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Germination of Caryopses of the Halophyte: *Aeluropus massauensis* from Saudi Arabia

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ABSTRACT. *Aeluropus massauensis* is a perennial grass. The species dominates one of the communities of the littoral salt marsh vegetation of the Red Sea coast, e.g. at Rabigh.

Freshly collected caryopses of *A. massauensis* were germinated over a range of fluctuating temperature regimes and also in varying salinity levels at two fluctuating temperature regimes. The responses of the caryopses to these environmental variables were compared with those obtained previously by the author and co-workers for *Halopeplis perfoliata* and *Limonium axillare*, which inhabit Rabigh salt marsh.

The caryopses of *A. massauensis* germinated rapidly to high percentages over the whole temperature range. The salt tolerance of the species was considerably lower than the salt content in the soil samples (0-5 cm depth) within its habitats. The inhibition of the germination of the caryopses of *A. massauensis* by excessive salinities (80 and 100 per cent seawater) is due to high osmotic potential of the medium.

The ecological significance of the responses of the caryopses of *A. massauensis* to these various environmental variables is discussed.

Aeluropus massauensis (Fres.) Mattei (= *A. brevifolius* Ness ex Steud., *A. mucronatus* Asch., *A. arabicus* Steud., partly) is a perennial grass. The distribution of this halophyte in Saudi Arabia includes north Hijaz (NH), Najd (NJ), South Hijaz (SH) and the southern region (S) (Fig. 1); Migahid 1978. Establishment of a species within a geographical region is dependent on closely adapted responses to temperature, day length and rainfall. Thompson (1970) showed that the geobotanical distribution of different species of Caryophyllaceae in Europe is reflected in their germination temperature responses. Experiments were therefore conducted to investigate the germination temperature responses of the caryopses of *A. massauensis*.

Numerous halophytic plant communities are associated with the Red Sea coast of Saudi Arabia. The littoral salt marsh vegetation is characterized by its zoned pattern and comprises distinct units, especially in areas that are little subjected to human interference. *Halopeplis perfoliata, A. massauensis* and *Limonium axillare*, and *Zygophyllum coccineum* are among the most important components of this vegetation. Mahmoud *et al.* (1982) studied the salt marsh vegetation at Rabigh

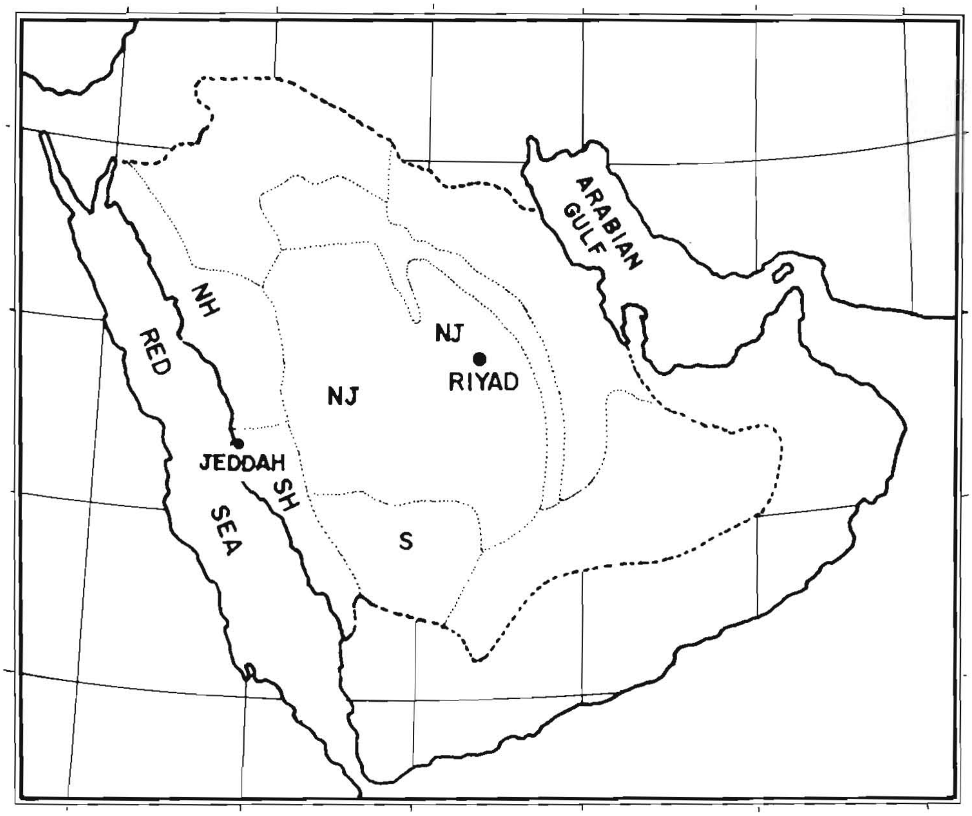

Fig. 1. Geographical distribution of *Aeluropus massauensis* in Saudi Arabia.

NH = North Hijaz representing the western part of Saudi Arabia that extends alongside the Red Sea coast north of Jeddah.

SH = South Hijaz representing the southern part of the western region extending south of Jeddah to Yemen boundaries.

NJ = Najd

S = Southern region, lying to the east of south hijaz, to the south of Najd to and the north of Yemen. It includes Abha, Bisha and Nagran areas (Redrawn with permission from Migahid's *Flora of Saudi Arabia*, 2nd ed. 1979)

(150 Km north of Jeddah). Here, the *H. perfoliata* zone is nearest to the shore line (Fig. 2) and the water table is shallow (40-50 cm) and keeps the coarse sandy soil continuously moist, but not water-logged. Because of this and the high evaporation rates, the habitat is characterized by excessive salts particularly at the surface of the soil (0-5 cm depth; Table 1). This shore line zone is bordered landwards by mud flats. In these mud flats, where the fine-textured soil contains comparatively high percentages of silt clay and fine sand, *L. axillare* and *A. massauensis*, the dominant grass, form an open community. The saline water table is lower (70-80 cm) than in the previous zone, yet the habitat is still under its influence as salts accumulate in upper layers of the soil profile because of high evaporation rates (Table 1). However, because of its proximity to dry land, the habitat of *A. massauensis* and *L. axillare* is subject to flushing by rain water carried by *wadis* draining the neighbouring Hijaz mountains. On account of leaching of the upper soil layers during the rainy season, and the fact that the saline water table is deeper than in the habitat of *H. perfoliata*, a salinity gradient develops within these two zones (Table 1). In inland saline habitats, *e.g.* Al-Shigga salt marsh, near Unayza in Najd, the halophytic vegetation is also zoned and *A. massauensis* occupies, with *Suaeda pruinosa* and *Seidlitzia rosmarinus*, the comparatively wettest and most saline part of the marsh. Control of germination by high salinities constitutes a major factor in the zonation of plant growth in saline habitats (Toole *et al.* 1956, Kassas and Zahran 1967). Mahmoud *et al.* (1983) tested this hypothesis in the case of *H. perfoliata* and *L. axillare* in Rabigh salt marsh.

The work reported in this paper is a close sequel to this. The caryopses of *A. massauensis* were germinated in various concentrations of seawater at two fluctuating temperature regimes. The responses of *A. massauensis* to these environmental variables were compared with those previously obtained for *H. perfoliata* and *L. axillare* (Mahmoud *et al.* 1983) and discussed in relation to the field ecology of the species.

Experiment 1

Methods

Freshly collected caryopses were cleaned; this allowed the selection of fully developed caryopses for the tests; the caryopses were sorted out to reject those that were broken or insect-damaged; there was no discrimination between large and small caryopses.

The caryopses were germinated over the range of 12 hourly alternating temperature regimes: 20/7, 23/8, 27/12, 32/16, 36/21, 42/23°C. These were selected from meteorological data at Unayza station within the habitat range of the species. The caryopses were germinated in germination flasks in dark incubators maintained at the appropriate temperature regimes. Four replicates (25 caryopses each) were

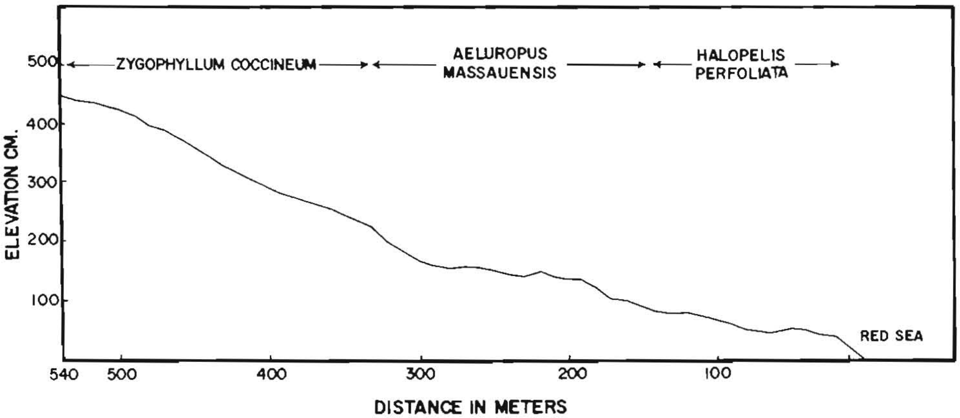

Fig. 2. A transect across the salt marsh at Rabigh showing the different zones of vegetation in relation to ground level. (Mahmoud *et al.* 1982).

Table 1. Total water soluble salts in soil samples (0-5 cm depth) collected within the habitats of *Halopeplis perfoliata*, *Aeluropus massauensis* and *Limonium axillare* at Rabigh salt marsh towards the end of dry season, 20 November, 1981 (Mahmoud *et al.* 1983).

species	Habitat	Soil sample no.	Total water soluble salts ppm
Halopeplis perfoliata	Shore line	1 2 3	112,000 128,000 134,400
	Shallow creek	4 5	102,400 89,600
Aeluropus massauensis and *Limonium axillare*	Mud flat	1 2	22,400 35,200 24,000 52,160 28,800

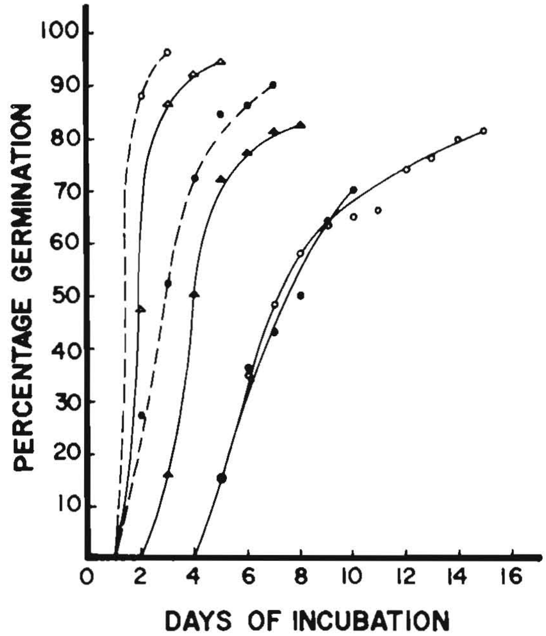

Fig. 3. Progress of germination of caryopses of *Aeluropus massauensis* at different fluctuating temperature regimes: 20/7°C ●—●; 23/8°C ○—○; 27/12°C ▲—▲; 32/16°C ●----●; 36/21°C ○----○; 42/23°C △—△.

Table 2. Germination percentages attained by the caryopses of *Aeluropus massauensis* germinated at different fluctuating temperatures and also the periods of incubation (days) needed by the maximum germinated caryopses to attain 50% germination. Ninety-five per cent confidence limits are included.

Temperature °C	**% germination**	**Time for 50% germination (days)′**
20/7	70 ± 3.182	6.350 ± 0.484
23/8	81 ± 2.756	6.550 ± 0.601
27/12	82 ± 3.182	3.725 ± 0.221
32/16	90 ± 3.182	2.700 ± 0.195
36/21	96 ± 2.250	1.425 ± 0.069
40/23	94 ± 3.182	1.975 ± 0.068

used. A caryopsis was considered to have germinated when the radicle emerged. Germinated caryopses were discarded immediately and counts were made daily until no caryopsis had germinated for seven successive days.

In counting the lid of the germinator was removed, allowing the change of air and briefly exposing the caryopses to light.

Results

The freshly collected caryopses showed no dormancy and germinated rapidly to high percentages over the whole range of the alternating temperature regimes, though they showed high temperature preference (Fig. 3, Table 2).

Experiment 2

Methods

The caryopses of *A. massauensis* were germinated over the following salt concentrations obtained by diluting Red Sea water collected at Rabigh: 2305.5 ppm (= 5% sea-water), 4611 (10%), 9222.5 (20%), 18445 (40%), 36890 (80%) and 46112 (100%). Germination took place in germination flasks in dark incubators maintained at two alternating (12 hourly) temperature regimes: 32/16 and 36/21°C. The selection of these temperature regimes was based on the germination temper-

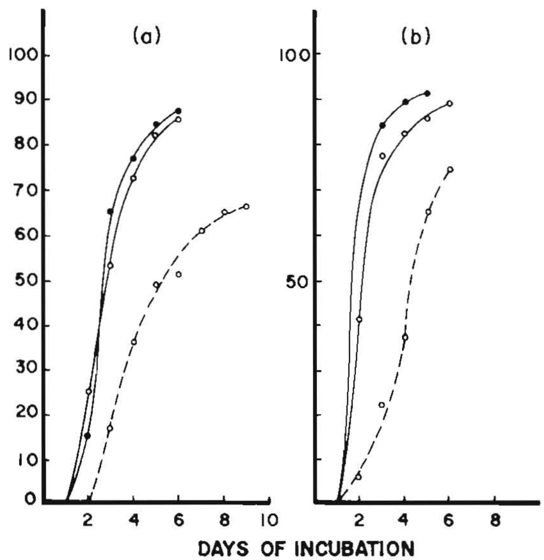

Fig. 4. Course of germination of caryopses of *Aeluropus massauensis* in different salinities; 2305.5 ppm ●—●; 4611 ppm ○—○; 9222.5 ppm ○----○. All at two fluctuating temperature regimes (32/16 and 36/21°C).

ature responses of the caryopses in distilled water (Experiment 1). The two regimes represent upper and lower limits of the optimal temperature range for germination of the species. The procedure then adopted was similar to that in Experiment 1.

Results

At both temperature regimes, the seeds germinated in 5, 10% seawater and in distilled water and attained comparable high germination percentages, though germination was slightly faster at 36/21°C than at 32/16°C (Fig. 4, Table 3). However, at both temperature regimes, germination decreased when the salinity reached 20% seawater and no germination was observed in 40% salt concentration.

Experiment 3

Methods

The caryopses of *A. massauensis* which did not germinate in excessive salinities (80 and 100% seawater) after 15 days, at 32/16 and 36/21°C, (Experiment 2), were thoroughly washed from salt by distilled water and were then germinated at the same temperature regimes in distilled water. The procedure then adopted was similar to that in Experiment 1.

Results

At both temperature regimes, the caryopses that did not germinate in 80 and 100% seawater germinated rapidly to high percentages after being transferred to distilled water (Fig. 5 and Table 4).

Discussion

The freshly harvested caryopses of *A. massauensis* exhibited no dormancy and germinated rapidly to high percentages under favourable conditions, (Table 2, Experiment 1). As in *H. perfoliata* and *L. axillare* (Mahmoud *et al.* 1983), the germination of *A. massauensis* over a wide range of fluctuating temperature regimes (Table 2), which represent the temperature cycles that prevail during the months of the rainy season as well as those of the dry season (Fig. 6), indicates that moisture and salinity control germination. Because the caryopses of *A. massauensis* are small in size, their successful natural germination and seedlings emergence may occur only in the upper soil surface, which generally contains the highest salt concentrations. In the natural habitat of *A. massauensis*, e.g. at Rabigh salt marsh, salt concentrations in the soil surface (0-5 cm depth; Table 1) are far beyond the concentrations tolerated by the caryopses (Table 3). This limited salt tolerance of *A. massauensis* is similar to that of the seeds of *H. perfoliata* and *L. axillare* (Mahmoud *et al.* 1983) and limits its germination to the rainy season; and,

Table 3. Germination percentages attained by the caryopses of *Aeluropus massauensis* germinated at two fluctuating temperature regimes in different salinities; the periods in days required by the maximum germinated caryopses to reach 50% germination as well as 95% confidence limits are also included.

	Distilled water		**2305.5 ppm (5% seawater)**		**4611 ppm (10%)**		**9222.5 ppm (20%)**	
Temperature °C	**% germination**	**Time for 50% germination (days)**	**% germination**	**Time for 50% germination (days)**	**% germination**	**Time for 50% germination (days)**	**% germination**	**Time for 50% germination (days)**
32/16°C	90 ± 3.182	2.700 ± 0.195	87 ± 2.756	2.550 ± 0.178	85 ± 3.468	2.700 ± 0.276	66 ± 5.511	4.075 ± 0.279
36/21°	96 ± 2.250	1.425 ± 0.069	91 ± 2.756	1.750 ± 0.367	89 ± 3.277	2.125 ± 0.068	74 ± 10.554	4.000 ± 0.112

therefore, successful germination of its caryopses, as in the case of the seeds of *H. perfoliata*, and *L. axillare* and others reported by Chapman (1960) and Waisel (1972), is not possible in their natural habitats without marked dilution of salts during the rainy season. Because of the unreliable rainfall within the habitat range of *A. massauensis* (Table 5), the appropriate combinations of environmental con-

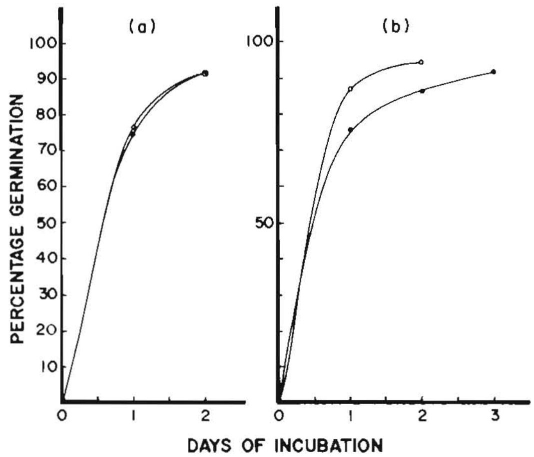

Fig. 5. Progress of the germination of the caryopses of *Aeluropus massauensis* which were preincubated for 15 days at (a) 32/16°C and (b) 36/21°C in 80% seawater (36890 ppm) ●—● and 100% seawater (46112 ppm) O—O and then germinated at the same temperatures in distilled water, after they were thoroughly washed from salt by distilled water.

Table 4. Germination percentages of the caryopses of *Aeluropus massauensis* which were preincubated for 15 days at 32-16°C and 36-21°C in different salinities and then germinated at the same temperatures in distilled water; the periods in days required by the maximum germinated caryopses to reach 50% germination as well as the 95% confidence limits are included.

Temperature °C	36890 ppm (80% seawater) then in distilled water		46112 ppm (100% seawater) then in distilled water	
	% germination	Time for 50% germination (days)	% germination	Time for 50% germination (days)
32/16	91 ± 14.494	0.462 ± 0.045	91 ± 8.267	0.450 ± 0.138
36/21	91 ± 6.316	0.462 ± 0.034	94 ± 3.183	0.438 ± 0.034

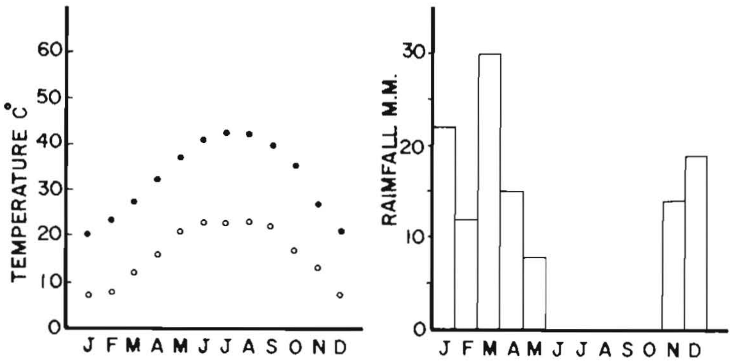

Fig. 6. Meteorological data obtained at Unayza station; (a) the mean daily temperature maxima (●) and minima (○); (b) monthly rainfall. (Data are averages of 9 years records).

Table 5. Monthly and annual rainfall records (mm) at Rabigh meteorological station for the period 1970-82.

Station	Year	J	F	M	A	M	J	J	A	S	O	N	D	Total
Rabigh	1970	12.5	0	0	0	0	0	0	0	0	0	0	0	12.5
	1971	0	0	0	0	0	0	0	0	0	0	30.0	0	30.0
	1972	0	0	0	2.0	0	0	0	0	0	0	4.0	4.0	10.0
	1973	7.0	0	0	0	0	0	0	0	0	0	3.0	8.0	18.0
	1974	3.0	0	8.0	0	0	0	0	0	0	0	10.0	3.0	24.0
	1975	8.0	0	0	13.7	0	0	0	0	0	0	0	5.0	26.7
	1976	0	0	2.0	0	0	0	0	0	0	0	0	0	2.0
	1977	4.0	0	0	0	0	0	0	0	0	0	0	4.0	8.0
	1978	6.2	6.0	0	0	0	0	0	0	0	2.0	0	4.0	18.2
	1979	15.5	0	0	0	0	0	0	0	0	10.0	0	0	25.5
	1980	0	0	0	0	0	0	0	0	0	0	0	0	0.0
	1981	0	0	0	0	0	0	0	0	0	0	0	0	0.0
	1982	20.0	3.0	0	0	10.0	0	0	0	0	0	0	0	33.0

ditions for successful germination do not frequently occur; it is only during a season of good rains does any substantial seed germination take place. Germination is thus tied to a good rainy season and, hence, increases the chances for subsequent seedlings survival, growth and establishment and contributes to the long-term survival of the species in its arid environment.

Natural reproduction of *A. massauensis* is mostly accomplished by vegetative propagation. In the mud flats in Rabigh salt marsh, the community of *A. massauen-*

sis is open, and the widely spaced individuals of this perennial grass (Plate 1) form cone-like tussocks (Plate 2) of interwoven roots, rhizomes and soil, from which aerial shoots creep on the soil surface. From these, new vegetative individuals are produced; these become notably numerous, and plant growth assumes a diffuse pattern, where aeolian deposits overly the original mud flats and form hummocks around the parent plant (Plate 3). Furthermore, this raised ground of fine soil deposits, unlike the comparatively low mud flats, will be less subjected to leaching by drainage water brought into the marsh via *wadis*; the salt concentrations in these deposits are therefore excessively high (Table 6). Unless effective dilution of salts takes place, vegetative propagation will remain the principal method of natural reproduction in these fine deposits.

Germination of *A. massauensis* (Table 2, Experiment 1), *L. axillare* and *H. perfoliata* (Mahmoud *et al.* 1983) over a wide range of temperature regimes indicates that ecological factors other than the critical germination temperature requirements have greater control over their zonal distribution in Rabigh salt marsh (Fig. 2), and to the restriction of *H. perfoliata* to the continuously moist, saline lands of the Red Sea coast north and south of Hijaz, and to the extended distribution of the other two species into arid inland saline habitats. Table 1 indicates that

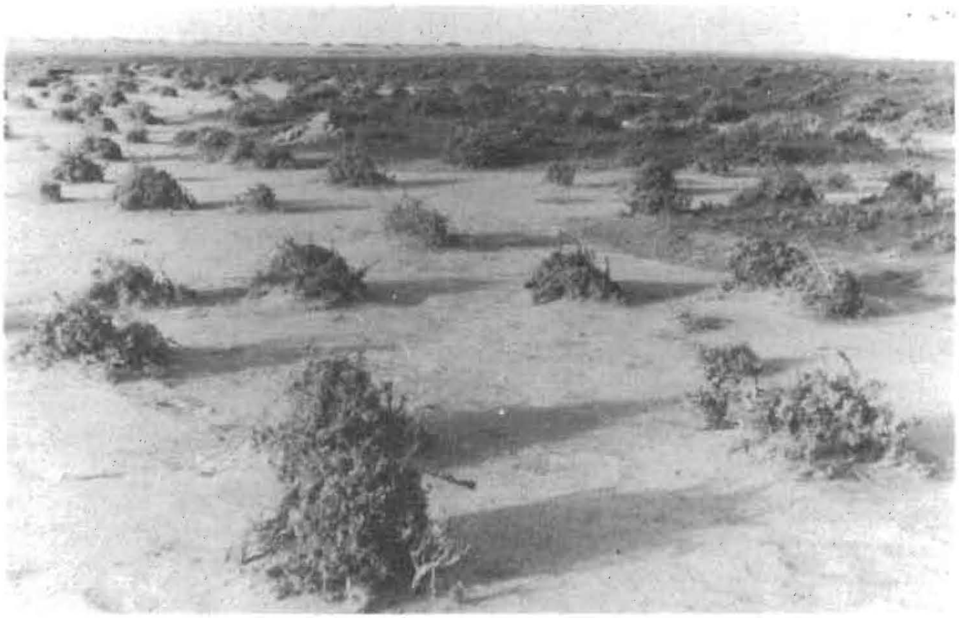

Plate 1. *Aeluropus massauensis* community type on the mud flats (foreground) of Rabigh salt marsh; observe the widely spaced conelike tussocks of the dominant perennial grass and the individuals of the herbaceous woody associated species – *Limonium axillare*.

Plate 2. A close-up photograph of *Aeluropus massauensis* forming a cone-like tussock of interwoven roots, rhizomes and soil. Observe the long hanging pendulous shoots.

Table 6. Total water soluble salts in soil samples collected, in May 1983, from hummocks (around *A. massauensis*) of fine soil deposits overlying the original mud flats.

Habitat	Profile no.	Depth cm	Total water soluble ppm
Hummocks of fine soil deposits (around *A. massauensis* plants)	1	0- 5 5-25	249,600 153,600
overlying the original mud flat	2	0- 5 5-25	249,600 192,00

the soil in the habitat of *H. perfoliata* is more saline than that (mud flats) of *A. massauensis* and *L. axillare*. A comparison of the salt tolerance of *H. perfoliata* and *L. axillare* (Mahmoud *et al.* 1983) with that of *A. massauensis* (Table 3, Experiment 2) indicates that the former species has more salt tolerance than each of the other two species; *A. massauensis* and *L. axillare* have comparable salt tolerance and occupy in Rabigh salt marsh the drier zone which borders, landward, the zone of *H. perfoliata* (Fig. 2, Plate 4).

Plate 3. *Aeluropus massauensis* on soft aeolian soil deposits overlying the original mud flats (hind-ground). Observe the diffuse growth of *A. massauensis* and the original cone-like tussocks from which rhizomes and creeping shoots produce new vegetative shoots. In the foreground the widely spaced individuals of *Aeluropus massauensis* and *Limonium axillare* grow on the lowlying mud flats.

A saline habitat can inhibit germination in two ways: (a) by poisoning the embryo due to toxic effects of certain ions (Uhvits 1946), or (b) by preventing uptake of water due to high osmotic potential of the medium (Ayers and Hayward 1948, Ayers 1952, Ungar 1962, Boorman 1968, Macke and Ungar 1971, Mahmoud *et al.* 1983). Evidence from Experiment 3 indicates that the inhibition of germination of caryopses of *A. massauensis* is due to high osmotic potential of the medium.

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Plate 4. *Halopeplis perfoliata* community type on a bar of sand heaped by tidal and low wave action. Observe the low sand bar separating the free water from the plant growth.

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إنبات حبوب نبات الأقرش الملحي (*Aeluropus massauensis*) من المملكة العربية السعودية

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نبات الأقرش من الحشائش الملحية، وينتشر في شمال وجنوب الحجاز وكذا في نجد وفي الجزء الجنوبي من المملكة العربية السعودية. ويعتبر هذا النبات من ضمن المكونات الأساسية للكساء النباتي في ملاحات شاطيء البحر الأحمر السعودى، ففي ملاحة شاطيء رابغ (١٥٠ كيلومتراً شمال مدينة جدة) ينتظم الكساء النباتي في مناطق محددة فتنمو نباتات *Halopeplis perfoliata* في شريط قريب من الماء على الرمال الخشنة دائمة الرطوبة والتي قذفتها أمواج البحر، بينما تنمو نباتات *Aeluropus massauensis* و *Limonium axillare* في المنطقة التي تليها في اتجاه اليابسة والأكثر جفافا؛ ملوحة التربة في منطقة *H. perfoliata* أعلى بكثير من تلك التي في منطقة النباتين الآخرين.

لقد تمت دراسة تأثير أنظمة مختلفة من درجات الحرارة المتبادلة (**٢٠/٧، ٢٣/٨، ٢٧/١٢، ٣٢/١٦، ٣٦/٢١، ٤٢/٢٣**°م) على إنبات حبوب نبات *A. massauensis* وكذلك تأثير تركيزات مختلفة من ماء البحر

(٥، ١٠، ١٥، ٢٠، ٤٠، ٨٠، ١٠٠٪) (= ٢٣٠٥,٥ ، ٤٦١١، ٩٢٢٢,٥، ١٨٤٤٥، ٣٦٨٩٠، ٤٦١١٢ جزءاً في المليـون على التـوالي) على الإنبات تحت نظامين حراريين (١٦/٣٢، ٢١/٣٦°م). لقـد تمت مقـارنة استجابة حبوب *A. massauensis* للمتغـيرات البيئيـة المختلفة التي تم اختبارها مع تلك التي تحصّل عليها الباحث ومعاونوه في دراسة سابقة مماثلة بالنسبة لنباتي *H. perfoliata* و *L. axillare* .

اتضح أن حبوب *A. massauensis* وكذلك بذور النباتين الآخـرين تتـماثل في استجابتها لدرجة الحراره إذ إنها تنبت في مدى حرارى واسع .

اتضـح أن قدرة تحمـل حبـوب *A. massauensis* وبذور كل من النبـاتـين الآخـرين للملوحـة ، أقـل بكثـير من تركيز الأملاح في بيئاتها الطبيعية، ولذلك لا تتم عملية الإنبات في الطبيعـة إلا في المـوسم المطـير حيث تخفف ميـاه الأمطـار من تركيز الأملاح عند سطح التر بة .

تتحمل حبوب *A. massauensis* وبذور *L. axillare* درجة ملوحه متماثلة ولكنها تقل كثيرا عن درجة تحمل بذور نبات *H. perfoliata* الـذى يعمـر في ملاحـة رابـغ منطقة ملوحتها أعلى بكثير من منطقة النباتين الآخرين .

لقـد تمت منـاقشـة هذه النتـائج وأ هميتها بالنسبة لهذه النباتات في بيئاتها الطبيعية .