drepanolobium* seeds do not have the problem of pronounced seed dormancy. For practical purpose scarification methods: both mechanical and acid treatments (for longer periods say about 2 hrs) extremely improve both the percent and rate of *Acacia drepanolobium* seed germination (Fig. 6 A & C). Improvement of germination by scarification portrays that seed coat probably limits germination, by preventing imbibition of water though high proportion of seeds were germinated under control condition. Nonetheless, high heat treatments (both dry and moist) killed the seeds.

Heat, insect damage (Sabiiti and Wein, 1987), predation by ungulates (Miller and Coe, 1993) and germination inhibitors like phenolics are some of the factors that influence seed germination besides seed dormancy (Agrawal, 1986). Plants vary in their seed dormancy and requirement for germination (Demel Teketay, 1996). It was indicated that seeds of legumes require pre-sowing treatments to give uniform, rapid and improved germination that will be helpful to improve the density and regeneration capacity of desired species artificially (Mekuria Argaw *et al.*, 1999). Scarification (mechanical and acid), chemical (e.g. gibberelic acid /GA3), and low and high temperature are seed dormancy breaking treatments among others (Agrawal, 1986).

Coppock *et al.* (1990) noted that seeds of *A. drepanolobium* exhibit soft rather than hard seededness. In the present study, of the different pre-sowing treatments applied to overcome seed dormancy including seed testa if any in *A. drepanolobium*, seeds treated with acid and mechanical scarification responded with the highest percent of germination. The percentage and rate of germination of *A. drepanolobium* increased with increasing exposure to sulphuric acid. This agrees with germination results of two different Acacia species investigated by Demel Teketay (1998). It was described that acid scarification is most effective for many African acacias than boiling (Doran *et al.*,1983), which also probably minimizes further infestation of seeds by bruchid beetles. However, percent germination response to mechanical scarification contrasts with Coppock (1994) who reported percent germination values of *A. drepanolobium* below the control condition.

In this work though some healthy looking seeds (about 9 % of the control experiment) found damaged by bruchid beetle**,** the control resulted in relatively high percentage of germination. There fore, the result tends to agree with that of Keesing (1997) and Coppock (1994) who reported more than 80% germination for *A. drepanolobium* under control condition.

High percentage germination of this species under control condition may disclose the absence of pronounced seed dormancy, which is also the characteristic of many encroaching invader plant species (Cronk and Fuller, 1995). According to Engel (2000), fast germination response can be an adaptation or mechanism to escape seed predation (but not necessarily seedling mortality) by such animals as rodents (Keesing, 1997), Bruchid beetle and the like. Treatment of *A. drepanolobium* seeds by heat for long periods did not improve seed germination so did cold-water treatment. Coppock (1994) described that hot water treatment for a period of 7 minutes hastened seed germination of *A. drepanolobium,* which is inconsistent with the present study**.** The susceptibility of *A. drepanolobium* seeds to heat (for 90 ^{o}C) may indicate that rangeland experts and pastoralists can manage the encroaching bush and its recruitment by burning from undesired areas.

5.7. Stumping Height and Coppicing Ability

The results of this study indicated that *A. drepanolobium* coppiced at all the sampled heights though its potential to coppice increased towards the bottom (soil surface). It was stated that coppicing is minimized by cutting trees late in the wet season than tree cut at any other time because this does not allow the stump time to replenish lost carbohydrates, forcing it to survive the entire dry season on limited resource. As a result, minimum reserves are probably available for early rainy season growth, and this may affect future production (Hardesty *et al.,* 1988). For management purpose in areas where there is a high density of *A. drepanolobium* cutting at 50 cm height late in wet season, and debarking as stated by Ahmed Jemal and Florian (1997) agrees with this result since coppicing ability declines as height increases though debarking was not carried out in this study.

Sprouting from cut stumps is the most common means of regeneration after cutting, and the neotropical trees were believed to produce new shoots sprouting from stems and roots in recovery following the cut that is rare in paleotropical trees (Uhl *et al*., 1981). Ran and Bell (1989) reported that Acacia species vary greatly in their response to cutting, ranging from a complete failure to extreme coppicing. Ahmed Jemal and Florian (1997) described that *A. drepanolobium* produces 4 to 6 new shoots (coppices) in average when cut at the bottom of a tree, which is about half of the present study. Seasons, technique of stumping, climate conditions, selected plant age and failure to clear branch materials may be accounted to the disparity between the earlier and the present reports. Moreover, type and frequency of injury, site, diameter and various growth regulators may account for the described variation (Blake, 1983).

5.8. Symbiotic Interactions of *A. drepanolobium*

5.8.1. *Acacia drepanolobium*- Ant interactions

Two genera with 4 ant species were found in the study area where each mature tree was occupied by one of the four ant species but *A. drepanolobium* in black cotton soil habitat hosted only one genus (*Crematogaster mimosae* & *Crematogaster nigriceps*). The highest proportion of *C. mimosae* occupant seed bearing plants may be explained by the effectiveness of the species in defending the plant against herbivory and their feeding behavior unlike *C. nigriceps* that prunes the auxiliary shoots. The presence of ant species protects the plant from the herbivory and supports for its successful regeneration in one hand, but on other hand, species like *C. nigriceps* reduce the reproductive potential of plant by sterilizing the flowers. Therefore, the acacia-- *C. nigriceps* relationship seems rather parasitic than mutualistic.

The absence of *Tetraponer penzigi* and *C. sjostedti* in black cotton soil habitats may be due to the environmental factors such as soil condition, altitude, plant community (e.g., *C. sjostedti* occupies *Acacia seyal* too) and the like may influence their distribution. Nonetheless, for precise explanation further investigation should be carried out.

Ant-acacia relationship was addressed by many authors (Vickery, 1984; Beattie, 1985; Stanton *et al.,* 1999). In the study area *A. drepanolobium* was found to host 2/3 of the known ant genera of tropical Africa i.e., *Crematogaster* and *Tetraponera* (Höllldobller and Winson, 1990). Each mature tree was occupied by one of the four ant species that is consistent with results from Young *et al.* (2003). These ants make holes and house inside galls (Stanton *et al.,* 1999), and they are supposed to protect the plant against herbivory as explained by Stapley (1998).In black cotton soil habitat the canopy is virtually a monoculture of *A. drepanolobium* where trees are highly restricted and more compact which is consistent with report from (Stanton *et al*., 1999). This may be explained by relatively higher proportion of *C. nigriceps* (56.9%) since this species reduces branching by pruning the shoot and flowers buds.

According to (Stanton *et al*., 1999), the four ant species are fiercely competitive and mutually exclusive. *C. mimosae* is the most aggressive competitor and *T. penzigi* is the least, and the others are intermediates. *C. mimosae* and *C. sjostedti* were supposed to be late successional groups. However, the capacity to defend other ant species effectively seems made *C. mimosae* the most successful occupants (Young *et al.*, 1997).

Even though ant-acacias represent a classic mutualism, a potential drawback is that ant-guards may drive away useful insects particularly pollinators (Raine *et al.,* 2002), and ants secretions may reduce pollen viability (Raine *et al*., 2002). Similarly, C. *nigriceps* prunes the neighboring canopy to reduce the reach of opponent ants. If its enemies occupy nearby trees earlier, competitively subordinate colonies of *C. nigriceps* prunes and consequently sterilize their own host tree to minimize the risk of contact with more dominant ants (Stanton *et al*., 1999). Thus, this species sterilizes the plant and reduces the reproductive potential (Stanton *et al.,* 1999; Pers. observation) that is the unique act in *C. nigriceps*.

The highest percentage of *C. mimosae* occupants in sampled seed bearing trees may be due to:

1. The species are strong defenders and they might have evicted earlier occupants (such as *C. nigriceps*) in search of food.
2. Unlike *C. nigriceps*, *C. mimosae* ants don't prune the auxiliary shoots and flower buds. As a result, trees could produce seeds and fruits and *C. mimosae* tends scale insects that feed on phloem extracts as assessed by Young *et al*. (1997).
3. Since *C. mimosae* are the most aggressive species, which probably defended the plant from predators such as herbivores and some invertebrates like insects, and
4. Foundress queens of *C. mimosae* were reported to occupy mostly small saplings (Stanton *et al.,* 2002). Such early occupation of young plants might have given a chance to inhabit many *A. drepanolobium.*

5. 8. 2. *Acacia drepanolobium*- Bruchid Beetle Interaction

The investigation of the extent of *A. drepanolobium* seed infestation by bruchid beetles, by means of seed extraction from mature pods didn't show the actual figure. Even in germination test, significant number of healthy looking seeds was found infested by bruchid. It is clear that the rate of seed damage by the bruchid beetle increases as the length of seeds storage increases. Fast rate and relatively high germination percentage as well as more seed production seem mechanisms of escaping seed predation by the study species.

However, I found more than 50 % of seeds damaged by bruchid beetle on trees (those that did not disperse) during my field observation at the end of February 2003, indicating that long storage makes *A. drepanolobium* seeds more vulnerable to bruchid damage. As the period of seed storage increases, the reinfestation rate also increases which in turn decreases percent germination of seeds as described by Sabiiti and Wein (1987).

Callosobruchus maculatus commonly known as bruchid causes loss of seed weight, quality and affects germination (Singh and Singh, 1990). It has two morphs: flightless morph that develops on stored seeds and the other flying morph feeds on legumes in the field; and the second beetle, *Acanthoscelides obtectus* more than one larva of it can live within a seed and cause complete destruction of seeds. It attacks all pulses, and can reproduce repeatedly in dried pulses (Richards and Davies, 1957).

According to Ernst *et al.* (1990), acacia seeds are hosts for bruchid beetle larvae. Bruchidae lay eggs in or on the green (young) pods some days after flower fertilization**,** and the larvae mine their way through until they reach the seed where they feed and pupate (Pellew and Southgate, 1984**)**. Under favorable climate six generation may occur within a year in the same batch of seeds (Richards and Davies, 1957). According to Miller and Coe (1993), secondary infestation following emergence may then occur on mature and dry seedpods on the tree and on the ground. However, in case of *C. maculatus* even its larvae can chew seeds with cutting edges of their mandible (Morgan *et al.*, 2003).

According to Mucunzugi (1995), plants evolved mechanisms that are partly helpful to escape too much seed predation for a given population seem parental morphology and the way of diaspore exposure, size, smoothness, hardness and seed chemistry, and high seed production. Thompson (1987) cited that a group of legumes with large seeds (mean weight = 3 mg) in average avoided attack by bruchid beetle larvae by possessing toxic chemicals but the smaller seeds (mean wt = 0.26 mg) don't prevent attack, and their greater number simply ensures that some seeds escape predation**.** Engel (2000) also proposed that fast germination response could be an adaptation to escape the seed predation (but not necessarily seedling mortality). Moreover, Sabiiti and Wein (1987) reported the adaptation of *Acacia sieberiana* seeds to fire, which are large (200mg) with thick testa that remains less susceptible to heat damage given that high fire intensities (50-60 ^{o}C) probably leads to crack in seed coats and certainly leads to killing the bruchid larvae.

Many Acacia species produce aromatic pods as a reward for primates, elephants and ungulates (Coe and Coe, 1987). According to Barnes (2001), seeds of *Acacia erioloba* escape bruchid infestation by means of dispersal by animals; the passage through gut may also kill bruchid larvae within seeds and prevents reinfestation (Miller and Coe, 1993). The exit holes on testa let entry of water, which facilitates germination only if the embryo is healthy. Pertaining to *A. drepanolobium* as assessed by Keesing (1997) and also from seed germination results (cf. section 4.6), relatively high seed production and fast germination seem quite adaptations to minimize seed predation by bruchid beetles. Thus, rapid dispersal of seed is possibly critical to the survival of acacia species (Ross, 1979; cited in Doran *et al.*, 1983).

Bruchid beetles are highly challenging the reproductive potential of some economically important Acacia species. Miller (1996) showed that an infestation rate of *Acacia tortilis* in S. Africa to be 68 %. The rate went up as seeds stored for a long. Insect- seed predation can play significant roles in reducing plant population growth both natural and agricultural ecosystems. According to Janzen (1970), predation leads to a low density and wide spacing between adult trees. This perhaps holds true in *A. drepanolobium* tree mainly in black cotton soil habitat, whose seeds might have been checked by bruchid beetles that led to wide spaced nature of *A. drepanolobium*.

5.8.3. Root Symbiosis

5.8.3.1. Root Morphology

The preliminary root excavation experiment indicated that *A. drepanolobium* has tough tap root system, perhaps suggesting that the plant obtains essential materials mainly deep from the soil. The extensive growth of taproot in case of the smallest plant (0.35m) may give highlight for: 1) the plant's strategy to extract water and other necessities from deeper by means of taproot. 2) that the plant remained inconscipicous inside grasses for a long or its height might have been checked by herbivory. On the other hand, the presence of lateral root may show considerable competition with herbaceous understorey. This might have contributed in decreasing the number of plant species. On the contrary, Coppock (1994) reported that *A. drepanolobium* with less extensive root system has considerable understorey plant species than other acacia species like *Acacia brevispica.* However, since the present study was highly limited in that it demonstrated only the highlight and an extensive study on the root morphology is required.

5.8.3.2. Acacia drepanolobium *–Rhizobium Interactions*

The present study indicated that nodules in *A. drepanolobium* were small, pale and poorly developed in clay soils. The study species was found to be nodulated by *Bradyrhizobium* species. The low number of nodule count and nodule dry weight in clay soils might have arisen from 1/ reduced aeration in clay soil 2/ rich essential nutrients such as nitrogen and 3/

reduced availability of trace elements like Molybdenum and Cobalt, and 4) slowness of fixer species.

Rhizobia are a group of bacteria, encompassing the genera *Rhizobium*, *Sinorhizobium* and *Bradyrhizobium*, normally found in the soil, which establish mutually beneficial relationship with legumes (USEPA, 2002). Tree legumes are nodulated by two kinds of rhizobia 1) *Bradyrhizobium*, slow growing but prevalent kind of tropical soils, nodulating many tropical trees (in all 3 subfamilies of Fabaceae) effectively and 2) *Rhizobium* which is a fast growing one. Several *Acacia species* are nodulated by these two bacteria species. Inert atmospheric nitrogen made available to most legumes in the form of ammonia (NH_3) by means of biological nitrogen fixation by bacteria.

Nodules vary in number depending on plant species. They can also be influenced by bacteria strains, poor nutrition, pod filling, or other plant stresses (Lindemann and Glover, 1998). Absence of phosphorus (Costa and Paulino, 1997), reduced molybdenum (Mo), water logging, dry and hot condition and acidic soils (Riddell and Lucky, 2003), availability of inorganic nitrogen in the soil at later growth of legumes (Danso *et al*.,1992;), inefficient supply of mineral elements such as Calcium, Boron and Iron (Robson, 1978; cited in George *et al.,* 1992), and salinity and rise of temperature (Wilkins, 1984) were reported to restrict nodulation (number and dry weight of nodules) in legumes.

According to Russel and Russel (1975), nitrogen fixation per hectare by a leguminous plants depends on the number of nodules per ha, their size and longevity, and the bacterial strain in them. This in turn depends on the availability of water and the nutrient status of the soil. For instance, the presence of high loam and clay content, and high nitrate content was suggested for the lower growth and number of root nodules in nitrogen fixing legume, *A. mangium* when *Rhizobium species* was inoculated (Lesueur *et al*.,1994), showing that legume plants don't form active symbiosis in the presence of necessary nutrients.

Therefore, the present study indicated that although *A. drepanolobium* capable of being nodulated by slow grower *Bradyrhizobium sp.*, nodulation was not much significant in clay soils probably it was slowed down due to poor aeration, availability of nutrients like nitrogen and phosphorous in clay and the like. However, it requires further research to quantify the exact contribution of each factor in nodulation of the study species.

5.9. Perception of Local Pastoral Community on *A. drepanolobium*

The informants mentioned that terrible woody encroacher, *A. drepanolobium*, was once restricted to black cotton soil habitat but today it became bushy with large number of individuals encroaching to gentle sloppy red soil habitat. Among the reasons given, 25% informants declared climate change in that rain seasons became unpredictable, and drought killed many grass species and favored growth of undesirable woody species like *A. drepanolobium.* They claimed that even if periodic burning is carried out there is no significant fuel load to burn due to low rainfall, in such cases they do not wish burning since they lose dry grass if it fails to rain; other 25% blamed the fire ban. In the past they used to burn their rangeland before rainy seasons to stimulate new growth, to kill encroaching bushes, and some unwanted insects. Some 25 years ago, during Dergue regime the law of fire ban prevented the above mentioned traditional practice, (42%, n = 5) of them stated that overgrazing caused by degradation of rangelands by farming activities that led to the concentration of large number of livestock on the remaining rangeland area. This in turn decreased the amount of perennial grasses by stimulating the growth of dense woody plants, and the rest 8 % stated the cause to be the will of God. Nevertheless, many agreed that *A. drepanolobium* increased in density since Dergue regime.

About 92 % agreed that wind is the main disperser of *A. drepanolobium* seeds, and 33 % forwarded that animals disperse the seeds by means of their droppings particularly goats and camels. The other 50% suggested that wind and water floods disperse the seeds of the study species.

Fifty percent of (n = 6) of the informants expressed their hatred for the occurrence of the species in their localities**.** Thus, they wish its extermination for it has no use and they mentioned that a pair of thorns and the ants on the plant defend against their livestock, and it also tends to harbor some predators such as lion. It also degrades their rangelands and agricultural lands that are best suited for grazing and cropping respectively. They do not prefer to use for construction purposes since it decays before 5 months. The rest 50% asserted that it provides forage for their camels and goats, used as a shade for livestock at dry seasons, firewood, and supplies edible gum during drought periods, and also used for making seasonal cattle fences. In addition, its root is strong and used to tie up materials. Further, young galls are edible by herd men and the large older galls were used as a fluid container by Boran in the past. Therefore, informants don't want its demise.

Regarding solutions to bush encroachment**,** 42 % of the informants agreed that bush fire should be carried out to manage the plant. The other (33%) suggested traditional grazing management systems, and agreed that the community as a whole should participate in the activity. However, from their past experience they are willing to be aided by the government or NGOs such as food for work when they used to clear a bush and the rest the other 25 %

supported selective bush clearing, and they are aware of the importance of other plant species that should not be cut with *A. drepanolobium*.

6. CONCLUSION AND RECOMMANDATION

Acacia drepanolobium, a monoculture ant-plant in *A. drepanolobium* wooded grassland, has a considerable number of understorey species. The wide spaced nature and the reduced canopy crowns of *A. drepanolobium*, its ability to fix nitrogen, the presence of good soil conditions and probably nutrient enrichment by the deposition of cattle urine and feaces might have favored the presence of the understorey plant species.

The invasion of *Acacia drepanolobium* into rangelands of Borana might have been favored by good soil conditions from which the plant extracts materials by means of its extensive root systems; symbiotic ants which protect against herbivory; symbiosis with nitrogen fixing bacteria; overgrazing of the rangeland that enhanced its competition against grass species and the fire ban. Consequently, it is capable of producing large number of seeds that are dispersed mainly by wind. These seeds germinate immediately under favorable moisture. Moreover, it has a capacity to sprout at all height levels when it is cut. Therefore, aforementioned factors facilitated its invasion in the rangelands of Borana.

On the other hand, pruning of shoots and flower buds by *Crematogaster nigriceps* that reduces its seed production capacity; seed predation by Bruchid beetles; little or absence of soil seed bank; low recruitment due to sticky nature of clay soils and recurrence of drought periods tend to limit an aggressive invasion of *Acacia drepanolobium* into the rangelands.

There fore, the above facts may suggest the possibility to manage *A. drepanolobium* by using combined or integrated bush management methods such as minimizing cultivation of depressions where dry season forage is available, encouraging traditional rangeland management systems such as periodic burning and reducing excess livestock, stumping late in rainy seasons. Moreover, management through utilization is also helpful. For instance, using the tree for firewood, for charcoal production, for temporary fencing and the like. Since *A. drepanolobium* in its native rangeland maintains the ecological balance in the rangelands of Borana, it is worthy to use the integrated methods so as to limit its further invasion rather than exterminating it completely. This can be done by educating the pastoral community about the present and future ecological impacts of the study species on the rangelands and mobilizing for self initiated bush management programs.

Recommendations

Based on the results obtained from the study and casual observation in the field, the following recommendations are forwarded.

1. Ethiopia in general and Borana in particularly are going to lose highly valuable treasure of rangeland meant for livestock industry due to bush encroachment unless immediate action is taken by the government and the community. Therefore, traditional range management systems including lifting the fire ban imposition by the government should be encouraged. Since the immediate beneficiary of bush management is the pastoral community, the community should get awareness of the impacts of bush encroachment on their rangeland, and should be motivated for bush management by the clan leaders, Abagada (traditional institution leader) and other concerned governmental bodies and NGOs.

With reference to the management of bush encroachment by *A. drepanolobium*, no single method was found to be effective. So, the use of more than one feasible method is worthwhile.

a. From the nature of seed reaction to heat, periodic burning where fuel load is promising can kill available soil seed bank thereby minimizing seedling establishment and growth of saplings, and also improving perennial forage grasses.

b. Stumping *A. drepanolobium* at about 50 cm height above the ground either meant for bush management purpose or other domestic uses. The community should be well informed and motivated to stump *A. drepanolobium* during late rainy seasons so that many individuals can be killed.

c. There should be proper land use policy since today every Boran is cultivating the depressions that are meant for dry season grazing, and degrading the rangeland, which becomes one of the causes for overgrazing which in turn accelerates bush encroachment. Further, attempts should be made to limit the number of livestock in accordance with the carrying capacity of the pasture. For example, encouraging pastoralists to sell excess livestock under viable market condition. Since no single method is suffice to combat bush encroachment, the use of combined or integrated bush management methods is recommendable though reversing the original state of rangeland can be a difficult task.

2. Among four ant species, *Crematogaster nigriceps* has magnified negative relation with *A. drepanolobium* than others because it sterilizes the plant shoots including flower buds. Consequently, it minimizes the reproductive potential of a plant. The effectiveness of the ant that sterilizes the plant should be exhaustibly investigated. If its aggressiveness against herbivory is modified, the ant may be utilized as a biocontrol. Similarly, although beetle species recently identified such as *C. maculatus*, are non-host specific that attack beans and cowpeas. Further, investigations should be carried out to utilize bruchids whether they act as biocontrol agents or not in managing *A. drepanolobium*.

3. The arid regions of E. Africa are homelands for *A. drepanolobium* where it evolved through time. Both natural factors like drought and natural vegetation succession, and man made factors such as fire ban and overgrazing might have accelerated its invasion over the study area. It has uses like dry season shade and acts as a feed for some livestock, feed for humans (young galls and gum), construction and fuel purposes and maintenance of ecological balance. It also fixes nitrogen. Furthermore, unlike *A. brevispica* it allows many understorey species that are important for grazing. Therefore, it should not be viewed as something that is an evil in the community.

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APPENDICES

Appendix I The main questions interviewed

1. What factors are responsible for A. *drepanolobium* bush encroachment?
2. What mechanisms or facilitating factors for its regeneration? How does it reproduce?
3. What is the economic importance of *A. drepanolobium?* i.e. both positive and negative sides?
4. How do you think bush encroachment by *A. drepanolobium* can be managed? Or what solutions would you suggest for its management?

Appendix II List of informants from different localities in Borana

	List of informants from different localities in Borana.			
Ser. No	Name	Age	Locality (Woreda)/Kebele	Occupation
1	Kamphare Godana	75	Liben / Hadeassa	Agropastoralist
2	Chulluu Alkkee	53	Liben / Korati	agropastoralist
3	Huka Balambel	56	Liben / Hadeassa	agropastoralist
4	Cheru Duba	48	Yabello	agropastoralist
5	Galgalo Haleke	50	Teltel	agropastoralist
6	Kararssa Kuracha	48	Liben	agropastoralist
7	Gatan Hamaressa	48	Liben	agropastoralist
8	Kanna Guyya	45	Liben	agropastoralist
9	Dida Bulcha	75	Liben	agropastoralist
10	Kajora Wako	48	Liben	agropastoralist
11	Mohammed Dhedecha	75	Liben	agropastoralist
12	Wario Liben	42	Liben	agropastoralist

Appendix III Floristic Composition under *A. drepanolobium* wooded grassland

S.no	Scientific name	Habit	Family	Vernacular name	Economic importance
1	*Abutilon fruticosum* Guill. and Perr.	S	Malvaceae	Bungala	forage
2	*Acacia brevispica* Harms	T	Fabaceae		charcoal, forage
3	*Acacia drepanolobium* Harms ex Sjostedti	T/S	Fabaceae	fulesa	firewood, construction,farage
4	*Acacia nilotica* (L.) Wild.ex Del.	T	Fabaceae	Burkukke	Fire wood & fence
5	**Acacia seyal** ***Del.***	T	Fabaceae	wacchuu	Fire wood & fence
6	*Acokanthera schimperi* (DC.) Schweinf.	T	Apocynaceae	kararu	fruit edible from female plant
7	**Adenium somalense**	P.Herb	Apocynaceae	Tititu	edible by camel
8	*Aerva lanta* (L.)Juss. ex Schult.	S	Amaranthaceae		
9	*Andropogon abyssinicus* (Fresen.). R.Br.	P.Herb	Poaceae		forage
10	*Aristida adscensionsis* L.	Per.H	Poaceae		forage
11	*Asparagus africanus*	P.Herb	Asparagaceae	Sariti	Forage for camel & goats
12	*Aspilla gilletti* Wild	Herb	Asteraceae	hadda	common cold and eye pain treatments, forage
13	*Asystasia charmian* S.Moore	H	Acanthaceae		forage
14	*Balanites aegyptica* Del.	Tree	Balanitaceae	Badanna	
15	*Barleria argentea* Balf.f.	H	Acanthaceae	Kelitiphee	edible by donkeys, camel
16	*Barleria orbicularis* T. Anders	H	Acanthaceae		forage
17	*Barleria quadrispina Lindau.*	H	Acanthaceae	Kelitiphee	
18	*Becium filamentosum* (Forssk.) Chiov.	H	Lamiaceae	hurggo harre	
19	*Bidens biternata*	H	Asteraceae	Chogge	weed

	(Lour.) Merr.				
20	*Blepharis boranensis* Vollesen	W.herb	Acanthaceae	kiltiphe woyamma	
21	*Blepharis integrifolia* (L.f.) Schinz	Pros.rhi.H	Acanthaceae		
22	*Boswellia microphylla* Chiov.	T	Burseraceae	Giirarssa	construction
23	*Botriochloa insculpta* (Hochst. ex A.Rich.) A.Camus.	P. herb	Poaceae		forage
24	*Brachiaria lanchnanta* (Hochst.) Stapf.	Per.H	Poaceae	Buyyo darrara	forage
25	*Cenchrus ciliaris* L.	P.h erb	Poaceae	Meta gudessa	forage
26	*Chlorophytum somaliense* Bak.	H	Antheriaceae	Buriworabessa	
27	*Chrysopogon plumulosus* Hochst.	P. herb	Poaceae	allalo	forage
28	*Cissampelos pareira* L. var.hirsuta (DC.) Forman.	ann.climber	Menispermaceae		
29	*Clerodendron myricoides* L.	S	Erbenaceae	Habdidutessa	
30	*Coccina grandis* (L.) Voigt	climber	cucurbitaceae	barambaroo	
31	*Combretum collinum* Fresen.	T	Combretaceae	Rukessa	fire wood, charcoal
32	*Combretum molle* D.Don	T	Combretaceae	Rukessa	shade
33	*Commelina africana* L.	Per.H	Commelinaceae	Kaayyoo	forage
34	*Commicarpus pedunculosus* (A. Rich.) Cuf.	pros.H	Nyctaginaceae	gallee	forage
35	*Commiphora africana* (A.Rich.) Engl.	T	Burseraceae	Hammaressa	for making utensils, forage for camels &goats
36	*Convolvulus alsinoides* (L.)	H	Convolvulaceae		
37	*Corallocarpus Schimperi* (Naudi) Hook.f.	climber	cucurbitaceae		
38	*Corchorus trilocularis* L.	P.herb	Tiliaceae		
39	*Crabbea velutina* S.Moore	P.herb	Acanthaceae		
40	*Crepis cabonaria* Sch.Bip.	P.herb	Asteraceae	kubitdhay	
41	*Crotolaria pychnostachya* Benth.	H	Fabaceae		forage
42	*Croton macrostachyus* Hochst. ex A.Rich.	T	Euphorbiaceae	Mekanissa	Fire wood

43	*Cucumis prophetarum* L. ssp.dissectus	herb	Cucurbitaceae	Buratee	forage

Appendix III continued

44	*Cusonia holstii* Harms ex Engl.	T	Araliaceae	Abratu	
45	*Cycniopsis obtusifolia* Skan	Pros.rhi.H	Scrophularaceae		
46	*Cymbopogon caesius* (Hook. &Arn.) Stapf.	P.herb	Poaceae	Tirra	bad smelling no forage value
47	*Cynanchyum hastifolium* N.E.Br.	P.herb	Asclepiadaceace		fruit edible by man, forage for camel
48	*Cynodon dactylon* (L.) Pers.	P.herb	Poaceae		forage
49	*Cyperus bulbosus* Vahl var. spicatus Boeck	Per.H	Cyperaceae	Saattuu billa	forage
50	*Cyphostemma adenocau*lis (A.Rich.) Wild and Drummond	climber,H	Vitaceae	choppi arba	
51	*Cystostemon virescens* (A.G. Millar& H.R. Riedl)	H	Boraginaceae		forage
52	*Diospyros abyssinica* (Hiern.) F.White	s/T	Ebenaceae		
53	*Dodonoea angustifolia* L.f	T	Sapindaceae	dhitcha	forage for camel, construction
54	**Echinops hispidus *Fresen.***	H	Asteraceae		
55	*Echiochilon lithospermoides* (S.Moore) Johnston	H	Boraginaceae		forage use
56	*Eragrostis Schweinfurthii* (Chiov.)	P.herb	Poaceae	chech	
57	*Euphorbia schimperiana* Scheele	H	Euphorbiaceae	Qorsa dida	** swells the skin
58	*Eustachys paspaloides* (Vahl) Lanza and Mattei	P.herb	Poaceae	Elmogori	forage
59	*Ferula communis* L.	H	Apiaceae	Wodeele	Forage for donkeys
60	*Flueggea leucopyrus* Willd	S	Euphorbiaceae		
61	*Gnidia chrysantha* (Solms-Laub) Gilg.	errec.Herb	Thymelaeaceae		
62	*Guizotia scabra* L.	Herb	Asteraceae	awaayyee	weed/forage
63	*Helichryssum* sp	H	Asteraceae	Gaddi berra	Edible by some livestock

64	*Helichryssum glumaccum DC.*	H	Asteraceae	Metaadi (Somaligna)	

Appendix IIIcontinued

65	*Heliotropium cinerascens* Steud.ex DC.	P.Herb	Boraginaceae		edible by camel
66	*Hermania sp.* aff. boranesis K. schum	W.Herb	Sterculariaceae	gurbi	forage
67	*Indigofera amorphoides* Jaub and Spach.	S	Fabaceae		
68	*Indigofera brevicalyx* Bak. f.	Ann.herb	Fabaceae		
69	*Indigofera zavattarii* Chiov.	H	Fabaceae		forage
70	*Ipomoea carica* (L.) Sweet	H	Convolvulaceae		
71	*Ipomoea marmorata* Britti and Rendle subsp. marmorata	Shrub	Convoluvulaceae	obbee	
72	*Ipomoea oenothera* (Vatke) Hall.f.	P.herb	Convolvulaceae		
73	Kalanchoe marmorata Baker	H	Crassullaceae		
74	*Lantana rhodesiensis* Moldenke	S	Verbenaceae	midan dubra	Gum decoration by girls, treatment of disease locally called "Mich."
75	*Leucas abyssinica* (Benth.) Brig. var. brachycalyx	Herb	Lamiaceae	gurbidalati	Used by honey bees, house construction
76	*Lippia javanica* (Burma. f.) Spreng	H	Verbenaceae	shukaye	
77	*Lippia javanica* Burm.f.(Spreng)	S	Verbenaceae	Gurbi dida	house construction
78	*Maytenus senegalensis* (Lam.) Ecell	T/S	Celastraceae	Jimma harre	forage for camel and goat
79	*Melhania velutina* Forssk.	W.herb	sterculariaceae		
80	*Monsonia angustifolia* A. Rich.	Ann.herb	Geraniaceae		
81	*Nicandra physaliodes* Scop	H	Solanaceae	onnonu onna	
82	*Notonia petraea* R.E.Fr.	H	Asteraceae	Gurro	
83	*Ocimum gratissimum* L.	P.herb	Lamiaceae	hahchabba	treatment for “mich" disease
84	*Oesteopsermam Vailliantii* (Decne.) I. Nort	H	Asteraceae	Gurbihalooftu	

Appendix III continued

85	*Orobanche minor* Smith	Saprophyte	Orobanchaceae	Ororo erra	
86	*Panicum ruspoli* Chiov.	P.herb	Poaceae	Darrara	forage
87	*Pelargonium sp*	Ann.herb	Geraniaceae		forage
88	*Phyllanthus maderaspatensis* L.	Ann.herb	Euphorbiaceae	Qorsa mini	forage
89	*Picris babylonica* Hand. Mazza	H	Asteraceae	Gurro	
90	*Plantago lanceolata* L.	H	Plantaginaceae		
91	*Plectranthus barbatus* Andr.	H	Lamiaceae		
92	*Plectranthus* sp	H	Lamiaceae	Teberi	*paralyses the livestock
93	*Polygala sp*	H	Polygalaceae		
94	*Priva curtisial* Kobusk	H	Verbenaceae		
95	*Pterocepohalus frutescens* Hochst.	Per.herb	Dipsacaceae		
96	*Ranunculus stagnalis* Hochst.	H	Rananculaceae	mitchu	root edible
97	*Rhus ruspoli* Engl.	T	Anacardiaceae		
98	*Rhus tenuinervis* Engl.	T/s	Anacardiaceae	dobobessa	fruits edible, fire wood
99	*Rhynchosia malacophylla* (Spreng) Bojer	P.climber	Fabaceae		forage
100	*Setaria verticillata* (L.) Beauv.	P.herb	Poaceae	Rhaphupha	forage
101	*Solanum incanum* L.	W.Herb	Solanaceae		edible by donkeys
102	*Solanum nigrum* L.	H	Solanaceae	Tutuf	Fruit edible by children
103	*Sonchus sp*	H	Asteraceae		forage
104	*Sporobolus pellucidus* Hochst.	P.herb	Poaceae	Sampee	forage
105	*Tephrosa subtriflora* Hochst. ex Bak.	S	Fabaceae		
106	*Tephrosia pentaphylla* (Roxb.) G. Don	Per. H	Fabaceae	dherka(Somaligna)	
107	*Themeda triandra* Forssk	P.herb	Poaceae	Luucallee	forage
108	*Trichodesma uniflora* Brand	H	Boraginaceae		
109	*Triumfetta flavescens* Hochst. ex A. Rich.	S	Tiliaceae	gurbihoola	

Appendix III continued

110	*Vernonia bipontini* Vatke	P.herb	Asteraceae	Gurbi	forage
111	*Vigna membranacea* A. Rich. sub sp membranace	Climber	Fabaceae	loolonsu	
112	*Vignia maranguensis* (Taub.) Harms	Climber	Fabaceae	chamme	roots edible, forage use
113	*Zinnia elegans* Jaquin	Ann.herb	Asteraceae	Bilitu	
114	*Zornia apiculata* Milne Redh.	H	Fabaceae		

Note: S= shrub, H = herb, Per.her = perennial herb. Pros. Rhi. H= prostrating rhizomatous herb, Ann. her= annual herb, errec.herb= erected herb, T=tree, T/S= tree or shrub, ann. Climber= annual climber, W. herb= woody herb.

Appendix IV The density of *A. drepanolobium* in the study area

a) ANOVA for *A. drepanolobium* density

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	49267921.875	3	16422640.625	27.648	.000
Within Groups	21383812.500	36	593994.792		
Total	70651734.375	39			

b) Mean density of *A. drepanolobium* among sites

Sites	N	Mean	Std. Error
1.00	10	1990.0000	220.8632
2.00	10	915.0000	88.6002
3.00	10	752.5000	82.3652
4.00	10	3535.0000	417.3528
Total	40	1798.1250	212.8135

c) Multiple ComparisonsTukey HSD

		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
(I)	(J)				Lower Bound	Upper Bound
1.00	2.00	1075.0000	344.6722	.018	146.7106	2003.2894
	3.00	1237.5000	344.6722	.005	309.2106	2165.7894
	4.00	-1545.0000	344.6722	.000	-2473.2894	-616.7106
2.00	1.00	-1075.0000	344.6722	.018	-2003.2894	-146.7106
	3.00	162.5000	344.6722	.965	-765.7894	1090.7894
	4.00	-2620.0000	344.6722	.000	-3548.2894	-1691.7106
3.00	1.00	-1237.5000	344.6722	.005	-2165.7894	-309.2106
	2.00	-162.5000	344.6722	.965	-1090.7894	765.7894
	4.00	-2782.5000	344.6722	.000	-3710.7894	-1854.2106
4.00	1.00	1545.0000	344.6722	.000	616.7106	2473.2894
	2.00	2620.0000	344.6722	.000	1691.7106	3548.2894
	3.00	2782.5000	344.6722	.000	1854.2106	3710.7894

* The mean difference is significant at the .05 level.

d. Mean density of *A. drepanolobium* Tukey HSD

sites	mean
3.00	752.50a
2.00	915.00a
1.00	1990.00b
4.00	3535.00c

a. homogeneous group 1 with p-value of 0.965.
b . Homogeneous group 2 with p-value of 1.000
c . other Homogeneous group 3 with p-value of 1.000