

2

82

A COMPARATIVE STUDY ON THE POPULATION STRUCTURE,
REPRODUCTIVE BIOLOGY AND CHROMOSOME CYTOLOGY OF TWO
ENDEMIC ALOE SPECIES (*ALOE PULCHERRIMA* Sebsebe and Gilbert AND
ALOE DEEPANA Christian) IN ETHIOPIA



A thesis
Submitted to
The School of Graduate Studies
Addis Ababa University

In Partial Fulfillment for the Degree
Master of Science in Botany

By

FIKRE DESSALEGN

JUNE, 1999



DEDICATION

To the late Dessalegn Boshe Birru, my father, who was deeply concerned with my education.

May God bless his soul

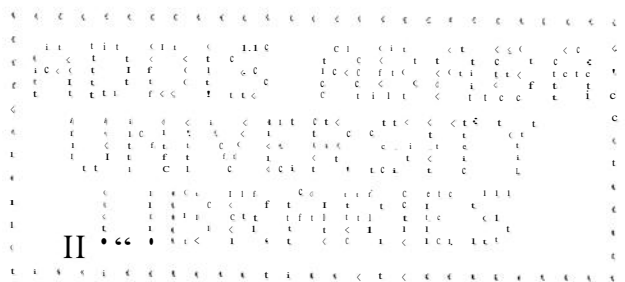
ACKNOWLEDGMENTS

First and foremost, I would like to express my deep gratitude to Prof. Sebsebe Demissew Prof. Inger Nordal (Oslo University) and Dr. Kifle Dagne, my research advisors who not only identified the research problem but also provided enthusiastic advice, consistent guidance, and encouragement throughout the research period.

I am particularly grateful for the help obtained from Ato Mirutse Gidey who started the pioneering work on the Reproductive Biology of the Aloes. The staff members of the National Herbarium, Department of Biology, Addis Ababa University deserve heartfelt thanks for rendering assistance and encouragement throughout the course of the project.

I would also like to acknowledge assistance, invaluable suggestions and encouragement from colleagues and friends Tilahun Tekelehaymanot, Menassie Gashaw, Afework Kassu and others who were always beside me. My thanks specially goes to my wife, W/ro Birtukan Bezabih for her patience in my absence from home during the study period and moral support given which was the source of inspiration. I am deeply grateful to the South Ethiopia Nations, Nationalities and Peoples Region Education Bureau (SENNPREB) for sponsoring me to participate in the Graduate Program.

Finally, I am highly indebted to the Petaloid Monocots Project supported by the Norwegian Council (NUFU) which covered the overall cost of the research.



3. LITERATURE REVIEW	23
3.1. The structure and dynamics of plant population	23
3.2. Reproductive biology	30
3.2.1. Reproductive systems in plants	30
3.2.2. Attributes to estimate reproductive success and dispersal efficiency in plants	33
3.2.3. Ecological forces influencing plant reproduction	36
3.3. Chromosome cytology	39
3.3.1. Chromosome number and morphology as characters used to determine taxonomic distinctiveness	39
3.3.2. Chromosome behavior (i.e., pairing and subsequent segregation) as indicator of fertility success in plants	42
4. MATERIALS AND METHODS	44
4.1. Field data collection and treatment for population structure and dynamics	44
4.2. Field data collection and treatment for reproductive biology	45
4.3. Laboratory work for chromosome cytological study	47

5. RESULTS	48
5.1. Population structure and dynamics	48
5.1.1. Population structure by clone size and rosette diameter	48
5.1.2. Ramet size relationship to flowering	54
5.1.3. Size and flowering relationship to growth rates of ramets	57
5.1.4. Population dynamics (flux) at ramet and genet levels	61
5.1.5. Pathogens	70
5.2. Reproductive biology	71
5.2.1. Vegetative propagation	71
5.2.2. Production of flowers and fruits	72
5.2.3. Seed production	74
5.2.4. Pollination and flower phenology	74
5.2.5. Pollen viability (fertility)	78
5.3. Chromosome cytology	79
5.3.1. Meiotic chromosomes (number, pairing and segregation)	79
6. DISCUSSIONS	83
7. CONCLUSIONS AND RECOMMENDATIONS	91
7.1. Conclusions	91
7.2. Recommendations	93
8. REFERENCES	95

LIST OF TABLES

1. Distribution pattern and endemism of Aloes in Ethiopia	11
2. Edaphic factors of the study site.	82
3. Monthly mean maximum and minimum temperatures and total rainfall at Fiche Meteorology Station, 15 km away from Debre Libanos, for the period January 1997 to December 1998.	19
4. Mean annual growth rates of <i>A. pulcherrima</i> for the period May 1997 to May 1998.	58
5. Mean annual growth rates of <i>A. debrana</i> for the period December 1997 to December 1998.	59
6. Population flux of <i>A. pulcherrima</i> at ramet-level in three (5 x 20 in ²) plots from 1997 – 1998.	62
7. Population flux of <i>A. debrana</i> at ramet-level in three (5 x 20 m ²) plots from 1997-1998.	63
8. Transition probabilities between stage classes of genets of population of <i>A. pulcherrima</i> .	66
9. Transition probabilities between stage classes of genets of populations of <i>A. debrana</i> .	68
10. Summary of data on the process of vegetative reproduction of populations of <i>A. pulcherrima</i> and <i>A. debrana</i> recorded in three respective (5 x 20 m ²) plots.	71
11. Production of flowers and mature fruits in <i>A. pulcherrima</i> populations in three respective plots in 1997 and 1998.	73

12. Production of flowers and mature fruits in <i>A. debrana</i> population in three respective plots in 1997 and 1998.	73
13. Seed production in the populations of <i>A. pulcherrima</i> and <i>A. debrana</i> on capsule and ramet basis.	74
14. The number of mature fruits and the mean number of seeds/capsule when experimentally given additional pollen and under normal pollination condition in marked flowers from 12 flowered ramets in <i>A. pulcherrima</i> and <i>A. debrana</i> population	76
15. Percentage pollen viability studied in two anthers of 14 flowered ramets (14 x 2 = 28 anthers) in <i>A. pulcherrima</i> and <i>A. debrana</i> populations.	78
16. Metaphase I chromosome pairing in <i>A. pulcherrima</i> and <i>A. debrana</i> .	81
17. Anaphase I/telophase I and anaphase III telophase II chromosome segregation in <i>A. debrana</i> and <i>A. pulcherrima</i> .	81

LIST OF FIGURES

1. Distribution map of <i>A. pulcherrima</i> .	7
2. Distribution map of <i>A. debrana</i> .	7
3. Photo of <i>A. pulcherrima</i> .	9
4. Photo of <i>A. debrana</i> .	10
5. Map showing the location and topography of the study area, Debre Libanos.	15
6. Map showing the geology of the study area.	17
7. Frequency distribution by clone size (the number of genets and ramets / genet) for <i>A. pulcherrima</i> populations.	49
8. Frequency distribution by clone size (the number of genets and ramets / genet) for <i>A. debrana</i> populations.	50
9. The population structure of <i>A. pulcherrima</i> in 10 cm classes of rosette diameter in 1997 and 1998.	52
10. The population structure of <i>A. debrana</i> in 10 cm classes of rosette diameter in 1997 and 1998.	53
11. Number and rosette diameter of ramets flowered in 1997 and 1998 in <i>A. pulcherrima</i> population in three (5 x 20 m ²) plots.	55
12. Number and rosette diameter of ramets flowered in 1997 and 1998 in <i>A. debrana</i> population in three (5 x 20 m ²) plots.	56
13. Size-specific difference in mean annual growth rate between the study period 1997 to 1998 for rosettes of two Aloe species.	60

14. Life stage classes: J= Juvenile; M= Mature sterile genet with one ramet; M* = Mature flowered genet with one ramet; P = Senile sterile genet with ≥ 2 ramets; P* = Senile flowered genet with ≥ 2 ramets.	64
15. Transition among life stage classes as defined by Fig.14 from 1997 to 1998 in <i>A. pulcherrima</i> population.	65
16. Transition among life stage classes as defined by Fig.14 from 1997 to 1998 in <i>A. debrana</i> population.	67
17. The proportion of ramets in <i>A. pulcherrima</i> population infected by rust fungus parasite in wet and dry seasons in the study period.	70
18. Photo of Sunbird feeding on the nectars of <i>Aloe vera</i> .	77
19. Meiotic chromosomes (A, B, C; D, E, F) Metaphase, Anaphase and Telophase chromosomes of <i>A. pulcherrima</i> and <i>A. debrana</i> respectively.	80

ABSTRACT

A study was carried out to investigate and compare the population structure, reproductive biology and chromosome cytology of two endemic Aloe species, *A. pulcherrima* (with rare occurrence) and *A. debricma* (common) on naturally occurring populations around Debre Libanos in central Ethiopia from May 1997 to February 1999.

The purpose of the study was to find out the causes for the rare occurrence of *A. pulcherrima* in comparison to the relative abundance of the sympatric species, *A. debricma* with the aim of developing appropriate conservation strategies to conserve these endemic plants.

Six plots of (5 x 20 m²) were established at the study site; three of these include the *A. pulcherrima* and the other three include *A. debricma* populations. In each plot, genets and ramets were sorted out and the population structure was described by clone size and rosette diameter of ramets. Size of ramet relationship to flowering and size of ramet and flowering relationship to growth rate were studied. In addition, population flux (dynamics) at genet and ramet level was calculated and compared for the two species.

Reproductive success and dispersal efficiency in the two species were estimated and compared based on the extent of vegetative propagation; production of flowers, fruits, seeds and also by pollinator availability and percentage pollen viability in the populations studied.

Chromosome cytological studies, i.e., number, pairing and segregation of meiotic chromosomes were conducted in the laboratory from flower buds at appropriate stages of development and comparison made.

Environmental factors which influence the development and distribution of the Aloes such as soil, climate, vegetation, herbivory and human oriented activities associated in the study site were obtained and analyzed.

The results of the study revealed that *A. pulcherrima* has very old stagnant “senile” population with no juvenilization (no recruitment from seed) but entirely depend on vegetative propagation and spread in spite of good seed set, satisfactory pollinatory activity (Sun birds and Bees) and high percentage pollen viability. In addition, it is attacked by a rust fungus parasite (*Uromyces aloes*) and heavily grazed by goats and baboons. *A. debrana* on the otherhand has a more viable population with adequate recruitment both from vegetative propagation and sexual reproduction. Moreover, the production of flowers, fruits and seeds were found to be greater than in *A. pulcherrima*. As in *A. pulcherrima*, it has satisfactory pollinatory activity (sun birds and bees) and high percentage pollen viability. *A. debrana* appears to be “buffered” from rust fungus attack, less often eaten by goats and baboons, and is expanding. The two species also differ in their flower phenology; *A. pulcherrima* flowering from June to August and *A. debrana* flowering from December to February. Thus, this avoids competition for pollinators and hybridization between them. Both species also show low mortality at both ramet and genet level.

Chromosome cytological study showed that the two species have diploid chromosome number $2n=14$; 8 large and 6 small sized. Meiotic activities from pollen mother cells (PMCs) were also found normal with 7 bivalent (711) formation at metaphase I and absence of aberrations such as laggards (univalents and/or separated chromatids), bridges and fragments at anaphase/telophase I and II that ultimately end up in micronuclei formation. These were also evidenced by high percentage pollen viability in the anthers of the species studied.

Thus with the need to protect these endemic species, appropriate conservation strategies have to be suggested.

1. INTRODUCTION

1.1. Scope of the Problem and Objectives of the Study

Ethiopia possesses a wealth of botanical diversity. The flora is estimated to include between 6,500 to 7,000 vascular plant species, 12% of which are endemic (Tewoldeberhan Gebre Egziaber, 1991). Endemism is particularly high on the plateau and in the mountains, in the Ogaden region of south-eastern Ethiopia, Borena region in Sidamo and western woodlands.

The genus *Aloe* belongs to the monocot family Aloaceae. It consists of more than 360 species which are indigenous to and distributed mainly in tropical (eastern and southern) Africa, island of Madagascar and Southern Arabia, but has been introduced into the West Indies and many other tropical countries (Mabberley, 1987). It is a unique genus with almost all of its members concentrated in the wild in Africa except for a few species which extend in to the Arabian Peninsula, and are also cultivated in warm regions of both hemispheres (Sebsebe Demissew, 1996).

Recent taxonomic studies on the genus *Aloe* in eastern and north-eastern Africa indicated the presence of a large number of endemic species. For example in eastern Africa, of the 83 species known 50 (60%) are endemic to the region (Carter, 1994). In north-east Africa (Ethiopia, Eritrea, Somalia, Djibouti, Sudan) of the 76 species reported to occur, 56 (74%) are believed to be endemic to the region. Of these, 36 species with 18 endemics occur in Ethiopia, 8 species with 2 endemics occur in Eritrea, 32 species with 22 endemics occur in Somalia, 2 species occur in Djibouti and 14 species with 2 endemics occur in the Sudan (Lavranos, 1995; Sebsebe Demissew, 1996; and Sebsebe Demissew and Gilbert, 1997).

The fact that the eastern and north eastern Africa has the highest concentration of *Aloe* species indicates perhaps that one of the centers of origin and probably diversity of the genus is in the Horn of Africa in addition to South Africa which has also large number of *Aloe* species

According to Court (1981), the ancestors of modern aloe seem to have had adaptable characters that enabled them to colonize desert, mountain, grassland and beach. Through genetic and evolutionary change, the *Aloe* also came up with apparently superb adaptations to harsh environments: tough, spiked leaves with unpalatable juice, sunken stomata, brilliant flowers to attract pollinators, seeds designed for wind dispersal, and in many cases a high degree of vegetative propagation. Members of the genus *Aloe*, however, have one inherent weakness, a relatively poor root system like other monocotyledons. They develop shallow and fibrous root systems that never achieve the deep permanence of the tap-root of the dicotyledons (Court, 1981).

From the dried juice, a drug called aloin is extracted. It is used to treat intestinal worms, to encourage menstruation and as cathartic. It is also used in chemical test for blood in faeces. The leaves also commonly produce anthraquinones and chelidonic acid, which serve as a source of dye, insecticide and tonic (Usher, 1974).

According to Ermias Dagne (1996) the bitter leaf exudates of some *Aloe* species are commercially important sources of laxative aloe drug and are also used in the cosmetic industry as additives in shampoos, shaving and skin care creams and in the treatment of skin disorder and in particular as tropical medication for treatment of burns. The exudate has also been used as bittering agents in alcoholic beverages. Medicinally, the gel and dried leaf exudates of *Aloe* species have been used since ancient civilization by the Egyptians, Greeks and Mediterranean

people. *Aloe* species have enjoyed a very wide folkloric usage and also now used in modern medicine in many parts of the world.

Because of the wide spread belief in the curative properties of these plants, many members of the genus have been exploited (Trease and Evans, 1983). According to Oketch-Rabah (1995) many *Aloe* species are valued for the healing properties associated with the leaf tissues, a factor that has led to over exploitation of natural population and endangerment of some local Kenyan species. While trade in native, wild *Aloe* stocks has been banned by a Presidential declaration, depletion continues, indicating the need to grow these plants as a field crops.

In Lesotho, serious over grazing that lead to the drying-out of the grassland habitat and increasing rarity of its pollinators, Malachite Sun birds together with pillage by plant collectors, had reduced the wild population of *A. polyphylla* to some 3000 survivors (Beverly, 1999).

Although some species of Aloes have never had large populations in South Africa, various factors have contributed to the decline in numbers of several species. These factors include urban and industrial expansion, agricultural development, afforestation, and mining activities. Unfortunately, a number of *Aloes* are also threatened by extensive collection and under no circumstances should plants be taken from the wild illegally. Nurseries specializing in indigenous and/or succulent plants should be sourced for propagation material (Ben-Erik *et al.*, 1996).

These days several *Aloe* species are threatened. This problem arises as a result of the fact that aloes are one of the highly sought after plants, due to their use in horticulture, medicine and commerce. It is, therefore, imperative to document information on the botany, ecology, distribution and chemistry of these species, in the hope that such knowledge will stimulate research and aid conservation and to take appropriate measures to conserve and promote the

sustainable utilization of these botanic treasures (Sebsebe Demissew, 1996).

According to Holsinger and Gottlieb (1991) besides the conservation status of particular species or population, to report that conservationist groups or biologists should present information about the biological attributes of the species such as population structure, breeding system (reproductive biology), genetic variability, (ploidy) chromosome number, unusual or interesting morphological or physiological attributes, taxonomic distinctiveness, or possible relationships to agronomically or medicinally important plant and the ecology of the species area distribution of which they are part.

Aloe debrana Christian and *Aloe pulcherrima* Gilbert & Sebsebe are two among the 18 endemic Aloe species in Ethiopia. According to Sebsebe and Gilbert (1997) *Aloe debrana* is a species that is common in grasslands on thin soil overlying basalt, usually on gentle slopes, between 2000-2700 m above sea level and is known only from Shewa and Wollo Regions (Fig. 2) whereas *Aloe pulcherrima* is a species commonly found on steep basalt slopes or cliffs with sparse vegetation cover of evergreen bushland, between 2480-2700 m above sea level in Shewa Region (Fig.1). This species is now observed in Wollo, Gojam and Gonder Regions as well although still only in inaccessible places (Sebsebe personal communication).

Aloe pulcherrima Gilbert & Sebsebe is a rare species and with few localities in Shewa, Gojam, Gonder and Wollo while *Aloe debrana* Christian is a very common species wherever it occurs, although it is restricted to Shewa and Wollo. The two species occur together around Debre Libanos, a site therefore selected for comparative studies.

According to Harper (1965), it is very dangerous to make statements about 'characteristic'

reproductive capacity of species and their population structure or to compare these biological attributes without specifying conditions under which they have been grown.

“The problem of rarity” is a topic heavily discussed among conservation biologists these days. To plan reasonable conservation strategies for plant species (i.e., its populations), it is necessary to understand why the plant in question is rare, and therefore possibly threatened. Plant rarity is based on a combination of dynamic factors relative to actual and potential species distribution, with the area the species occupies being the operative term in establishing degree of rarity. Rarity is a two-fold concept associated with the biology of the species and the ecology of the area. Threat is more difficult to characterize since it may be a natural consequence of a biological or geological process or the result of past or present human activities directly or indirectly influencing the plant population or their environment (Reveal, 1997).

Thus, the reason for rarity might be at least three fold:-

1. Relatively unefficient reproductive systems leading to declining populations (negative growth rates of populations) and inefficient dispersal capacity.
2. Particular requirements of the plant, rarely met in nature (niches are rare).
3. Habitat destruction and over utilization by man or by other aggressive herbivores.

As already mentioned above, due to its value in commerce, medicine and horticulture over exploitation and threat of the members of the genus *Aloe* has been reported in different parts of Africa. Some species like *A. pulcherrima* of Ethiopia has restricted and thinly scattered geographical distribution, thus is given the conservation status rare. Threatened and rare plants are of great conservation interest; hence the need to conserve them becomes primary issue among conservationist group or agencies. In order to conserve and set a reasonable conservation

strategies, information on biological attributes of the species, human oriented activities associated with the species area distribution (habitat) and supporting environmental data are highly required. Except for the taxonomy and the chemistry, studies have been scarce on the genus *Aloe*. Thus, this study was undertaken with the following objectives (purposes):

GENERAL OBJECTIVES

To compare the population structure, reproductive biology and chromosome cytology of *Aloe pulcherrima* and *Aloe debrana*

SPECIFIC OBJECTIVES

1. To characterize and compare the two endemic *Aloe* species on the basis of their population structures, dynamics, reproductive out put (or, performance) and chromosome cytology.
2. To study the environmental factors i.e., topography, soil, climate and vegetation of the study site to find out or trace the major environmental factors that play significant roles for the species rarity
3. To observe, record, and interview habitat alterations and utility by man or overgrazing by aggressive herbivory.

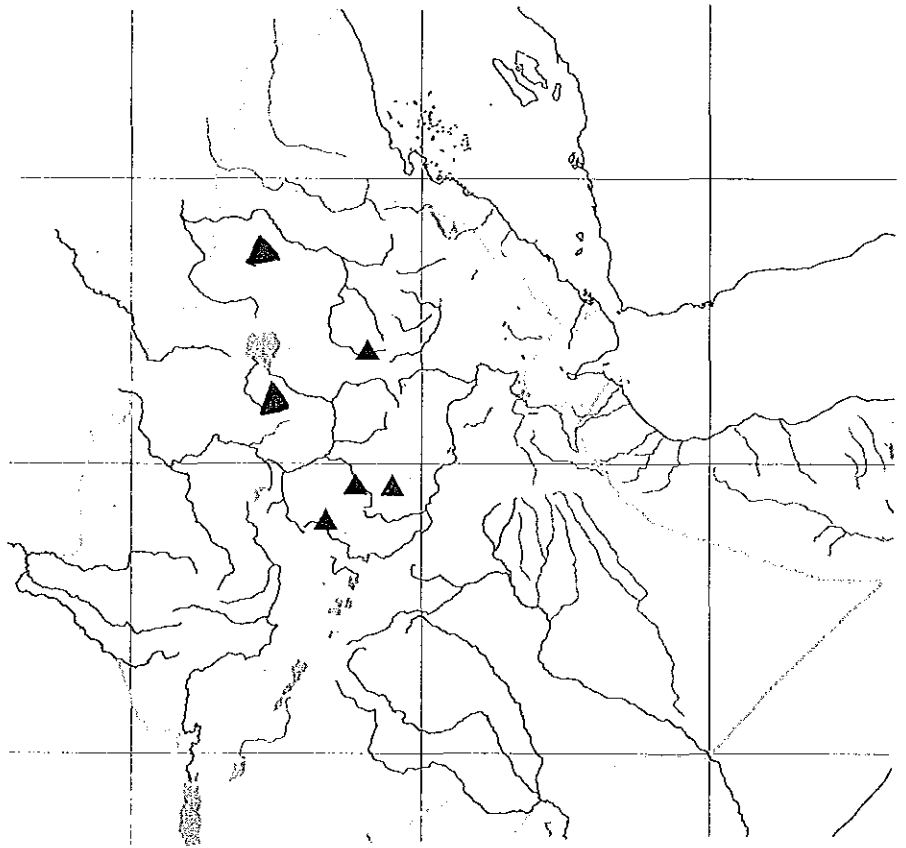


Fig 1 Distribution of *Aloe pulcherrima* in Ethiopia

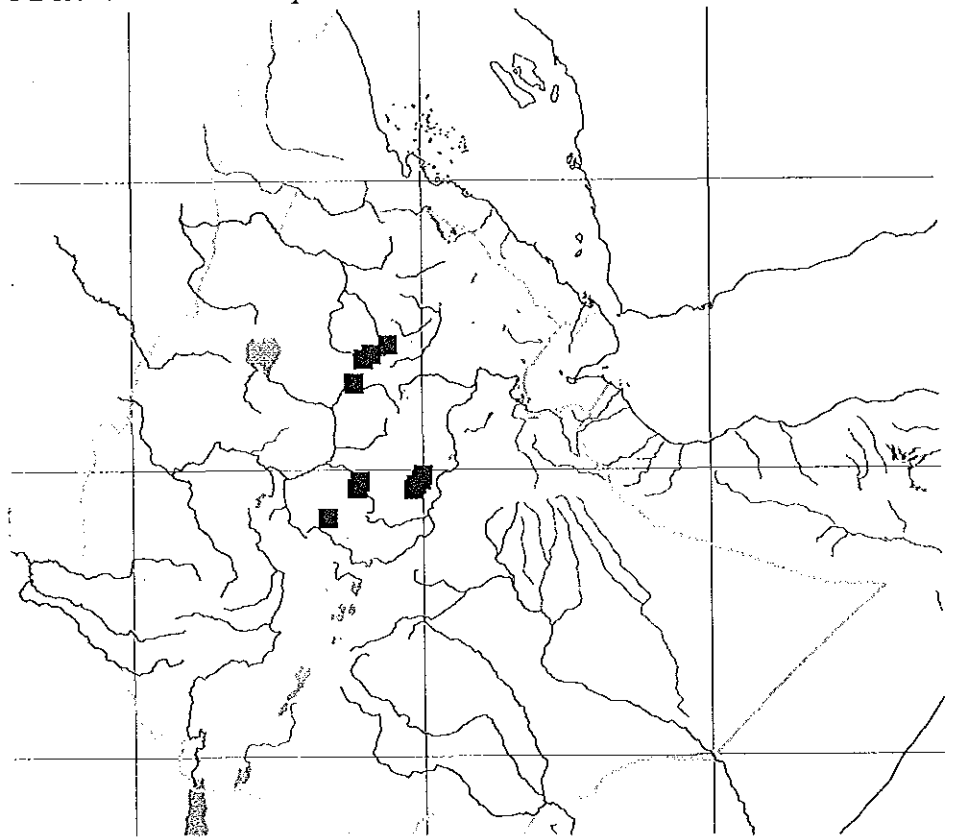


Fig 2 Distribution of *Aloe debrana* in Ethiopia

1.2. Description of the genus and the species Studied

According to Sebsebe Demissew & Gilbert (1997) the genus *Aloe* and the species studied (*A. pulcherrima* and *A. debrana*) are well described as follows:

Aloe L. (1753); Berger (1908).

Perennial leaf succulents, sometimes developing into shrubs or even trees. Roots thick, rarely fusiform, usually bright yellow. Stems often \pm hidden, very fibrous, rarely with well-developed secondary thickening. **Leaves** usually crowded into rosette, less often more widely spaced along stem, amplexicaul with thin basal sheath, sublinear to ovate, very fleshy, glabrous, often marked with pale spots, upper surface often canaliculate, margin usually armed with sharp horny teeth. **Inflorescence** an axillary, very rarely terminal, raceme occasionally simple, usually branched. **Flowers** 1 in each bract and pedicle never articulated; perianth usually very fleshy, slightly zygomorphic, 6-lobed, glabrous or hairy; stamens 6, free for most of length, exerted at anthesis; anthers linear to oblong; ovary superior; ovules numerous; style longer than stamens; stigma lobes capitate. **Fruit** a loculicidal capsule, papery or slightly woody when mature. **Seeds** irregularly 3-sided to flattened, narrowly to broadly winged.

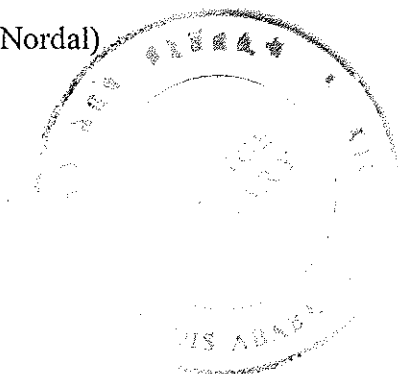
Aloe pulcherrima Gilbert & Sebsebe (1997).

Prostrate or pendent **shrub**, mostly unbranched, stem to 1 m long, ca. 8 cm thick, sometimes branching dichotomously at apex within leaf rosette, especially when cultivated. **Leaves** 35-50 in dense rosette, arcuate, upto 50 x 12 cm, pale blue-green, slightly glaucous, with fine but distinct longitudinal lines and especially in dry season, red margin, marginal teeth almost absent, up to 3 per 10 cm, 0.2–0.3 mm high, hardly visible; sap turning purple, as do old leaves. **Inflorescence** at first descending then ascending forming a U-shape, branched; racemes 3-6 (-11) erect, 12–28 cm

long, lax (3–5 flowers per cm). Bracts ovate, 8–9 (-15) x 7–8 mm, acuminate, rather fleshy. Pedicels 8–12 mm long. Perianth cylindrical, 32–33 x 6–8.5 mm when pressed, red; outer lobes free for ca. 20 mm.



Fig.3. *Aloe pulcherrima* (Photo by Inger Nordal)



Aloe debrana Christain (1947).

Succulent herb, suckering from base to form small groups, mostly stemless but some old plants developing thick, prostrate stems. Leaves in very dense rosette, spreading-recurved, 25–60 x 7.5–15 cm, dull-green, old leaves drying brown; marginal teeth 7–10 (-14) per 10 cm 2–4 mm long, red tipped. Inflorescence ca. 100 cm high, compoundly branched; racemes 8–15, capitate to cylindrical, 5–15 cm long, triangular, 3–6.5 (-8.5) x 1.5–3 mm, scarious. Pedicels 10–15 (-17 in fruit) mm long. Perianth cylindrical, 17–30 x 4–6 mm when pressed; outer lobes free for 5–10 mm.



Fig. 4. *Aloe debrana* (FEE, Vol. 6, 1997)

1.3. Distribution and Endemism of *Aloe* Species in the Flora of Ethiopia

Table.1. Distribution pattern and endemism of *Aloes* of Ethiopia

Aloes of Ethiopia	Endemic or wide spread	Vegetation type	Altitude (m)
<i>Aloe adigratana</i> Reynolds	E	DEG	2000–2700
<i>Aloe ankoberensis</i> Gilbert and Sebsebe	E	DEG/AA	3000–3500
<i>Aloe calidophila</i> Reynolds	NE	AC	1200–1620
<i>Aloe camperi</i> Schweinfurth	NE	AC/DEG	550–2200
<i>Aloe citrina</i> S. Carter & Brandham	NE	AC/SD	275-1000
<i>Aloe debrana</i> christain	E*	DEG	2000-2700
<i>Aloe elegans</i> Todaro	NE	AC/DEG	1500-2400
<i>Aloe ellenbeckii</i> Berger	NE	AC	1600
<i>Aloe gilbertii</i> Sebsebe & Brandham	E	AC	1300-1900
<i>Aloe harlana</i> Reynolds	E	SD	1650-2100
<i>Aloe jacksonii</i> Reynolds	NE	AC	1050
<i>Aloe kafaensis</i> Gilbert and Sebsebe	E	DEG	1800
<i>Aloe lateritia</i> Engler	WS	AC	1550
<i>Aloe macrocarpa</i> Todaro	WS	DEG/AC	1400-3000
<i>Aloe mcloughlinii</i> Christain	NE	AC/SD	1060–1250
<i>Aloe megalacantha</i> Baker	NE	DEG	1100-1850
<i>Aloe monticola</i> Reynolds	E	DEG	2460
<i>Aloe otallessis</i> Baker	E	AC	1200-1600

<i>Aloe parvidens</i> Gilbert and Sebsebe	NE	AC	1200-1450
<i>Aloe percrassa</i> Todaro	E	DEG	2100-2700
<i>Aloe pirottae</i> Berger	E	AC	1300-1820
<i>Aloe pubescence</i> Reynolds	E	DEG	1800-2550
<i>Aloe pulcherrima</i> Gilbert and Sebsebe	E*	DEG	2400-2700
<i>Aloe retrospiciens</i> Reynolds	NE	AC	1000
<i>Aloe rivae</i> Baker	NE	AC/DEG	1365-2000
<i>Aloe rugosifolia</i> Gilbert and Sebsebe	NE	AC	1350-1700
<i>Aloe ruspoliana</i> Baker	NE	AC/SD	300-1450
<i>Aloe shelpei</i> Reynolds	E	DEG/SD	1700-2470
<i>Aloe secundiflora</i> Engler	WS	AC	1350-1550
<i>Aloe sinana</i> Reynolds	E	SD	1250-1950
<i>Aloe steudneri</i> Schweinfurth	E	DEG	2600-3150
<i>Aloe tewoldei</i> Gilbert and Sebsebe	E	DEG	-
<i>Aloe trichosonata</i> Burger	NE	AC	900-1700
<i>Aloe trigonantha</i> Leach	E	AC	2100
<i>Aloe vituensis</i> Baker?	NE	AC	1200
<i>Aloe yavellana</i> Reynolds	E	DEG/SD	1600-1900

* Endemic species selected for study

Source: (Sebsebe Demissew, 1996 and Sebsebe Demissew and Gilbert, 1997)

(Legend: E- Endemic, NE- Near Endemic, WS- Wide Spread)

Ethiopia has 36 *Aloe* species named and described of which 18 (50%) species are endemic. The remaining species are also near endemic except few of which are wide spread in different parts of the east and north east Africa (Table.1).

Recent taxonomic survey and mapping has increased the number of species to 37 (Sebsebe

Demissew pers. communication). These species are distributed in almost every parts of the country in different vegetation regions or types at various altitude. Dry evergreen (DEG), *Acacia-Commiphora* (AC), Semi-desert (SD), and Afro-alpine (AA) are some of the vegetation types where *Aloe* inhabit. The altitudinal range varies from 550 m in *Acacia-Commiphora* to 3500 m in Afro-alpine vegetation regions.

2. THE STUDY AREA

2.1. Location and Topography

Debre Libanos, the study area (Fig. 5) is situated 110 km north of Addis Ababa and 4 km from the main road between Addis Ababa and Fiche. The area is renowned throughout Ethiopia as one of the main monasteries of the Ethiopian Orthodox Church.

The monastery is located on the upper shelf of the Zega Wedem Gorge, one of a series of deep canyons created over a period of more than twenty million years by tributaries of Abay River (Blue Nile). The canyons are cutting through the vast central plateau of Shewa (Davidson, 1994).

The Shewan plateau to which Debre Libanos is part has the general elevation of about 2200 m. Its surface consists of plateau basalts into which the important tributaries of the Abay have cut deep gorges isolating smaller table lands like that of Merhabete which is situated east of the study area (Beyene Dolich *et al.*, 1991).

The altitude of the plateau just above the area where the plots were established is 2600 m., while the river at the bottom of the gorge runs at an altitude of 1500 m. The study area is situated in

escarpment of the plateau at latitude $9^{\circ} 45'N$ and longitude $38^{\circ} 50'E$. The slope of the site (inclination) is about 50-55%. A series of shelves takes you down from the plateau to the bottom of the canyon. The domains of the monastery are on the upper shelf mainly between 2300 and 2500 m and include the upper escarpment where a remnant of a montane forest still exists along a distance of 1500 m. The monks monastery and the church of Debre Libanos are situated at the central parts of the shelf just above a creek in a smaller gorge that divides the shelf about 4 km. from the main road. Going down into the Debre Libanos shelf you are met with lots of plantation trees especially *Eucalyptus* species. A forest is climbing the southern escarpment and from a far you see the main church embedded in lush green.

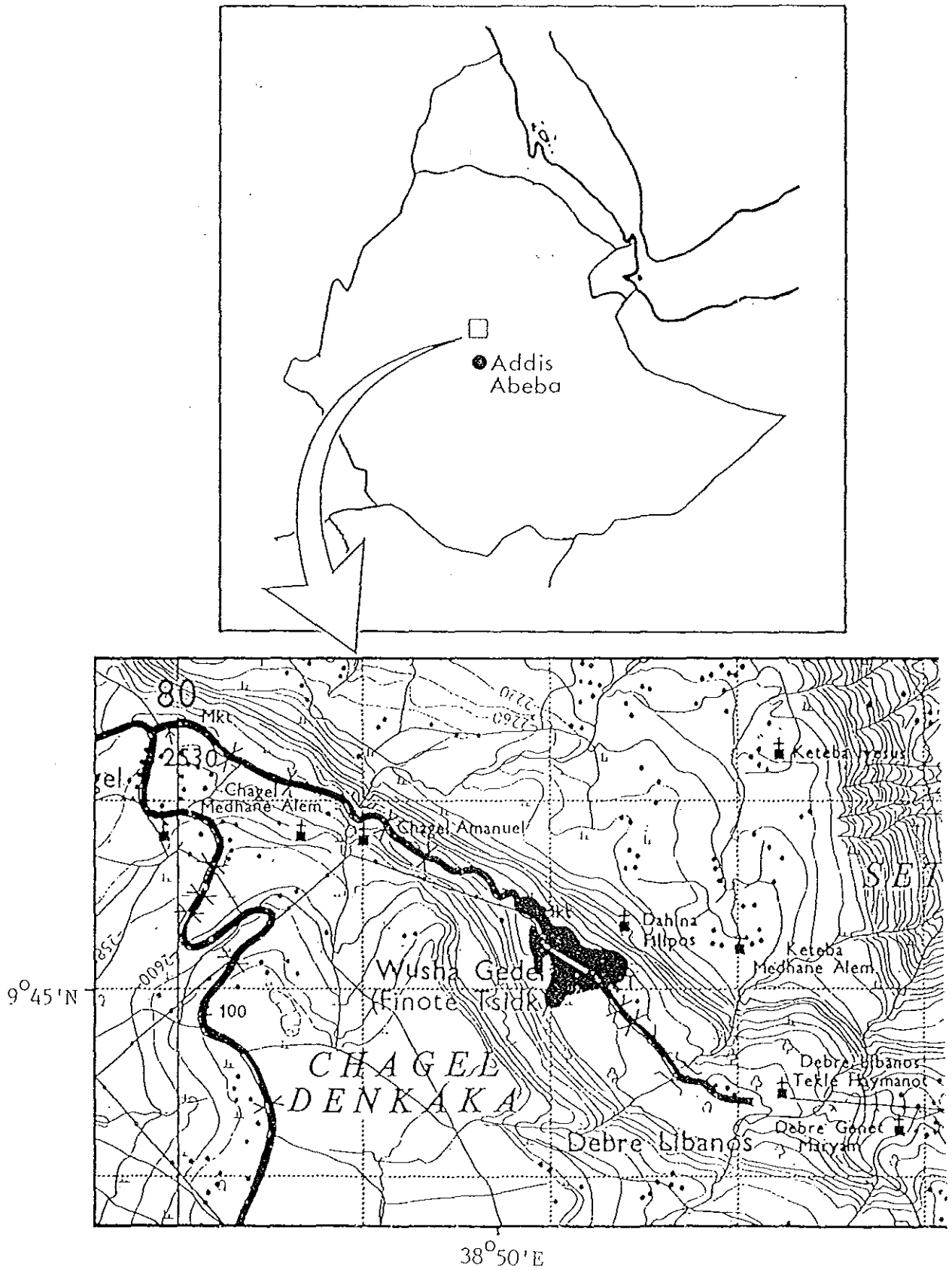


Fig.5. Map showing the location and topography of the study area (Debre Libanos)

(Source: Davidson, 1994)

2.2. Geology and Soil

The geological setting of Debre Libanos was described by two authors one through detailed study and the other through keen observation. According to Getaneh Assefa (1980) the central highlands of Ethiopia to which Debre Libanos is part (Fig. 6) has the mesozoic sequence, which is more than 2,000 meters in thickness consists of a renaceous, argillaceous, calcareous and gypsiferous sedimentary rocks resting unconformably on rocks of either precambrian or palaeozoic age and overlain unconformably by cenozoic volcanic (basalt) rocks. These areas are structurally simple and thus almost all of the sedimentary rocks are in their original depositional position. The mesozoic sequence which is about 2000 meters in thickness, is subdivided into five lithological units: the Lower Sandstone unit; the Abbay Sahale and Gypsum unit; the Limestone unit; the Shaly Sandstone unit; and the Upper sandstone unit (Getaneh Assefa, 1980).

Davidson (1994) stated that the geological setting of Debre Libanos through keen observation as the hard rocks making up the ground of the plateau and the vertical upper cliff of the escarpment seem to be basaltic lava material. Among the more easily eroded lower layers one can find both limestone, sandstone and conglomerates. An interesting aspect of the geology of Debre Libanos is the numerous artesian wells and the spring water coming out from the cliff above the escarpment or from the slope of the escarpment. This water supply is said to be permanent, which means that even during the dry season there is water in the ground in the escarpment. Thus, the infiltration through fissures in the basalt layer of the valley during the rainy season seems to be enough to give the escarpment vegetation a water supply all year round (Davidson, 1994)

Scale: 1cm = 3,200 km

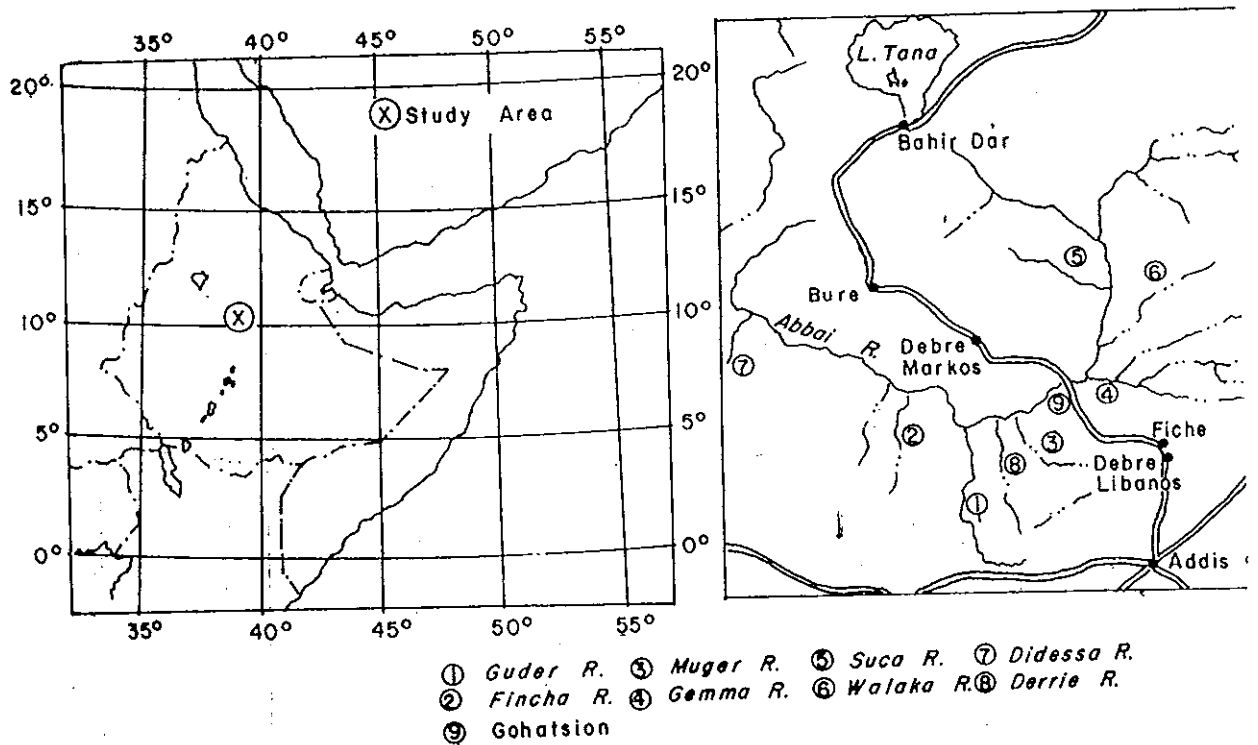


Fig.6. Map showing the area covered by the geological study (Getaneh Asefa, 1980)

The reddish brown lateritic soils are found in extensive areas of the highlands of Ethiopia. It has loamy texture, deep profile and fragile nature. The typical soils of the highland regions are brown clay soils (Beyene Dolicho *et al.*, 1991). Thus, the Debre Libanos soil is similar to the general region and seems to be brown clay as observed by the writer.

In areas with undisturbed natural forest the brown clay soil is covered with a layer of organogenic black top-soil.

2.3. Climate

2.3.1. Rainfall

During summer (June, July, August), the ITCZ (the Inter Tropical Convergence Zone) runs nearly parallel to or along red sea coast. At this time, the whole of the country except the south eastern lowlands comes under the influence of the Atlantic (Equatorial) Westerlies from Gulf of Guinea which produce the main rainy season when ascending the mountains (Daniel Gemechu, 1977). Thus, for most of the highlands of Ethiopia the “Kiremt” becomes the main rainy season.

Central highlands of Ethiopia to which Debre Libanos is a part also get small rainfall in autumn (September, October, November) and spring (March, April, May). The average annual rainfall in central plateau of Ethiopia is between 1000 and 2000 mm (Beyene Dolicho *et al.*, 1991). Thus, Debre Libanos enjoys three rain seasons, the “big rain” of summer and the “small rain” of autumn and spring (Table. 3)

2.3.2. Temperature

With diversified topography of land surface, variations in temperature from place to place are highly pronounced in Ethiopia (Daniel Gemechu, 1977). In Ethiopia both the mean annual temperature and annual range of temperature are related to the altitude of the area. Thus, areas with the elevation between 2300–3000 m has mean annual temperature 15–18⁰C and annual range of temperature between 3-4⁰C and called “Dega” climate zone (Beyene Dolicho *et al.*, 1991).

Table.3. Monthly mean maximum and minimum temperatures and total rainfall at Fiche Meteorology Station (Alt. 2750 m, Long. 38⁰ 42'E, Lat. 9⁰ 48'N), 15 km away from Debre Libanos for the period January 1997 to December 1998.

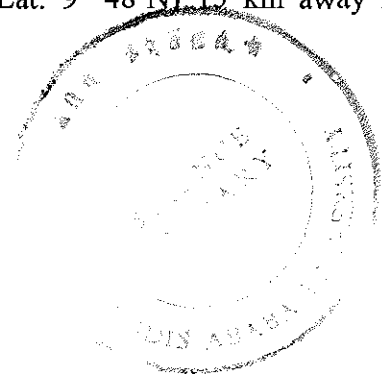


Table.3. Monthly mean maximum and minimum temperatures and total rainfall at Fiche meteorology station (Alt. 2750 m, Long. 38° 42'E, Lat. 9° 48'N) 15 km away from Debre Libanos for the period January 1997 to December 1998.

Year	Months												
		J	F	M	A	M	J	J	A	S	O	N	D
1997	M.max T (0C)	19.7	21.6	22.2	21.9	22.9	21.0	17.4	17.7	19.5	18.9	19.1	20.1
	M.min T (0C)	8.3	6.0	8.9	9.1	9.0	9.7	9.4	9.1	9.1	8.1	7.9	6.1
	RF (mm)	43.4	0.1	72.0	45.1	29.0	149.8	347.7	276.8	51.1	62.6	20.1	1.8
1998	M.max T (0C)	20.9	21.6	22.2	21.9	22.9	21.0	17.4	17.7	19.5	18.9	19.1	20.1
	M.min T (0C)	8.1	9.4	9.9	10.8	10.4	9.9	9.2	9.7	9.0	8.1	4.6	3.9
	RF (mm)	11.2	9.0	49.1	58.3	45.8	87.8	266.9	383.8	181.1	40.5	0.2	0.0

2.4. Vegetation

Topography, climate, soil and geology are very important factors that determine the type of vegetation that can be expected in an area. Debre Libanos is in the lower part of climatic region called “Dega”. The type of forest (vegetation) to be expected in Debre Libanos according to the climate and geological situation is what is called “dry forest” of the plateau (Davidson, 1994).

According to Ensermu Kelbessa *et al.* (1992) the plateau of Ethiopia above 1900 m is a mosaic of forest, woodland and grassland that has provided different habitat for endemic plants and animals to evolve in. The term “dry evergreen forest” is often used to describe all the vegetation of this area. This type of vegetation is expected between 1900 m–3200 (-3400) m in the central plateau of Ethiopia, where an average annual rainfall is between 500-1500 mm and average annual temperature between 14⁰C and 18⁰C.

As observed in the study site of *A. pulcherrima* and *A. debrana*, the trees have been cut down and even the shrub vegetation is scarce. However, in the tree layer one can find an occasional *Juniperus procera* and *Olea europaea sub sp. cuspidata*. Some *Acacia pilispina*, and *Croton macrostachyus* are also rising above the lower, from browsed cushion-like *Myrsine africana* shrubs. A few perennial herbs such as *Verbascum sinaiticum*, *Rumex nepalensis*, *Salvia nilotica* also recorded.

Others like *Opuntia ficus-indica*, *Carissa edulis*, *Vernonia sp.*, *Leucas martinisensis*, *Asparagus africanus*, *Otostegia fruticosa*, *Rhoicissus tridentata*, *Hibiscus macranthus*, *Pavetta abyssinica*, *Lippia adoensis*, *Maytenus arbutifolia*, *Osyris quadripartita* are found in shrub layer. Tall herbs, climbers, grasses and rushes are mingeling with the shrubs, for example *Argemone mexicana*,

Kniphofia foliosa, *Acyranthes aspera*, *Rumex nervosus*, *Hypoestes triflora*, *Pennisetum* sp, *Agrostis viridis*, *Tagetes minuta*, *Cyperus auricimos* are very common.

Estimated vegetation cover in *A. debrana* plots was generally 40-45% mainly grasses, small herbs with scattered shrubs while on *A. pulcherrima* plots it was 50-55% mainly herbs and shrubs.

2.5. Human settlement, Population and Land use

The establishment of permanent human settlements around Debre Libanos is associated with the history and establishment of the monastery of Debre Libanos. It was established in 1275 by Saint Tekele Haymanot, who had gained a formidable reputation for miracles and wonderful works during his evangelizing mission (Personal communication).

The first shelters and buildings were erected in caves under the escarpment cliffs. A cave church that is said to be the original Tekele Haymanot Monastery church is still open for visitors.

The permanent settlements are scattered in the areas around Debre Libanos. The villages of Wusha Gedel, the plateau, and the vicinity of Zega Wedem gorges are some worth mentioning.

The villagers in the Wusha Gedel have increased in number since the establishment of the monastery. They mainly live on rendering services to the monasteries, the pilgrims and tourists. An estimate of the real number of people on the shelf was made by an old villager with good connection with both the monks and the nuns at the monasteries. There are, he said "800 monks, 300 nuns and 800 families living in the village of Wusha Gedel that would amount around 5000 persons".

The plateau and the vicinity of Zega Wodem gorge are inhabited by peasants. They depend on mixed agriculture i.e., by cultivating food crops such as tef, wheat, barely, noug and others; and animal husbandry. Land clearing for cultivation, fuel, and overgrazing by domesticated and wild animals has already taken place in Debre Libanos shelf.

According to the interview with the priests and peasants, in the villages both people and animals have increased in number. The villagers keep animals such as goats, sheep, cattle, and mules. There are also large number of baboons in the gorge and caves. The main part of the animal's food comes from the meadows, thus the whole shelf of Debre Libanos is being extensively grazed and that includes the forests in the escarpment.

The grazing is especially intensive west of the monastery meadows where the plots were established because it is there that the villagers have grazing rights. This implies that almost the only things growing there are plants rejected by animals. The need for fuel wood has increased in the area for most of the food is being prepared centrally in the monastery kitchen. In addition, the recently established bread bakery is known to consume a large amount of fuel wood.

During the course of the study, a multitude of other ways villagers use the resources of the vegetation have been observed. Wild plants are used as source of food, as human and animal medicine, dyes, and so on. There are two small areas within the escarpment clearly uninfluenced or little influenced by human activities. These areas are within the most holy part of the escarpment forest. All other areas are continuously being used by the villagers. Natural regeneration is hindered by shrub cutting and replaced by tree planting especially *Eucalyptus* spp. Only those species being rejected by the grazing animals have a chance of regeneration, if they can survive the increased erosion, the loss of the black organogenic top-soil that is the result of

this combination of grazing and cutting of shrubs and trees.

It has further been observed that *Aloe* species, especially the soft leaves and that lack marginal teeth *A. pulcherrima* has been destroyed by the goats and baboons. According to the interview, the villagers or local people use the leaf exudates of *Aloe* as traditional medicine for treatment of meseals, “chiritti” and other diseases of the skin. They also keep *Aloes* in their houses to counteract the evil spirit.

3. LITERATURE REVIEW

3.1. The Structure and Dynamics of Plant Population

For an ecologist a population is often defined simply as the total number of individuals of a single species in an area circumscribed for the purpose of study, often a quadrat or a series of quadrats (Crawley, 1997).

The structure of a population of plants can be described in terms of ages, sizes and life stages (states) of individuals that compose it (Harper and White, 1974). These structures that we can identify in populations of plants result from the action of biotic and abiotic factors to which their members, and in some cases their ancestors, have been exposed in the past. The forces experienced by the ancestors of a population can clearly affect its genetic structures (although this may not be perceptible) (Hutchings, 1997).

Size structure of a plant population is the most conspicuous aspect of population structures and the size of individuals in plant populations are far from uniform (Crawley, 1997). Even in a pure

stand of a single species sown at the same time and forest plantation in which plants are even aged a hierarchy of size develops, particularly if there is density stress (Harper and White, 1974). Many factors promote variation in the size of plant populations. First, seed size is rarely constant within a species (Hendrix and Sum, 1989) and seedling size at a given age is often correlated with the size of the seed from which it grew (Crawley and Nachapong, 1985). Second, relative growth rate (RGR) is genetically determined. Third, the time of germination relative to that of neighbours is a major determinant of the future of plants (Crawley, 1997). Thus, plant interactions together with abiotic factors also mould the size structures of population. The population, therefore, often is composed of a small number of large plants that account for most of the population's biomass and many small one (Weiner and Solbrig, 1984).

Thus, distance, size, species and spatial arrangement of neighbours together can account for much of the variation in individual plant size (Mack and Harper, 1977). In the words of Ross and Harper (1972), "an individual's potential to capture resources is dictated by the number and proximity of neighbours already capturing resources from the same resource pool". Thus, competition from neighbours can affect plant size and survival.

Herbivory could also influence the size structures (Weiner, 1993). Since many aspects of performances such as the reproductive activity are correlated with size, they too vary from plant to plant (Hutchings, 1997).

The few dominant individuals contribute disproportionately to the total seed production so that the reproductive activity of the population is largely accounted for by the size frequency distribution of its members (Harper and White, 1974). The frequency distribution of plant size reflects the interplay between size specific birth (growth) and death rates and such factors as plant

competition and size specific attack by natural enemies (Hara, 1984). Relative position in the size hierarchy of a plant and its immediate neighbours clearly has dramatic effect on future growth and survivorship. It is also a major determinant of life time reproductive success as shown by long-term field studies on *Astrocaryum mexicana* (Palmaceae) (Sarukhan *et al.*, 1984).

In many species, the probability of flowering is also size dependent, so that plants must exceed a critical threshold size before flowering (Klinkhamer *et al.*, 1987). Generally, flowering and seed production is correlated with the size of the producing plant (Solbrig, 1984). Thus, the probability of surviving in successive years is strongly correlated with the size structure of the population and both the frequency of flowering and mean annual fecundity are much higher for plants from larger size classes (Sarukhan *et al.*, 1984).

Plant population can also be described by their life state (stage) (Rabotnov, 1969); because plant species have certain consistently recognizable life state (stage) in their ontogeny. These are called seed, seedling, juvenile, immature, vegetative, reproductive, sub senile and senile (Gatsuk *et al.*, 1980). Each life state may be characterized by a particular combination of quantitative and qualitative characteristics or features and differ in their response to environmental factors and in their influence on soil microclimate (Harper and White, 1974). On the same work Harper and White (1974) stated that three major groups of populations are defined:

- a). Populations of invasive type that do not yet have all stages present,
- b). Populations of normal type that have all stages present, and
- c). Populations of regressive type that have lost the ability to reproduce by seed.

Each succeeding stage is characterized by the appearance of new structures that were lacking in earlier stages of development and by the loss of previous ones. The average duration of life state

of each plant species is fixed genetically, but since environmental condition may vary greatly, and different individuals may infact reach a certain life state at different time (Gatsuk *et al.*, 1980). Unlike age, the succession of life state (stage) is reversible and senile perennial plants may revert to reproductive activity if environmental conditions change (Rabotnov, 1969) and some population disappear before ever reaching a reproductive stage.

Mehrhoff (1989) has shown that plant in stable populations of the endangered Orchid *Sotria medeoloides* either flowered every year or alternated between flowering and non-flowering whereas plants in declining populations were increasingly non-flowering or dormant. Uranov and Smirnova (1969) stated that “normal” populations are in equilibrium with the environment (analogous to the stable age distribution of animal demography) and those that are relatively rapidly changing their spectrum of life stages referred to as “successive”; the same study also showed that these spectra are sensitive to small environmental changes.

This type of population analysis has been applied to e.g. *Narthecium ossifragum* (Summerfield, 1972). The population studied did not produce seed but persisted in a habitat no longer suitable for seedling development, yet conditions were not severe enough to eradicate the population. The population structure of a wide range of species has been studied in this way by the Russian school; these species include: *Galeobdolon luteum* (Smironva and Toropova, 1972), *Phleum pratense* (Matveev, 1972), *Dactylis glomerata* (Ergova, 1972), *Carex pilosa*, *Viola mirabilis* (Smirnova, 1968), *Ranunculus acris*, and *R. auricomus* (Saurina, 1972), *Artemisia tianschanica* (Trulevich, 1960), *Medicago falcata* (Sanagovskaja, 1966).

The recognition of life- state has greater significance than calender age in analyzing the structure and dynamics of populations. Individual plants of different life states do not necessarily have

similar ecological properties, and they may play different roles in the life of a population (Gatsuk *et al.*, 1980). Thus, the value of determining the life-state structure of a population is that the spectrum of developmental states may be a much better indicator of its condition than its age structure (Hutchings, 1985).

Size or life stage distributions are much easier to assemble than true age distributions (Harper and White, 1974). However, attempts to correlate size or other easily measured aspects of performance with age tend always to give inaccurate results, since size variation increases rapidly as plants age and this variation is increased by habitat heterogeneity and competition (Hutchings, 1985). According to Hutchings (1985) there are few short-cut methods of determining age structure in populations of growing plants. These are: first, if the population can be sacrificed, some type of annually produced morphological marker such as tree rings or bud scars, that can be counted. Second, individual plants can be recorded as they enter the population (as a zero year olds), and uniquely tagged or mapped so that their survival can be followed.

For herbaceous plants, precise estimates of chronological age may be made if the plant has some organ (usually a rhizome) that persists for many years without decaying and shown well-defined annual increments. The number of leaf scars on a rhizome may be a good indicator of length of life when the mean annual leaf production is known (Harper and White, 1974). Using such techniques (Rabotnov, 1969; Harper and White, 1974) were able to determine with some accuracy the age structure using year classes of a few populations of herbaceous perennials: *Anemone fasciculata*, *Polygonum carneum*, *Libanotis transcaucasia*, *Peucedanum pschavicum*, *Pedicularis condensata*.

Once determined, the age structure of populations must be interpreted with care; a structure

dominated by young individuals may represent an expanding population with a few old early colonizers and a large number of their descendants, or stable population. An excess of old individuals may mean that a population is moving to local extinction with no successful new recruits or that the systems is stable (Harper and White, 1974).

Change in plant number like structures of population are brought about by interactions of several biological and physical factors (Watkinson, 1997). It is by quantifying demographic factors that one can confront with questions as to why some species are rare and others are common, and what processes are responsible for fluctuation in their number. Crawley (1997) suggested that the relative importance of various processes in plant population dynamics could be ranked as follows: interspecific competition > herbivory > intraspecific competition for microsites > seed limitation. However, in order to understand what factors determine the abundance of plants, it is necessary to understand how demographic parameters are affected by the age and size of plants, and by population density, competitors, herbivores, pathogens, weather, soil conditions and various hazards like fire (Watkinson, 1997).

There are several matrix methods devised that allow one to model population changes where individuals fall into different age, stage or size classes and have different rate of reproduction and death at various classes and give insights into population growth (Silvertown, 1983). The value (λ) calculated from the matrix is referred to as the “finite rate of increase of the population”, and is the most important single parameter in plant population dynamics. “ λ ” determines whether the population will increase ($\lambda > 1$), decrease ($\lambda < 1$), or remain constant ($\lambda = 1$) in number (Watkinson, 1997).

According to Silvertown & Lovett (1983) their study showed that *Ranunculus repens*

(Ranunculaceae) had ($\lambda=0.50$), *Digitalis purpurea* (Scrophulariaceae) ($\lambda=1.82$) and *Astrocaryum mexicana* (Arecaceae) ($\lambda=1.0086$). When one population leaves more descendants than another because of superior ability to survive or to reproduce offspring or due to superiority in both of these characters; it has relative evolutionary advantage of fitness. However, these fitness of a particular species is not a fixed value, but is determined in the context of prevailing ecological conditions and reproductive success of other population which occur in the same area (Silvertown, 1982).

Werner and Caswell (1977) compared the accuracy of prediction of population number made by matrix models based upon age-related transition probabilities and stage-related transition probabilities. They found that the stage-related models predicted changes in number of seeds and vegetative or flowering rosette in experimental populations better than the age-related model eventhough the transition probabilities for both types of models were derived from the same population. Because of the modular nature of plant growth, age and size are only loosely correlated and two individuals of the same age may vary considerably in size. Moreover, in plants, it has been shown that size or stage rather than age is the major factor influencing survival and fecundity (Watkinson, 1997).

3.2. Reproductive Biology

Why do closely related sympatric species that persist together differ in their abundance, one being common and the other rare with small number of populations and restricted geographical distribution?. These seem to be crucial question in any attempt to understand the reproductive biology of the species concerned.

In the words of Harper (1965) “by reproductive biology of a species one must mean the whole biology because a plant is only the means by which one seed produce more seed and the whole of life cycle must be considered as part of the strategy of reproduction”. He further stated that a successful reproductive strategy must imply at least that a species maintain its abundance in a changing environment.

3.2.1.Reproductive system in plants

It is the function of the reproductive system of any organism to produce offspring; but merely to produce offspring is not enough. To be successful the system must satisfy further requirement imposed by natural selection–requirements which are in fact not always the same (Kenneth, 1965). The system of reproduction in higher plants fall into two main classes. Asexual reproduction that results in the offspring which has the same genetic constituents as the parent and thus reduces variation. The most familiar asexual means are those which come under the heading vegetative reproduction (clonal growth). These depend on the distribution and separate establishment of physiologically independent individual (ramets) from the segment of the parent plant (genet). These segments may be apical meristems carried on stolons as in strawberry, fragments of the shoot as in joined cactus, underground rhizomes as in many grasses and herbs;

or small propagules, readily detachable from the shoot such as the bulbils of onions (Crawley, 1997).

Sexual reproduction, on the other hand, involves crossing among more or less genetically different individuals that lead to heterozygotes which in turn give rise to segregation and recombination of the genes in their progenies and in principle it is a system of variation (Kenneth, 1965).

Depending on the genetical, physiological and morphological factors, sexually reproducing plants can be inbreeders or outcrossers; or combine both. In those of self-pollinating (self-compatible) plants the heterozygosity is reduced. In such plants self-pollination is promoted by the close proximity of anthers and stigma, and by the synchrony of anther dehiscence and stigma maturity (Crawley, 1997). Where outbreeding occurs, that means effectively where selfing is avoided, it can equally be a system of variation.

According to Harrison (1983) several structural and functional features may promote outcrossing. These mechanisms are dependent either on structural adaptation such as dioecy and monoecy, herkogamy and flower characteristics affecting the foraging behavior of pollen visitors, or dependent on developmental timing (dichogamy, including protandry and protogony) or control of the pollen tube: self-incompatibility systems.

Data tabulated by Yampolsk and Yampolsky (1922) showed that dioecy occurs in less than 4% of angiosperms, and the sexual polymorphism of any kind is found in only 7% of dicotyledons genera and 6% of monocotyledons. Of the monomorphic genera some 78% are hermaphrodites, taking dicotyledons and monocotyledons together, the remainder showing various forms of

monoecy. The prevalency of self-incompatibility has been recorded on reasonable secure experimental grounds for several thousands species widely distributed among 330 or so families of angiosperms (Harrison, 1983). The consequence of dioecy, monoecy, self-incompatibility, herkogamy, and dichogamy is that they favour cross- pollination and so promote out breeding; whereas, autogamy, geitonogamy and cleistogamy favour self-pollination and so promote inbreeding (Crawley, 1997).

However, breeding systems are not static, or fixed, but are variable and flexible. Genetically controlled and heritable variation for all breeding system attributes occurs between plants in many populations. Further variation, or novel attributes can also arise by mutation. As a result, breeding system are subjected to natural selection and adaptive evolution in nearly all plants in every generation (Richards, 1997).

Most angiosperms show some forms of sexual behavior at some period of their existence; many combine with it a capacity for asexual means, having abandoned sexuality. In sexually reproducing plants also many species are known like wild oats of California which are preponderantly inbreeders but which occasionally out-cross (Harrison, 1983)

In plants combining both sexual and asexual reproduction, the two types of reproduction are competitive because they depend upon the same limited resources and the balance between the two often depend on soil conditions, light and temperature, and on the intensity of competition with neighbours (Abrahamson, 1980). He that the balance shifts towards vegetative reproduction in the favourable years or habitat, and towards sexual reproduction in harsh condition or when population density increases.

Study showed that e.g. *Mimulus primuloides* (Scrophulariaceae) reproduce both by vegetative and sexual reproduction. Due to competition their size reduced resulting in lowered vegetative

reproductive allocation; however, reduction in density allows increased size and therefore increased vegetative reproductive allocation. Severe environmental condition also reduces the size of the plants and hence lowered this allocation (Douglas, 1981).

3.2.2. Attributes to estimate reproductive capacity (success) and dispersal efficiency in plants

Fitness is defined as the relative ability to survive and reproduce; and no organism will have any evolutionary effect unless it manages to reproduce sexually (Crosby, 1965). He also pointed out that evolutionary fitness of an organism can be measured in principles by the extent to which its genes appear in future generation and this depends on its reproductive capacity.

According to Hutchings (1997), the ultimate measure of plant's performance is the number of its offspring that reproduce in future generations. However, in field studies involving many plants it is normally not possible to tell which parent produce which emerging seedling. In such a case, the most practical estimate of offspring contributed to future generations may simply be a direct count of the seed production of individual plants.

Even when we feel clear in our minds what we mean by reproductive capacity or success, the difficulties in estimating it in any real situation are considerable (Crosby, 1965). We might think of reproductive capacity as measured by the production of seeds or vegetative propagules; however, effective reproduction is not just a matter of seed production-it involves germination and development to maturity of the next generation.

Reproduction is a long and complex process. We might be interested in one stage of the process and judge the efficiency of plant's reproduction by its efficiency in this stage. It may be meiosis,

or pollination mechanism, flower, fruit, and seed production, or suitably phased germination (Webb, 1965). He also stressed that efficiency in any one of these may be nullified by inefficiency at some other point.

Crosby (1965) stated that "even if we use seed production only as a relative measure of reproductive capacity, we should have to use it with great caution. Because, the proportion of seeds which will be ultimately viable may vary considerably in different habitats, from one season to another from individuals to individuals". Thus, we can not only limit reproductive capacity in this way because a plant will leave descendent through its pollen as well as through its ovule. For any individual plant there is no necessary connection between its capacity for reproduction through ovules and that through pollen; some plants are dioecious. Pollen production of a plant may be relatively easy to estimate; however, estimation of its effectiveness interms of ultimate viability (fertility) may be much more difficult even than in the case of ovules (Van der Pijl, 1965).

There are many ways in which pollen can go astray and fail to reach a stigma. Thus, the effectiveness of the pollination mechanism is one of the factors which has to be taken into consideration (Free, 1965); because it may vary widely in the same species and from one habitat to another. It may depend to a great extent upon climatic conditions and in the case of entomophilous plants upon the availability and behavior of the relevant insects.

The mean number of seeds maturing within fruit is defined as "brood size", and is correlated with different modes of dispersal. Annuals have significantly higher brood sizes (21.7) than perennials (<9.9). Among perennials, woody plants have lower brood size (3.3) than herbaceous perennials (13.5) (Weins, 1984). Thus, all previous studies of reproductive success have mostly stressed

whole fruit abortion or total seed production (Salisbury, 1942; Stephenson, 1981). Because patterns of fruit and seed maturation and abortion influence the size and quality of the seed crops and these are related to plant reproductive success (Zimmerman, 1988).

There is a broad correlation between reproductive capacity and wide spread distribution or dispersal efficiency (Harper, 1965). Efficient dispersal and establishment can only come into play if there is a sufficiency of seed available (Webb, 1965); and there are numerous species whose reproductive efficiency up to the production of seeds is good but which find their limiting factor in quite unexplored difficulties in dispersal and establishment.

The ability to colonize is, therefore an essential part of a plant's reproductive biology. It seems automatically to follow that if a plant produces sufficient propagules to effect successful new colonization, it will be over-producing in areas which it has already colonized (Harper, 1965). Thus the colonizing ability of a plant must be a function of the number of viable propagules it produces from which may be derived "the intrinsic rate of natural increase" and the distance over which these may be spread (Cole, 1950).

The most precise method that exist for measuring the ultimate reproductive success of individuals as stressed by Crawley (1997) is to determine genetically the maternity and paternity of surviving seedlings in the field. Generally, we may say that the reproductive capacity of a plant may depend on the genetic environment in which it finds itself and it can not be considered in isolation (Crosby, 1965). Thus, the evolutionary or territorial advance of a species may depend not only on its ability to maximize its reproductive capacity, but also on its ability to minimize that of its competitors through aggressive hybridization.

3.2.3. Ecological forces Influencing Plant Reproduction

A great diversity of ecological factors both intrinsic and extrinsic affect reproduction in plants. The intrinsic factors include nectar reward, flower phenology and morphology of plants and the extrinsic factors includes both abiotic growing conditions such as temperature, light and wind and biotic factors like competition, herbivory, pollinators and dispersal vectors (Crawley, 1997).

The trait of plants that might prove able to influence pollinator behavior, hence pollination and reproductive success, are rate of nectar production and flowering phenology (Zimmerman, 1988). Lacking pollen transfer from the males is one of the factors that limit seed and fruit set. Increased visitation rates increases the probability that a plant's pollen will be picked up and distributed by a pollinator. Thus, floral nectar production is a trait central to plant-pollinator interactions (Campbell, 1985).

Numerous studies have shown that flower opening at different times during the season vary in seed production per flower, while others have shown that plants with different flowering schedules differs in total seed set (i.e. total female fitness) (Levin and Anderson, 1970).

It has been suggested that flower phenology (or, the seasonal time of flowering) is responsive to selection pressure from such variables as pollinator availability and interspecific competition for their services, intraspecific competition for pollinators, seed predation, fruit dispersal, environmental variable and mutualistic interaction among co-occurring species (Real, 1981).

Plant morphology (the size, height, shape, and positioning of plant parts) also affects reproductive performances and dispersal on several scales: whole plants, branch or ramet, inflorescence, flower, and seed (Waller, 1988).

Competition (interference) is ubiquitous in its influences on plants. It is rare to find a plant which has not been affected negatively by neighbouring plants (Harper, 1965).

There are several possible effects of competition on the reproductive behavior and success of plants. Interference may: (a) reduce the probability that an individual will reproduce or reduce the amount of reproduction (number or size of seeds or ramets produced) (Krebs, 1985); (b) change plants reproductive allocation (proportion of resources in reproductive tissue (Evenson, 1983); (c) change the timing of reproduction (onset and duration of reproductive activities); (d) change the mode of reproduction (eg. the proportion of ramets versus genets production or asexual versus sexual reproduction); (e) change in mating behavior (eg. gender allocation, proportion of cleistogamous versus chasmogamous flowers (Zimmerman, 1988). Also competition may change the frequency and spatial distribution of these behaviours within a population (i.e., the amount of individual variation).

Thus, interference (competition) can clearly play an overriding role in determining whether or not a particular biology represents a successful reproductive strategy (Harper, 1965); and interference from neighbouring plants also offers a means by which population may be regulated and these is a special complexity that the plant may react differently to different sorts of neighbours- sometimes by mortality and some times by plasticity.

One important selection pressure faced by all or nearly all plant results from removal of vegetative and reproductive structures by herbivores (West, 1968). Herbivores have a long evolutionary association with plants and although today the number of order of animals utilizing plants either partially or completely as a food source is relatively small (Southwood, 1985). The

diversity of herbivores within certain of these orders is enormous. Most striking is that approximately 50% of all insect species and 65% of mammal species are partially or completely phytophagous. Moreover, the accumulated evidence from numerous studies of effects of herbivory on both agricultural and natural setting leads to the inescapable conclusion that herbivory is a major factor influencing the reproductive success of plants (Hariston *et al.*, 1960).

While plant mortality is the most dramatic means by which herbivores affect plant reproduction, decrease in growth and subsequent reproduction rather than outright death are the more usual effects of herbivore damage to vegetative parts (Marquis, 1984).

Herbivory may affect seed quality as well as seed number when vegetative tissues are removed. Herbivores destruction of flowers, seeds, and fruits by both invertebrates and vertebrates can substantially reduce the reproductive output of plants (Janzen, 1969).



3.3. Chromosome Cytology

Chromosome cytological study (i.e., number, morphology, pairing behavior and subsequent segregation) of chromosomes has helped in taxonomic and phylogenetic studies and also in estimating fertility success in plants (Stace, 1980; Kifle Dagne, 1994).

3.3.1. Chromosome Number and Morphology as Characters used in Determining Taxonomic Distinctiveness.

The number of chromosome in each cell of all individuals of a single species is constant. Except for simple multiples of that number, the more closely related species are, the more likely to have the same chromosome number and the more distantly related species are, the more likely that they are to have different numbers. This relative conservativeness renders chromosome number an important and much used taxonomic character (Stace, 1980). Interspecific variation (within one genus) in chromosome numbers has proved to be one of the richest sources of cytological data of value to taxonomists. At generic level there is usually a single base number derived to produce aneuploids and polyploids (Shaw, 1972).

Polyploidy is known to arise by either somatic or meiotic processes and is extremely widespread in plants and has been a major feature in plant evolution (Stace, 1980).

A variation in chromosome number can also be due to fragmentation (breakage), division, or fusion (Shaw, 1972). Thus chromosome number of apparently related species might be substantially different.

According to Love (1951) differences in chromosome base number should not be tolerated within a single genus. In *Luzula spicata*, for example, plants can have $2n=12, 14$ or 24 which apparently looks like different base numbers but the total chromosome volume is about the same in all and this indicates that the higher numbers are probably derived by fragmentation (agametoploidy) (Stace, 1980). On the other hand, all the known taxa of the genus *Guizotia* have $2n=30$, which indicates that speciation within the genus did not involve changes or variation in chromosome number (Kifle Dagne, 1994). Thus makes it difficult to determine or to fix the rules about basic chromosome number of the genus.

Species may be characterized not only by the number but also by the metaphase morphology of its chromosomes (Sinha, 1980). The over all size of chromosomes, the position of centromers (i.e., the arm length ratio of each chromosome in the genome), the position of secondary constriction which delimit the occurrence of satellites are important chromosome features used in taxonomic studies (Stace, 1980). The length of chromosome is a constant and characteristic property and chromosome may arbitrarily be classified as long ($>10\mu\text{m}$), medium ($4-8\mu\text{m}$) or short ($<2\mu\text{m}$) (Bernard, 1976). These measurements are sometimes inaccurate since the degree of coiling and the actual length of the standards vary with individuals, with cells and of course with organisms. Nevertheless, they provide at least the best information available on the relative size of the chromosomes (Cohn, 1964). The most commonly utilized aspect of chromosome structure is the position of the centromer. Terminologies such as teleocentric, acrocentric, sub-acrocentric, sub-metacentric, and metacentric are often used to indicate the position of centromer (Bernard, 1976). Forexample, one can talk the karyotypes of the genus *Calystegia* ($2n=22$) as containing or consist of 8 short metacentric, 2 short sub metacentrics and 1 short metacentric within addition a well defined secondary constriction and satellites (Stace, 1980). Karyotype can be represented diagrammatically either by karyogram or by ideogram (Sharp, 1943). It was found that recording of

satellites is problematic because they are often very variable in appearance, at sometimes being very conspicuous and at others indiscernible and it is not always possible to obtain consistent results (Stace, 1980). From the 1970s onwards, our ability to distinguish morphologically between chromosomes, at least in favourable material, has been greatly enhanced by new staining techniques using Giemsa and Fluorochrome dyes which stain chromosomes in a consistent banding pattern instead of with uniform intensity, as in the cases with the usual basic Fuchsin Feulgen reagents (Vosa, 1975).

The morphology of somatic chromosomes at metaphase is a constant feature from cell to cell and among individuals of the same species with little variation encountered (Sinha, 1980). The fact that karyotypes (the appearance of basic chromosome set) are species specific and make them useful in taxonomic and phylogenetic studies; and karyotypes of different species may differ in the number, size and form of chromosomes, and in the number, size and position of secondary constrictions and satellites etc.(Stace, 1980; Kifle Dagne, 1994). Differences between the karyotypes of related species are the result of karyotype evolution (Stebbins, 1979) which are brought about by the well known processes of translocation, inversion, duplication and deficiency of various parts of chromosome may also readily explain the rapid and large change in chromosome structure (Jones, 1978).

However, karyotypes of some related species can not often be distinguished just by gross morphology. They may differ only in some genes or differ by equal translocations or inversions, which become evident only when chromosomes pair in interspecific hybrids (Stebbins, 1950).

However intraspecific variation in chromosome size, centromeric position and number of satellited chromosomes have been reported (Patel *et al.*, 1983); but high intraspecific difference in chromosome absolute length were not evidenced by significant differences in DNA amount

(Hiremath *et al.*, 1992), and thus suggested that chromosome length and ratio are known to be affected by a number of non-genetical factors.

3.3.2. Chromosome Behavior (pairing and subsequent segregation) as Indicator of Fertility Success in Plants.

The chromosome number and homology largely determine pairing behavior at meiosis, which in part governs the level of fertility and hence the breeding behavior and pattern of variation of a population (Stace, 1980). Not only does the regularity of pairing bivalent formation largely determine the fertility of a plant but it enables a chromosome for chromosome comparison of the degree of homology between genomes (Cohn, 1964). If one is investigating meiosis in anther i.e., Pollen Mather Cells(PMCs), it is necessary to look at early stage, metaphase I, to see if homologous chromosomes pair to form bivalent or do remain as univalent, in which case what happens at anaphase I is the presence of micronuclei which form when chromosome get left behind on the equator when the rest have moved off to the poles (Shaw, 1972). Meiotic abnormalities (aberration) are manifested at various stages of meiotic division. Forexample, in *Guizotia hybrides* (Kifle Dagne, 1994). These abnormalities include the occurrence of univalents at metaphase I, unequal segregation, laggards (undivided univalents and/ or separated chromatids), bridges and fragments at anaphase and teleophase I and II, which ultimately ended up as micronuclei. On the same study these abnormalities are evidenced in reduction of pollen fertility.

Under natural conditions usually the occurrence of abnormalities such as these are not regular feature, but represents the product of chance hybridization between two plants with genomes which are sufficiently unlike and these cause mechanical problems in pairing (Stace, 1980).

It has also been found out that duplication, deficiency, inversion and translocation of chromosome parts bring about variation in chromosome morphology, and thus affect the pairing behavior (Shaw, 1972). Forexample, in the genus *Oenothera* all species are diploid with $2n=14$. Many of these exhibit a normal meiosis (bivalent formation at metaphase I), but in the sub genus *Oenothera* the species are heterozygous for translocations involving varying number of chromosomes so that multivalents of varying sizes arise at meiosis (Stace, 1980).

4. MATERIALS AND METHODS

The *Aloe pulcherrima* and *Aloe debrana* populations used in the study were those occurring naturally around Debre Libanos.

4.1. Field Data Collection and Treatment for Population Structure and Dynamics

To study the population structure six plots of (quadrats) 5 x 20 m² were established in the study site; three plots for *Aloe pulcherrima* and three plots for *Aloe debrana* populations.

In each plot genets and ramets were sorted-out and marked with a double numbers (G-R) by water- proof marker. Here G stands for putative genet and R stands for the individual ramet. Individuals (genets) were also given coordinates (X-Y) within the plots. This mapping was done to avoid confusion during the second season recording.

For every genet, stem length and stem diameter and for every ramet, rosette height, rosette diameter, and number of inflorescence(s) were measured and counted. These measurements and counting were undertaken in two successive seasons (December to February for *A. debrana* and June to August for *A. pulcherrima* in 1997 and 1998) following their flower period. During the second season recording, new vegetative daughters and seedlings recruited in the plots were also included.

Based on the data, the population structure of the two species were described by clone size (number of genets and ramets/genet) and compared for the two species. The ramets were also classified by 10 cm size classes of their rosette diameter and the relative frequency distribution in each class was established by using methods of descriptive statistics. The ramet size relationship

to flowering was also performed for 1997 and 1998. Mean annual growth rates were calculated for ramets defined by 10 cm size classes of rosette height from change between the seasons and compared for the two species.

The rust fungus parasite found on rosettes of *A. pulcherrima* population during the course of study was recorded and identified.

To study the population dynamics (i.e., to estimate and compare the growth rate of populations of the two species) between seasons, the genets in the plots of each species were characterized by life (developmental) stages (Juvenile, Mature and Senile), number of ramets, flowered rosettes and sterile rosettes. Based on these criteria, all genets were referred to one of 5 life stage classes as defined in Fig.14 (J, Juvenile genet; M, Mature sterile genet with one ramet; M*, Mature flowering genet with one ramet; P, Senile sterile genet with ≥ 2 ramets; and P*, Senile flowering genet ≥ 2 ramets).

Depending on the transition probabilities among the stage classes from a stage structured projection constructed for 1997–1998; growth rate “ λ ” of the populations were calculated and compared by using Levokovitch matrix model (Nordal *et al.*, 1997). Besides that, population flux at ramet-level was also analyzed and compared.

4.2. Field Data Collection and Treatment for Reproductive Biology.

To estimate reproductive success and dispersal efficiency of the two species (i.e., *A. pulcherrima* and *A. debrana*) the populations in the plots were studied and compared.

Their ability to reproduce by vegetative propagation was obtained from the lateral offshoots (new vegetative daughters or ramets) from every genets recorded in successive year 1997 to 1998. Number of flowers produced per inflorescence(s) and fruits mature were counted from every flowered ramets in the plots for the two species. Fruits to flowers ratio was calculated from the data and comparison made. Seed count was carried out in five randomly selected fruits (capsules) from 50 flowered ramets ($5 \times 50 = 250$ capsules) in the population for the two *Aloe* species. The average seed set was calculated both per capsule and per ramet basis and compared for the two species by using methods of inferential statistics.

In the population of each species, 12 flowered ramets (4/plot) were selected randomly and coded A, B, C, D. In each individual, flowers were marked with different colored thread; 10 for manipulation and 10 as control. Hand pollination (crossing) was made from A to B, B to C, C to D and D to A. Mature capsules from both manipulated and control were harvested in separate bags and seed count was made. Finally, the average seed set for manipulated and control capsules was calculated and compared. Besides that, qualitative observation was also made on pollinators (i.e., flower visiting animals) and the specific bird and insects were recorded.

Pollen fertility was determined from two anthers of randomly selected 14 flowered ramets ($2 \times 14 = 28$ anthers) of each species. Freshly released pollen grains were stained in the study site with cotton blue lactophenol on slides and covered with cover slips. They were allowed to stain for several hours before scoring. Stained and unstained pollen grains were classified as fertile and sterile, respectively by observing under light microscope. Percentage pollen fertility was calculated and compared for the two species.

4.3. Laboratory Work for Chromosome Cytological Study.

For meiotic chromosome study i.e., number, pairing and subsequent segregation, flower buds at appropriate stage of development of respective species were obtained at their flowering season from the study site, Debre Libanos. The flower buds were fixed in ethanol–chloroform–acetic acid (6:3:1) for 24 hrs and stored in 70% alcohol at 4^oC until used (Kifle Dagne and Hennen, 1992). Buds were stained in snow's carmine (Snow, 1963) for about a week at room temperature. Pollen mother cells (PMCs) were released in a drop of 45% acetic acid on glass slides, squashed and observed under light microscope. Preparation with the right meiotic phase made semi-permanent by sealing around the edges of the cover slip with paraffin wax. The PMCs were analyzed and photographed mainly at metaphase I for chromosome pairing, and anaphase/telophase I and II for aberration such as laggards (univalents and/or separated chromatids) bridges, and fragments manifested during segregation. The meiotic activities (pairing behavior and subsequent segregation) of the two species were related to pollen fertility and thus used as a criteria to estimate ultimate reproductive success of the species studied.

Soil Analysis

For the detailed study and analysis of the soils of the study site, 18 samples i.e., nine were taken from the plots of *Aloe pulcherrima* and nine from plots of *Aloe debrana* and analyzed at the National soil Lab of Ethiopia. Methods of analysis applied were as described in (Bernard *et al.*, 1993). The samples were taken from 10–15 cm depth and the method of sampling used was what is known as Composite. Particle Size Classes (PSC), pH, CEC, Na, K, Ca, Mg, Total Nitrogen, Available Phosphorus, and Organic Carbon were studied and analysis made.

5. RESULTS

5.1. POPULATION STRUCTURE AND DYNAMICS

5.1.1. Population structure by clone size and rosette diameter

The population structure of two *Aloe* species was described by the clone size and rosette diameter of ramets that constitute the population. As described by clone size, the number of genets and vegetative daughters (ramets)/ genet was different for the two *Aloe* species studied. In both species most genets consisted of only one ramet. However, there were more multi-rameted (2-12) genets in *A. pulcherrima* compared to *A. debrana* with fewer multi-rameted genets. Thus, *A. pulcherrima* and *A. debrana* differ significantly in the extent of potential clone formation ($X > 0.01$)

Besides that, *A. debrana* population contained the greater number of genetic individuals (genets), 192 as compared to *A. pulcherrima* that contained 141 genets in their respective plots circumscribed for study. Nevertheless, the population of *A. pulcherrima* had greater number of ramets that resulted from clonal growth (vegetative propagation), 317 and the population of *A. debrana* had less number of ramets, 268 (Fig. 7 and 8)

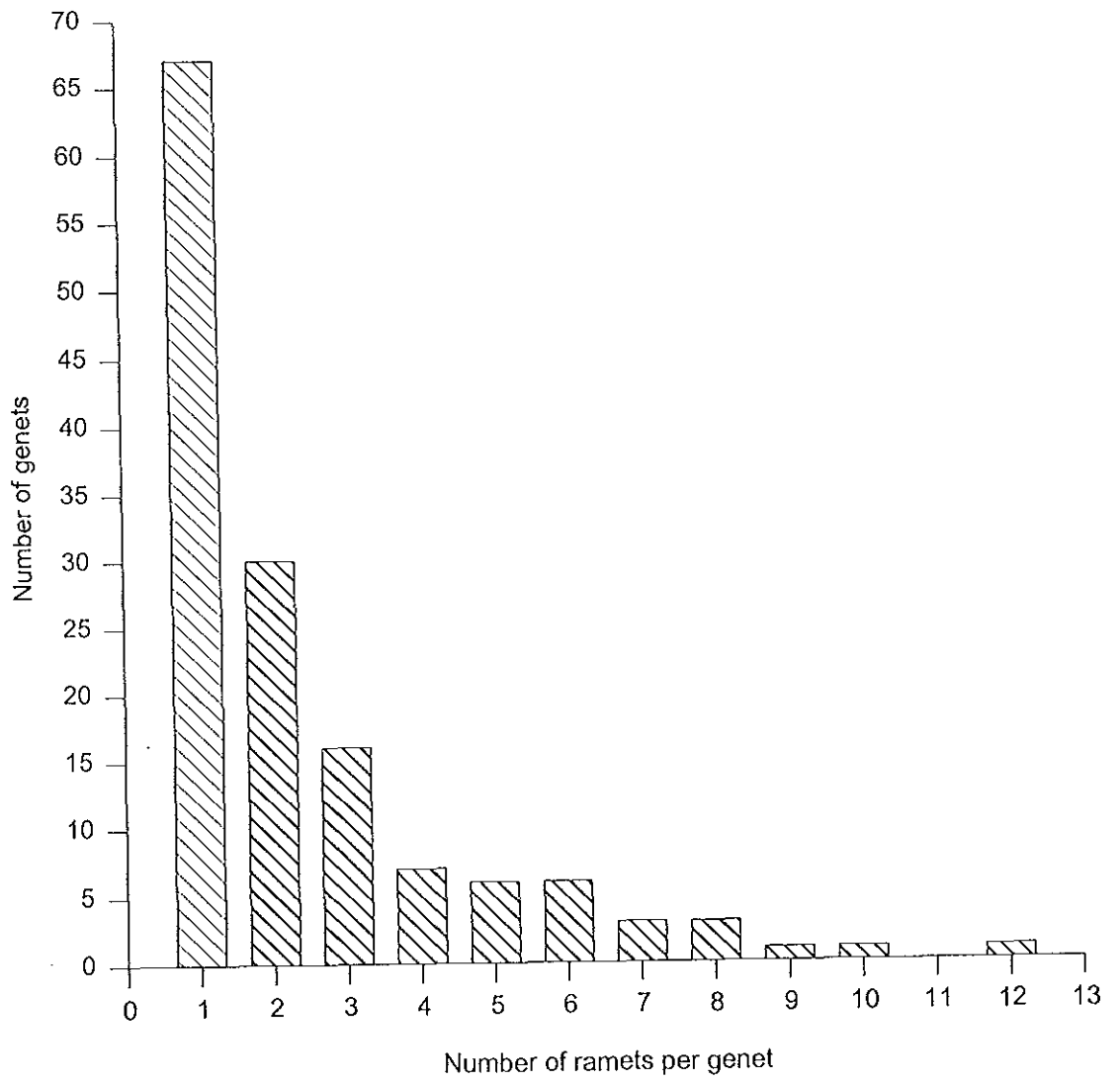


Fig.7. Frequency distribution by clone size (the number of genets and ramets/genet) for *A. pulcherrima* population.

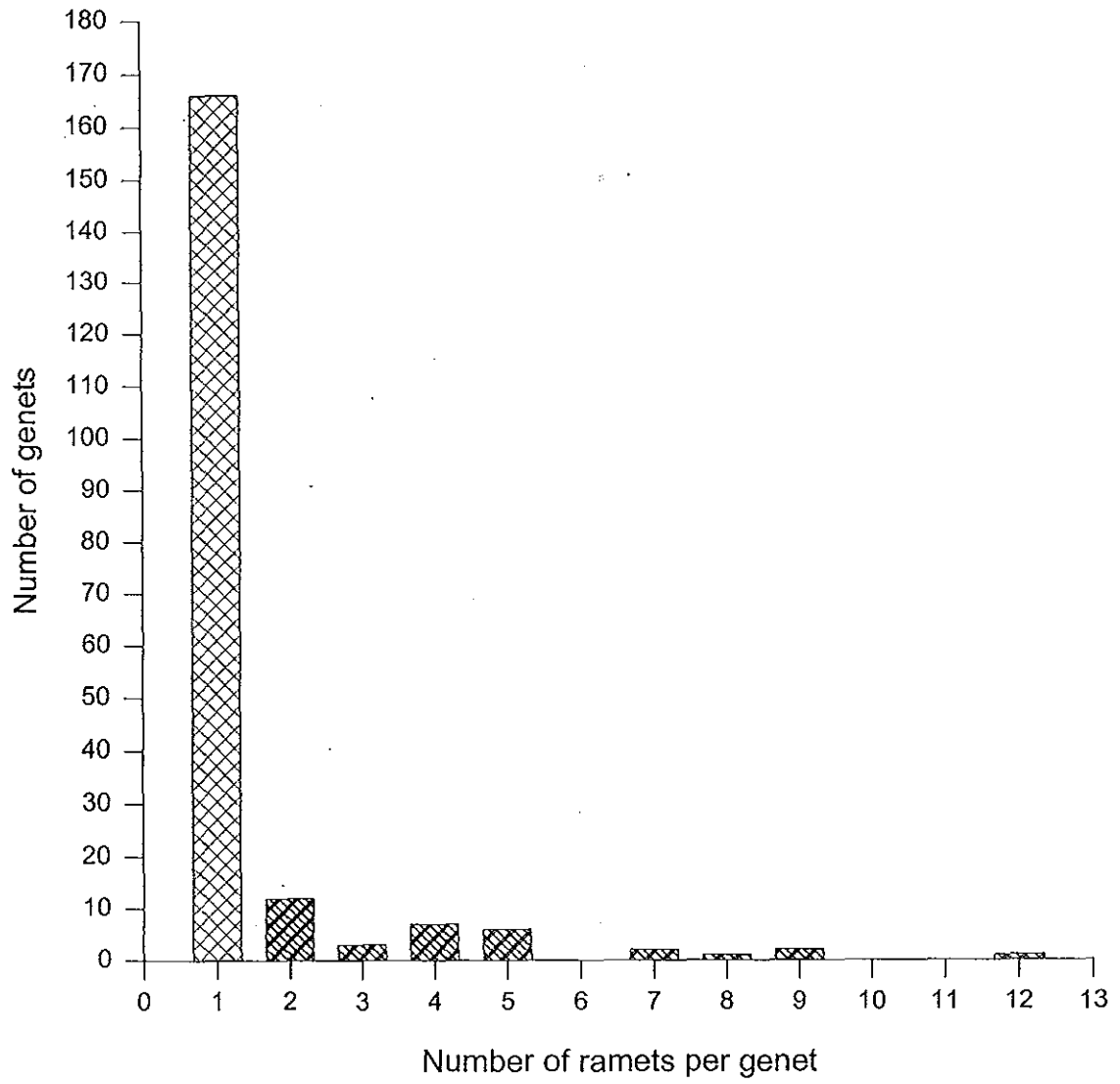


Fig.8. Frequency distribution by clone size (the number of genets and ramets/genet) for *A. debrana* population.

The populations of *A. pulcherrima* and *A. debrana* also displayed different size class distribution. Size classes here defined by the rosette diameter of ramets in the populations.

As described by 10 cm size class of the rosette diameter, the relative frequency of ramets in the population of *A. pulcherrima* whose rosette diameter is less than 30 cm (small sized relatively young) comprised 2.2%; those between 30–90 cm (medium sized mature ramets) comprised 86.3%; and those above 90 cm (large sized relatively old or senile ramets) comprised 11.5%. On the contrary in *A. debrana* population ramets with rosette diameter less than 30 cm (small sized relatively young) accounted for 26.3 %; those with rosette diameter between 30–90 cm (medium sized mature ramets) accounted for 71.5%; and those with rosette diameter above 90 cm (large sized relatively old or senile ramets) accounted for 2.2%. Percentage representation indicated above are the mean proportion of ramets in size class distribution for 1997 and 1998 (Fig. 9 and 10).



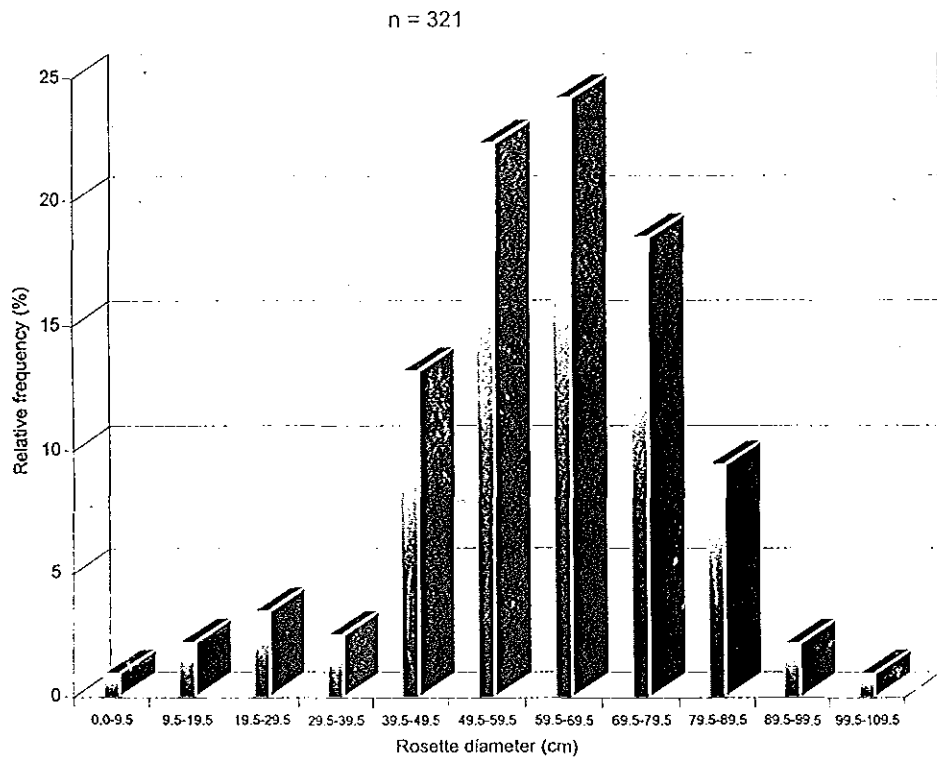
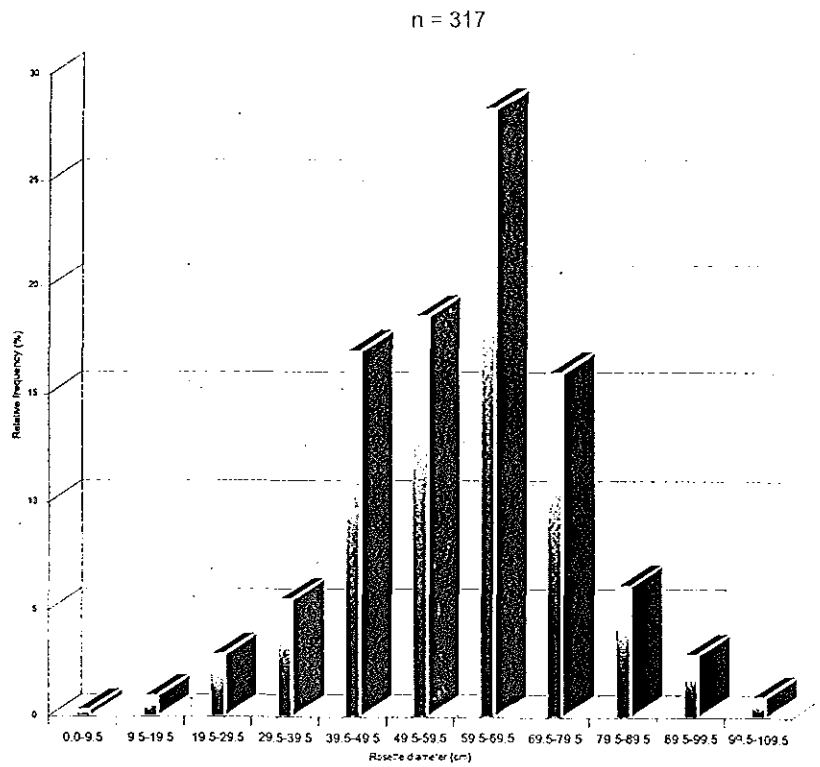


Fig.9. The population structure of *A. pulcherrima* in 10 cm size classes of rosette diameter of ramets in 1997 and 1998.

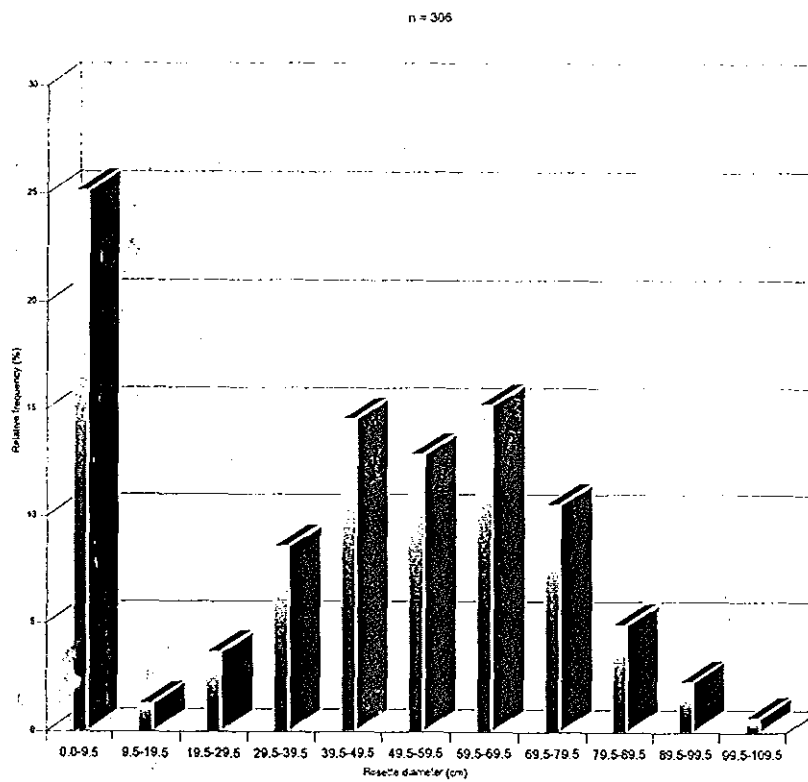
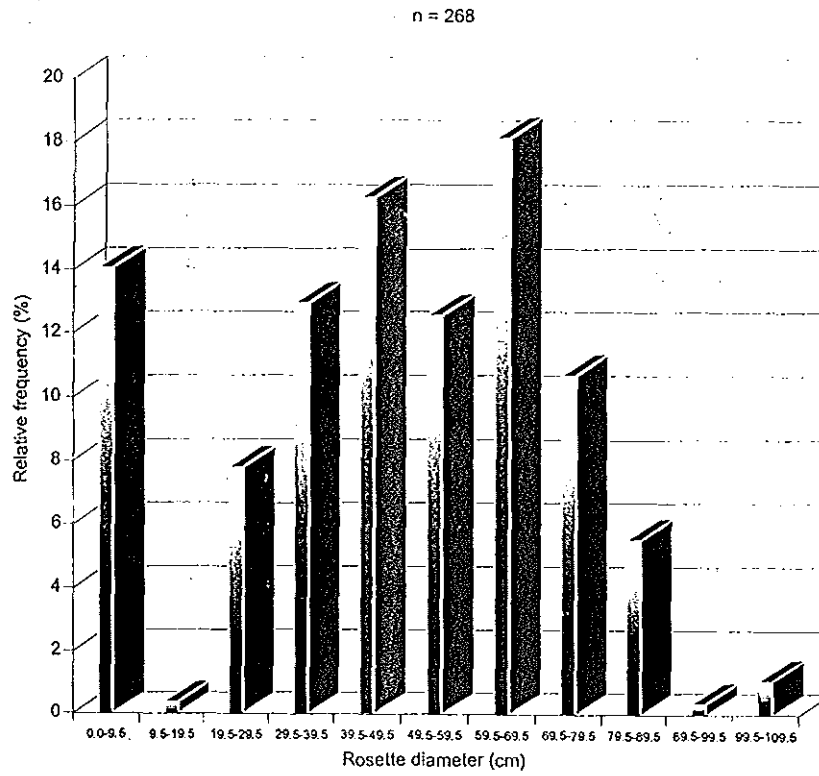


Fig.10. The population structure of *A. debrana* in 10 cm size classes of rosette diameter of ramets in 1997 and 1998.

5.1.2. Ramet size relationship to flowering

The size class distribution of ramets that flowered in the populations of the two *Aloe* species studied were performed for 1997 and 1998 (Fig.11 and 12). Ramets that flowered in successive seasons or alternated flowering and non-flowering were normally the medium sized ramets in the populations. Thus, the probability that ramet will flower from season to season is highest for the medium sized ramets. However, only small proportions about 30% of ramets that produced flowers in 1997 had flowers in 1998 in the two species.

In *A. pulcherrima* population the majority of ramets i.e., about 98%, flowered from season to season or alternated flowering and the non-flowering had rosette diameter between 50-100 cm. Relatively few ramets, 1 to 5, flowered whose rosette diameter is less than 50 cm and is above 100 cm in both seasons. Nevertheless, none of the ramets with rosette diameter less than 30 cm flowered and only 1 to 2 ramets flowered whose rosette diameter is above 90 cm in *A. debrana* population. Similarly, the majority, about 99% of those flowered from season to season or alternated flowering and non-flowering had rosette diameter between 30–90 cm in 1997 and 1998 (Fig. 11 and 12).

This ramet size relationship to flowering showed that the minimum size that has to be attained by a ramet to flower is 50 cm rosette diameter in *A. pulcherrima* whereas it is 30 cm rosette diameter in *A. debrana*. Besides that, the number of ramets that flowered in the two species in 1997 and 1998 was variable. It was 95 and 119 ramets flowered in the *A. pulcherrima* population, and 87 and 82 in *A. debrana* population respectively.

5.1.2. Ramets size relationship to flowering

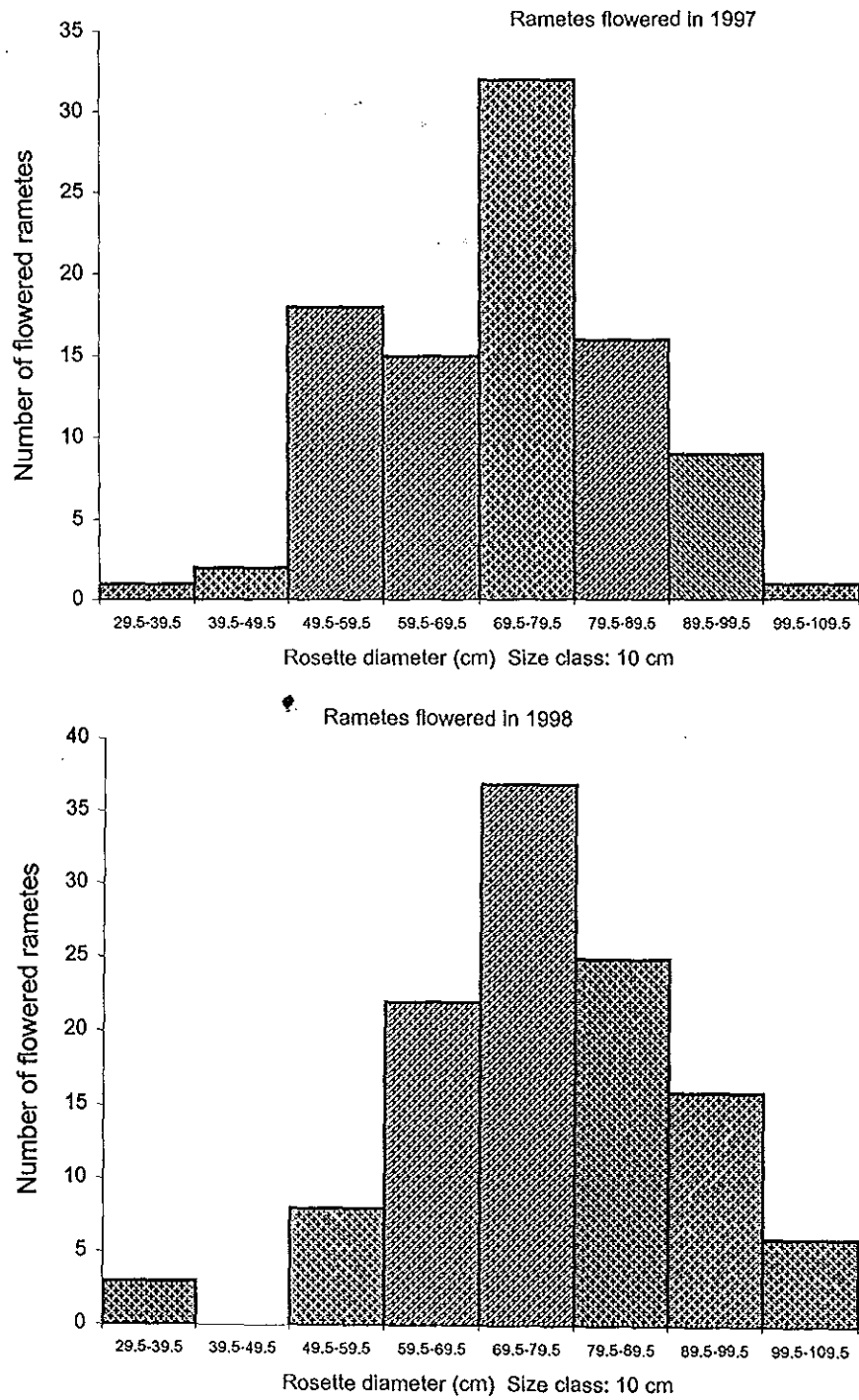


Fig.11. Number and rosette diameter of ramets flowered in 1997 and 1998 in *A. pulcherrima* population in three (5 x 20 m²) plots.

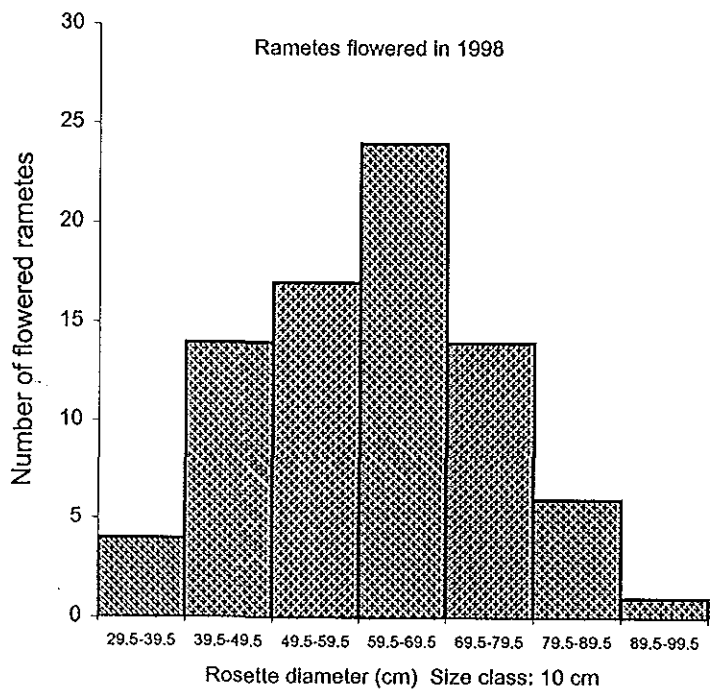
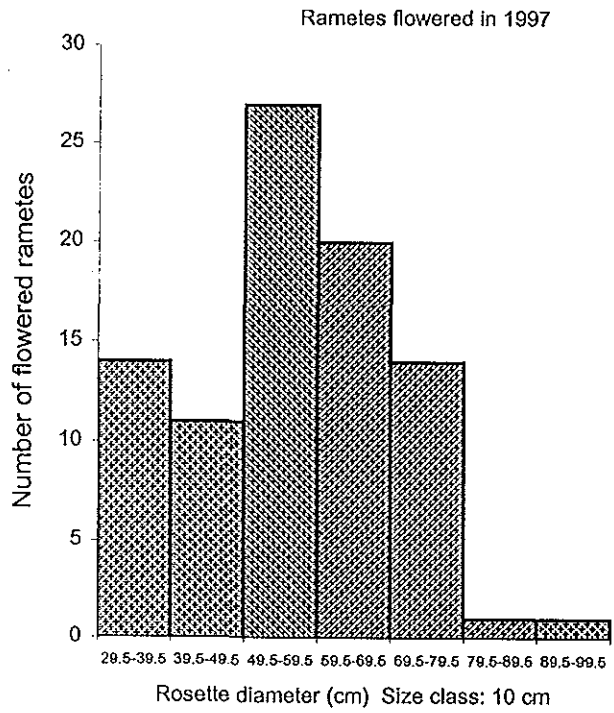


Fig.12. Number and rosette diameter of ramets flowered in 1997 and 1998 in *A. debrana* population in three (5 x 20 m²) plots.

5.1.3. Size and flowering relationship to growth rate of ramets

Result of measurements in successive years showed that ramets in *A. pulcherrima* and *A. debrana* populations have the potential to grow, stay the same, or actually shrink. However, the mean annual growth rates calculated for different size classes by 10 cm RH (rosette height) revealed that the maximum mean annual growth rate was for small ramets which were initially smaller than 20 cm rosette height. It was 0.34 ± 0.28 cm for ramets of *A. pulcherrima* population and 0.31 ± 0.41 cm for ramets of *A. debrana* population (Table. 4 and 5).

Among ramets of potential flowering size, mean annual growth rates decreased with increasing size. Thus, all medium and larger rosette height classes of both species had lower mean annual growth rates. However, in comparison, ramets from *A. pulcherrima* population have relatively larger size and high mean annual growth rates as compared to *A. debrana* (Fig.13).

Table.4. Mean annual growth rates of ramets of *A. pulcherrima* population for the period May 1997 to May 1998. T, total number of ramets in each size class at the beginning of the study period; D, number died during the study; F, number that flowered in 1997. Growth, is calculated mean annual rate (\pm SD) and size here defined in 10 cm size classes of rosette height (RH).

Size (RH)	T	D	F	Mean annual growth rate RH \pm SD (n)
9.5-19.5	7	0	0	0.34 \pm 0.28 (7)
19.5-29.5	40	4	6	0.26 \pm 0.22 (36)
29.5-39.5	126	3	44	0.20 \pm 0.14 (123)
39.5-49.5	104	4	37	0.06 \pm 0.08 (100)
49.5-59.5	37	1	8	0.02 \pm 0.09 (36)
>59.5	3	0	0	0.003 \pm 0.04 (3)

Table.5. Mean annual growth rates of ramets of *A. debrana* population for the period December 1997 to December 1998. T, total number of ramets in each size class at the beginning of the study period; D, number that died during the study; F, number that flowered in 1997. Growth is calculated mean annual rate (\pm SD) and size here defined in 10 cm size classes of rosette height (RH).

Size RH (cm)	T	D	F	Mean annual growth rate RH \pm SD (n)
Very small ramets	39	-	-	-
9.5-19.5	27	3	1	0.31 \pm 0.41 (24)
19.5-29.5	72	2	27	0.17 \pm 0.34 (70)
29.5-39.5	81	2	29	0.06 \pm 0.19 (79)
39.5-49.5	35	2	22	-0.03 \pm 0.11 (33)
49.5-59.5	12	0	7	-0.05 \pm 0.15 (12)
>59.5	2	1	1	0.05* \pm 0.00 (1)

* Annual growth rate for single ramet.

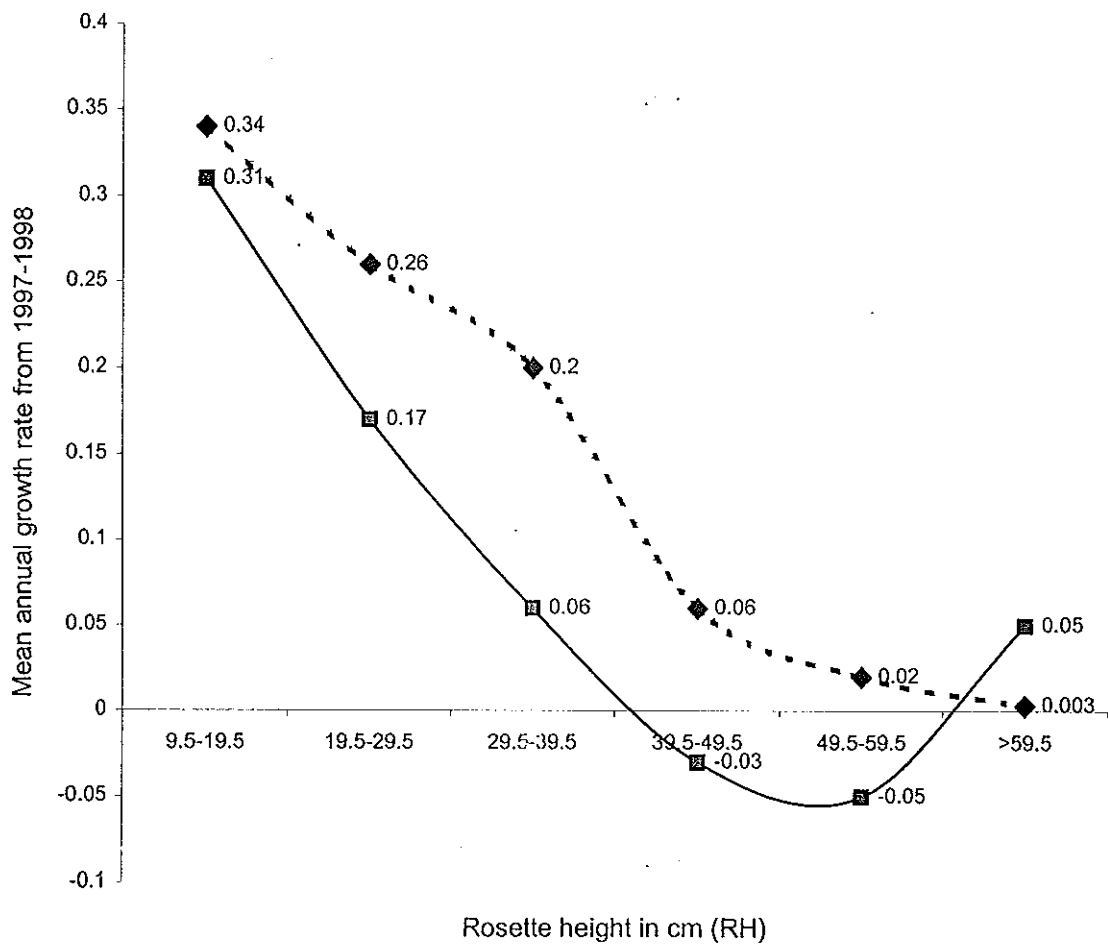


Fig.13. Size specific differences in mean annual growth rate between the study period 1997 to 1998, for ramets of *A. pulcherima*(◆) and *A. debrana* (■).

5.1.4. Population flux (dynamics) at ramet and genet levels

Populations of *A. pulcherrima* and *A. debrana* at ramet level in their respective plots had different densities and remarkable similarities and differences in attributes of population dynamics (flux)(Table.6 and 7). The differences and similarities can be summarized as follows:

1. The densities of ramets are different between and among plots of the two species. However, density didn't change appreciably in one year period in *A. pulcherrima* plots as compared to *A. debrana*. This was attributed to relatively high recruitment of ramets both by vegetative propagation and seedling establishment in *A. debrana* plots. On average, 16 and 5.3 new ramets were emerged between years in *A. debrana* and *A. pulcherrima* respectively in their plots.
2. Despite the difference in recruitment of ramets, mean percentage survival and percentage annual mortality on average tend to be similar. It was 96.2% and 3.8% in *A. debrana* population while 96.3% and 3.7% in *A. pulcherrima* population respectively in their plots.
3. Net increase (population growth rate) of ramets in the populations of the two species calculated was found to be on average $\lambda = 1.15$ for *A. debrana* and $\lambda = 1.01$ for *A. pulcherrima*. These values revealed that *A. debrana* is expanding whereas *A. pulcherrima* is nearly stable (stagnant) at ramet level in the period of study.

Table.6. Population flux of *A. pulcherrima* at ramet-level in three (5 x 20 m²) plots from May 1997 to May 1998.

SPECIES	PLOT NUMBER		
	1	2	3
<i>pulcherima</i>	1	2	3
a. No.of ramets in May 1997	86	112	119
b. No.of ramets in May 1998	92	112	117
c. Net change (b-a)	6	0	-2
d. Net increase (b/a)	1.07	1.00	0.98
e. Ramets 'born' between May 1997 to May 1998	6	6	4
f. Ramets lost between May 1997 and May 1998	0	6	6
g. Ramets surviving from May 1997 to May 1998	86	106	113
h. Percentage of ramets surviving (g/a x100)	100	94.6	94.9
i. Percentage annual mortality (f/g x100)	0	5.7	5.3
j. Total ramets recorded over the year	92	118	123

A.

Table.7. Population flux of *A. debrana* at ramet level in three (5 x 20 m²) plots from December 1997 to December 1998.

SPECIES	PLOT NUMBER		
	1	2	3
<i>A. debrana</i>	1	2	3
a. Number of ramets in December 1997	75	86	107
b. Number of ramets in December 1998	98	92	116
c. Net change (b-a)	23	6	9
d. Net increase (b/a)	1.3	1.06	1.08
e. Ramets 'born' between December 1997 to December 1998	26	9	13
f. Ramets lost between December 1997 to December 1998	3	3	4
g. Ramets surviving from December 1997 to December 1998	72	83	103
h. Percentage of ramets surviving (g/a x100)	96	96.5	96.2
i. Percentage annual mortality (f/g x100)	4.2	3.6	3.9
j. Total ramets recorded over the year	101	95	120

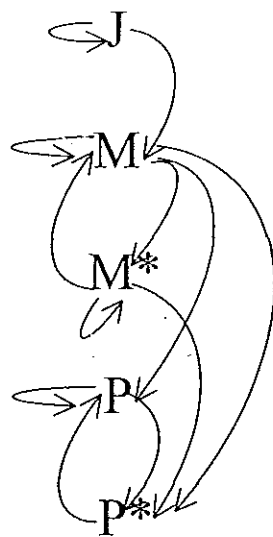


Fig.14. Life stage classes: J = Juvenile; M = Mature sterile genet with one ramet; M* = Mature flowering genet with one ramet; P = Senile sterile genet with ≥ 2 ramets; P* = Senile flowering genet with ≥ 2 ramets. The realized transitions from one year to the next are visualized by the arrows.

1997→1998.

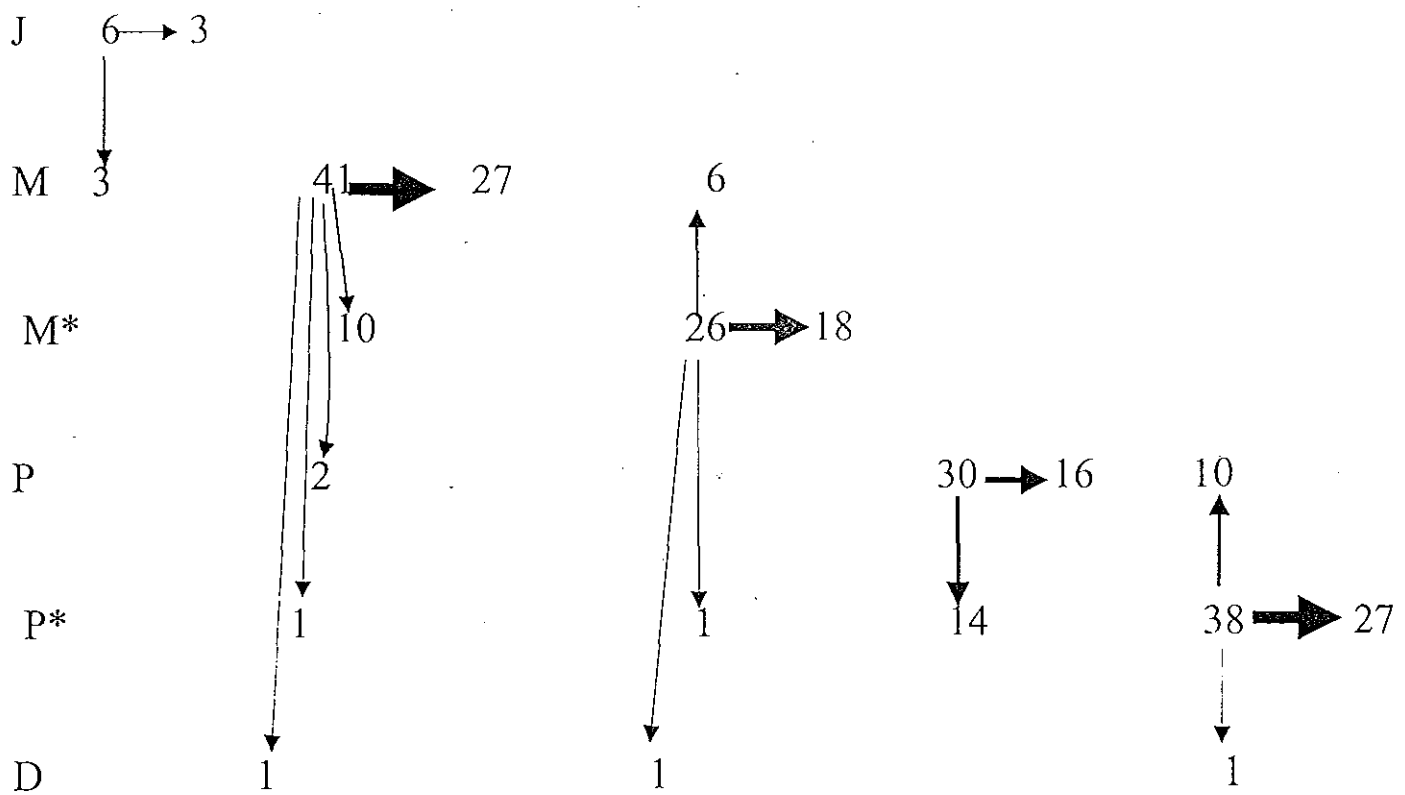
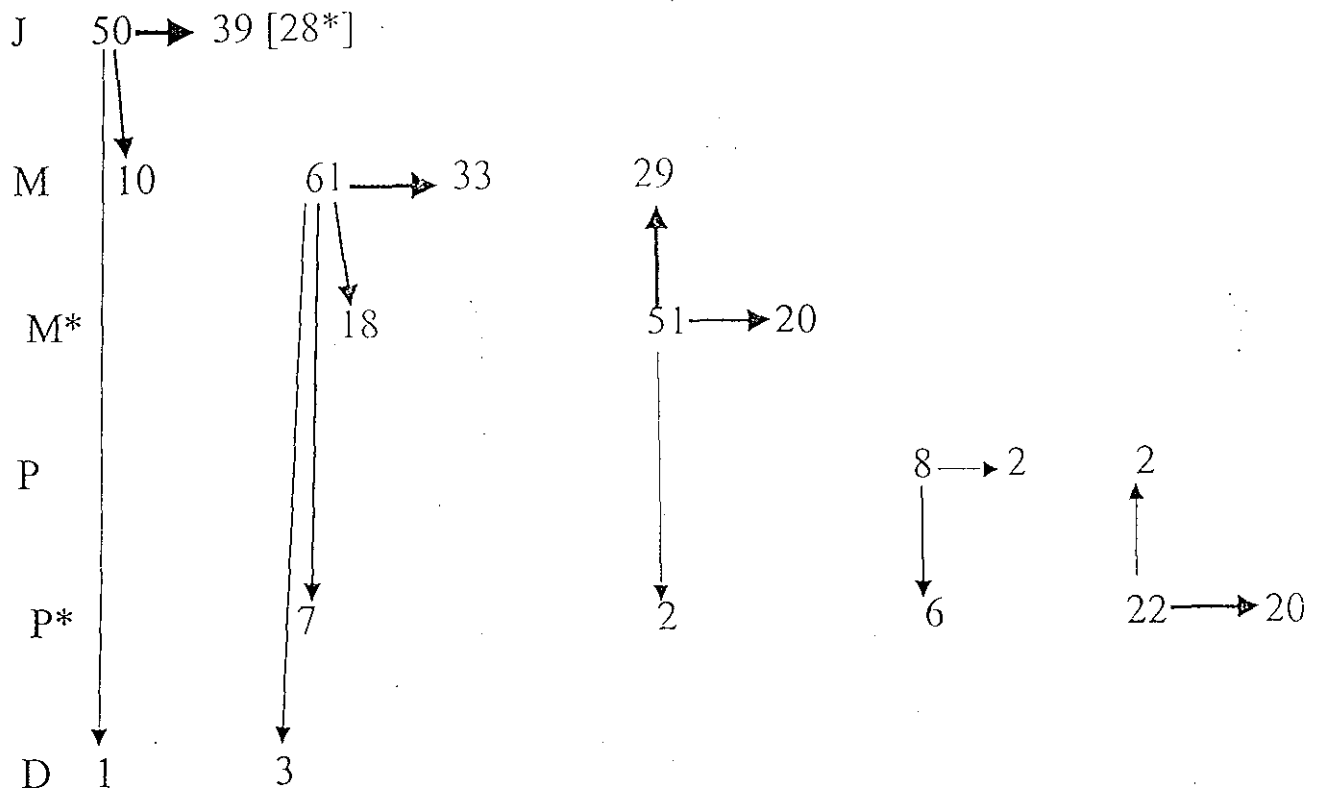


Fig.15. The fate, 1 year later, of Juvenile genet (J), Mature sterile genet with one ramet (M), Mature flowering genet with one ramet (M*), Senile sterile genet with ≥ 2 ramets (P), Senile flowering genet with ≥ 2 rametes (P*) of *A. pulcherrima* marked in 1997.

1997 → 1998



* New seedlings recruited

Fig.16. The fate, 1 year later, of Juvenile (J); Mature sterile genet with one ramet (M); Mature flowering genet with one ramet (M*); Senile sterile genet with ≥ 2 ramets (P); Senile flowering genet with ≥ 2 ramets (P*) of *A. debrana* marked in 1997.

Table.9. Transition probability between stage classes of genets of *A. debrana* population.

Mortality during the time interval 1997 to 1998 equals the category of "dead"

Transition probabilities 1997 → 1998.

J - J - 0.78

J - M - 0.2

J - dead - 0.02

N = 50

M - M - 0.54

M - M* - 0.30

M - P* - 0.11

M - dead - 0.05

N = 61

M* - M - 0.57

M* - M* - 0.39

M* - P* - 0.04

N = 51

P - P - 0.25

P - P* - 0.75

N = 8

P* - P - 0.09

P* - P* - 0.91

N = 22



The stage classes presented above (Fig. 14) and the transition among them as shown in flow diagram (Fig.15 and 16) from 1997 to 1998 were used for analyses of population dynamics at genet level. The dynamics is apparent in *A. debrana* with relatively high rejuvenation (recruitment) as compared to *A. pulcherrima* population even if mortality of genet is less pronounced in both species.

J (Juvenile), M (Mature sterile genet with one ramet) and M* (Mature flowering genet with one ramet) comprised the largest proportion of the population in *A. debrana* as compared to *A. pulcherrima* whose population had large number of P (Senile sterile genet ≥ 2 ramets) and P* (Senile flowering genet ≥ 2 ramets). Intermittent flowering is clearly demonstrated by large exchange between M and M* in the year in *A. debrana* and exchange between P and P* in *A. pulcherrima*.

The transition probabilities presented (Table. 8 and 9) constituted the raw data for Levkovitch matrices. The growth rate (λ) of the populations resulted from the calculation was found to be $\lambda = 1.10$ for *A. debrana* and $\lambda = 0.98$ for *A. pulcherrima*. These values indicate that *A. debrana* population is expanding whereas *A. pulcherrima* is declining or nearly stable (or stagnant) at genet level in the study period.

5.1.5. Pathogens

The population of *Aloe pulcherrima* studied had large proportion of ramets whose rosettes were infected by rust fungus parasites. The infection rate differed between wet and dry seasons of the study. As quantitative observation made during the course of study the proportion of ramets infected in dry season was 30 %(season 1) and wet season was 11%(season 2) (Fig. 17), the main reason for the differences needs further investigations. Nevertheless, the fungus was only rarely observed on adjacent *A. debrana* plants.

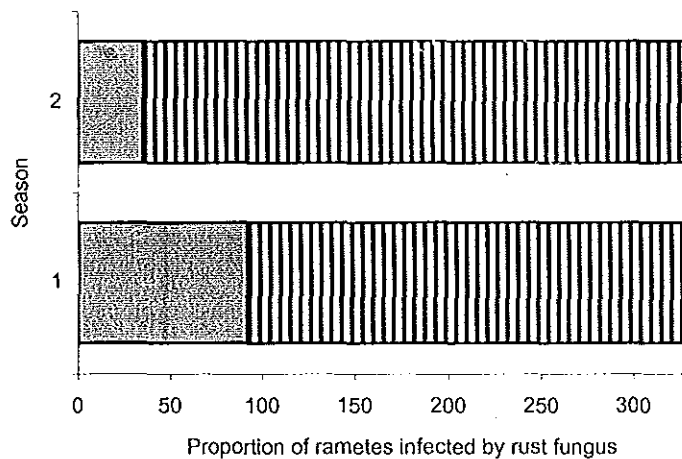


Fig.17. The proportion of ramets in *A. pulcherrima* population infected by rust fungus parasite in dry and wet season in the study period.

5.2. REPRODUCTIVE BIOLOGY

5.2.1. Vegetative Propagation

Of the total ramets gained in the seasons about 41.7% were due to vegetative reproduction and the remainder (58.3%) were due to seedling establishment in *A. debrana* population. But the ramets gained in the seasons were all due to vegetative reproduction and seedling establishment was not observed in *A. pulcherrima* population studied (Table.10). Thus *A. pulcherrima* and *A. debrana* differ in the extent of vegetative propagation and seedling establishment. *A. debrana* can produce new ramets both by vegetative propagation (asexually) and by seedling establishment. *A. pulcherrima* on the other hand entirely produced new ramets by vegetative propagation i.e., there was no recruitment of new genets.

Table.10. Summary of data on the process of vegetative reproduction of the populations of *A. debrana* and *A. pulcherrima* recorded in their three respective plots from 1997 to 1998.

Species	Plot	New ramets gained from 1997 - 1998	Ramets resulted from veg. prop.	Representation of veg. Prop. (%)
<i>A. debrana</i>	1	26	8	30.0
	2	9	8	88.8
	3	13	4	30.8
	TOTAL	48	20	41.7
<i>A. pulcherrima</i>	1	6	6	100
	2	6	6	100
	3	4	4	100
	TOTAL	16	16	100

5.2.2. Production of Flowers and Fruits

The first remarkable point in this section is the sharp difference between the number of flowers produced and fruits mature by the two *Aloe* species in the years of study (Table. 11 and 12). These indicate that many flowers were aborted prematurely in both years. Thus, the number of fruits mature on a plant was much less but proportional to the number of flowers produced.

The number of flowers and fruits produced either per ramet or per plot was smaller for *A. pulcherrima* as compared to *A. debrana*. These reduction in number of flower and fruit production was not by the reduced number of ramets flowered in the seasons of study but by reduction in the number and size (branches) of inflorescence produced per ramet and number of flowers produced per inflorescence in *A. pulcherrima* population. Besides these differences in total number of flowers and fruits produced, the Fr: Fl ratio was small for *A. pulcherrima* (% average \pm SD) 31 ± 8.36 and for *A. debrana* (% average \pm SD) 41.3 ± 2.61 even if the means are not significantly different at ($P < 0.01$). This may be connected to resource allocation i.e., higher allocation of resource for vegetative than sexual reproduction in *A. pulcherrima*; because resource (allocation) availability play a major role in determining the number of reproductive modules produced.

Table.11. The number of flowers produced and fruits mature by the population of *A. plucherrima* in three plots in 1997 and 1998.

Year	Plot	No. of flowers produced/ plot	No. of Fruits mature/ plot	Fruits : Flowers (%)
1997	1	1,757	485	27.6
	2	2,821	774	27.4
	3	2,622	746	28.4
1998	1	2,160	810	37.5
	2	1,655	733	44.2
	3	7,344	1,535	<u>20.9</u> 31±8.36

Table.12. The number of flowers produced and fruits mature by the population of *A. debrana* in three plots in 1997 and 1998.

Year	Plot	No. of Flowers produced / plot	No. of Fruits mature / plot	Fruits : Flowers (%)
1997	1	9, 179	3,943	42.9
	2	8, 202	3,194	38.1
	3	26,765	10,212	43.9
1998	1	17, 694	7789	44.0
	2	13, 267	5831	40.1
	3	13, 004	5211	<u>43.9</u> 41.3±2.61

5.2.3. Seed Production

Seed production varied from capsule to capsule and ramet to ramet in the populations of *A. pulcherrima* and *A. debrana*. Thus, the total number of seeds produced by the two species is proportional to the number of flowers produced, the number of flowers that successfully mature “flower survive” and the number of seed set per successful fruit (capsule). Despite the plasticity in seed production within the populations, the average seed set per capsule and per individual ramet was significantly different at ($P > 0.001$) for *A. pulcherrima* as compared to *A. debrana* (Table.13).

Table.13. Seed production in *A. pulcherrima* and *A. debrana* on capsule and ramet basis.

Species	Average seed set / capsule			Average seed set / ramet		
	X	SE	N	X	SD	N
<i>A. pulcherrima</i>	33.8	1.37	50	1282.9	478.28	50
<i>A. debrana</i>	36.3	2.51	50	4255.2	831.42	50

5.2.4. Pollination and Flower phenology

Pollination

The proportion of marked flowers that mature into fruits under normal pollination conditions and when experimentally given additional pollen differed in the two *Aloe* species populations studied (Table.14). 66.6% of marked flowers manipulated (hand pollinated) and 55% of marked untreated (control) flowers mature into fruits in *A. pulcherrima* population whereas 69.2% of marked flowers manipulated hand pollinated and 61.6% of marked untreated (control) flowers

mature into fruits in *A. debrana* population. Thus this result shows that excessive pollination increased the extent of mature fruit set.

Besides these, there were also differences among manipulated and control fruits in the number of seeds produced per capsule. However, there was no significant difference ($P < 0.01$) between the two treatments in the mean number of seeds produced. This indicates that seed production in these species is not pollen limited, the cause of which undoubtedly be reduced visitation of flowers by pollinators or pollinators scarcity.

The slight increase in the number of fruits mature and mean number of seeds produced per capsule under normal pollination condition (control) in *A. debrana* as compared to *A. pulcherrima* may be related to difference in climatic conditions i.e., hot and dry during *A. debrana*; and cold and wet during *A. pulcherrima* flowering time that influence the visitation rate of pollinators.

Eventhough systematic observations were not made i.e., on behavior and rate of visitation of pollinators, qualitative observation on abundance and specific flower visiting animals was made in the course of study. The major pollinators in abundance were found to be Sun birds > Bees > Butter flies in the two species studied. Thus, pollination system in the two species combines both ornithophilly and entomophilly.

Table.14. The number of fruits mature and mean number of seeds produced/capsule when experimentally given additional pollen and under normal pollination condition in marked flowers from (4 x 3 = 12) flowered ramets in *A. pulcherrima* and *A. debrana* populations. (N= total number of marked flowers and n= number of fruits mature).

Species	Treatment	Number of fruits mature			Mean number of seeds per capsule		
		n	%	N	X	SD	n
<i>A. pulcherrima</i>	Hand pollinated (manipulated)	80	66.6	120	32.4	8.61	80
	Control	66	55	120	32.2	12.75	66
<i>A. debrana</i>	Hand pollinated (manipulated)	83	69.2	120	37.1	5.93	83
	Control	74	61.6	120	36.7	4.12	74

Flower phenology

The seasonal timing of flowering (flower phenology) is different in *A. pulcherrima* and *A. debrana*. Flowering stalk begin to emerge in May with peak flowering in June and July in *A. pulcherrima*. These months are when 75% of the yearly precipitation falling whereas *A. debrana* starts to flower in early December with peak flowering in January and February (dry months) (Table.3). This shows the absence of interspecific competition for pollinators between them.



Fig.18. Sunbird feeding on the nectars of *A. vera* (Source: Photo by Jone Cancalosi, 1997)

5.2.5. Pollen viability

Despite the differences in pollen viability among ramets and flowers, the mean percentage viable pollen in anthers of *A. pulcherrima* and *A. debrana* populations studied was not significantly different ($P < 0.01$). It was found to be 96.5% with (SD \pm 2.62; 28 anthers) and 94.9% with (SD \pm 4.80; 28 anthers) (Table.15). The slight variation in mean percentage pollen viability between the species studied was may be due to the difference in stage of floral development when the samples were taken in the two species in the study period. Nevertheless, high percentage pollen viability were also in evidence by the normal meiotic activity in the pollen mother cells (PMCs) of the species.

Table.15. Percentage pollen viability in two anthers of 14 flowered ramets ($14 \times 2 = 28$ anthers) in *A. pulcherrima* and *A. debrana* populations.

Species	Pollen viability (%)		
	X	SD	N
<i>A. pulcherrima</i>	96.5	2.62	28
<i>A. debrana</i>	94.9	4.80	28

5.3. CHROMOSOME CYTOLOGY

5.3.1. Meiotic Chromosomes (number, pairing behavior and subsequent segregation)

The two *Aloe* species studied (*A. pulcherrima* and *A. debrana*) have diploid chromosome number $2n=14$, 8 large and 6 small sized ones. Meiotic activities in *A. pulcherrima* and *A. debrana* were found to be normal with regular formation of 7-bivalent (7II), and absence of univalents or multivalents formation at metaphase-I (Fig.19 and Table.16).

The meiotic abnormalities which are normally exhibited at anaphase and telophase I/II such as unequal segregation, lagards (undivided univalents and/or separated chromatides), bridges and fragments were not observed in the pollen mother cells (PMCs) of the two *Aloe* species studied (Fig.19 and Table.17). The occurrence of normal meiosis i.e., regular bivalent formation and absence of aberrations of the type mentioned above manifested during subsequent segregation at anaphase and telophase I/II were also evidenced by high percentage of pollen viability (Table .15).

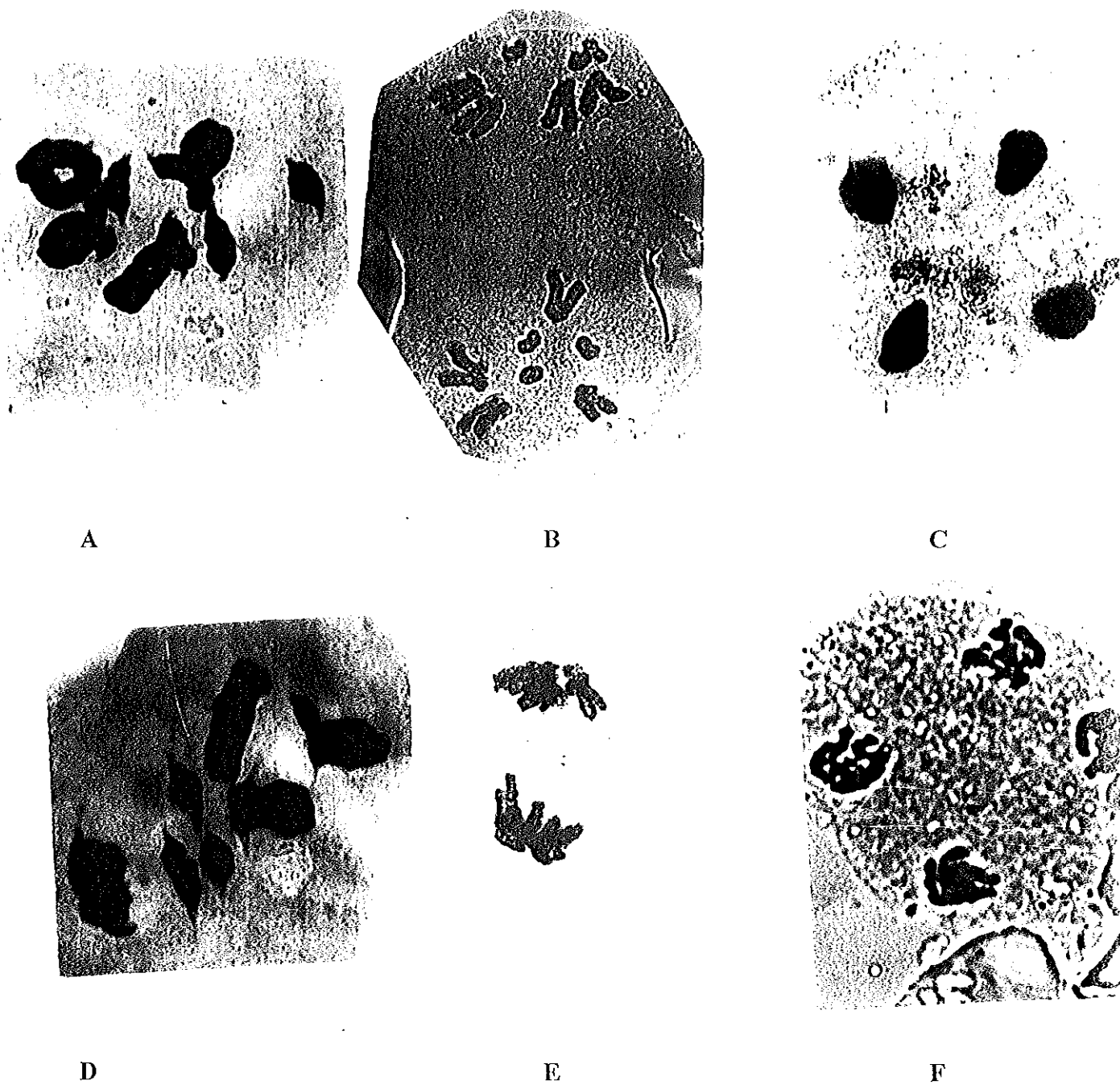


Fig.19. Meiotic chromosomes (A, B and C; D, E and F are Metaphase-I; Anaphase I and Telophase II of *A. pulcherrima* and *A. debrana* respectively).

Table.16. Metaphase I chromosome pairing in *A. debrana* and *A. pulcherrima*.

Species	No. of cells Examined	No. of cells with	
		7 Bivalents only	Univalents/ multivalents
<i>A. debrana</i>	469	469	0
<i>A. pulcherrima</i>	25	25	0

Table.17. Anaphase I/telophase I and anaphase II/telophase II chromosome segregation in *A. pulcherrima* and *A. debrana*.

Species	No. of cells Examined	No. of cells with	
		Normal segregation	Deviant (aberrants)
<i>A. debrana</i>	7	7	0
<i>A. pulcherrima</i>	55	55	0

Table. 2. Edaphic factors of the study site

PARAMETERS	SPECIES	
	<i>A. pulcherrima</i> Plots	<i>A. debrana</i> Plots
Particle Size Class PSC (%)		
Sand (0.2-2 mm)	41.9	44.7
Silt (0.02-0.2 mm)	36.7	32.7
Clay (< 0.02 mm)	21.4	22.6
PH	6.68	6.67
Na (Meq/100 mg)	0.51	0.43
K “	1.74	1.42
Ca “	54.52	42.98
Mg “	13.78	15.21
CEC “	68.5	60.36
Total Nitrogen (%)	0.76	0.16
Organic Carbon (%)	9.05	1.89
Available Phosphorus (ppm)	50.5	18.37

6. DISCUSSIONS

6.1. Population structure and dynamics

The population structure and dynamics of two *Aloe* species was studied and compared by size structures (clone size and rosette diameter of ramets) and life stage structures of the individuals that constitute the populations. The results from clone size description revealed that, the relative proportion of genets and ramets (vegetative daughters)/genet differed in the populations of the two species. Clone size of the individuals that make up the population has some indication to the predominant system of reproduction (i.e., vegetative propagation or seedling establishment) attempted by the species and the variability among the individuals in the population for comparative purpose. It is also indicative of the probability of the survivorship (mean age) of individuals, because increased rate of clonal growth increases the probability of genet survival. In the light of the result obtained, it is reasonable to state that *A. pulcherrima* with large proportion of multi-rameted (2-12) genets attempted extensive clone size formation and comprise individuals with greater mean age than *A. debrana* with large number of genets with only single ramet (Fig. 7 and 8).

The results from size class distribution of rosette diameter of ramets revealed that, *A. debrana* population has significant proportion of small sized generally young ramets, compared to the population of *A. pulcherrima* where the small sized (young) ramets are by far outnumbered by medium and large sized (mature and old) ones (Fig. 9 and 10). It is apparent from this pattern that rejuvenation is more prevalent in *A. debrana* population. The size class distribution patterns in the successive years 1997 and 1998 are fairly stable within each species, meaning that a “snapshot” of size distribution may give an indication of the dynamics of a population at least for comparative purposes. The difference between the species in size structure clearly reflects the underlying variation in attribute of population i.e., recruitment either from seed or by vegetative

propagation.

Nordal *et al.* (1997) on *Papaver radicum* populations reported that “ high number of seedlings and juvenile plants may be indicative of a dynamic vegetation under establishment, whereas a low number of seedlings and a high number of old rosettes would characterize a senescent population in a mature community at late successional stage”. These observations fit very well with our own, that the *A. debrana* population in former situation, and the *A. pulcherrima* population in the latter.

There was minimum size at flowering for ramets of both species. As the results indicate from size relationship to flowering, *A. pulcherrima* requires larger rosettes than *A. debrana* before flowering (Fig. 11 and 12). The difference in flowering frequency (proportion of ramets flowered) between the two species studied and the causal factor promoting flowering seems to be difference in moisture availability in their flowering seasons (June, July, August for *A. pulcherrima* and December, January and February for *A. debrana*) and difference in major soil nutrients (Table.2 and 3). Thus, simple correlation with precipitation total in current or preceding year and soil nutrients are significant.

Mehrhoff (1989) reported that plants in stable population of endangered Orchid *Storia medeoloides* either flowered every year or alternated between flowering and non-flowering, whereas plants in declining population were increasingly non-flowering or dormant. Based on our observation, since significant proportion of ramets flowered from year to year or alternated between flowering and non-flowering in the populations of the two *Aloe* species, it is reasonable to state that these populations are either stable or expanding with regard to flowering.

Mean annual growth rate of ramets of two *Aloe* species studied also differed with size and state of flowering (Table. 4 and 5; Fig. 13). This is probably related to inter and/or intracolonial competition for resources from larger ramets or investment of resources for flowering than

vegetative growth (cost of production); a situation that may be more likely to occur mainly below ground.

Long lived (perennial) plants generally have high mean annual growth rates as juvenile and as they age (increase in size), they experience reduced annual growth rates (Wilson, 1988). He also pointed out that plants from poor soil and under density stress tend to grow slowly.

Increase in size due to greater mean annual growth rate may be the reason for increased vegetative reproductive allocation in *A. pulcherrima*. However, according to Crawley (1997) relative growth rate (RGR) and resource allocation for vegetative growth and reproduction are determined by genotype dependent factors. Thus, low mean annual growth rate in *A. debrana* and relatively high mean annual growth rate in *A. pulcherrima* is determined either by environmental factors such as soil conditions or genotype dependent features that determine resource allocation for vegetative growth and reproduction.

Population dynamics (flux) at ramet and genet levels studied was based on successive census in 1997 and 1998 (Table. 6 and 7); and Levokovitch transition matrix model that was applied by using stage structured transition probabilities (Table. 8 and 9; Fig. 14, 15 and 16) respectively have indicated the trend of population growth (Instantaneous demography) in the populations of the species at least for comparative purpose. The difference in trends of population growth i.e., *A. debrana* expanding and *A. pulcherrima* population stable or stagnant at these levels were attributed to difference in recruitment. Despite low mortality rate at genet and ramet levels, variation in mortality was smaller than variation in recruitment between the population of two species. This difference in trends of population growth observed can be more connected to genotype dependent factors and loosely connected to environmental factors.

It is, however, important to note here that the size of the population sampled and one year duration considered in the study were not sufficient to be more realistic to estimate the growth rate and represent a whole population. Nevertheless, it has indicated the trend (direction) of the

population growth in the populations of the two species at least for comparative purpose.

“The rust on *A. pulcherrima* from Debre Libanos is *Uromyces aloes* (Cooke) P. Magn. It has only got teleutospores, and it is known from several Aloe species and is widely distributed in Africa, and in addition on species of the genera *Haworthia* in South Africa and *Lomatophyllum* in Madagascar. In Ethiopia (including Eritrea) the species has been recorded on *A. abyssinica* and *A. eru*. I have never seen it recorded for *A. pulcherrima* nor for *A. debrana*. That the species occur on one but not the other when growing side by side is very interesting” (Halvor Gjaerum pers. communication).

Since the fungus is so widespread and even represented in different genera, it is reasonable to believe that resistance is a derived character that *A. debrana* possibly has evolved, but not *A. pulcherrima*.

A. pulcherrima is being the host to the rust fungus parasite, but not *A. debrana*. This may be attributed to lack of genetic recombination or dependence on asexual (vegetative) reproduction for multiplication of the species.

The detrimental effect that pathogens often have on their host are, they regulate host population size, affect genetic variability in host populations and influence species co-existing in communities (Crawley, 1997). Since my observation was largely descriptive and had not focused on the effect of parasite on the host; investigation was not made on its effect on the rates of reproduction, recruitment and survival between ramets of health and diseased. However, it seems that the presence of senile genet – ramets long lived infected by the rust fungus parasite suggests that pathogen damage had little effect on survivorship. Mortality in year interval was also substantially occurred among heavily grazed ramets and those severely damaged by man in the population but was not by rust fungus parasite attack.

Reproductive Biology

Flowering clonal plants like *Aloes* with under ground rhizome combine both sexual and asexual reproduction. Thus reproductive success and dispersal efficiency of the two *Aloe* species were estimated and compared in their potential to rejuvenate and spread by vegetative propagation and at the various phases of sexual reproduction such as meiosis, the extent of flower, fruit and seed production and also by pollinator availability and pollen viability (male fitness).

Low seedling recruitment is a predictable features of species with aggressive vegetative propagation (Douglas, 1981). *A. pulcherrima* is such a species capable of forming large clonal net works i.e., vegetative propagation was much more common and establishment from seed was not observed in the period of study (Table. 10).

According to Scheller *et al.* (1982) “vegetative propagation and spread is much more economical than seed dispersal in removing the daughter plant from the competitive influence of its parent. There are of course inherent costs such as the lack of genetic recombination and reduced ability to disperse to far away places”. The fact that *A. pulcherrima* seems to depend on vegetative dispersal rather than seed dispersal and establishment, may explain its extreme patchiness.

Ogaden (1980) also reported the striking relationship that exist between the degree of stability and the widespread nature of the population of a species and reliance by that species on seed as opposed to vegetative propagation for multiplication.

As to our observation, it is reasonable to state that *A. debrana* is common or widespread because it depends on both seed dispersal and vegetative propagation whereas *A. pulcherrima* is rare (uncommon) with restricted and thinly scattered distribution because for it depends mainly on vegetative propagation.

The populations of the two species differed both in flower and fruit production; and also in Fr:Fl ratio even if the means from (%) Fr:Fl ratio was not significantly different ($P < 0.01$).

Flowers that did not survive to develop into fruits (aborted) during the two seasons observed and the study of natural fruit set amounted to 69% in *A. pulcherrima* and 58.7% in *A. debrana* (Table. 11 and 12). These flowers either had not been fertilized probably due to low pollinator density or shortage of resource that probably constitute the main limiting factor.

According to Aker (1982) "the one possible explanation for the whole flower abortion is that plants regulate fruit maturation (production) by aborting excess flowers whenever pollination, post fertilization survival of fruits, or resources are unpredictable at the time of flower determination".

Sarukhan (1973) also reported that the fraction of its available resources that a species devotes to reproduction may vary with environmental and genetic factors and is a co-adapted part of the whole process that constitutes its life history.

A major difference in rainfall (moisture availability) between the flowering periods of the two species i.e., *A. pulcherrima* flowering in wet season (June, July and August) and *A. debrana* flowering in dry season (December, January and February) (Table.3) and difference in major soil nutrients from the plots of the two species populations (Table.2) do not correlate with the extent of flower production and mature fruit set between the two species.

Seed production varied from fruit to fruit, ramet to ramet, and quadrat to quadrat in the two species studied. The rate of seed production of *A. pulcherrima* was significantly different ($P < 0.001$) as compared to *A. debrana* on ramet basis (Table. 13). This is probably related to the balance between vegetative propagation and reproducing sexually.

According to Weins (1984) “ the mean number of seeds matured per capsule “brood size” is reduced in higher plants due to ecological factors such as environmental stress, lack of (or inadequate) pollination, maternal control, and post zygotic abortion that is controlled genetically”. Thus, the number of seeds produced by the two species can be affected either by any of a number of genetic or ecological factors.

If a plant produces sufficient propagules (seeds) to effect successful new colonization, it will be over-producing in areas which it has already colonized (Harper, 1965). Thus, the colonizing ability of a plant must be a function of the number of viable propagules it produces from which may be derived, ‘the intrinsic rate of natural increase’ and the distance over which these may be spread.

According to Webb (1965) efficient dispersal and establishment can only come into play if there is a sufficiency of seed available. However, there are numerous species whose reproductive efficiency up to the production of seed is good, but which find their limiting factor in quite unexplored difficulties in dispersal and establishment.

Thus, producing large number of viable seeds capable of germination permits the multiplication of genets and wide spread dispersal and establishment in *A. debrana*. However, seed production is good in *A. pulcherrima* but seedling establishment was not observed and thus needs further investigation for the viability of the seeds produced and factors that control germination. Thus, possible reproductive problem for the rare (uncommon) occurrence of *A. pulcherrima* is the absence of new recruitment in natural habitat from seed, thus its narrow (thinly) scattered distribution.

A pollinator, as opposed to a visitor of a flower, must visit many flowers and individuals of the same plant species within the time of pollen viability, and visits should result in pollen deposition

on receptive stigma (Kevan, 1972). Eventhough systematic observation was not made on behaviour and rate of visitation of pollinators to estimate the density; qualitative observation on specific birds and insects and also pollination experiment showed that adequate number of pollinators were present on the flowering time of the two species.

My observation on the pollinator is similar to Court (1981); Jone (1997) report; “*Aloe* flowers are very rich in nectars and generally pollinated by Marco Sun birds (*Cinnyris*)” (Fig. 18).

According to Carol and David (1993) when co-occurring related species maintain separate flowering periods, it avoids pollinator competition and is also a mechanism of reproductive isolation to prevent possible deleterious effects of interspecific hybridization (pollination). This statement holds true for the two sympatric *Aloe* species having different flowering schedules.

Pollen viability is one measure of male fertility (fitness) and thus is one measure of the reproductive success of the populations studied (van der Pijl, 1965). Thus previous studies of reproductive success in terms of male function (fitness) have mostly stressed in pollen viability.

The results from pollen viability test of the two *Aloe* species studied revealed that, the mean percentage viable pollen was high with no significant difference ($P < 0.01$) between them that latter evidenced by normal meiosis from the PMCs of the two species studied.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1. CONCLUSIONS

The population structure, dynamics, reproductive biology and chromosome cytology of the two endemic species (*A. pulcherrima* and *A. debrana*) was studied in naturally occurring populations around Debre Libanos. The study was conducted through field data collection, laboratory work, interview, observation and recording the required information. Based on the results of this study the following conclusions are made:

1. *A. pulcherrima* and *A. debrana* displayed different population structure as described by clone size and rosette diameter of ramets. Owing to the extensive development of clones, the former has large number of vegetative daughters (ramets) per genet that have all been produced from the parent by clonal growth (vegetative propagation). This increased rate of clonal growth increased the probability of genets survival and thus the population is dominated by large sized mature and old (senile) individuals. The *A. debrana* population; however, has greater number of genetic individuals (genets) single rameted that originate from seeds mainly as seedlings (juveniles) which have relatively small size.
2. The overall trends in the population dynamics both at ramet and genet-levels are different in the two species studied. *A. debrana* population is expanding where as *A. pulcherrima* population is stable or stagnant at these levels. This is attributed to their difference in the recruitment from seed and extent of clonal growth. *A. debrana* population show recruitment both by vegetative propagation and sexually from seed where as *A. pulcherrima* population

doesn't recruit from seed but entirely depends on vegetative propagation. Despite the low mortality rate at genet and ramet levels in the two *Aloe* species populations studied, variation in mortality was small relative to variation in recruitment. This difference in trends of population growth observed between the two *Aloe* species can be more connected to genotype dependent features and loosely connected to environmental factors.

3. The extent of flower production, mature fruit set, fruits to flowers ratio and average seed set per capsule and ramet was low in *A. pulcherrima* as compared to *A. debrana*. The flexibility in germination (seedling establishment) and clonal growth and moreover, production of large number of viable seeds capable of germination has allowed *A. debrana* to occupy large area (habitats) and thus its abundance unlike *A. pulcherrima* which doesn't recruit from seed in spite of the good seed set. Nevertheless, satisfactory pollinator activities by Sunbirds and Bees; and high percentage pollen viability are common for the two species.
4. Attributed to morphological features (i.e., lack of marginal teeth in their leaves and softness) *A. pulcherrima* is often grazed by goats and baboons and is host to rust fungus parasites (*Uromyces aloes*). The attack by the fungus may be attributed to lack of genetic recombination or dependence on vegetative propagation for multiplication. However, *A. debrana* is less often grazed by the above animals and is 'buffered' from the rust fungus parasite attack.
5. The seasonal timing of flowering 'flower phenology' is different for the two species. In *A. debrana* flowering stalk begin to emerge in early December with peak flowering in January and early February and in *A. pulcherrima* flowering start in May with peak flowering in June and early July. This avoids interspecific competition for pollinator and hybridization between

the two species.

6. *A. pulcherrima* and *A. debrana* have diploid chromosome number $2n= 14$; 8 large and 6 small sized ones. Meiotic activities; pairing and subsequent segregation from pollen mother cells (PMCs) in their flower buds studied were found to be normal with regular formation of 7 bivalents (7II) at metaphase I (MI) and absence of aberration such as lagards(univalents and /or separated chromatids), bridges and fragments at anaphase and telophase I/II (A and T I/II). This was also evidenced by increased percentage pollen viability in the two species.

7.2. RECOMMENDATIONS

Currently, the need to conserve threatened and rare plants in particular and biodiversity in general has become the primary issue all over the world. Nevertheless, conservation biologists and agencies not only require information on conservation status (or, the degree of threat) but also on the biological attributes such as population structure, dynamics, reproductive biology and ploidy level or chromosome number etc.. They also need other supporting environmental parameters and human oriented activities associated with the habitat of the species concerned; to plan, formulate, and select appropriate conservation strategies and techniques.

Though, this study is a pioneer work in this area, the scientific information obtained from the project could be used by various institutions (national or international) or conservation agencies engaged in conserving plant diversity especially endemic plants of the country. In addition, academic institutions can relay on the result to promote further research on this line.

In the Ethiopia situation, Institute for Biodiversity Conservation, Environmental Protection

Authority and NGOS involved in conservation issues could benefite from the result to set appropriate conservation strategies and techniques.

Based on the findings of the project, the writer makes the following recommendations:

7.2.1. The possible conservation strategy suggested (recommended) to conserve this rare endemic plant (*A. pulcherrima*) is *in situ* conservation approach through protecting the habitat and the plant. This is because the species seems to have habitat (niche) preference. It usually lives on the cliffs or on escarpments. It was also reported in the literature that it can't be propagated with ease under cultivation in the gardens i.e., vegetative propagation was rare and vegetative nursery propagation was found to be difficult. Moreover, seed storage (gene bank) is the least likely recommended for the establishment from seed was not observed in a natural setting, longer time required from seed to flower (reproduce) and also due to further need to study seed storage behaviour of the species.

7.2.2. Seed production was good for the species i.e., *A. pulcherima*; however, seedling establishment in nature was not observed. Recruitment may be controlled through the intrinsic germination behaviour of the seed or something related to the local environmental conditions such as soil or vegetation. Thus, further investigation has to be made to confirm the viability of these seeds and dynamics of the population in the seed bank to study predation, the dormancy behaviour and factors responsible for it that control germination.

7.2.3. Since one year duration and the size of population sampled in this study were not adequate enough to show the whole picture, more widen study should be continued.

7.2.4. The effect of rust fungus parasite (*Uromyces aloes*), identified from rosettes of *A. pulcherrima* on reproduction, recruitment and survival of the host population also needs further study.

REFERENCES

- Abrahamson, W. G. (1980).** Demography and Vegetative Formation. In: Solbrig, O. (Ed.), Demography and Evolution. Botanical Monographs Vol. 15. pp.86-106. Blackwell Scientific Publications, Oxford.
- Aker, C. L. (1982).** Regulation of Flower, Fruit and Seed Production by a Monocarpic Perennial.; *Yucca whipplei*. *J.Ecol.*, **70**: 357-372.
- Ben. E.; Van, W.; and Gideon, S. (1996).** Guide to the aloes of South Africa. Briza, Prietoria, South Africa.
- Berger, A. (1980).** *Liliaceae-Asphodeloideae-Aloineae*. In: Engler, A.(Ed.), Pflanzenreich IV.38.III Leipzig, Engelmann.
- Bernard, J. (1976).** *Population Cytogenetics*. Longman, London.
- Bernard P. K. Y, Sahlemedhin Sertsu and Teklu Baisa (1993).** Manual for soil analysis (Vol I). National Soil Res. Lab. Addis Ababa.
- Beverly, J. (1999).** Endangered African Aloe thrives in California- *Ex-situ* Conservation in Gardens. *Plant Talk*, **16**: 45-59.
- Beyene Dolicho, Esayeyas Shall and Fekade Shewakena (1991).** Introduction to the Geography of Ethiopia. A Preliminary Teaching Material. Addis Ababa University Press,

Addis.Ababa

Campbell, D. C. (1985). Pollinator Sharing and Seed Set of *Stellaria pubera*: Competition for Pollination. *Ecology*, **66**: 544-533.

Carol, A. K. and David, W. I. (1993). *Techniques for Pollination Biologists*. Colorado University Press, Colorado (USA).

Carter, S. (1994). The Family Aloaceae. In: Polhill, R. M. (Ed.), *Flora of Tropical East Africa*. Balkema, Rotterdam and Brook field.

Cohn, N. S. (1964). *Elements of Cytology*. New York Press, New York.

Cole, L. C. (1950). The Population Consequences of Life Cycle Phenomena. *Quart. Rev. Biol*, **29**: 134-137.

Court, D. (1981). *Succulent Flora of South Africa*. Academic Press, London.

Crawley, M. J. (1986). The Structure of Plant Communities. In: Crawley, M. J. (Ed.) *Plant Ecology*. pp. 429-453. Blackwell Scientific Publications, Oxford.

Crawley, M. J. (1997). *Plant Ecology* (2nd Ed). Blackwell Scientific Publications, Oxford.

Crawley M. J. and Nachapong, M. (1987). The Establishment of Seedlings from Primary and Regrowth Seeds of Ragwort (*Senecio jacobea*). *J. Ecol.*, **73**: 255-261.

- Crosby, J. L. (1965).** Reproductive Capacity in the Study of Evolutionary Processes. In: Hawkes J. G.(Ed) Reproductive Biology and Taxonomy of Vascular Plants. pp. 122-130. Botanical Society of British Isles, Oxford.
- Daniel Gemechu (1977).** Aspects of Climate and Water Budget in Ethiopia. Addis Ababa University press, Addis Ababa
- Davidson, L. (1994).** An Inventory of the Forest Vegetation of the Debre Libanos Monastery Forest in Ethiopia. Unpublished Paper.
- Douglas, A. D. (1981).** The Balance Between Vegetative and Sexual Reproduction of *Mimulus primuloides* (Scrophulariaceae) at Different Altitudes in California. *J. Ecol.*, **69**: 295-310.
- Ensermu Kelbessa, Sebsebe Demissew, Zerihun Woldu and Sue Edwards (1992).** Some Threatened Endemic Plants of Ethiopia. In: Sue Edwards and Zemedede Asfaw (Ed), The Status of Some Plant Resources in Parts of Tropical Africa. *NAPRECA, Monograph*, **2**: 35-55.
- Ergova, V. N. (1972).** The Life Cycle of Orchard Grass (*Dactylis glomerata* L) in the Flood Meadows of River Oka. *Bull. Moscow Soc. Natur.*, **77** (4): 118-29
- Ermias Dagne (1996).** Review of the Chemistry of Aloes of Africa. *Bull. Chem Soc. Ethiopia*, **10**: 89-103.
- Evenson, W. E. (1983).** *Experimental Studies of Reproductive Energy Allocation in Plants*. New

York Press, New York.

Free, J. B. (1965). The Foraging Behaviour of Bees and its Effect on the Isolation and Speciation of Plants. In: Hawkes J. G.(Ed) *Reproductive Biology and Taxonomy of Vascular Plants*. pp. 76-92. Botanical Society of British Isles, Oxford.

Gatsuk, L. E., Smironova, V. O., Vorontzova, L. I., Zaugolnova, B. L. and Zhukora, A. L. (1980). Age States of Plants of Various Growth Forms: A Review. *J. Ecol.*, **68**: 675-696.

Getaneh Asseffa (1980). Stratigraphy and Sedimentation of the Type of Gohatsion Formation (Lias-Malm), Abbay River Basins, Ethiopia. *SINET- Ethiopian J. of Science*. **3**(2): 88-94.

Hairston, N. G.; Smith, F. E. and Slobodkin, L. B. (1966). Community Structure, Population Control, and Competition. *Am. Nat.*, **94**: 421-425.

Hara, T. (1984). A Stochastic Model and the Moment Dynamics of the Growth and Size Distribution in Plant Populations. *J. Biol.*, **109**: 173-190

Harper, J.L. (1965). The Reproductive Biology of the British Poppies. In: Hawkes J. G. (Ed.), *Reproductive Biology and Taxonomy of Vascular Plants* pp.26-39. Botanical Society of British Isles, Oxford.

Harper, J. L., and White, J. (1974). The Demography of Plants. *A Rev.Ecol.Syst.* **5** : 419-463.

Harrison, H. J. (1983). *The Reproductive Versatility of Flowering Plants*. An Overview.

Academic Press, London.

Hendrix, S. D. and Sum, I. F. (1989). Interspecific and Intraspecific Variation in Seed Mass in Seven Species of Umbellifers. *New phytologists*, **112**: 445-451.

Hill, A. F. (1952). *Economic Botany*. Mc Graw-Hill Book Company, New York.

Hiremath, S. C., Murthy, H. N. and Solimath, S. S. (1992). Quantitative Nuclear DNA Difference Associated with Genome Evolution in Guizotia (Compositae). *Genetica*, **85**: 241-247.

Holsinger, K. E. and Gottlieb, L. D. (1991). *Conservation of Rare and Endangered Plants. Principle and Prospects*. Oxford Univ. Press, New York.

Hutchings, M. J. (1985). Plant Population Biology. In: Moore P. D. and Chapman S. B. (Ed), *Introduction to Plant Ecology*. pp. 377-435. Blackwell Scientific publications, Oxford.

Hutchings, M. J. (1997). The Structure of Plant Population. In: Crawley M. J. (Ed), *Plant Ecology*. pp.325-358 Blackwell Scientific Publications, Oxford.

Janzen, D. H. (1969). Seed Eaters Versus Seed Size, Number, Toxicity and Dispersal. *Evolution*, **23**: 1-27.

Jone, C. (1997). The Natural Moment: Desert Desert. In Natural History, pp. 90-91. American Museum of Natural History, USA .

- Jones, K. (1978).** Aspects of Chromosome Evolution in Higher Plants. *Adv. bot. Res.*, **6**: 119-194.
- Kenneth, M. (1965).** Breeding Systems and Response to Selection. In: Hawkes J. G. (Ed), *Reproductive Biology and Taxonomy of Vascular Plants*. pp. 13-19. Botanical Soc. of British Isles, Oxford.
- Kevan, P. G. (1972).** Insect Pollination of High Arctic flowers. *J. Ecol.*, **60**: 831-847.
- Kifle Dagne (1994).** Meiosis in Interspecific Hybrids and Genomic Interrelationships in *Guizotia* cass.(Compositae). *Hereditas*, **121**: 119-129.
- Kifle Dagne and Heneen, W. K. (1992).** The Karyotypes and Nucleoli of *Guizotia abyssinica* (Compositae). *Hereditas*, **117**: 73-83.
- Klinkhamer, P. G. L.; Jong, T. D. and Meelis, E. (1987).** Delay of Flowering in the Biennial *Cirsium vulgare* Size Effects and Deveneralization. *Okps*, **49**: 303-308
- Krebs, C. J. (1985).** Ecology. The Experimental Analysis of Distribution and Abundance (3rd Ed). Academic Press, London.
- Lavranos, J. (1995).** The Family Aloaceae. In: Thulin, M. (Ed.), Flora of Somalia. Royal Botanic Gardens, Kew.
- Levin, D. A. and Anderson, W. W. (1970).** Competition for Pollinators Between

Simultaneously Flowering Species. *Am. Nat.*, **104**: 455-467.

Linnaeus, C. (1753). *Species Plantarum*, Ed. I. Holmiae.

Love, A. (1951). Taxonomical Evolution of Polyploids. *Caryologia*, **3**: 263-284.

Mabberley, D. J. (1987). *The Plant Book: A Portable Dictionary of Higher Plants*. Cambridge University Press, Cambridge.

Mack, R. N. and Harper, J. L. (1977). Interference in dune Annuals: Spatial Pattern and Neighbourhood Effects. *J.Ecol.*, **65**: 345-363.

Marquis, R. J. (1984). Leaf Herbivores Decrease Fitness of a Tropical Plant. *Science*, **226**: 537-539.

Matveev, A. R. (1972). The Great Life Cycle of *Phleum pratense* L. *Bull Moscow Soc. Natur.*, **73(2)**: 114-23.

Mehrhoff, L. A. (1989). The Dynamics of Declining Population of an Endangered Orchid *Isotria medeoloides*. *Ecol*, **70**: 783-786.

Nordal, I., Hestmark, G. and Solstad, H. (1997). Reproductive Biology and Demography of *Papaver radicum*: A key Species in Nordic Plant Geography. *Opera Botanica* **32**: 77-87.

Ogaden, J. (1980). The Reproductive Strategy of Higher Plants (II). The Reproductive Strategy

of *Tassilago farfara* L. *J. Ecol.* **62**: 291-324.

Oketch-Rabah, K. (1995). Leaf Compounds in Potential Population Species of Aloe in Kenya. Kenya Univ. Press, Nairobi.

Patel, O. P., Singh, C. B., Mishra, R. K. and Govr, V. K. (1983). Karyological Studies in *Guizotia abyssinica* Cass. *Cytologia* ,**9**: 249-253.

Rabotnov, T. A. (1969). Life Cycles of Perennial Herbage Plants Meadow Communities. *Bot. Inst. Acad Scie Ser* , **3**(6): 7-240

Real, L. (1981). Uncertainty and Pollinator Plant Interactions. The Foraging Behavior of Bees and Wasps on Artificial Flowers. *Ecology*, **62**: 20-26.

Reveal, J. C. (1997). Documenting Plant Rarity and Population Threats Presented at the Symposium on Geographical Data Organization for Rare Plant Conservation. The New York Press, New York.

Richards, A. J. (1997). *Plant Breeding System* (2nd Ed). Academic Press, London.

Ross, M. A. and Harper, J. L. (1972). Occupation of Biological Space During Seedling Establishment. *J. Ecol.*, **60**: 77-88.

Salisbury, E. J. (1942). *Reproductive Capacity of Plants*. Bell, London.

- Sarukhan, J., Martinez-Ramos, M. and Pinero, D. (1984).** The Analysis of Demographic Variability at the Individual level and its Population Consequences. In: Dirzo, R. and Sapukhan, J. (Ed.), Perspectives on Plant Population Ecology. pp.83-106. Sinauer, Sunderland and Massachusettes.
- Saurina, N. I. (1972).** Dynamics of Numbers of Individuals and Age Spectrum in some Populations of *R. acris* and *R. auricomus*. *Bull Moscow Soc. Nature*, 77(5): 115-120.
- Schellner, A. R., Newell, S. J. and Solbrig, T. O. (1982).** Studies on the Population Biology of the Genus *Viola*. *J. Ecol.*, 70: 273-290
- Sebsebe Demissew (1996).** Botanical Aspects of Aloes of North East Africa. *Bull.Chem.. Sco of Ethiopia* 10(1): 74-88.
- Sebsebe Demissew and Gilbert, M. G. (1997).** The Family Aloaceae. In Edwards, S. and Sebsebe Demissew and Hedberg, I. (Ed.), *Flora of Ethiopia and Eritrea*. Addis Ababa and Uppsala.
- Sharp, L. W. (1943).** *Fundamentals of Cytology*. Mc Graw Hill Camp. New York
- Shaw, G. W. (1972).** *Chromosome Studies*. Cambridge University Press, London.
- Sinha, S. (1980).** *Cytogenetics, Plant Breeding and Evolution* (2nd Ed.). New Dell University Press, India.

- Silvertown, J. W. (1982).** Introductions to Plant Population Ecology. Longman, London and New York.
- Silvertown, J. W. and Lovett, D, J. (1993).** Introduction to Plant Population Biology. Blackwell scientific publications, Oxford.
- Smirnova, O. V. (1968).** Number and Age Composition of Population of Some Components of the Herbaceous Cover Oak Woods. In: Uranov, A. A.(Ed.), Problems of Morphogenesis of Flowering Plants and the Structure of their Populations, pp.155-182. Moscow.
- Smirnova, O. V. and Toropova, N. H. (1972).** The Great Life Cycle of *Galeobedolon luteum* Huds. *Bull Moscow Soc. Natur.*, **77(1)**: 76-87.
- Snagovskaja, M. S. (1966).** Comparative Characteristics of *Medicago falcata* Population Under Different Ecological Conditions. *Bull. Moscow Soc. Natur.*, **71**: 51-59.
- Snow, R. (1963).** Alcoholic Hydrochloric Acid Carmine as a Stain for Chromosomes in Squash Preparations. *Stain Technol.*, **38**: 9-13.
- Solbrig, O. T. (1984).** Studies on the Population Biology of the Genus *Viola*. II. The Effect of Plant Size on Fitness in *Viola sororia*. *Evol.*, **35**: 1080-1093.
- Southwood, T. R. E. (1985).** Interaction of Plants and Animals Patterns and Processes. *Oikos*, **44**: 5-11.

- Stace, C. A. (1980).** Plant Taxonomy and Biosystematics. Edward Arnold, London.
- Stebbins, G. L. (1950).** Variation and Evolution in Plants. Columbia University Press, New York and London.
- Stebbins, G. L. (1979).** Chromosomal Evolution in Higher plants. Edwards Arnold, London.
- Stephenson, A. J. (1981).** Flower and Fruit Abortion, Proximate Causes and Ultimate Function. *Ann Rev. Ecol System*, **12**: 253-279.
- Summerfield, R. J. (1972).** Biological inertia - An example. *J. Ecol.*, **60**: 793-798.
- Tewolde berhan Gebre-Egzibher (1991).** Diversity of the Ethiopian Flora. In: Engles, J.M.M., Hawkes, J.G. and Melaku Worede (Ed.), Plant Genetic Resources of Ethiopia. pp.75-81. Cambridge University Press, Cambridge.
- Trease, G. E. and Evans, W. C. (1983).** Pharmacology, (12th Ed). Bailliere Tindall, London.
- Trulevich, N. V. (1960).** Composition of Bushes and Structure of Population of *Artemisia tianschanica* in a Series of Pastures. Moscow State Pedagog. Inst., USSR.
- Uranov, A. A. and Smirnova, O. V. (1969).** Classification and Basic Features of the Development of Perennial Plant Populations. *Bull. Moscow. Soc. Natur.*, **74**: 119-34.
- Usher, G. (1974).** Plants Used by Man. Coastable and Company Ltd. London.

- van der Pijl, L. (1965).** Pollination Mechanisms in Orchids. In: Hawkes, J.G. (Ed), Reproductive Biology and Taxonomy of Vascular Plants. pp. 61-75. Botanical Society of British Isles, Oxford.
- Vosa, C. G. (1975).** The Use of Giemsa and other Staining Techniques in Karyotype Analysis. *Adv. pl. Sci*, 6 (4): 14-28.
- Walter, D. M. (1988).** Factors Influencing Seed Number in *Impatiens capensis* (Balsaminaceae). *Am. J. Bot.*, 69: 1470-1475.
- Watkinson, A. R. (1997).** Plant Population Dynamics. In: Crawley, M.J. (Ed), Plant Ecology. pp. 359-400. Black well Scientific Publication, Oxford.
- Webb, D. A. (1965).** Dispersal and Establishment, What do we really know?. In: Hawkes J.G. (Ed), Reproductive Biology and Taxonomy of Vascular Plants. pp. 93-102. Botanical Society of British Isles, Oxford.
- Weiner, J. and Solbrig, O. T. (1984).** The Meaning and Measurement of Size Hierarchies in Plant Population. *Oecologia*, 61: 334-336.
- Weiner, J. (1993).** Competition, Herbivory and Plant Size Variability in *Hypochaeris radicata* Grazed by Snails (*Helix aspera*). *Func. Ecol.*, 7: 47-53.
- Werner, P. A. and Caswell, H. (1977).** Population Growth Rates and Age vs. Stage-Distribution Models for Teasel (*Dipsacus sylvestris* Hids) *Ecol*, 58: 1103-1111.

- West, N. E. (1968).** Rodent-Influenced Establishment of Ronderosa pine and Bitterbush Seedlings in Central Oregon. *Ecology*, **49**: 1009-1011.
- Wiens, D. (1984).** Ovule Survivorship, Brood Size, Life History, Breeding Systems, and Reproductive Success in Plants. *Oecologia*, **64**: 47-53.
- Wilson, J. B. (1988).** The Effect of Initial Advantage on the Course of Plant Competition *Oikos*, **51**: 19-24.
- Yampolsky, C. and Yampolsky, H. (1922).** Distribution of Sex Forms in the Phanerogamic flora. *Bible Genet.*, **3**: 1-62.
- Zimmerman, M. (1988).** Nectar Production, Flowering Phenology, and Strategies for Pollination. In: Doust J. L. (Ed), *Plant Reproductive Ecology*. pp. 157-178. Oxford University Press, Oxford.