THE EFFECT OF SOIL MOISTURE ON SEED PRODUCTION, SEED CHARACTERISTICS AND SHORT-TERM DYNAMICS OF *Cenchrus biflorus* (Roxb.) IN ARID RANGELANDS OF WESTERN SUDAN

BY

MOHAMMED DAW EL BAIT EISA

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR A DEGREE OF MASTER OF SCIENCE IN RANGE MANAGEMENT, FACULTY OF AGRICULTURE, UNIVERSITY OF NAIROBI.

KENYA

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DECLARATION

I, Mohammed Daw EL Bait Eisa, hereby declare that this is my original work and has not been presented in any other university

Signature.......................   Date 25/5/1999....

This thesis has been submitted for examination with our approval as University supervisors;

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DEDICATION

To my late mother, Sharfa Mohammed
For the fondly remembered love, care, and support
she had given all of us throughout her life.
Thus this thesis is dedicated to her and to those
who still lovingly remember her, my father,
brothers and sisters.

TABLE OF CONTENTS

	Page
Table of contents	iv
List of figures	vii
List of tables	viii
List of Appendices	x
Acknowledgement	xi
Abstract	xiii
CHAPTER 1. INTRODUCTION	1
1.1. Historical Background	1
1.2. Study Assumptions	2
1.3. Objectives of the Study	3
1.4. Significance of the Study	3
CHAPTER 2. LITERATURE REVIEW	5
2.1. General Considerations	5
2.2. Seasonality and Short-term Dynamics	6
2.3. Competition	9
2.4. Plants and Water Requirements	11
2.5. Germination and Seedling	13
2.6. Flowering and Seed set	15
2.7. Seed Characteristics	16
2.7.1. Seed Number	16
2.7.2. Seed weight and size	17
2.8. Adaptability and Biological Efficiency	20
CHAPTER 3. MATERIALS AND METHODS	23
3.1. Study Area	23

3.1.1. Location 23

3.1.2. Rainfall 23

3.1.3. Topography 23

3.1.4. Soil 23

3.1.5. Vegetation 23

3.2. Field Study 27

3.2.1. Experimental Design 28

3.2.2. Watering Regimes 30

3.2.3. Watering Durations 30

3.2.4. Experimentation 31

3.2.5. Data Collection 32

3.2.6. Data Analysis. 35

CHAPTER 4. RESULTS AND DISCUSSIONS 36

4.1. Seedling Mortality 36

4.1.1. Seedling Mortality under different watering regimes and durations 36

4.1.2. Seedling Mortality and Competition 37

4.2. Days before Flowering 42

4.2.1. Flowering in *C. biflorus* under different watering regimes and durations. 42

4.2.2. Flowering in *C. biflorus* under different watering regimes, watering durations and competition 43

4.3. Seed Numbers 48

4.3.1. Average Number of Seeds under different watering regimes and duration 48

4.3.2. Average Seeds Number in *C. biflorus* under different watering regimes, watering duration and competition 49

4.4. Seed Weight 54

4.5. Seed viability 61

4.5.1. Viability of *C. biflorus* Seeds Produced under different watering regimes and durations 61

4.5.2. Viability of *C. biflorus* Seeds Produced under different watering regimes, watering durations and Competition 63

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS 67

5.1. Conclusions 67

5.2. Recommendations 71

APPENDICES 73

LITERATURE CITED 77

LIST OF FIGURES

Figure No.	Title	Page
1	Eco-Climatic zones of the Republic of Sudan	25
2	Annual Rainfall at El Odaiya from 1983 to 1994.	26
3	Layout of Experimental Design	29

LIST OF TABLES

Table No.	Title	Page
(1)	Per cent seedling mortality in a pure stand of *C. biflorus* under different watering regimes and durations at the end of the third week after sowing	40
(2)	Per cent seedling mortality in *C. biflorus* in combinations with *E. termula* under different watering regimes and durations at the end of the third week after sowing	41
(3)	Number of days before flowering in a pure stand of *C. biflorus* under different watering regimes and durations	46
(4)	Number of days before flowering in *C. biflorus* in combination with *E. termula* under different watering regimes and durations	47
(5)	Average number of seeds per spikelet in a pure stand of *C. biflorus* under different watering regimes and durations	52

(6) Average number of seeds per spikelet in *C. biflorus* in combination with *E. termula* under different watering regimes and durations 53

(7) Average weight of 100 seeds of *C. biflorus* under different watering regimes and durations 59

(8) Average weight of 100 seeds of *C. biflorus* in combination with *E. termula* under different watering regimes and durations 60

(9) Per cent germination in *C. biflorus* seeds from a pure stand under different watering regimes and durations 65

(10) Per cent germination in *C. biflorus* seeds from a combination of *C. biflorus* and *E. termula* under different watering regimes and durations 66

LIST OF APPENDICES

Appendix No.	Title	Page
I	ANOVA table: Mortality rate in *C. biflorus* seedlings under different watering regimes, watering durations and competition	73
II	ANOVA table: Days before flowering in *C. biflorus* plants under different watering regimes, watering durations and competition	74
III	ANOVA table: Average number of seeds per spikelet in *C. biflorus* under different watering regimes, watering durations and competition	75
IV	ANOVA table: Effect of different watering Regimes, watering durations and competition on seed weight in *C. biflorus*	76
V	ANOVA table: Viability of *C. biflorus* seeds produced under different watering regimes, watering durations, and competition .	77

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ABSTRACT

This study deals with a phenomenon observed to occur in the arid rangelands of Western Sudan. During a sequence of seasons of relatively high or above average rainfall, a dominant annual grass species, namely *Cenchrus biflorus* (Roxb.), was noticed to decrease and almost disappear in some areas while other grass species such as *Eragrostis termula* (Steud) tend to increase and almost dominate. It was noticed that this phenomenon occurred even in places where *C. biflorus* was growing almost in a pure stand. Considering the apparently favourable soil moisture conditions prevailing the dynamics of decrease or disappearance of *C. biflorus* seemed to be abnormal.

It has been reported that the dominance of some grass species and the decrease or disappearance of others during periods of favourable soil moisture conditions is mainly due to the competitive ability of the former species.

This study approached the phenomenon from a different point of view assuming that a factor or factors other than just competition could be involved in this seemingly complex dynamism. The study focused on the effect of high soil moisture conditions experienced during a short rainy season on seed production and seed reproductive characteristics in *C. biflorus*.

The study, further, investigated the effect of competition between *C. biflorus* and *E. termula* on seed production and seed reproductive characteristics in *C. biflorus* under different levels of soil moisture.

The study comprised a field experiment in which *C. biflorus* was grown under different levels of soil moisture in a pure stand as well as in combination with *E. termula* which was used as a competitor. Data collected included seedling mortality during the early stages of growth, days before flowering, seed numbers, seed weight, and seed viability in *C. biflorus*.

Results obtained showed that *C. biflorus* seedlings had better chances to establish under conditions of high soil moisture than under conditions of low soil moisture. Competition on the other hand demonstrated significant effect on mortality rate but it could not eliminate *C. biflorus* seedlings under any of the soil moisture conditions used. At the flowering stage results showed that high soil moisture conditions prolonged the vegetative phase in *C. biflorus* resulting in delayed flowering. The study also demonstrated that under high soil moisture levels *C. biflorus* produced larger numbers of seeds but relatively lighter in weight than those produced under low soil moisture levels. Finally the viability of seeds produced was tested and the results showed that seeds of *C. biflorus* produced under conditions of high but limited soil moisture were less viable than those produced under conditions of low soil moisture.

CHAPTER ONE

1. INTRODUCTION

1.1. Historical Background

This study, to some extent, has a historical background that goes back to the late 1980's. In the course of the researcher's field work as a range officer in western Sudan, his attention was drawn to a phenomenon that appeared to be abnormal. It was noticed that after a sequence of years of relatively high rainfall in one area, one grass species, ie *Cenchrus biflorus* (Roxb.), locally known as "Haskanit", which used to be dominant in the area, noticeably decreased and almost disappeared in some places. On the other hand, other grass species, example *Eragrostis termula* (Steud), locally known as "Banu", were noticed to be increasing and almost dominating. The dominance of the later species seemed to be normal regarding the seemingly favourable conditions prevailing at that time, but the dynamics of *C. biflorus* seemed to be astonishing and abnormal.

C. biflorus was abundant in the first year of relatively higher rainfall, together with *E. termula*, before the former started to decrease as the relatively high rainfall continued. This dynamism occurred even in places where the two species were growing almost in pure stands. The decrease or even disappearance of *C. biflorus* under seemingly favourable soil moisture conditions was the question at that time. However, that question went unanswered as the phenomenon was considered, at least to then levels of knowledge, as far from being understood.

1.2. Study Assumptions

This study explains, at least partially, the phenomenon of decrease or disappearance of *C. biflorus* during a sequence of years of relatively high rainfall, noticed to occur in the arid rangelands of Western Sudan. The study assumes that under conditions of high soil moisture, *C. biflorus* which normally has a short biological cycle, tends to exhibit a longer biological cycle with a longer vegetative phase. For *C. biflorus* plants to compete with neighbouring individuals of the same or different species for the available resources most of the dry matter production will be utilized to maintain the vegetative expansion of the plant. At the end of the rainy season, which is normally short and ends abruptly, the plants will have insufficient dry matter production for flowering and seed formation, and they may die without producing seeds. Consequently the number of individuals of *C. biflorus* in the next generation would be expected to decrease significantly due to seed depletion from the soil, and obviously the species may disappear if the same or similar soil moisture conditions continue.

Another assumption is that by exhibiting a longer biological cycle with a longer vegetative phase and delayed reproductive phase under a limited growing season, *C. biflorus* plants will be susceptible to a drought stress at a critical stage of their life-cycle, the reproductive phase. The ultimate consequences of drought stress during the plant reproductive phase are obvious. The plant may completely fail to reproduce or the produced seeds may be of poor quality. Such seeds may be fewer in number, smaller in size, lighter in weight or even immature, and hence less viable. As a result fewer individuals of *C. biflorus* would be expected in the next generation and the species may completely disappear if the conditions of relatively higher soil moisture are to continue.

1.3. Objectives of The Study

The main objectives of the study are the following:-

1. To assess the effect of various soil moisture levels on seed production and seed characteristics in *C. biflorus*.

2. To assess the effect of competition between two species, *C. biflorus* and *E. termula* on seed production and seed characteristics of *C. biflorus* under different levels of soil moisture.

1.4. Significance of The Study

Grasses are the most useful to man of all plant families, which in itself is sufficient to justify massive inputs of research (Watson, 1990).

Whenever a plant or an animal species demonstrates that it is able to live and reproduce in its surroundings, then it is concluded that it is adapted to the conditions of its environment (Collier et. al., 1973). Grasses have proved to be adapted to a very wide range of environmental conditions. It has been suggested that the success of grasses lies primarily in the evolution of a versatile life-cycle adapted to unstable or fluctuating environments, particularly those associated with strongly seasonal rainfall regimes (Clayton, 1986). This constant ability to adapt to changing environmental conditions and biotic factors underlines the essential role that grasses are playing in maintaining ecological stability in disturbed and fragile ecosystems, particularly in the arid regions of the world.

Species dominance is an essential aspect of productivity and management in rangelands, particularly with useful forage species. Drought tolerant herbaceous species with short life-cycle are best suited and adapted to the dry and unpredictable conditions of the arid rangelands. Better knowledge of factors determining dominance and productivity of these species is a valuable information for range managers in their efforts to maintain sustainable productivity under limiting and unstable environmental and biotic factors.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. General Considerations

Available information from ILCA report (1986/87) refers to the recent recurrent droughts in the Sahel, in the past twenty years, as the major cause of the widespread changeover from a perennial to an annual grass cover. It states that, these droughts significantly reduced the vegetation cover, density and biomass. The composition of the flora has also changed. It pointed out that in many grassy savannas of the Niger Delta, the hitherto predominant perennial grasses have been replaced by annuals, most of which are short cycle species adapted to the drought stress of pasture lands, including *C. biflorus*.

This situation was dramatically confirmed by the results of the ecological studies carried in Mali during the period 1976-80 covering a transect between 50 mm and 600 mm rainfall isohytes. Those studies showed that the entire grass cover biomass was produced by annual grasses chiefly *C. biflorus, Dihetropogon hagerupii* and *Schoenefelda gracilis* (Kernick, 1990).

Houerou (1989) asserts that in the western Sahel *C. biflorus* is replacing the more valuable annual grass *Aristida mutabilis* whose seed stock in the soil have become seriously depleted after successive droughts. He also pointed out that in Northern Nigeria close to the 600 mm isohyte, the 1970-1980 drought period caused the replacement of the perennial *Andropogon gayanus* grassland by the annual grass *C. biflorus*.

Kernick (1990) stated that for the immediate future it would seem that a low rainfall is likely to be expected in the Sahel for several more decades. Faced with the threat of continuing droughts, further ecological degradation in the world's arid zones, can probably be arrested only by adopting ecologically sustainable forms of production that make maximum use of local plant species, among which the adapted grasses must play a prominent role.

2.2. Seasonality And Short-Term Dynamics

The climate of the Sahel is typically tropical with a monomodial precipitation pattern and rainfall occurring in a short summer season. The rainy season starts in June and ends in September, the period from September to June is virtually without rain (Le Houerou, 1989).

Le Houerou (1989) stated that the botanical composition of the herbaceous layer in the Sahel may change considerably from one year to the next depending on the amount and distribution of the current rainfall as well as the amount and distribution of rainfall that had occurred in the previous years. He mentioned that a survey on 36 permanent quadrats in the Sudano-Sahelian zone of Mali over a period of three years (1976-1978) showed that the coefficient of similarity was about 60% for two consecutive years and only 45% for the three years.

It has been reported that a given species may be dominant in a specific place for one or several years then almost disappear for a number of years for no obvious reasons (Walter, 1971; Le Houerou, 1989).

According to Walter (1971) the current rainfall determines the botanical composition of the herbaceous layer for the following reasons:-

1. Individual annual species only germinate within very narrow ranges of temperature, which may be higher or lower. Therefore, the temperature relations after the rain determine which species germinate and which remain dormant.

2. Among annual species there is a range of rates of growth and water requirements. There are hygromorphic plants that grow rapidly but can not endure extreme conditions of water shortage. Others are of more xeromorphic nature, and these can endure a short dry period within the rainy season much better.

3. Competition amongst annual plants occurs during the favourable period just as noticeably as in any other plant community. If much rain falls during the rainy season keeping the soil and air damp for a longer period, hygromorphic and fast growing species are favoured and the more xeromorphic species are suppressed. If, by contrast, rainfall occurs irregularly so that the upper soil layers dry up in between showers, the xeromorphic species become dominant since they can endure a greater decline in soil water.

According to Le Houerou (1989) the dynamics of disappearance of some annual plant species during some rainy seasons is very complex and far from being fully understood. He added that, there seems to exist complex interactions between rainfall events and history, seed production, seed consumption and storage by granivores, and seed hardness.

Cisse (1986) studied the germination and establishment of a number of herbage species in the Sudano-Sahelian eco-climatic zone of Central Mali (Le Houerou, 1989). His findings showed that seedling establishment appeared to result from a combination of various eco-physiological characteristics. He identified those characteristics as seed hardness, germination speed, length of growing cycle, seed production, size of species and drought tolerance in early establishment phase. That study also indicated that drought tolerant species that tend to dominate during a sequence of drought years have soft seeds, quick germination, short biological cycle and drought tolerant seedlings able to withstand competition. Conversely during years of high rainfall species having opposite characteristics of hard seeds, slow germination, and mediocre drought tolerance of their seedlings would be granted a selective advantage over their competitors.

Le Houerou (1989) asserted that similar facts have been reported by various authors, but no in-depth study of the phenomenon of disappearance of some species has been attempted to date, except for the above mentioned dynamics of productivity in Central Mali.

It can be clearly seen that Cisse (1986), in explaining the phenomenon of vegetation dynamics, attributed the dominance of some species during drought years to their advantageous characteristics of drought tolerance. On the other hand, he attributed the disappearance of those same species during years of good rainfall to the competitive ability of their competitors.

2.3. Competition

The definition of competition is one of the longest-running semantic debates in biology (Fitter and Hay, 1987). According to Grace and Tilman (1990) several authors have attempted to define competition as a precise term but it seems unlikely that a narrow definition is possible for a term that has been used so broadly. Most simply competition has been defined as a reciprocal negative interaction between two organisms (Fitter and Hay, 1987). Grace (1990), quoting Begon et.al.(1986) in their attempt to define competition, stated that competition is an interaction between individuals, brought about by a shared requirement for a resource in limited supply, and leading to reduction in the survivorship, growth and/or reproduction of the competing individuals.

Grime (1979) stated that, whenever plants grow in close proximity to each other, whether they are of the same or of different species, differences in vegetative growth, seed production, and mortality are observed. He added that it would be a mistake, however, to attribute all such differences to the process of competition. According to Grime (1979) competition refers exclusively to the capture of resources and is only part of the mechanism whereby a plant may suppress the fitness of a neighbour by modifying its environment.

Although the importance of competition in structuring communities has been evident and can be evaluated in various ways, yet to demonstrate unequivocally its occurrence in nature has often proved to be difficult (Connel, 1990).

Goldberg (1990) illustrated that over the past few decades, experimental field evidence has accumulated to show that competition between plants in natural communities is common, although not ubiquitous, phenomenon. He added that there is still much debate over what determines which species will be successful in competition, and the relative importance of competition itself in determining species composition in plant communities.

Most vegetations in the world's ecosystems contain mixtures of species. No science of plant population dynamics would therefore be complete if it could not take interactions between components in these mixtures into account. However, in considering competition we should not forget two things. Firstly, the immediate effect of competition is to depress plant size or performance, not plant numbers. Plant numbers only change when a change in performance leads to mortality or changes in seed production. Secondly the outcome of competition between species is the result of a mechanism which, as Grime points out, operates between neighbours (Silvertown and Silvertown, 1987).

Cisse (1986) attributed the dominance of some grass species during a sequence of years of high rainfall, and consequently the disappearance of other species, to the competitive ability of the former species over the later species. The dangers of such assumptions will be clear if it is recognized that disparities in the performance of neighbouring plants may rise from independent responses to the prevailing physical and biotic environment (Grime, 1979).

Plant competitive ability has been defined by Grime (1979) as a function of the area, the activity and the distribution in space and time of the plant surface through which resources are absorbed, and as such it depends upon a combination of plant characteristics. According to Walter (1971), a necessary attribute for the ability to compete is the amount of dry matter production. He stated that the larger the dry matter production of a plant, the better and taller it will develop, thus greater dry matter production is usually correlated with increased ability to compete.

It has been noticed that the majority of annual plants have a limited capacity of vegetative expansion, continuing resource capture, and monopolization of the environment, so that they can suppress their competitors (Grime, 1979).

2.4. Plants And Water Requirements;

Water is the matrix of all life. Its essentiality for life is biochemical and biophysical, internal and external. Yet the environment frequently fails to provide optimum water requirements (Leopold, 1975; Tershow, 1970; Mayer and Mayber, 1989).

Tershaw (1970) stated that the health and survival of a plant depend on a proper water balance. Any degree of water imbalance will produce a proportionally deleterious deviation in physiological activity, growth and reproduction. Moisture relations might be technically adverse when they are not optimal, but the point of imbalance at which the stress becomes measurably meaningful is hard to delimit.

According to Larcher (1983) the life of any organism begins with a reproductive process. This is followed by developmental processes such as growth and formation of organs which in turn are followed by the reproductive process leading to the next generation, the cycle is then complete. He added that all these phases of development proceed according to genetically set norm, coordinated by hormones, and modified by environmental factors or influences, and in each phase a plant responds differently to these environmental influences. Larcher (1983) stated that the seedling phase, as a rule, is critical for the survival and spread of a population. In the juvenile phase the plant is most capable of adaptation. In the adult phase environmental factors that affect assimilative processes are reflected chiefly in the frequency of flowering, the setting and development of fruits, and the ability of seeds to germinate, all properties that determine the future of the next generation.

2.5. Germination and Seedling

Germination has been considered by Mayer and Mayber (1989) as those consecutive events which cause a dry quiescent seed in response to water uptake, to show a rise in its general metabolic activity and to initiate the formation of a seedling from the embryo. They added that the process of germination leads eventually to the development of the embryo into a seedling, and as seeds are the means of propagating the species, their germination should occur at a time which will favour the survival of those seedlings. Various factors regulate the germination of seeds in their natural habitat, some of which are internal, whereas others are external environmental factors. As for the internal factors, Kneebone (1972) pointed out that, an important aspect of seedling survival and establishment is seed or seedling vigour. He defined seedling vigour as the realized capacity for rapid growth in the early seedling stage. Pollock and Roos (1972) stated that, there are two aspects of seedling vigour, genetic and physiological. They said that genetic vigour can be seen in heterosis or the difference in vigour between two genetic lines. Physiological vigour on the other hand can be seen in difference in vigour between seed lots of the same genetic line.

Probably the most crucial external factor in determining germination of seeds in the soil is a suitable combination of soil moisture and temperature (Mayer and Mayber, 1989).

Soil moisture, in deficiency or excess, is probably the most common stress encountered by germinating seeds. In an experiment, carried out by Harper in (1966), seeds of three different species were sown under conditions of varying water supply. The results showed that increasing water tension reduced the chance that a seed would germinate and this chance was affected differently for the three species (Harper, 1990).

Daubenmire (1974) stated that most land plants can not send their roots down into saturated soil, a high water table enforces shallow rooting. If the water table at a time is so high that it enforces shallow rooting then the soil dries out below that level, the plants may suffer a severe water deficiency stress leading to their death or failure even though the soil dries but little below the surface.

In arid regions where there is no control over seed bed environment, especially water supply, plant establishment can succeed only if the seedlings have sufficient vigour to maintain rapid root growth and contact with the water supply which rapidly recedes during the growing season. In this natural ecological situation, seedling vigour is also necessary if the seedling is to compete with neighbouring plants for light, water and mineral nutrients. It has been found that cereal seedlings competed well with weed seedlings under adverse soil moisture conditions, but under adequate soil moisture the weed competed much more effectively (Pollock and Roos, 1972).

Williams (1980) reported that, characteristics of the competitive ability of the species may change at different stages of growth from seedling to vegetative and reproductive stage and also with environmental conditions of water supply, soil fertility, temperature, and light.

Daubenmire (1974) concluded that it is important for plants growing in an environment where water is available for only a limited part of the year to be able to make full use of the period of favourable conditions for vegetative and reproductive growth.

2.6. Flowering and Seed Set

In the typical life history of a herbaceous flowering plant, there is usually an initial phase of vegetative growth, which sooner or later is followed by the reproductive phase (Wareing and Phillips, 1981). According to Salisbury (1963), the reproductive phase begins with the onset of flowering, which he described as an environmental conditioned response. He added that the change from the vegetative to the reproductive phase may often be initiated by some change in the environment.

However, Wareing and Phillips (1981) pointed out that plants differ very greatly in their sensitivity to external conditions. They stated that the development of some species being relatively insensitive, so that provided that the environmental conditions are not so unfavourable that growth is completely prevented, they will ultimately flower under a wide range of conditions. They added that in other species, however, the initiation of flowering is very sensitive to external conditions and will not occur under certain conditions, example of temperature or day length, even though these may be quite favourable for growth. They emphasized that, an important thing to be noticed is that, the requirements for growth are not necessarily the same for flowering process.

Wareing and Phillips (1981) stated that, although the question of flowering has been a little bit ambiguous, yet they concluded that the behaviour of the plant apex to initiate flowering is determined by influences from the mature parts of the plant.

2.7. Seed Characteristics

2.7.1. Seed Number

In grasses the seed number is fixed at fertilization. Seed abortion appears to be caused by lack of assimilates and is greatest in lower regions of the plant (Simpson, 1981).

According to Harper (1990) the number of the seeds produced by a plant is a product of three variables, the weight of the plant, the proportion of that weight allocated to seeds, and the number of seeds per unit weight. He pointed out that, experiments have shown that seed number can be sacrificed before seed size is reduced in normal conditions but the seed size can be reduced when the environment is distorted. As reported by Simpson (1981), the reduction in seed number is most severe under drought stress which reduces the over all plant growth rate and photosynthate production. As reported by Turner and Kramer (1980), the damage occurs with only brief periods of atmospheric stress and occurs even under apparent wet soil conditions, and the greatest susceptibility arises at about half way between flowering and maturity.

According to Pollock and Roos (1972), Campbell et.al. (1969) studied the effect of excess soil moisture on seed set in wheat. They found that excess moisture reduced oxygen diffusion in the soil resulting in decreased seed set and yield. In another experiment on wheat, Fischer (1980) found that seed weight and number were affected by water stress resulting in fewer shrivelled seeds.

2.7.2. Seed Weight and Size

The biological role of the seed is to protect and nourish the living cell of the embryo until the seedling is established. Pollock and Roos (1972) stated that a major feature of post fertilization seed development is accumulation of nutrient reserves. The greater the supply of stored nutrients in the seed, the greater the vigour of the seedling and its potential for survival. They also reported that seed vigour is an important aspect determining survival and establishment of seedlings, and it has been shown that seed vigour is correlated to seed properties such as seed size and weight.

Seed size and weight are extremely important characteristics associated with seedling vigour. McKell (1972) reported that under normal field conditions, the size of the endosperm is an important factor in determining the potential ability of a species to establish itself. Harper (1990) stated that the establishment of a seedling from a seed involves a series of precise deterministic events within an environment in which the scale of heterogenity is determined by the size of the seed. He noted that seed size effects appear to be related to the size of the seed itself whatever the reason for the size differential. According to Kneebone (1972), experiments have shown the importance of seed size and weight in the establishment of seedlings from deeply buried seeds. He said results have shown that within any given species, seedlings from large seeds emerge faster than seedlings from smaller seeds.

All experiments suggest that only seeds with extensive reserves are likely to be able to form established seedlings from deeply buried seed (Harper, 1990).

Harper (1990) illustrated that when small and large seeds of the same species were sown together in high density, the mortality was concentrated almost conclusively amongst the plants derived from the small seeds. He stated that small seeds produce small and weak seedlings that are more likely to die in natural thinning.

Rapid development of a root system sufficient to garner water and nutrients for the young seedling, and enable it to develop and compete with neighbours, has been found to be correlated with seed size (Kneebone, 1972).

Pollock and Roos (1972) illustrated that when seeds of uniform size were planted at equal stand densities, the number of plants surviving decreased throughout the growing season as competition between plants eliminated a percentage of the population. However, when large and small seeds were planted together, the number of plants from large seeds remained approximately constant, whereas two-thirds of the plants from small seeds were eliminated by competition. They also indicated that size differences in seed were found to be expressed in yield. They stated that, this fact, together with the fact that seedling vigour and potential for survival is a function of the nutrients reserves in the seed, is the basis of the art of seed cleaning in which large and/or high density seeds are separated from small and/or light seeds for the same crop.

Harper (1990) indicated that the size of the seed is a very constant characteristic of a plant. He added that plants respond to stress phenotypically by varying almost every other component of yield before the seed size is affected. However, the effect of environmental stresses in reducing final seed weight and size is very common (Harper, 1990).

It has been suggested that seeds reach maximum quality at physiological maturity (Abdul Baki and Anderson, 1972). According to Bewly and Black (1985), carbohydrates such as free sugars, starch and other polysaccharides reach a maximum concentration in the vegetative parts of the mother plant around the time of anthesis "dehiscence of the anthers" after which they start to decrease. Some of these stored carbohydrates are translocated to the growing grain, and they may provide up to 15-20% of the dry weight of the grain.

Slatyer (1969) reported that the greatest contribution to the grain filling is usually from photosynthesis in other parts of the plant after anthesis. He pointed out that the translocation of assimilates out of the leaves is slowed and prolonged by water stress. Slatyer (1969) concluded that, this phenomenon, combined with the evidence that water stress hastens, rather than slows, maturation, and with the direct effect of stress on photosynthesis in the leaves and other parts of the plant, contributes to lower grain weight in stressed plants.

Simpson (1981) stated that favourable moisture condition during seed filling can compensate to some degree for stress at earlier stages. Conversely drought stress during seed filling stage can limit the overall yield despite favourable moisture conditions earlier in development.

2.8. Adaptability and Biological Efficiency

Plants that survive in their habitat are said to be adapted to their environment (Collier et.al., 1973; Fitter and Hay, 1987). Adaptation, as defined by Kramer (1980), is a heritable modification in structure or function, or both, that increase the probability of an organism surviving and reproducing in a particular environment. Biological efficiency has been used to describe the biological success of organisms, and this has to be expressed in biological units. For example, the success of a species is usually described in terms of its numbers, rate of population increase or the number of different habitats it can occupy, or its competitive success relative to other species. According to Spedding et.al. (1981) biological efficiency in a wider view can be defined as the efficiency of a biological process or processes .

Bannister (1976) stated that all plants have certain basic requirements without which they can not exist. Each factor required, usually has a minimum and a maximum level beyond which the plant can not survive. However, the extreme values tolerated by one plant are not necessarily identical to those tolerated by another. Daubenmire (1974) added that, even the combination of factor intensities, most favourable to the welfare of a plant differs at different stages of plant life-cycle. He stated that in natural course of events, identical combinations of environmental conditions are repeated only at rare and irregular intervals. Adding that environmental factors are unrelated and dynamic, and because they often exhibit delayed effects, an alteration in one factor frequently initiates a series of adjustments of far-reaching and often unpredictable consequences.

In nature, the change from favourable to unfavourable seasons in a single locality, or from benign to severe or stressful environments results in a reduction in plant productivity (Mooney, 1980). According to Watson (1990), plants have evolved various morphological and physiological mechanisms to maintain productivity when the principal seasonally limiting factors are high temperature and low moisture.

Clayton (1986) asserted that grasses have shown to be adapted to a wide range of environmental conditions available. They occur in every habitat available for flowering plants except sea bed. He suggested that this constant ability to adapt to changing environmental conditions and biotic factors lies primarily on the evolution of a versatile life-cycle.

Daubenmire (1974) stated that adaptation at first appears to be a process constantly conferring benefits on organisms. However, in the long run it is frequently disastrous as proved by the paleontologic records. When adaptation steadily pursue a given course without interruption, it may eventually lead to such a high degree of specialization as to make survival absolutely dependent upon the maintenance of the environmental complex by which adaptation was guided.

Environmental conditions are changing, and the properties that enable individuals of one generation to reproduce under certain environmental conditions may not be the properties that will enable their descendants to produce young if the environmental conditions change. The adaptive nature of most evolutionary changes rest on the fact that the overall environmental conditions in successive generations are similar (Wallace et.al., 1961).

Grime (1979) considered adaptation to any sub-optimal set of environmental conditions reduces the ability of a species to compete for all resources by diverting energy away from adaptations contributing to resource capture. Accordingly the adapted species has a lower growth rate under nonstressfull conditions than does the nonadapted species, regardless of what resource is limited (Grime, 1979; Grace, 1990).

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Study Area

3.1.1. Location

The study area (Elodaiya) is located in the drier part of the semi-arid zone in Western Kordofan State of the Republic of Sudan (Figure 1).

3.1.2. Rainfall

The area has a monomodial pattern of precipitation with summer rains occurring between June and September. The long term average annual rainfall in Elodaiya is about 450 mm, but because of the recent drought the average annual rainfall for the last ten years is a mere 360 mm (figure 2).

3.1.3. Topography

The area is relatively flat except in places where run-off is sufficient to cause the formation of dry water courses known locally as "Wadis".

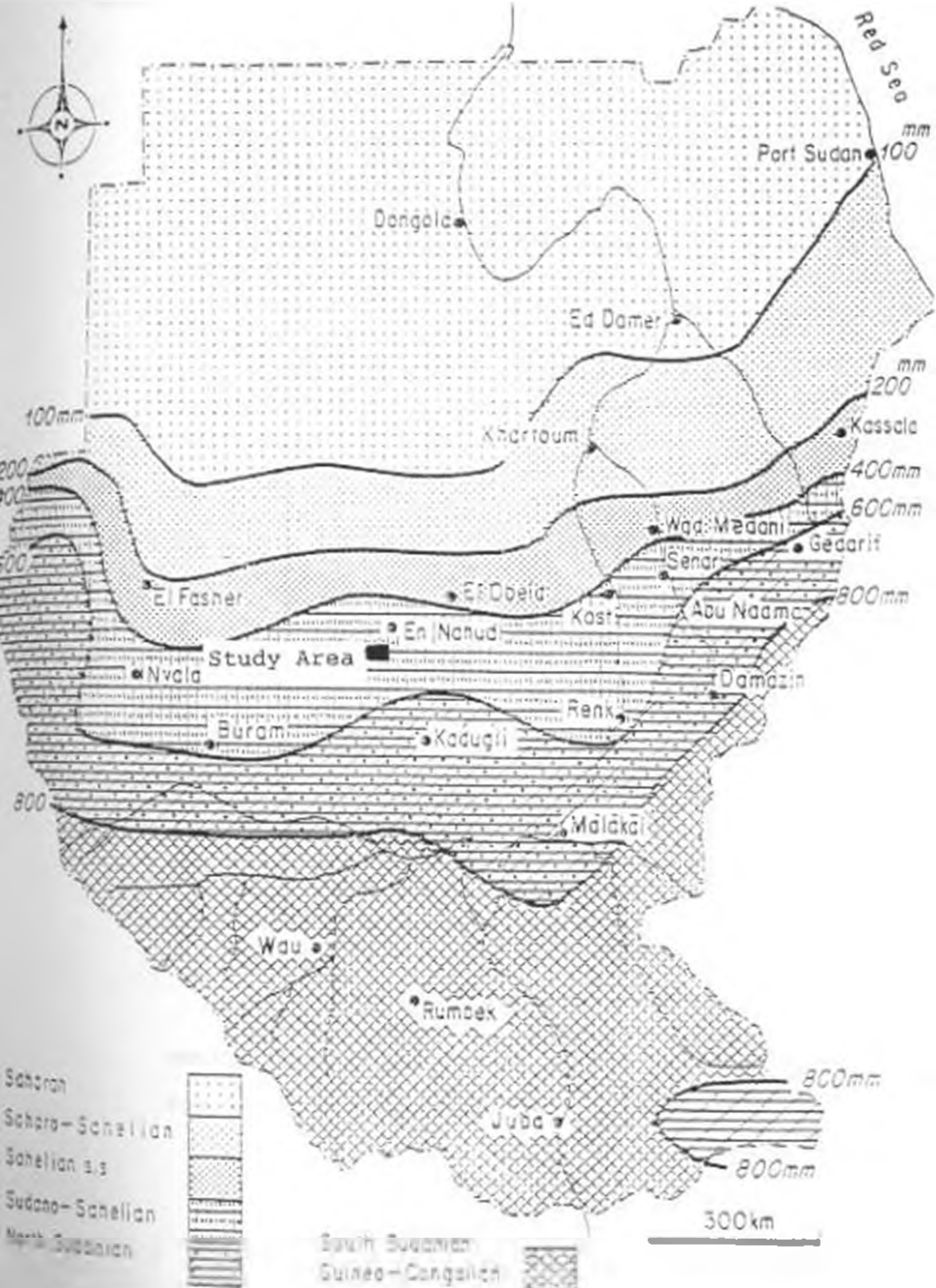
3.1.4. Soil

The soils are generally sandy except in degraded areas where the underlying cemented soils have been exposed through wind and water erosion. The area being a water point in an arid zone the soil has been greatly degraded due to animal and human pressure.

3.1.5. Vegetation

The vegetation of the area can be classified as woodland savanna. The dominant woody species of good and excellent condition rangelands are: *Albizzia amara*, locally known as "Aarad", *Combretum* *cordofanum* "Habil", *Dalbergia melanoxylon* "Abanus" and *Acacia senegal* "Hashab". The woody species of degraded area include: *Acacia mellifera, Acacia nubica* "Sunut", *Guinea senegalensis* "Ghibbesh" and *Boscia senegalensis*. The under story of good and excellent condition is dominated by: *Ctenium elegans, Andropogon gayanus* and *Stylosanthes flavicans*. Poor condition rangelands in the area is characterized by: *Zornia diphylla* "Shilini", *Cenchrus biflorus* "Haskanit", *Eragrostis termula* "Banu", and *Aristida pallida* "Simema",(Integrated Resource Management for Desertification Control - EL Odaiya, Sudan, Project Document No. 1, 1989).

Figure 1.



Bioclimatic zones of the Republic of Sudan (Modified after Watson et al. 1977)

Figure 2.

Annual Rainfall at EL Odaiya from 1983 to 1994.

Year	Rainfall(mm)
1983	174
1984	142
1985	465
1986	376
1987	315
1988	532
1989	333
1990	199
1991	250
1992	468
1993	364
1994	412

source : Rainfall Records, Integrated Resource Management for Desertification Control, El Odaiya - Sudan, 1995.

3.2. Field Study

The study investigated the effect of different soil moisture levels on seed production as well as seed characteristics in *Cenchrus biflorus* grass. The study also investigated the effect of competition between *C. biflorus* and *Eragrostis termula* on seed production and seed characteristics in *C. biflorus* under different conditions of soil moisture. The ultimate objective of the study was to assess the factors that contribute to the phenomenon of disappearance of some grass species, such as *C. biflorus*, during a sequence of years of high rainfall.

The study comprised a field experiment in which *C. biflorus* was grown in pure stand as well as in combination with *E. termula* under controlled soil moisture conditions comprised of different watering regimes and watering durations.

Cenchrus biflorus (Roxb.) is an annual grass species widely common in arid rangelands of the African Sahel. It was selected in the account that it is one of the dominant grass species in the study area, and has been noticed to undergo the dynamics of disappoarance during sequence of years of relatively high rainfall. *C. biflorus* has shown a great adaptability to drought conditions by replacing many other grass species following the recurrent droughts experienced in the African Sahel. Although this grass is not a highly palatable one, yet it is a promising species considering the drought episodes expected to strike the African Sahel from time to time.

Eragrostis termula (Steud) is an annual grass species found throughout tropical Africa and India. It is commonly found in association with *C. biflorus* on sandy soils in degraded areas around water points (Kernick, 1990). In the study area this species tends to dominate during years of relatively high rainfall.

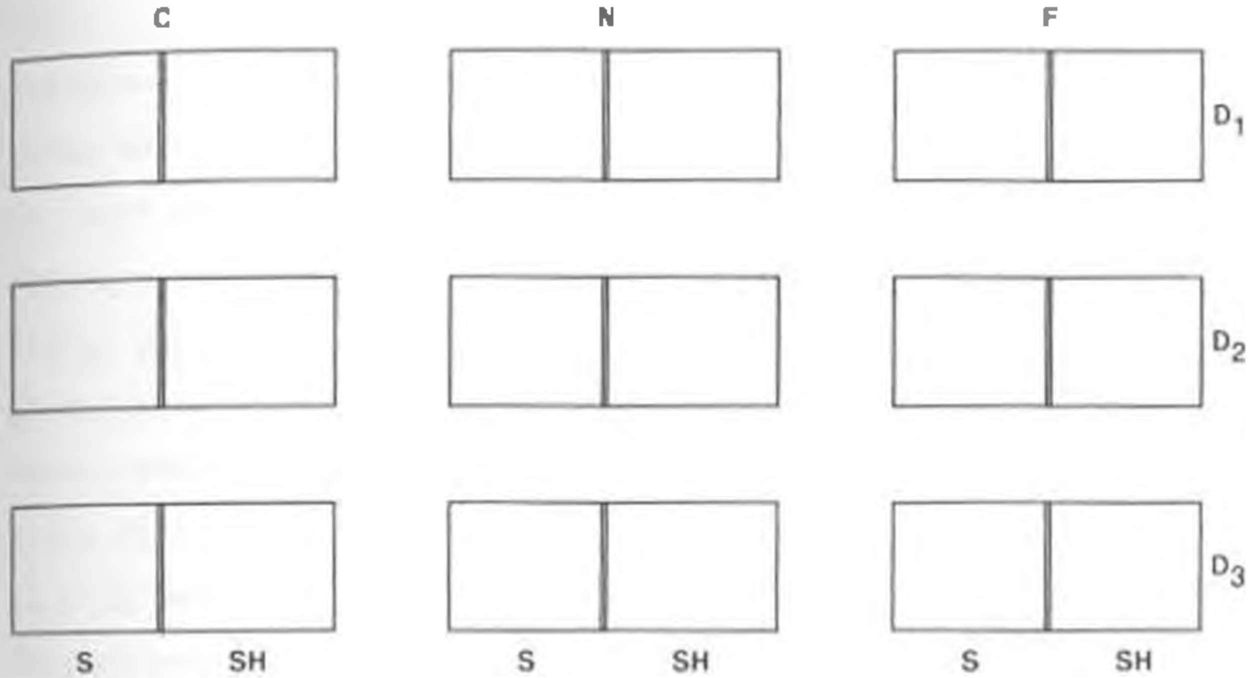
3.2.1. <u>Experimental Design</u>

The experiment was laid in a split-split plot experimental design with three replicates. Each replicate was a plot with an area of 136 m^2 (17 x 8 m). The plot was divided into three main plots on which three different watering regimes were randomized for the three replicates. Then each main plot was subdivided into three sub-plots on which three different watering durations were randomized. Finally each sub-plot was split into two sub-sub-plots on which a pure stand of *C. biflorus* and a combination of *C. biflorus* and *E. termula* were randomized (Fig. 3).

The area of each sub-sub-plot was about 4 m^2 (2 x 2 m) and they were one metre apart from each other. This experimental design was selected and implemented in such a way that to minimize the effect of underground water seepage between neighbouring units.

Figure 3.

Layout of Experimental Design



C, N and F = Main plots containing water regimes

D_1, D_2, and D_3 = split plots containing water durations

S and SH = split-split plots containing the pure stand of *Cenchrus biflorus* (S) and the combination of *Cenchrus biflorus* and *Eragrostis termula* (SH).

3.2.2. Watering Regimes

The watering regimes simulate the amount of water received by the soil during each rain event in the rainy season. Three different watering regimes were selected to simulate three different moisture levels applied to the soil at a time. Those three watering regimes were as follows:-

a) Light watering regime (C) simulating dry conditions or low soil moisture and demonstrated by applying water at a level of four litres per square metre each watering time.

b) Moderate watering regime (N) simulating a medium soil moisture level. Water was applied at a level of eight litres per square metre at a time.

c) High watering regime (F) in which the soil was fully saturated in each water application period.

3.2.3. Watering Durations

Watering durations were meant to simulate the dry spell between each rain event and the next. Each watering regime was applied in three different durations. Those watering durations were as follows:-

a) Watering every day (D_1)

This was a daily water application keeping the top soil moist at different levels of moisture.

b) Watering every week (D_2)

An interval of one week was adopted between waterings. This was meant to allow the top soil to dry out to different levels of moisture, depending on the watering regime, but not to impose severe water shortage.

c) Watering every two weeks (D_3)

Water was applied at an interval of two weeks leaving the top soil to dry out to lower moisture levels, especially under the light watering regime. This simulates the long dry spells between different rain events in nature.

3.2.4. Experimentation

The plots were prepared according to the lay out of the experimental design (Fig. 2). To eradicate weeds and other plant species, the plots were adequately irrigated and left for one week, to allow seeds in the soil to germinate, then the soil was turned and left to dry. This procedure was carried out twice to ensure that the plots were free from seeds of weeds and other unwanted grass species.

The watering regimes (C,N,F) were randomized on the main plots in each replicate and labelled accordingly. The watering duration (D_1,D_2,D_3) were randomized on the sub-plots within the main plots in each replications. The sub-sub-plots within each sub plot were assigned at random to either a pure stand of *C. biflorus* or a combination of *C. biflorus* and *E. termula.*

Seeds of the two species were collected from the study area and tested for germination ability. Gemination test with three replicates each with hundred seeds was carried out for the two species. *C. biflorus* seeds gave an average germination rate of about 65%, while those of *E. termula* had a germination rate of about 70%. Seeds of the pure stand and the mixture were sown according to the randomization layout produced for each replication then water was applied according to the watering regimes and durations as designed. Water application continued for thirteen weeks, simulating the length of the known rainy season in the area.

3.2.5. Data Collection

The data collection and observations started in the first week of experimentation and continued throughout to the end of the experiment. The data collected included the following:

A. Seedling Mortality:

The aim of seedling mortality study was to investigate the effect of the of different moisture levels and competition and their interactions on the mortality and survival of *C. biflorus* during the early seedling stage. At the end of the first week after sowing small quadrats of 20 x 20 Cm were placed in the sub-sub-plots and the number of *C. biflorus* seedlings inside each quadrat was counted and recorded. The counting of seedlings inside the quadrats was repeated at the end of the third week after sowing. Seedling mortality was thus obtained by calculating the differences between the two readings in each quadrat. Plant mortality was noticed to occur throughout the experiment and at different stages of plant development. The study did not account for that because it was interested in seedling mortality in *C. biflorus* seedlings in the early stages of development, in the first place. Secondly high seedling mortality was noticed to occur mostly among *E. termula* seedlings and plants under low moisture conditions.

B. Days before Flowering

The main assumption of this study is that high soil moisture levels prolong the vegetative phase in *C. biflorus* and consequently subject the plant to drought stress during the reproductive phase resulting in some reproductive failures. In plants the transition from the vegetative to the reproductive phase is demonstrated by flowering. Differences in flowering dates may show differences in the length of the vegetative phase and the reproductive phase since the growing period is limited by the short rainy season.

Data pertaining to flowering dates were obtained by observing and recording the starting of flowering in each sub-sub-plot. The numbers of days required by plants under different treatments to initiate flowering was then calculated and tabulated against the soil moisture conditions under which they occurred.

C. Seed Number

Seed setting and development have been found to be affected by soil moisture conditions, whether in short or excess. This study was meant to determine the effect of different levels of soil moisture, and their interactions, on the number of seeds produced by *C. biflorus*. The study also investigated the effect of competition between *C. biflorus* and *E. termula* under the same soil moisture levels.

Data were collected in terms of average number of seeds per spikelet. A sample of ten spikelets was selected randomly from each sub-sub-plot and the average number of seeds per spikelet in each sample was recorded. The average numbers of seeds per spikelet were then tabulated against their production conditions and finally analyzed for the differences.

D. **Seed Weight**

Seed weight and size are important characteristics associated with seedling vigour and health. The study investigated the effect of different moisture levels on seed weight in *C. biflorus*, and its effect on germination and survival of the next generation.

Data on seed weight were collected on the basis of average weight of hundred seeds. Five samples, each of one hundred seeds of *C. biflorus* were randomly selected from each sub-sub-plot. Each sample was weighed using a sensitive balance measuring up to 0.1 gramme. The average weights of 100 seeds drawn from each sub-sub-plot were recorded then tabulated against their treatments and finally analyzed for the differences.

E. **Seed Viability Test**

As previously mentioned this study assumes that *C. biflorus* seeds produced under conditions of high moisture and limited growing season may be of lower seed quality which could be reflected on their ability to germinate and establish into mature plants in the next generation. Seeds produced by the experiment under the different watering regimes, watering durations, and competition were tested for their viability under field conditions. A sample of 100 seeds of *C. biflorus* was selected randomly from seeds produced by each sub-sub-plot and germinated in a sandy seedbed prepared in the field. Water was evenly supplied to all samples. The test was repeated three times for each seed lot then the average germination percentage was calculated for the different seed lots. Results were tabulated against their treatments and then analyzed for the differences.

3.3. Data Analysis

Data were analyzed using the analysis of variance (ANOVA) method after Steel and Torrie (1980). The analysis showed the significance of the differences in results pertaining to the different treatments implemented in the study. It also showed the significance of the different results due to the interactions between the variables used, namely watering regimes, watering durations and competition.

CHAPTER FOUR

4. RESULTS AND DISCUSSIONS

4.1. SEEDLING MORTALITY

Water is a vital factor that plays a crucial role in the process of plant development. The influence of water on plants differs with the different stages of plant development, however, it is very much crucial in the early stages of plant development and growth which determine the outcome of the late stages. The seedling stage is the most crucial stage in the plant life cycle. Seedlings are very sensitive to environmental changes and other types of disturbance.

4.1.1. SEEDLING MORTALITY UNDER DIFFERENT WATERING REGIMES AND DURATIONS

Results of per cent seedling mortality in *Cenchrus biflorus* in pure stand at the end of the third week after sowing are presented in table (1). The data shows that there was a steady decrease in seedling mortality rate with the increase of water. On the other hand there was an increase in mortality rate with the increase in the dry spell between waterings. Appendix I, displaying the statistical analysis of the resultant differences in mortality rate, shows that both watering regimes (A) and watering durations (B), displayed a highly significant ($P \le 0.05$) mortality rate (Appendix I, A and B).

Table (1) shows that the light watering regime (C) gave the highest seedling mortality rate under all watering durations, while the daily watering duration (D_1) gave the lowest seedlings mortality rate under all watering regimes. The highest mean of seedling mortality rate was obtained under the condition of light watering regime with two-weeks watering duration (CD_3). On the other hand the lowest mean of seedling mortality for the durations was obtained under the condition of medium watering regime with daily watering (ND_1). The high watering regime (F), although it gave the lowest mortality rate for the regimes, yet it did not give the lowest mortality rate for the interaction with watering duration (Table 1).

As shown in Appendix I the interactions between the watering regimes and watering durations gave significant difference in the mortality rate of seedlings ($P \leq 0.05$).

4.1.2. SEEDLING MORTALITY UNDER DIFFERENT WATERING REGIMES, WATERING DURATIONS AND COMPETITION

Results of seedling mortality in *Centhrus biflorus* grown in combination with *Eragrostis termula* under the same watering regimes and watering durations, as in the pure stand, are demonstrated in table (2).

Data in table (2) shows almost the same mode of performance of *C. biflorus* seedlings displayed in table (1). The difference that can be seen between the two tables is that the mortality rate in the mixture was higher than that in the pure stand under all water regimes, but the difference tended to decrease under the high water regime (F). These differences in mortality rate could be attributed to the competition which appeared to have significant effect on mortality rate at $P \leq 0.05$ (Appendix I).

These results showed that seedlings of *C. biflorus* had a better chance to establish and develop into mature plants under relatively high soil moisture conditions. Although competition between *E. termula* and *C. biflorus*, appeared to have considerable effects on seedling mortality during the early stages, yet it did not demonstrate a devastating reduction or complete elimination of *C. biflorus* seedlings. Moreover, the effect of competition appeared to be reduced by the increase of soil moisture.

These observations seem to differ with what have been suggested by Cisse (1986) as quoted to by Le Houerou (1989) stating that the dominance of hard seed species, and consequently the disappearance of soft seed species, during years of good rainfall is mainly due to the competitive ability of the hard seed species. The observations agree with (Grace, 1990), citing Begon et. al. (1986), stating that competition is an interaction between individuals, brought about by a shared requirement for a resource in limited supply, and leading to a reduction in the survivorship, growth and/or reproduction of the competing individuals. Because water is the most crucial factor for seedling survival in the early stages, thus competition was expressed in terms of high seedling mortality rate under light (C) and medium (N) watering regimes. However, in case of the higher watering regime (F) water was not limiting, therefore, the effect of competition was not expressed in terms of seedling mortality (Survivorship). Of course this does not refute the role of competition as an effective factor since one or more other resources might have become limiting and their effect could be expressed during the coming stages of plant development in terms of growth or reproduction as pointed out by Begon et. al. (1986).

It can be concluded that during the seedling stage, when soil moisture is not limiting, competition between *C. biflorus* and *E. termula*, and may be any other associated species, has no such influence that could lead to a reduction in the number of seedlings of *C. biflorus* to the extent that it is eliminated or disappear. This is in agreement with what has been noticed during the first year of a sequence of years of relatively good rainfall when *C. biflorus* was abundant before it started to decrease in the next year, and almost disappeared in some places as the years of relatively high rainfall continued.

Table (1)

PER CENT SEEDLING MORTALITY IN A PURE STAND OF *CENCHRUS BIFLORUS* UNDER DIFFERENT WATERING REGIMES AND DURATIONS AT THE END OF THE THIRD WEEK AFTER SOWING.

		I	II	III	MEAN
	D1	00	05	04	03.0 ± 2.2*
C	D2	17	18	12	15.7 ± 2.6
	D3	30	34	40	34.7 ± 4.1
	D1	04	02	04	03.3 ± 0.9
N	D2	09	12	15	12.0 ± 2.4
	D3	12	17	20	16.3 ± 3.3
	D1	07	05	07	06.3 ± 0.9
F	D2	07	09	09	08.3 ± 0.9
	D3	13	12	18	14.3 ± 2.6

C , N and F = watering regimes

D_1 , D_2 and D_3 = watering durations

I, II, and III = replications

* Mean ± standard deviation.

Table (2)

PER CENT SEEDLING MORTALITY IN *CENCHRUS BIFLORUS* IN COMBINATION WITH *ERAGROSTIS TERMULA* UNDER DIFFERENT WATERING REGIMES AND DURATIONS AT THE END OF THE THIRD WEEK AFTER SOWING.

		I	II	III	MEAN
	D1	04	07	06	05.8 ± 1.3*
C	D2	18	20	22	20.0 ± 1.8
	D3	40	36	42	39.3 ± 2.5
	D1	00	05	04	03.0 ± 2.2
N	D2	12	20	13	15.0 ± 3.6
	D3	30	32	38	33.3 ± 3.4
	D1	05	02	03	03.3 ± 1.3
F	D2	07	10	09	08.7 ± 1.3
	D3	17	15	21	17.7 ± 2.5

C , N and F = watering regimes

D_1 , D_2 and D_3 = watering durations

I, II, and III = replications

* Mean ± standard deviation.

4.2 DAYS BEFORE FLOWERING

Flowering is an environmental conditioned response. The change from the vegetative to the reproductive phase in higher plants may often be initiated by some change in the environment.

4.2.1. Flowering in *C. biflorus* under different watering regimes and durations

Table (3) shows the number of days required by *Cenchrus biflorus* plants in pure stand to flower under the different watering regimes and watering durations adopted in the study. Data shows that the number of days required for flowering increases steadily with the increase in the amount of water applied under different watering regimes. On the other hand a steady decrease in the number of days before flowering can be noticed under the increased watering duration under each watering regime. These differences, assumed to be brought about by the different watering regimes (A) and watering durations (B), appeared to be highly significant ($P \leq 0.05$) as indicated in Appendix II. The interaction between the watering regimes and the watering durations (AB) showed significant results at ($p \leq 0.05$) (Appendix II).

These results support the study argument that high moisture levels prolong the vegetative phase in *C. biflorus* and hence delay the reproductive phase. When this takes place under environmental conditions with short and limited rainy season the plants may experience a severe water shortage at the end of the rainy season leading to various reproductive failures.

4.2.2 Flowering in *C. biflorus* under different watering regimes, watering durations and competition

Table (4) presents the number of days required for flowering of *Cenchrus biflorus* in combination with *Eragrostis termula* under the different watering regimes and watering durations adopted in the experiment. Table (4) shows the same general performance displayed in table (3). The number of days before flowering started in *C. biflorus* increased steadily with the increase of the amount of water applied at a time.

There was a steady decrease in the number of days before flowering with the increase in the dry spell between water applications under each watering regime (duration). Comparisons between table (3) and table (4) show no sharp differences in the number of days before flowering between plots having the same watering treatments but differing in competition (combination and pure). These observations are confirmed by the statistical analysis in Appendix (II) which shows insignificant difference for competition (C), ($P \leq 0.05$). The interaction between watering regimes and competition (AC) , watering duration and competition (BC) and watering regime, watering duration and competition (ABC) all appeared to have insignificant effect on the number of days before flowering in *C. biflorus*. These results obtained indicate that competition between *C. biflorus* and *E. termula*, and may be any other species, has no effect on the vegetative phase of the former, *C. biflorus*. According to these results it could be stated that competition has no direct significant influence on the initiation of the reproductive phase in *C. biflorus*. Although these results obtained did not show the role of competition as part of the mechanism by which species may suppress the fitness of neighbours as stated by Grime (1979), yet that role of competition could not be refuted. The insignificant results of the interaction between competition and watering regimes as well as watering durations, can not be explained to their absolute meaning. In fact looking back into the results of seedlings mortality rate study, these insignificant results could easily be explained.

The mortality rate study showed an increased seedling mortality rate under light watering regime as well as under longer durations. This means fewer individuals could establish under interaction conditions, and this in turn reduces the effect of competition between individuals whether of the same species or of different species. Moreover, it was noticed that *E. termula* was almost eliminated in plots under treatments with light watering with a two-weeks watering duration (CD_3), and only a few individuals were able to establish under other low watering regimes and less frequent watering (CD_1 and CD_2). This could have resulted in the insignificant difference brought about by competition and its interaction with watering combinations.

It is now well known that drought stresses can limit the yield of plants despite the favourable moisture conditions earlier in their development (Simpson, 1981). The damage can occur with only brief periods of drought or atmospheric stress, and can occur even under apparent wet soil conditions, and the greatest susceptibility arises at about halfway between flowering and maturity (Turner and Kramer, 1980). Results of flowering days study showed that high soil moisture prolongs the vegetative phase in *C. biflorus* and consequently delays the reproductive phase. Under environmental conditions with a short unpredictable rainy season, such delay in flowering may subject the plants to severe water stress during the very critical period, the reproductive phase, resulting in reproductive damages or failures.

Table (3)

NUMBER OF DAYS BEFORE FLOWERING IN A PURE STAND OF *CENCHRUS BIFLORUS* UNDER DIFFERENT WATERING REGIMES AND DURATIONS.

		I	II	III	MEAN
	D1	48	46	50	48.0 ± 1.6*
C	D2	45	44	45	44.8 ± 0.5
	D3	40	40	40	40.0 ± 0.0
	D1	50	54	50	51.3 ± 1.9
N	D2	45	46	47	46.0 ± 0.8
	D3	45	45	44	44.8 ± 0.5
	D1	70	69	68	69.0 ± 0.0
F	D2	62	64	66	64.0 ± 2.0
	D3	50	49	48	49.0 ± 0.8

C , N and F = watering regimes

D_1 , D_2 and D_3 = watering durations

I, II, and III = replications

* Mean ± standard deviation.

Table (4)

NUMBER OF DAYS BEFORE FLOWERING IN *CENCHRUS BIFLORUS* IN COMBINATION WITH *ERAGROSTIS TERMULA* UNDER DIFFERENT WATERING REGIMES AND DURATIONS.

		I	II	III	MEAN
	D1	48	45	50	47.7 ± 2.1*
C	D2	45	45	45	45.0 ± 0.0
	D3	40	40	40	40.0 ± 0.0
	D1	50	55	50	51.7 ± 2.4
N	D2	45	45	45	44.8 ± 0.5
	D3	45	45	45	45.0 ± 0.0
	D1	69	70	70	69.8 ± 0.5
F	D2	60	64	65	62.7 ± 1.9
	D3	50	50	45	48.3 ± 2.4

C , N and F = watering regimes

D_1 , D_2 and D_3 = watering durations

I, II, and III = replications

* Mean ± standard deviation.

4.3. SEED NUMBERS

In plants seed numbers are important characteristics in determining the overall yield. In grasses seed numbers are fixed at fertilization. Severe drought stress can cause great reduction in seed number because seed number is the first to be scarified rather than other seed characteristics.

4.3.1. Average seed number in *C. biflorus* under different watering regimes and durations

Table (5) demonstrated the average number of seeds per spikelet in *Cenchrus biflorus* in pure stand under different watering regimes and durations. This table (5) shows that the average number of seeds per spikelet increased steadily with the increase of soil moisture and decreased with the increase of the dry spell between waterings. These differences in seed number per spikelet brought about by the different watering regimes (A), watering durations (B) and their interaction (AB) appeared in Appendix III. Table (5) shows that the full saturation watering regime (F) gave the highest average number of seeds per spikelet under all durations. Also it could be noticed that the daily watering produced the highest number of seeds per spikelet under the different watering regimes. The lowest number of seeds per spikelet was produced under conditions of light watering (C) and two weeks watering durations (D_3).

4.3.2. **Average seed number in *C. biflorus* under different watering regimes, watering durations and competition**

Results of average number of seeds per spikelet from *Cenchrus biflorus* grown in combination with *Eragrostis termula* under the different watering regimes and durations are displayed in table (6). Those results showed almost the same performance demonstrated in table (5). The average number of seeds per spikelet steadily increased with the increase in the amount of water applied at a time (watering regime). The average number of seeds per spikelet also decreased with the increase of the dry spell between waterings (durations). The high watering regime (F) produced the highest average number of seeds per spikelet while the light watering regime (C) gave the lowest average number of seeds per spikelet. The different watering regimes produced highly significant ($P \leq 0.05$) average number of seeds per spikelet, and similarly the watering durations and the interaction between the two (A, B and AB) (Appendix III).

These results have revealed that seed setting was affected by soil moisture conditions. This is in agreement with Larcher (1983) stating that the environmental factors that affect assimilative process are reflected chiefly on the properties that determine the future of the next generation. He defined those properties as the frequency of flowering, the setting and development of seeds and the ability of seeds to germinate.

Seed setting and consequently the average number of seeds per spikelet were affected by water stress resulting in fewer seeds when water was limiting. The results showed that a high average number of seeds per spikelet was produced under high moisture level. Applying such results in nature *C. biflorus* would be expected to produce large number of seeds during years of high rainfall and consequently larger numbers of individuals would be expected in next generation each year. Of course this is contrary to what has been noticed to happen in nature during years of high rainfall. Although seed number is an important characteristic in determining the future of the next generation, yet the question of the other characteristics such as the development of seeds and their ability to germinate should be considered.

Comparison between table (5) and table (6) show that the pure stand of *C. biflorus*, in most cases, produced higher average number of seeds per spikelet than the combination of the two species *C. biflorus* and *E. termula*. But these differences appeared to be insignificant at ($P \leq 0.05$) as displayed in Appendix III (C). This means that competition between *C. biflorus* and *E. termula* had only little effect on seed setting, and hence it could not reduce the average number of seeds significantly. It has been stated that the importance of competition in structuring communities can be evaluated in various ways, yet to demonstrate unequivocally its occurrence has often proved to be difficult, (Connel, 1983, 1990; Folwer, 1986; Goldberg, 1990).

The interaction between competition and soil moisture conditions (AC, BC, and ABC) showed significant ($P \leq 0.05$) differences in seed number (Appendix III). This indicates that although competition as a sole factor had only little influence, yet when it interacted with other factors (soil moisture) significant effects on seed number featured. That was clearly observed when the water was limiting i.e. low watering regimes and long durations (tables (5) and (6). When water was not limiting the combination produced higher average of seeds number than did the pure stand of *C. biflorus.* Begon et al (1986) stated that competition is brought about by a shared requirement for a resource in limited supply, that is why competition appeared to have noticeable effect under low moisture conditions.

It can be concluded that competition is only one of the many factors that constitute the overall environment of the plant and its effect adds to the final aggregate of effects. The effect of competition between *C. biflorus* and *E. termula* in reducing the number of seeds produced by *C. biflorus* is enhanced by water stress. However, this does not seem to be effective to the extent that it might lead to a significant reduction in the number of individuals in the next generation or completely eliminate the plant species. Under adequate soil moisture conditions competition for water has almost no effect on the number of seeds produced by *C. biflorus,* but competition for resources other than water may exist leading to effects on characteristics other than seed number.

Table (5)

AVERAGE NUMBER OF SEEDS PER SPIKELET IN A PURE STAND OF *CENCHRUS BIFLORUS* UNDER DIFFERENT WATERING REGIMES AND DURATIONS.

		I	II	III	MEAN
	D1	18	18	18	18.0 ± 0.0*
C	D2	17	17	17	17.0 ± 0.0
	D3	15	16	16	15.7 ± 0.5
	D1	15	16	16	15.7 ± 0.5
N	D2	20	20	20	20.0 ± 0.0
	D3	17	17	17	17.0 ± 0.0
	D1	22	22	22	22.0 ± 0.0
F	D2	21	21	21	21.0 ± 0.0
	D3	18	18	19	18.3 ± 0.5

C , N and F = watering regimes

D_1 , D_2 and D_3 = watering durations

I, II, and III = replications

* Mean ± standard deviation.

Table (6)

AVERAGE NUMBER OF SEEDS PER SPIKELET IN *CENCHRUS BIFLORUS* IN COMBINATION WITH *ERAGROSTIS TERMULA* UNDER DIFFERENT WATERING REGIMES AND DURATIONS.

		I	II	III	MEAN
	D1	17	18	18	17.7 ± 0.5*
C	D2	17	16	17	16.7 ± 0.5
	D3	15	15	15	15.0 ± 0.0
	D1	19	20	20	19.7 ± 0.5
N	D2	18	18	18	18.0 ± 0.0
	D3	17	16	17	16.7 ± 0.5
	D1	23	23	23	23.0 ± 0.0
F	D2	21	22	22	21.7 ± 0.5
	D3	17	17	18	17.3 ± 0.5

C , N and F = watering regimes

D_1 , D_2 and D_3 = watering durations

I, II, and III = replications

* Mean ± standard deviation.

4.4. SEED WEIGHT

Seed size and weight are important properties associated with seedling vigour which is an essential aspect in determining seedling establishment and survival in arid lands where moisture and other environmental irregularities are dominant features. Post-flowering conditions are important factors determining seed weight. Moisture conditions that impair assimilative processes after flowering may lead to reduction in seed weight.

Table (7) demonstrates the average weight of 100 seeds produced by *Cenchrus biflorus* in pure stand under different watering regimes and durations. Table (8) on the other hand presents the average weight of 100 seeds produced by *C. biflorus* grown in combination with *Eragrostis termula* under the same moisture conditions as of the pure stand. Considering watering regimes, both tables (7) and (8) show a decrease in the mean average seed weight with the increase of moisture.

This steady decrease in seed weight indicates that the amount of water applied has a significant effect on the weight of seeds produced by *C. biflorus* as shown in Appendix IV ($P \leq 0.05$). Results from the study of flowering days had shown that the number of days required for flowering in *C. biflorus* increased with the increase of water applied. Plants under high moisture regime flowered only a few days before the watering stopped and continued without watering to the end of their life-cycle. Slatyer (1969) has pointed out that the greatest contribution to the grain fillings is usually from photosynthesis after anthesis by the vegetative parts of the plant. He also stated that the translocation of assimilates out of the leaves is slowed and prolonged by water stress. Combined with evidence that water stress slow maturation and with the direct effect of stress on photosynthesis , low seed weights in late flowering plants can be explained.

Tables (7) and (8) show that within each watering regimes the change in seed weight due to watering duration was not consistent. Within the light watering regimes (C) the three watering durations D_1, D_2 and D_3, gave almost equal average weights in both the pure stand and the combination. In the medium watering regime (N) the daily watering (D_1) gave the lowest mean weight then the weight increased in the weekly watering duration then dropped with the longer dry spell of two weeks (D_3). In the full saturation watering regime (F) a steady increase in the mean weight of 100 seeds was observed with the increase of the dry spell. The daily watering produced the lowest weight while the two-week duration gave the highest. Under the light watering regime (C) in both the pure stand (table 7) and the combination (table 8) *C. biflorus* produced the highest average weight of seeds regardless of the duration, with only a slight reduction in weight under the longer dry spell (D_3). This reduction could be attributed to the more dry conditions resulting from the interaction between the watering regimes and watering durations (AB) which showed to have significant effect ($P \leq 0.05$) on seed weight (Appendix IV).

Combining this result with the other results from the studies of number of days before flowering and numbers of seeds it can be seen that *Cenchrus biflorus* under light watering regimes produced heavy seeds in a short time but in few number. Plants under this condition were under stress for the whole of their life. Harper (1990) stated that plants respond to stress phenotypically by varying almost every other component of yield before the seed size and weight are affected. The seed number being the most plastic characteristic in the seed was the first to be sacrificed before seed weight. This same argument applied to the results of the second watering regime (N) in both the pure stand (table 7) as well as the combination (table 8). It is to be noticed that under the medium watering (N) the weekly and the two-weeks watering durations produced seed weight averages that are relatively similar to those produced under the light watering regime (C). The daily watering (ND_1) on the other hand produced the lowest average weight, tables (7) and (8), despite the relatively early flowering (table (3) and table (4) i.e. the low seed weight obtained can not be attributed to a water stress during the reproductive phase. The plants in this case were not subjected to drought , but it seems that they were subjected to another type of water stress, that was excess water stress. According to Pollock and Roos (1972), it has been found that excess moisture reduced oxygen diffusion in the soil resulting in a decrease in yield. *Cenchrus biflorus* under this condition of daily watering might have experienced such excess water stress resulting in a decrease in yield and that was expressed in terms of low seed weight.

In the full saturation watering regime (F) in both , the pure stand (table 7) and the combination (table 8), the two-weeks watering duration D_3 which flowered relatively earlier than the others (table (3) and (4) produced the highest average of seed weight followed by the weekly watering duration (D_2). The plants under these condition did not experience any water shortage during the reproductive phase. The reduction in seed weight in this case could have resulted due to excess water stress or nutrients deficiency in the soil which might have occurred because of leaching of nutrients from the sandy soil. The daily watering (D_1) under the full saturation watering regime (F) produced the lowest seed weight (Tables 7 and 8). It was noticed that plants under this condition started to flower shortly before watering seized and they had to go to the end of their life cycle without watering. It seems that the plants were subjected to two different types of water stress, firstly excess water stress during the vegetative phase resulting in weak plants and lower yield expressed in terms of low seed weight. Secondly a water shortage stress during the reproductive phase. Watering stopped at a time when water was very crucial to the plant and the plants were subjected to water shortage before seed maturation during the seed filling stage. The very low seed weight was obvious due to the reduced photosynthate production and the slowing of the assimilates translocation from the production sites to the grain or seed (Slatyer 1969). In addition to this high soil moisture might have resulted in low soil nutrient concentration due to leaching thus affecting the yield.

Larcher (1983) stated that environmental factors that affect assimilative processes are reflected chiefly on the properties that determine the future of the next generation. Simpson (1981) stated that drought stress can limit the yield of the plants despite the favourable moisture conditions earlier in development. The damage can occur with only brief periods of drought or atmospheric stress and can occur even under apparent wet soil conditions, and the greatest susceptibility arises at about halfway between flowering and maturity (Turner and Krammer, 1980).

Data analysis in Appendix IV shows that competition between *C. biflorus* and *E. termula* (C) produced insignificant ($P \leq 0.05$) differences in seed weight. The interactions between competition and water variables Ac, BC and ABC appeared to have significant ($P \leq 0.05$) effect on seed weight. Under low watering regimes there was excessive seedling mortality during the seedling stage (Tables (1) and (2)), as a result most of *E. termula* seedlings were eliminated thus leaving stands of low densities to establish. This might have reduced the effect of competition in those low moisture regimes. In the high moisture regimes (F) both species existed in high densities but because water was not limiting competition for soil moisture seemed to have insignificant effect on seed weight particularly under the daily and weekly watering conditions.

Table (7)

AVERAGE WEIGHT OF 100 SEEDS FROM A PURE STAND OF *CENCHRUS BIFLORUS* UNDER DIFFERENT WATERING REGIMES AND DURATIONS.

		I	II	III	MEAN
	D1	1.8	1.7	1.7	1.73 ± 0.05*
C	D2	1.7	1.7	1.8	1.73 ± 0.05
	D3	1.7	1.8	1.7	1.70 ± 0.00
	D1	1.6	1.5	1.5	1.53 ± 0.06
N	D2	1.8	1.8	1.7	1.77 ± 0.05
	D3	1.7	1.7	1.7	1.70 ± 0.00
	D1	1.3	1.4	1.2	1.30 ± 0.08
F	D2	1.7	1.6	1.6	1.63 ± 0.05
	D3	1.6	1.7	1.8	1.70 ± 0.08

C , N and F = watering regimes

D_1 , D_2 and D_3 = watering durations

I, II, and III = replications

* Mean ± standard deviation.

Table (8)

AVERAGE WEIGHT OF 100 SEEDS OF *CENCHRUS BIFLORUS* IN COMBINATION WITH *ERAGROSTIS TERMULA* UNDER DIFFERENT WATERING REGIMES AND DURATIONS.

		I	II	III	MEAN
	D1	1.8	1.8	1.7	1.77 ± 0.05
C	D2	1.8	1.7	1.8	1.77 ± 0.05
	D3	1.7	1.7	1.8	1.73 ± 0.05
	D1	1.5	1.4	1.4	1.43 ± 0.05
N	D2	1.8	1.8	1.7	1.77 ± 0.05
	D3	1.8	1.7	1.8	1.77 ± 0.05
	D1	1.2	1.2	1.0	1.13 ± 0.09
F	D2	1.6	1.5	1.6	1.57 ± 0.05
	D3	1.6	1.7	1.8	1.70 ± 0.08

C , N and F = watering regimes

D_1 , D_2 and D_3 = watering durations

I, II, and III = replications

* Mean ± standard deviation.

4.5. SEED VARIABILITY

One of the assumptions of the study was that high moisture conditions during years of good rainfall might have adverse effects on the properties of seeds of *C. biflorus* produced. Expected reduction in seed weight, size or other seed properties may affect the viability and/or vigour of the seeds. Seed properties as general determine the future of the next generation. Impairment of seed viability or vigour will be reflected on the density , strength and competitive ability of seedlings in the next generation. In this study viability test for seeds of *C. biflorus* produced under different watering regimes, watering durations and competition was carried out under field conditions. That was to demonstrate, at least to some extent, the natural environmental conditions prevailing during germination with only water under control.Data were obtained in terms of per cent seed germination for each seed lot.

4.5.1. Viability of *C. biflorus* seeds produced under different watering regimes and durations

Table (9) shows the percent germination in seeds produced by a pure stand of *C. biflorus* under different watering regimes and watering durations. Data shows that there was a decrease in seed viability with the increase in the amount of water applied (regimes). Also the seed viability increased when the dry spell within each water level was increased. The difference in seed viability brought about by the different watering regimes (A) and the different watering durations (B) and their interactions (AB) appeared to be significant ($P \leq 0.05$) as shown in Appendix V.

Seed viability results (Table (9)) were correlated with the results of seed weight study indicating that seed viability decreased with decreased seed weight. A major feature of seed development is the accumulation of nutrients reserves. The greater the supply of nutrients in seed, the greater the vigour of the seed and the ability to germinate. Pollock and Roos (1972) stated that the art of seed cleaning in which light seeds are removed from high density is based on the fact that high density seeds have greater potential for germination and seedling survival.

The flowering period study showed that *C. biflorus* under high moisture regime flowered later than it under light and moderate watering. The first plants to flower started that only a few days before watering stopped. As a results the plants under high moisture conditions were forced to complete their life cycle under drought conditions. The effect of water stress during the reproductive phase on seed weight and other properties is quite known (Simpson, 1980; Turner and Krammer, 1981; Larcher, 1983). In addition to the reduction in seed weight due to the impairment of the assimilative process and assimilates translocation in the plant organs, seed abortion and immaturity are common features in plants subjected to drought stress during the critical reproductive phase. According to Pollock (1972) the general conclusion which can be drawn from the vast literature on seed maturity is that the more mature a seed, the greater the vigour and potential for germination and therefore, potential for establishment of a new seedling.

4.5.2. Viability of *C. biflorus* seeds produced under different watering regimes,watering durations and durations

Table (10) shows the percent germination in *C. biflorus* seeds produced from a combination of *C. biflorus* and *E. termula* under different watering regimes and durations. The data demonstrated that the general performance followed the one of the pure stand discussed above (Table 9). Viability of seeds produced decreased with the increase of moisture applied (regime). Within the light watering regime (C) the viability of seeds produced decreased with the increase of the dry spell . However, this trend was completely reversed in the moderate (N) and saturated regime (F). Comparisons between table (9) and table 10 show the light watering regime (C) giving a higher seed germination mean under the combination than the pure stand, but this was reversed under the moderate (N) and saturated regime (F) where the pure stand gave higher germination mean than the combination. Results from other studies discussed before showed that *C. biflorus* under low moisture conditions (C) produced fewer but heavier seeds. Also the plants flowered earlier in the season thus giving a better chance for the seeds to mature, before watering was stopped.

The differences in seed viability between table (9) and table (10) expected to be brought about by the effect of competition, show insignificant ($P \leq 0.05$) effect (Appendix V). However, the interaction between competition and water variables showed a significant ($P \leq 0.05$) effect on seed viability (AC, BC and ABC Appendix V). These results correlate with the results obtained from seed weight study discussed above. It has been proved that changes in seed viability and vigour are results of changes in seed weight (Pollock, 1972). Considering the fact that seed weight is the least plastic plant characteristic it will be clear that environmental changes brought about by only competition may not be devastating to the extent that they cause a significant reduction in seed viability. Seed viability was effected only when competition was accompanied by water stress.

Table (9)

PER CENT GERMINATION OF SEEDS FROM A PURE STAND OF *CENCHRUS BIFLORUS* UNDER DIFFERENT WATERING REGIMES AND DURATIONS.

		I	II	III	MEAN
	D1	60	61	59	60.0 ± 0.8*
C	D2	62	61	60	61.0 ± 0.8
	D3	61	62	62	61.7 ± 0.5
	D1	58	60	60	59.3 ± 0.9
N	D2	60	61	61	60.7 ± 0.5
	D3	62	64	61	63.3 ± 1.3
	D1	52	55	53	53.3 ± 1.3
F	D2	57	53	58	57.7 ± 0.5
	D3	60	59	61	60.0 ± 0.8

C , N and F = watering regimes

D_1 , D_2 and D_3 = watering durations

I, II, and III = replications

* Mean ± standard deviation.

Table (10)

PER CENT GERMINATION OF *CENCHRUS BIFLORUS* SEEDS FROM A COMBINATION OF *C. BIFLORUS* AND *ERAGROSTIS TERMULA* UNDER DIFFERENT WATERING REGIMES AND DURATIONS.

		I	II	III	MEAN
	D1	62	63	62	62.3 ± 0.5*
C	D2	62	63	60	61.7 ± 1.2
	D3	60	60	61	60.3 ± 0.5
	D1	60	58	61	59.7 ± 1.2
N	D2	59	60	61	60.0 ± 0.8
	D3	60	62	60	60.7 ± 0.9
	D1	52	55	53	53.3 ± 1.2
F	D2	56	57	57	56.7 ± 0.5
	D3	59	58	59	58.7 ± 0.5

C , N and F = watering regimes

D_1 , D_2 and D_3 = watering durations

I, II, and III = replications

* Mean ± standard deviation.

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

This study investigated the effect of different soil moisture conditions on seed production and seed reproductive characteristics in an important grass species noticed to dominate the pastures in arid regions as a result of the recurrent drought experienced recently, namely *Cenchrus biflorus*. The study also investigated the effect of competition between this grass species and another associated grass species, *Eragrostis termula*, under those different soil moisture conditions. Production aspects and characteristics investigated included; seedling mortality, days before flowering, number of seeds produced per spikelet, average weight of seed and viability of seeds produced.

Seedling mortality study showed that seedling survival was affected by the amount of soil moisture available to the seedlings. Seedling mortality decreased with the increase of soil moisture level. Although *C. biflorus*, may have drought tolerant seedling, yet the seedling loss under low soil moisture conditions was greater than it under relatively high soil moisture conditions. It could be concluded that, under high soil moisture conditions, *C. biflorus* seedlings have better chances to establish and develop into mature plants given that environmental conditions other than soil moisture are not limiting.

Competition between *C. biflorus* and *E. termula* significantly increased seedling mortality in *C. biflorus*. However, it did not demonstrate a devastating effect to the extent that *C. biflorus* seedling were completely eliminated under any of the soil moisture conditions. *C. biflorus* seedlings showed a considerable drought tolerance under low soil moisture conditions contrary to *E. termula* seedlings which were noticed to be completely eliminated under some conditions of low soil moisture. Seedlings of *C. biflorus* also demonstrated their ability to compete with other seedlings, *E. termula,* and establish under conditions of relatively high soil moisture.

Observations of the number of days before flowering started in *C. biflorus* revealed that the vegetative phase in *C. biflorus* was significantly prolonged under high soil moisture conditions. *C. biflorus* plants conditions of low soil moisture flowered earlier and completed their life-cycle before watering was stopped. On the other hand those under conditions of relatively high soil moisture flowered later, a few days before watering seizure, and completed their life-cycle under drought conditions. The importance of this would be clear considering the well known effects of drought stress, during the crucial reproductive phase on the seed characteristics such as weight, size, number and ability to germinate, characteristics that determine the future of the next generation.

The study of seed number showed that the average number of seed per spikelet in *C. biflorus* was directly related to moisture conditions prevailing. Plants under high watering regimes and/or short watering durations produced higher number of seeds per spikelet than those under low moisture regime and or short watering durations. These results appeared to be obvious since seed number was determined during fertilization which occurred at a time at which plants did not experience any change in the moisture conditions they were going through, consequently seeds were set in correlation with the moisture conditions available. The number of seed per plant unit is an important factor in determining the seed weight and size which will be determined later. Competition seemed to have no significant effect on seed number, yet it appeared to interact with different watering regimes and watering durations leading to significant differences in seed number.

Seed weight is determined by the environmental conditions prevailing during the reproductive phase, especially during the grain filling stage. The study showed a steady decrease in seed weight with the increase of moisture. At the first time these results appeared to be as if they were reversed, but considering the results of the other studies these results could be justified. Under low moisture conditions *C. biflorus* exhibited its normal short life-cycle completing it under relatively dry but consistent moisture conditions. From seed mortality study it could be seen that natural thinning and competition played a considerable role in cutting down the stand density to a level that could be supported by the available moisture. The study of flowering periods indicated that under low moisture conditions *C. biflorus* flowered earlier and was able to complete its life-cycle within the limits of the simulated short growing season, without experiencing any further adverse moisture conditions. From the results of seed number study it could be seen that *C. biflorus* produced fewer numbers of seeds per spikelet thus enabling the assimilating processes in the plant to furnish the developing seeds with adequate amounts of nutrients reserves accumulated in terms of seed weight and size.

On the other hand plants under high moisture conditions developed in high stand densities, increasing competition between individuals, of the same or different species, for other resources. Under such conditions most of the production would be directed towards the vegetative expansion of the plant so that it could maintain its competitive ability and withstand competition. The plants needed a longer time to maintain the level of net production that enabled them to initiate flowering and go into the reproductive phase as shown by results from the study of flowering periods. Because of the bigger plant size larger numbers of flowers were produced and fertilized to develop into seeds. Then all of a sudden the simulated growing season came to an end before the plants completed their life-cycle and hence they ran into a drought stress during the reproductive phase. Considering the reduction in photosynthate production brought about by water shortage coupled with the slow translocation of assimilates from production sites to the grain and the large number of seeds to be nourished, the nutrient supply to the grain would no doubt fall far behind the requirement. The ultimate results would be a large number of small shrivelled or even immature seeds.

The study of seed viability carried out for the seeds produced by *C. biflorus* under different condition of moisture and competition finally demonstrated results which were correlated to those of seed weight study. It indicated that the low seed weight resulting from high moisture level for a short limited growing season was reflected in the next generation in terms of low germination rates and may be loss of seedling vigour and ability to compete. This would lead to a decrease in the number of surviving individuals of the species in the next generation and eventually may lead to the complete disappearance of the species if the high moisture conditions continue.

5.2. Recommendations

This study was carried out under field conditions where there was no control on environmental factors other than soil moisture. The study also investigated the effect of soil moisture for a limited period of time simulating the rainy season in the study area. The study has shown a number of areas for research study that need to be investigated. The following recommendations can made for further in-depth studies considering the effect of other environmental factors and their interactions and hence their contribution to the phenomenon under consideration.

1. The same experiment can be repeated with water application being continued until the plants finish their life-cycle. This will provide another dimension for studying the effect of soil moisture on seed characteristics in *C. biflorus*.

2. It is recommended that the same study be carried out under controlled conditions of soil moisture, temperature, humidity, and other necessary factors. This will provide a wider range of

environmental factors to be investigated and their contribution to the short-term dynamics of *C. biflorus* can be assessed.

3. Competition between *C. biflorus* and *E. termula* was investigated using a single combination of the two species, for more precise information about the effect of competition further studies can be carried out using different combinations of the two species.

4. The above mentioned research areas can be studied for the short-term as well as for the long-term to provide more in-depth information about the dynamics of *C. biflorus*.

APPENDICES

APPENDIX I

ANOVA TABLE

MORTALITY RATE IN *CENCHRUS BIFLORUS* SEEDLINGS UNDER DIFFERENT WATERING REGIMES, WATERING DURATIONS AND COMPETITION

Source of variation	D.F.	SS	MS	F	F_t
Total	53	6791.3333			
Blocks	2	84.1111	42.0556	6.53^{ns}	6.96
Watering Regimes (A)	2	900.1111	450.0556	69.84^{**}	6.94
Error	4	25.7778	6.4445		
Watering Durations(B)	2	4327	2163.5	232.26^{**}	3.89
Interaction (AB)	4	704.5556	176.1389	18.91^{**}	3.26
Error	12	111.7777	9.3148		
Competition (C)	1	170.6667	170.6667	34.52^{**}	4.41
Interaction (AC)	2	91	45.5	9.20^{**}	3.55
Interaction (BC)	2	171.4444	85.7222	17.34^{**}	3.55
Interaction (ABC)	4	115.8889	28.9722	5.86^{*}	2.93
Error	18	89	4.9444		

* significant   ** highly significant   ns = not significant

APPENDIX II

ANOVA TABLE

DAYS BEFORE FLOWERING IN *CENCHRUS BIFLORUS* UNDER DIFFERENT WATERING REGIMES, WATERING DURATIONS AND COMPETITION

Source of variation	D.F.	SS	MS	F	F, 0.05
Total	53	4518.3148			
Blocks	2	2.8259	1.4031	0.30^{ns}	6.96
Watering Regimes (A)	2	2701.5926	1350.7863	230.01**	6.94
Error	4	19.2963	4.8241		
Watering Durations(B)	2	1245.5829	622.7930	117.18**	3.89
Interaction (AB)	4	469.6296	117.4074	22.09**	3.26
Error	12	63.7778	5.3148		
Competition (C)	1	0.4630	0.4630	0.87^{ns}	4.41
Interaction (AC)	2	0.2592	0.1298	0.24^{ns}	3.55
Interaction (BC)	2	1.8148	0.9074	1.70^{ns}	3.55
Interaction (ABC)	4	3.6297	0.9074	1.70^{ns}	2.93
Error	18	9.5925	0.5329		

* significant ** highly significant ns = not significant

APPENDIX III

ANOVA TABLE

AVERAGE NUMBER OF SEEDS PER SPIKELET IN

CENCHRUS BIFLORUS UNDER DIFFERENT WATERING

REGIMES, WATERING DURATIONS AND COMPETITION

Source of variation	D.F.	SS	MS	F	F, 0.05
Total	53	265.5			
Blocks	2	1.4444	0.7222	25.98*	6.96
Watering Regimes (A)	2	137.4444	68.7222	2472.02**	6.94
Error	4	0.1112	0.0278		
Watering Durations(B)	2	105.4444	52.7222	299.69**	3.89
Interaction (AB)	4	11.4445	2.8611	16.26*	3.26
Error	12	2.1111	0.1759		
Competition (C)	1	0.4630	0.4630	3.57ns	4.41
Interaction (AC)	2	1.1482	0.5741	4.43*	3.55
Interaction (BC)	2	1.5926	0.7963	6.14*	3.55
Interaction (ABC)	4	1.5926	0.4907	3.79*	2.93
Error	18	2.3333	0.1296		

* significant ** highly significant ns = not significant

APPENDIX IV

ANOVA TABLE

EFFECT OF DIFFERENT WATERING REGIMES, WATERING DURATIONS AND COMPETITION ON SEED WEIGHT IN *CENCHRUS BIFLORUS*

Source of variation	D.F.	SS	MS	F	F, 0.05
Total	53	1.8231			
Blocks	2	0.0058	0.0030	0.84^{ns}	6.96
Watering Regimes (A)	2	0.5031	0.2541	72.07**	6.94
Error	4	0.0141	0.0035		
Watering Durations(B)	2	0.6237	0.3119	29.56**	3.89
Interaction (AB)	4	0.4497	0.1124	10.66*	3.26
Error	12	0.1266	0.0106		
Competition (C)	1	0.0046	0.0046	4.13^{ns}	4.41
Interaction (AC)	2	0.0282	0.0141	12.66*	3.55
Interaction (BC)	2	0.0282	0.0141	12.66*	3.55
Interaction (ABC)	4	0.0140	0.0035	3.10*	2.93
Error	18	0.0200	0.0011		

* significant   ** highly significant   ns = not significant

APPENDIX V

ANOVA TABLE

VIABILITY OF SEED OF *CENCHRUS BIFLORUS*

PRODUCED UNDER DIFFERENT WATERING REGIMES,

WATERING DURATIONS AND COMPETITION

Source of variation	D.F.	SS	MS	F	F, 0.05
Total	53	399.3333			
Blocks	2	8.1111	4.0556	4.29^{ns}	6.96
Watering Regimes (A)	2	220.1111	110.0556	116.53**	6.94
Error	4	3.7778	0.9445		
Watering Durations(B)	2	57.0000	28.5000	15.95**	3.89
Interaction (AB)	4	62.8889	15.7222	8.80*	3.26
Error	12	21.4444	1.7870		
Competition (C)	1	0.6667	0.6667	3.00^{ns}	4.41
Interaction (AC)	2	4.3333	1.1667	9.75*	3.55
Interaction (BC)	2	8.8888	4.4444	20.00**	3.55
Interaction (ABC)	4	8.1112	2.0278	9.13*	2.93
Error	18	4.0000	0.2222		

* significant   ** highly significant   ns = not significant

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