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Full Length Research Paper

Soil seed banks of a rangeland area White Nile State, Sudan

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Three soil depths (0 to 5, 5 to 10 and 10 to 15 cm) were chosen at the study area and the soil seed bank was analyzed for the number of live and dead seeds for each of them. The analysis revealed the following: The seed bank density was higher in the upper soil depths (0 to 5 and 5 to 10 cm) as compared to the lower ones (10 to 15 cm). It was found that the seed density had decreased with increasing depth. The live seed density ranged from 1015 to 5371 seeds/m^2, whereas that of the dead seeds ranged from 3215 to 6957 seeds/m^2. The dominant plant species to which the live seeds belonged were grasses including *Schoenefeldia gracilis*, *Brachiaria* spp., *Dactyloctenium aegyptium* and *Aristida spp.* The dominant species to which the dead seeds belonged were mixed life- forms including *Panicum turgidum, Euphorbia aegyptiaca* and *Cyperus rotundus.*

Key words: Seed bank, density, species composition, semi-arid environments, rainfall variability, dispersal, viable seeds and dead seeds.

INTRODUCTION

Sudan is the largest country in Africa and the nineth largest in the world with an area of about 2.5 million square kilometers. It exhibits a wide range of variation in its topography, climate, soil, and hydrology.

The study area (Um Rimmitta) lies between latitudes 14°36/ and 14°49/N and longitude 32°05/ and 32°11/ E. It is bordered from the east by the White Nile and from the west by North kordofan State and from the north by Guetaina province about seventy kilometers north of Ed Dueim town.

LITERATURE REVIEW

Soil seed banks are important components of vegetation dynamics affecting both ecosystem resistance and resilience. In arid ecosystems, seeds are characterized by high spatial and temporal variability and are particularly affected by spatial patterns of vegetation. Rainfall unpredictability is the underlying factor causing the huge soil seed banks found in arid environments.

According to Roberts (1981) the term soil seed bank has been used to designate the live seed reservoir present in a soil. For Baker (1989), this reservoir corres-ponds to seeds not germinated but, potentially capable of replacing the annual adult plants, which had disappeared by natural death or otherwise and perennial plants that are susceptible to plant diseases, disturbance and human or animal consumption. Simpson et al. (1989) defined the soil seed bank as all the viable seeds present in the soil or mixed with soil debris.

The persistence of seeds in the soil is a major component of plant succession and plays a substantial role in the evolution of plant communities (Robert, 1981). Seeds that remain incorporated in the soil form a reserve that can be depleted for potential regeneration over a period of time that may extend to a century.

The seasonal pattern of rainfall, as it influences the size and composition of the soil seed bank is the major factor affecting recruitment of species (Orr, 1991). Kropac (1966) divided the techniques for estimating the population of the soil seed bank into two groups. The first

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group is the physical extraction which includes sieving, flotation and subsequent viability determination. The second group is the germination techniques that rely on direct assessment of seedlings arising from soil samples. Both have merits as well as disadvantages.

The physical extraction of seeds from the soil tended to overestimate the number of germinating seeds, since extraction counts may include dormant and dead seeds. The seed numbers are normally expressed as number of seeds/m^2 related to certain depth. The determination of the proportion of dead seeds present in the soil seed bank is important in studying population dynamics and consequently methods of determining viabilities have been developed.

The germination technique, although undoubtfully useful, may be less efficient than the extraction method (Jensen, 1969). The time of sampling in relation to the vegetation cycle must also be taken into account, either by occasional samples at different sites or sampling at the same time in different years (Barralis, 1972).

To determine the soil weed seed bank, Fay and Olson (1978) described a simple technique for rapid determination of weed seed, rhizome, and corm or bulb population in the soil. Soil samples were placed in nylon mesh bags and washed by machine, leaving only small residues including the desired propagules. These were hand-separated and the soil population of a given plant species was then calculated. The total manipulation time per sample was approximately 10 min.

The size of soil samples is an important factor in soil seed bank determinations. Different soil sample sizes were used by different workers, depending on the condition under investigation. Malone (1976) worked on chemical extraction of seeds using aqueous sodium hexa- meta-phosphate. He adopted individual soil samples of 500 gm, but he mentioned that 100 gm are more conveniently manipulated. In his study, individual soil samples of 250 gm were used for extraction by calcium chloride ($CaCl_2$).

The size of weed seed bank varies to a great extent. Jensen (1969) found that the average seed bank size within the upper 20 cm was 50258 living seeds/m^2 in 57 Danish fields. In a British investigation (Roberts and Stokes, 1966), values between 1600 and 86000 live seeds/m^2 were recorded in 58 fields within the upper 15 cm. Von Hofsten (1947) reported an estimate of 1777 seeds/m^2 for *Sinapis arvensis* in Sweden. Another way for estimating changes of the size of the seed bank is to register the number of emerged seedlings in the field. According to Ebregt et al. (1988) weed surveys give a poor estimation of the seed bank due to large annual fluctuations in emergence and growth conditions. Thus soil sampling is a more reliable method than field surveys to estimate the seed bank.

The soil depth is another determination factor in soil seed bank studies. Demel and Granstrom (1995) reported that in dry Afromontane forests of Ethiopia at least 167 plants species were identified in the 0 to 9 cm soil layer with total densities ranging between 12300 and 24000 seeds/m^2. In Sudan, Mustafa (1997) found about 20 seeds/m^2 under the canopy of *Acacia seyal*. In Kenya, Schimidit in Tybrik et al. (1994) found 1510 seeds/m^2 whereas Kaarakka (1996) found a maximum of 6 seeds/m^2 under the canopy of *Acacia zanzibrica*. Ibrahim (2005) recorded seed bank densities of about 19700 dead seeds/m^2 and 7238 live seeds/m^2 in the low rainfall savannah.

The weed species have survived through time, because of their ability to resist several adverse climatic conditions including tolerance to high or low temperatures, dry or humid environments and variations in oxygen supply (Hafliges, 1990).

The composition of seed bank is variable and is classified as temporary or persistent with respect to the regeneration of the vegetation during different times of the year temporary banks are composed of seeds of short life, which do not have dormancy (Garwood, 1989). Persistent seed banks are composed of seeds that live for more than one year and can buried remain in the soil for many years. Generally, seed bank composition depends on seed longevity and viability.

Seed longevity in the soil varies with plant species, burial depth, soil moisture in addition to internal and external seed factors. Freitas (1990) reported a seed longevity of 40 years for *Portulaca oleracea*. Seeds in the soil last longer in the deeper layers than on the surface (Taylorson, 1970; Qi et al., 1996) and those with impermeable coats are mostly likely to last longer in the soil (Owen, 1950). Bekker et al. (1997) found that change in soil moisture contents could have a large effect on seed longevity.

Several internal and external factors prevent seed germination. Among the internal seed factors, the most important are the presence of the seed coat, a biochemical inhibitor in the seed, and immature embryo. Among the external factors the most common are soil water content and temperature (Fernandez et al., 1991). The dormancy represents a main mechanism of species preservation in the seed bank, thus distributing germination through the year (Carmona, 1992).

Different factors affect the viability of seed bank in the soil. Grazing and cutting intensity affect the seed bank, through effects on the seeds return. O'Connor et al. (1992) studied the seed bank of *Aristida bipartia* and other spp. in savanna grassland and reported that the seed bank was dominated by less palatable species in areas subjected to heavy grazing.

The dynamics of a seed bank involves a series of events including time and land preparation that influences the seed dispersion in the soil profile (Simpson et al. 1989). Clements and Bentoit (1996) studied the influence of land preparation types on the seed bank. They found that more than 70% of the seeds were present in the layers of 0 to 5 cm in plots where no mechanical method was used and 30% for plots mechanically managed.

Other events include management of soil depth and fair or

uniform distribution of seeds in the soil profile (Dessaint et al., 1991).

MATERIALS AND METHODS

Preparation of soil samples

Six transects were made and soil samples were taken from 42 sample plots in the study area from depths (0 to 5, 5 to 10 and 10 to 15 cm) along each transect. The samples were mixed thoroughly and sub-samples of 250 gm were prepared for seed extraction.

The soil sub- samples were placed in a set of sieves with pores of 1, 0.5, 0.25, and 0.1 mm and washed for 10 to 15 min under continuous flow of water. The soil was washed away and the seeds there in were transferred to a 500 ml beaker containing water. The dead seeds were observed to float and the water containing the floating dead seeds was immediately filtered in a Bunchner funnel. The residue (dead seeds) was air-dried.

The live seeds at the bottom of the beaker were extracted as follows: A weight of 1.5 g of $CaCl_2$ was accurately weighed and dissolved in 250 ml of distilled water. The solution was added to the live seeds in the beaker and left for 40 min.

The live seeds were observed to float in the $CaCl_2$ solution. These were then filtered in a Buchner funnel and air-dried.

Determination of soil seed density

The density of seeds was determined by the following formula:

$$\text{Density of seeds} = \frac{\text{Number of seeds/soil depth x 2 x 10000}}{\text{Quadrat area x number of quadrats/soil depth}}$$

Identification of soil seeds

The extracted seeds were identified by comparison with a reference seed collection from known plants growing in the study area. Magnifying lenses and an Mbc-10 dissection microscope were used for seed identification.

RESULTS

Species composition at Site A

At Site A, 21 species were identified from the live seeds whereas 20 species were identified from the dead seeds. The most dominant species identified from the live seeds included *Indigofera arrecta*, *Cyperus rotundus*, *Dactyloctenium aegyptium*, *Tephrosia uniflora*, *Brachiaria mutica Indigofera hochstetteri*, *Aristida adescensionis*, *Panicum turgidum*, *Scheonefeldia gracilis* and *Euphorbia aegyptiaca*. The most dominant species identified from dead seeds included *Brachiaria sp., Euphorbia aegyptiaca*, *Panicum turgidum*, *Aristida adescensionis*, *Schoenefeldia gracilis*, *Cleome escaposa*, *Mullugo nudicaulis*, and *Corchorus spp* (Table 1).

Soil seed density for Site A

The number of seeds/m^2 was calculated for each soil depth by the following equation:

$$\text{No. of seeds/m}^2 = \frac{\text{Number of seeds/depth x 2 x 100 x 100}}{\text{Quadrat area (m}^2\text{) x Number of quadrats/depth}}$$

The following results represent the number of live and dead seeds/m^2 for each of the three soil depths at Site A:

Depth 0 to 5 cm:
Number of live seeds/m^2 = 163 x 2 x 10000/ 1400 = 2329
Number of dead seeds/m^2 = 283 x 2 x 10000/1400= 4043
Depth 5 to 10 cm:
Number of live seeds /m^2 = 17 x 2 x 10000/ 1400 = 243
Number of dead seeds/m^2 = 75 x 2 x 10000/ 1400 = 1071
Depth 10 to 15 cm:
Number of live seeds/m^2 = 10 x 2 x 10000/ 1400 = 143
Number of dead seeds/m^2 = 70 x 2 10000/ 1400 = 1000

Species composition at Site B

At Site B, 26 species were identified from the live seeds whereas 28 species were identified from the dead seeds. The most dominant species identified from live seeds included *Indigofera arrecta, Dactyloctenium aegyptium, Tephrosia uniflora, Brachiaria mutica*, (*Indigofera hochstetteri, Aristida adescensionis, Cenchrus biflorus*, *Panicum turgidum.* The most dominant species identified from dead seeds included *Cyperus rotundus, Dactyloctenium aegyptium, Brachiaria eruciformis, Cenchrus biflorus, Aristida adescensionis, Panicum turgidum* and *Indigofera hochstetteri* (Table 2).

Soil seed density for Site B

The following is a summary of the number of live and dead seeds/m^2 for each of the three soil depths at site B:

Depth 0 to 5 cm:
Number of live seeds/m^2 = 201 x 2 x 10000/ 1400 = 2871
Number of dead seeds/m^2 = 199 x 2 x 10000/1400= 2843
Depth 5 – 10 cm:
Number of live seeds /m^2 = 126 x 2 10000/ 1400 = 1800
Number of dead seeds/m^2 = 205 x 2 x1000/ 1400 = 2971
Depth 10 to 15 cm:
Number of live seeds/m^2 = 49 x 2 x 10000/ 1400 = 700
Number of dead seeds/m^2 = 80 x 2 x 10000/ 1400 = 1143

Species composition at Site C

At Site C, 16 species were identified from live seeds whereas 18 species were identified from dead seeds. The most dominant species identified from live seeds included *Aristida adescensionis, Schoenefeldia gracilis, Mullugo nudicaulis*. The most dominant species identified

Table 1. Soil seed bank at Site A: Depths (cm).

Species	0 - 5		5-10		10-15		Total	
	Live	Dead	Live	Dead	Live	Dead	Live	Dead
Acacia oerfota	-	2	-	-	1	-	1	2
A. tortilis	1	-	-	-	-	-	1	-
Abutilon figarianum	-	-	-	-	-	2	-	2
Aristida adscensions	9	39	-	1	-	7	9	47
Brachiaria mutica	5	2	-	-	-	-	5	2
B. reptans	12	75	3	26	-	8	15	99
Chloris virgata	-	2	1	-	-	-	1	2
Cleome escaposa	2	10	-	1	-	6	2	17
Corchorus sp	4	8	-	3	2	-	6	11
Cyperus rotundus	20	3	2	3	-	6	22	12
Cyperus spp.	36	2	-	1	-	-	36	3
Dactylectonium aegyptium	15	3	3	-	-	1	18	4
Eragrostis sp.	1	3	-	-	-	1	1	4
Euphorbia aegyptiaca	8	60	-	6	4	26	12	92
Fimbristilis biss-umbellta	7	-	-	-	-	-	7	-
Indigofera hochstetteri	3	2	4	-	1	-	8	2
Mollugo nudicaulis	3	3	1	9	-	3	4	15
Ocimum sp	5	-	1	1	-	-	6	1
Panicum turgidum	11	41	2	20	2	10	15	71
Schoenefeldia gracilis	9	21	-	1	-	-	9	22
Senna alexandrina	6	4	-	3	-	-	6	7
Solanum dubium	5	-	-	-	-	-	5	-
Tribulus terrsitris	-	2	-	-	-	-	-	2
Zornia sp	1	1	-	-	-	-	1	1
Total	163	283	17	75	10	70	190	418

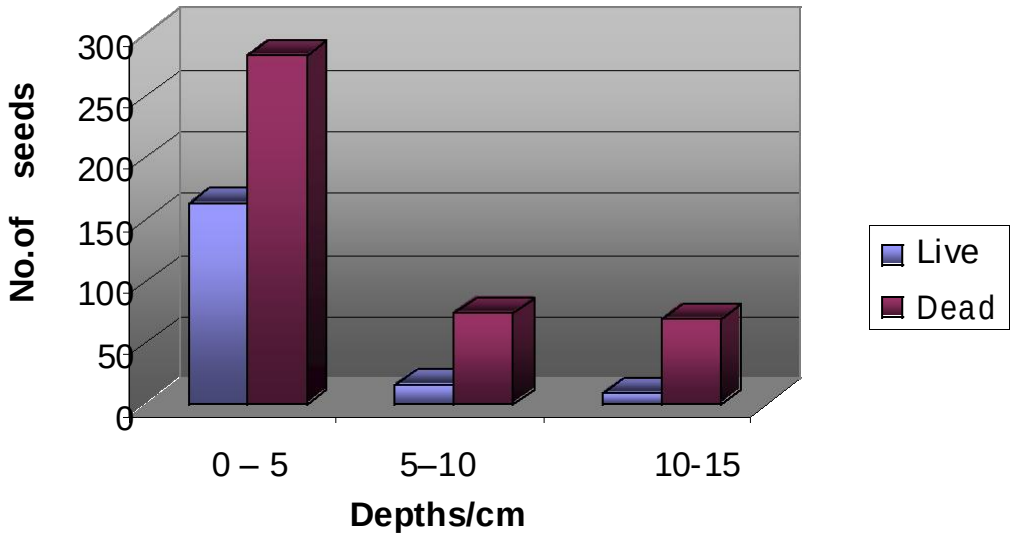

Figure 1. Histogram showing the number of live and dead seeds at each soil depth for Site A.

from dead seeds included *Aristida adescensionis, Cyperus rotundus, Schoenefeldia gracilis* and *Mullugo nudicaulis* (Table 3).

Soil seed density at Site C

Here is a brief summery of the numbers of dead and

Table 2. Soil seed bank at Site B: Depths (cm).

Species	0 - 5		5-10		10 -15		Total	
	Live	Dead	Live	Dead	Live	Dead	Live	Dead
Abutilon figarianum	-	-	-	-	4	-	4	-
Achyranthes aspera	-	-	-	1	-	-	-	1
Aristida adscensionis	13	18	6	14	8	7	27	39
Brachiaria mutica	3	-	1	2	-	-	4	2
B. reptans	18	19	20	20	3	2	41	41
Cenchrus biflorus	8	19	11	19	3	12	22	50
Chloris virgata	-	-	3	2	-	-	3	2
Cleome escaposa	1	-	-	8	-	-	1	8
Corchorus spp.	4	4	5	4	5	-	14	8
Cyperus rotundus	7	42	6	13	4	13	17	68
Cyperus spp.	5	10	4	15	-	7	9	32
Dactyloctenium aegyptium	28	27	43	34	8	18	79	79
Eragrostis sp.	3	5	-	2	2	-	5	7
Euphorbia aegyptiaca	1	2	-	-	-	2	1	4
Fagonia cretica	1	2	-	-	-	-	1	2
Fimbristylis biss-umbellata	1	5	-	1	2	-	3	6
Hibiscus vitifollus	-	1	-	-	-	-	-	1
Indigofera arrecta	42	5	1	11	-	-	43	16
I. hochstetteri	17	12	13	17	2	1	32	30
Leucas urticifolia	1	-	-	-	-	-	1	-
Mollugo nudicaulis	6	-	2	1	-	2	8	3
Ocimmum spp.	-	1	3	-	-	-	3	1
Panicum turgidum	10	18	8	34	5	14	23	66
Schoenefeldia gracilis	9	7	2	4	1	1	12	12
Senna alexandrina	1	1	-	1	-	-	1	2
Sesamum alatum	-	1	-	-	-	-	-	1
Solanum dubium	-	-	-	-	1	-	1	-
Tephrosia uniflora	19	-	-	-	-	-	19	-
Tribulus terrestris	-	-	-	-	1	-	1	-
Zornia spp.	3	-	1	2	-	1	4	3
Total	201	199	129	205	49	80	379	484

liveseeds for each of the three ssiol depths at Site C:

Depth 0 to 5 cm:
Number of live seeds/m^2 = 44 x 2 x 10000/ 1400 = 629
Number of dead seeds/m^2 = 128 x 2 x 10000/ 1400
Depth 5 to 10 cm:
Number of live seeds/m^2 = 17 x 2 x 10000/ 1400
Number of dead seeds/m^2 = 46 x 2 x 10000/ 1400 = 657
Depth 10 to 15 cm:
Number of live seeds/m^2 = 10 x 2 x 10000/ 1400 = 143
Number of dead seeds/m^2 = 51 x 2 x 1000 / 1400 = 729

The results of soil seed bank presented in Tables 1, 2 and 3 were statistically analyzed using the variance ratio (F) test. The results of the statistical analysis for live and dead seeds have been presented in Tables 4 and 5, respectively.

Summary of soil seed bank in the study area

From the results aforementioned, it can be seen that the seed bank density was higher in the upper depths as compared to the lower ones. The live seed density in the study area (semi-arid) ranged between 1015 and 5371 seeds/m^2 while that for the dead seed density was ranged between 3215 to 6957 seeds/m^2. The soil seed bank density for both live and dead seeds in the study area was in the range 3034 to 8462 seeds/m^2.

DISCUSSION

The soil seed bank of the study area was quantitatively determined at each of Sites A, B and C. The herbs and grasses recorded the highest number of seeds, as

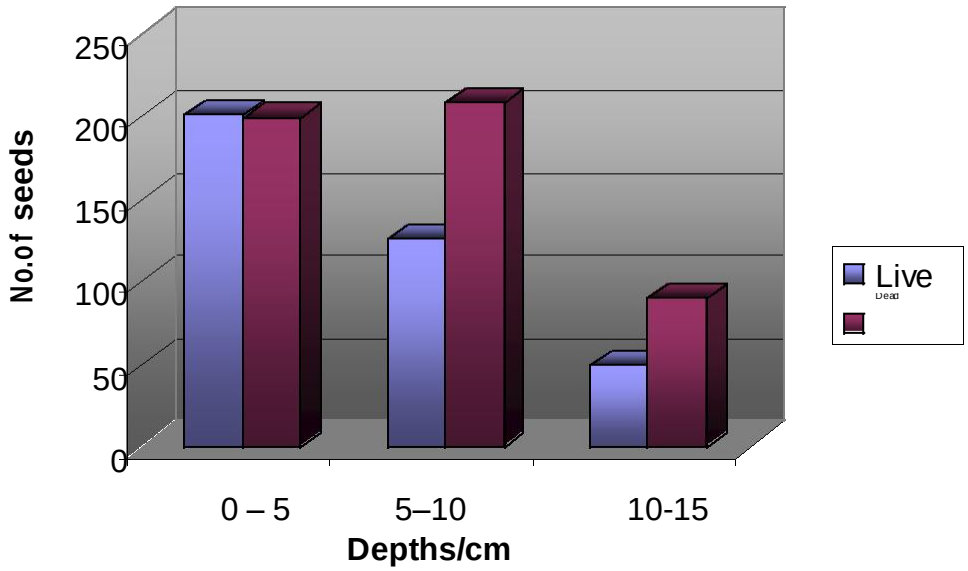

Figure 2. Histogram showing the number of live and dead seeds at each soil depth for Site B.

Table 3. Soil seed bank at Site C: Depths (cm).

Species	0 - 5		5-10		10-15		Total	
	Live	Dead	Live	Dead	Live	Dead	Live	Dead
Aristida adscensionis	14	65	5	8	1	6	20	79
Brachiaria mutica	2	-	1	1	-	3	3	4
B. reptans	1	-	-	1	-	-	1	1
Cenchrus biflorus	-	2	1	-	-	4	1	6
Cenchrus ciliaris	-	-	1	2	-	-	1	2
Cleome escaposa	-	-	-	1	-	-	-	1
Corchorus sp.								
Cyperus rotundus	4	23	4	9	-	17	8	49
Cyperus spp.	5	-	-	1	-	2	5	3
Dactyloctenium aegyptium	-	6	1	-	2	-	3	6
Echinochloa spp.	-	-	-	1	-	1	-	2
Eragrostis spp.	-	-	1	-	1	-	2	-
Indigofera arrecta	-	-	-	-	-	2	-	2
I. hochstettri	2	-	-	-	-	1	2	1
Mollugo nudicaulis	2	10	1	11	3	5	6	26
Ocimmum spp.	1	-	-	-	-	2	1	2
Panicum turgidum	-	-	-	-	-	3	-	3
Schoenefeldia gracilis	13	21	-	8	-	5	13	34
Tribulus terrestris	-	1	-	-	-	-	-	1
Total	44	128	17	46	10	51	71	225

compared to the other life forms across the three sites (Tables 1, 2 and 3 respectively). The woody species recorded a low number of seeds, which agrees with Mustafa (1997), Tybrik et al. (1994) and Kaarakka (1996). This may be attributed to land over-use through a number of practices including the use of fruits as forage, marketing of seeds, excessive felling of trees, predation, pathogenicity, seed suffocation in water-logged areas and wild fires used in land clearance for shifting cultivation.

In depth A (0 to 5 cm), the density of live seeds was 5829 seeds/m^2 whereas the dead seeds recorded a density of 8715 seeds/m^2. In depth B (5 to 10 cm), the density of live seeds was 2286 seeds/m^2 as compared to

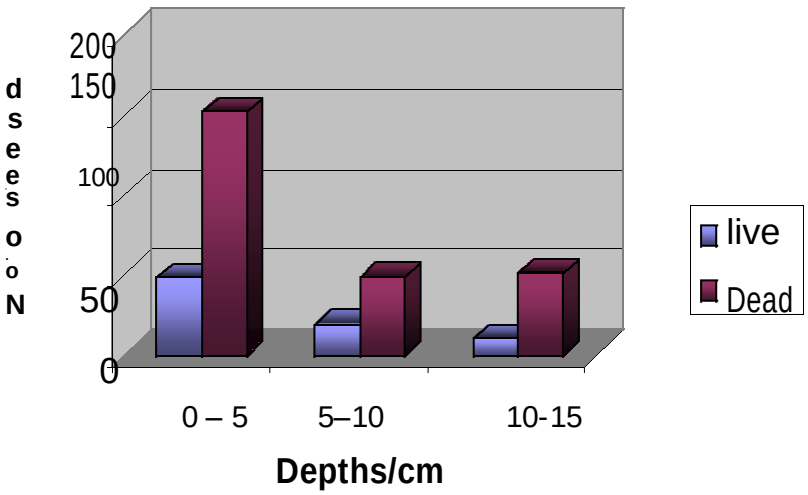

Figure 3. Histogram showing the number of live and dead seeds at each soil depth for Site C.

Table 4. ANOVA table for the live soil seed bank data in the study area.

Site	Source	df	Mean S	F. value	P.
A	Species	23	23.940 34.000	0.7041	0.8178
B	Species	29	136.454 44.422	3.0717	0.0001
C	Species	18	8.957 6.456	1.3874	0.1938

Table 5. ANOVA table for the dead soil seed bank data in the study area.

Site	Source	df	Mean S	F. value	P.
A	Species	23	309.295 117.750	2.6267	0.0024
B	Species	29	180.523 25.933	6.9610	< 0.0001
C	Species	18	147.121 67.649	2.1748	0.0218

a density of 4699 seeds/m^2 for the dead seeds. In depth C (10 to 15 cm) the density of live seeds was 986 seeds/m^2 while that of the dead seeds was 2872 seeds/m^2. From these results, it can be seen that the vertical distribution and soil seed density were higher in the upper soil layers and that both vertical distribution and soil seed density decreased with increasing depth. This is in line with what was found by Clements and Bentiot (1996) and Dessaint et al. (1991). The total soil seed bank density in the study area was low when compared with Demel and Granstrom (1995). That is explained by the fact that they determined the density under forested areas, whereas the present study was conducted at non-forested areas.

The density of live seeds was low in the study area as compared to Roberts and Stocks (1966). This may probably be due to the differences in site conditions and environmental factors.

The study also revealed that the percentage of dead seeds was higher as compared to that of live seeds. The low viability of seeds may be attributed to suffocation resulting from water- logging, predation, shedding of seeds before maturity and high temperatures.

The study has also revealed that the live seeds in depth A (0 to 5 cm) belonged to 21 species, while the dead seeds belonged to 20 species. In the depth B (5 to

10 cm) the live seeds belonged to 8 species and the dead seeds belonged to 12 species. However, in depth C (10 to 15 cm) the live seeds belonged to 5 species and the dead seeds belonged to 10 species. The number of species to which the live and dead seeds belong confirm the previous findings with respect to vertical distribution and seed density for the three soil depths. That is the number of species to which the seeds belong decrease with increasing depth.

The dominant soil seed flora were *Indigofera arrecta, I. hochstetteri, Dactyloctenium aegyptium, Schoenefeldia gracilis, Aristida adscensionis, Brachiaria spp., Panicum turgidum, Euphorbia aegyptiaca, Cenchrus biflorus,* and *Cyperus* spp. The dominance of the aforementioned species in the soil seed bank may be attributed to their prolific seeding and good growth and establishment. Moreover, these species are: tolerant to decay, protected from predators and resistant to several adverse climatic conditions.

There are differences among the dominant species in the percentages of the total live seeds. For instance, the frequencies of the total live seeds for *Dactyloctenium aegyptium, Cyperus spp., Indigofera spp.,* and *Brachiaria spp.* were 15, 14.9, 13.1 and 10.2% respectively. From field observations and soil seed bank identification at the study area, it was found that some grasses and herbs were dominant and this agreed with Hafliges (1990). This indicates that some of the dominant species have different seed production capacities at the different sites and can survive for a long time because of their ability to resist several adverse climatic conditions. However, some species have different percentages of the total number of dead seeds as follows: *Aristida spp*. and *Panicum turgidum*, have frequencies 14.4 and 12% respectively. This may be due to the intolerance of these species to adverse climatic conditions, predation, suffocation, decay besides the shedding of seeds before maturity.

The results of statistical analysis for soil seed bank data (Tables 1and 2) showed a very highly significant difference for the live seeds in site B and non- significant differences for sites A and C. The very highly significant difference of live seeds at site B significant difference was probably due to site conditions, diversity of species, prolific seeding and resistance to decay. The non-significant differences in sites A and C may be attributed to different seed production capacities of the species under different sites.

As for the dead seeds at the three sites, a very highly significant difference was found at site B, a highly significant difference was found at site A and a significant difference was found at site C. This may probably be due to the site conditions and floristic composition. The soil seed analysis had also shown that the less palatable species were dominant.

This agrees with O'Conner and Pickett (1992), who reported that heavy grazing results in the dominance of the less palatable species.

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