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Authors: Benfekih, L., Chara, B., and Doumandji-Mitiche, B.

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Influence of anthropogenic impact on the habitats and swarming risks of *Dociostaurus maroccanus* and *Locusta migratoria* (Orthoptera, Acrididae) in the Algerian Sahara and the semiarid zone

L. Benfekih, B.Chara and B. Doumandji-Mitiche

(LB) Laboratoire de Zoologie, Département dé Agronomie, Faculté Agrovétérinaire et Biologique Université de Blida, BP 270, Algérie. E-mail: acirdo@yahoo.fr (BC) Département de Prospection et de Lutte Antiacridienne, Institut National de la Protection de Végétaux, El Harrach, Alger, Algérie. (BDM) Laboratoire d'Entomologie, Département de Zoologie Agricole et Forestière, Institut National Agronomique , El Harrach, Alger, Algérie.

Abstract

Shistocerca gregaria, *Dociostaurus maroccanus* and *Locusta migratoria* remain the most fearsome orthopteran pests in Algeria. While multiple efforts are engaged in the forecasting and control of *S. gregaria*, Moroccan and migratory locusts draw less attention. Survey and antilocust control teams have indicated infestations of *D. maroccanus* in the western and eastern highlands and of *L. migratoria* in the Central Sahara. Field investigations reported here show that the initial swarming of both locusts may occur as a consequence of human agricultural practices that make them more successful in their new habitats: increasing locust densities are correlated with human-induced changes in vegetation structure. In this paper anthropogenic impact on locust population density is analyzed using various data methods.

Key words

Moroccan locust, migratory locust, anthropogenic, habitats, Sahara, outbreak

Introduction

Besides the desert locust, two other major acridid pests, *Dociostaurus maroccanus* (Thunberg) and *Locusta migratoria* (L.), are liable to inflict important damage on crops, pastures and forestry resources in Algeria. The Moroccan locust ranges from the Madeira and Canary islands in the west, through the Mediterranean zone (Spain: del Canizo 1950, Cyprus: Dempster 1957) to Afghanistan and south Kazakhstan in the east (Latchininsky & Launois-Luong 1992). In Algeria, swarms of this locust set off from seven gregarization areas, distributed in the highlands in the northern part of the country (Pasquier 1937). The newest outbreak of this acridid started in 1999 and continues in the western zones, where more than 21,000 ha were treated (Anonymous 2000).

As for the migratory locust, Chopard (1945) indicated this species from both the coastal and oasis zones, and also mentioned that Saharan biotic and abiotic factors are unsuitable for *L. migratoria* to change totally into the economically important gregarious phase from the solitarious one. However, human activity during the last 20 y in the Central Sahara, especially the introduction of irrigated crops under pivoting sprayers, has favored the multiplication of this locust.

In this paper, we evaluate the effect of human alteration of habitats on the swarming behavior of both locust species in two environmental types, geographically distant and ecologically different: the Algerian Sahara and the semiarid zone.

Material and Methods

Site selection.— Studies of *D. maroccanus*' populations were carried out in the semiarid highlands between lat 36°N, long 6°W and lat 36°N, long 0°W (Fig. 1). Elevation of this breeding area ranges from 1000 m in the west to more than 1400 m centrally. Climatically, the area is classified as a semiarid zone with two distinct winters (Emberger 1971): a severe winter in the eastern highlands and centrally, which is significantly colder than the temperate one in the western highlands. Annual precipitation is from 200 to 600 mm. Alongside some plants resistant to cold, such as *Pistachia terebrunthus*, *Ononis atlantica* and *Genista myriantha*, is a diversified and close-cropped vegetation which develops on compact and clayey soils after a winter or a spring rainfall. This environment type is characterized by short and overgrazed pastures dominated by *Stipa tenacissima*, *Artemisia herba alba* and *Ampelodesma mauritanica* in isolated communities.

From 1991 to 1992, we investigated two sites situated in the cold semiarid area, in Aïn Boucif region, southeast of Medea (Fig.1). The first site (El Benia, S1) is an ancient and very open fallow overgrazed by sheep. The vegetation is dominated by herbaceous plants such as *Poa bulbosa* and *Artemisia herba alba*. The second site (Aïn Sefra, S2) is also an ancient fallow, where the height and the density of the vegetation is more diverse, with a dominance of *Dactylis glomerata*, *Genista tricuspidata* and essentially *Asteraceae* species. This second site was more moderately disturbed: overgrazing was not so intense and sometimes absent. During 1999-2001 additional investigations were accomplished in many eastern and western regions of the country (Fig.1) situated in the permanent breeding areas of the Moroccan locust. Most of these zones were remote locations where there was no human disturbance and no grazing by sheep. The plant cover was very closely cropped, punctuated by large bands of bare soil.

The migratory locust was studied in the Central Sahara desert between lat 27°05'N, long 0°08'W and lat 28°15'N, 0°10'W, at altitudes between 150 m and 300 m (Fig. 2). The climate is typically Saharan, with annual precipitation <100 mm (from the Ghardaïa region to the extreme south of Algeria, Fig.1) (Emberger 1971, Ozenda 1977). Temperatures are elevated from June (33.5°C) till September (31.0°C) [(max.+ min.)/2]. The natural vegetation is rare or absent and ephemeral, but there are perennial plants: *Acacia radiana*, *Tamarix*, *Calligonum* and *Rhus tripartitum*. In Saharan environments, the presence of *L. migratoria* is limited to oases; this led us to expect its establishment in the irrigated perimeters created by human agriculture. *L. migratoria* populations were studied from 1995 to 1997 in 9 sites (Fig. 2, Table 1), distributed along a transect of 150 km through the Adrar region of the Central Sahara, including areas of cereal fields irrigated by pivoting sprayers.

Study of anthropogenic influence on the activity of both locusts.— Human pressure on the swarming levels of the two locust species was assessed by examining the floristic composition of locust habitats, the human activity level in these habitats and by making locust density measurements, the latter taken during the period of maximum activity of the insects: June for *D. maroccanus* and April for *L. migratoria*.

Locust sampling and density measurements.— Sampling of *D. maroccanus* specimens was conducted between 0800 and 1000 in a 1-ha randomly selected area divided into 10 quadrats of 3 X 3 m (Voisin 1986). Sampling of *L. migratoria* was carried out late in the afternoon along a 100-m transect. The *L. migratoria* hoppers and adults which flew away or remained in the vegetation, were counted in a 1-m wide band. Population density was calculated following Duranton *et al.* (1982): larval density ha^{-1} = (number of observed larvae / number of repetitions) x 10,000; adult density ha^{-1}= (number of observed adults / sampled surface) x 10,000.

Floristic sampling, global vegetation cover and cover rate of weeds.—At each study site, the floristic composition was determined by visual survey of a randomly placed quadrat of 500 m^2. Plant species were censused within this quadrat, with reference to the flora proposed by Quezel & Santa (1962). (Weeds are all non-crop plants: adventitous, including grasses.) A biocenometer of 50 cm per side was thrown ten times in a 1-ha randomly selected area to estimate the different plant cover rates. For each plant, the cover was estimated by calculating the surface area occupied by the orthogonal projection of the aerial part of the considered plant/weed species, across the global area surface, according to Duranton *et al.* (1982). The total cover rate is the sum of the different rates of each weed species in the study sites. The vegetation structure and physiognomy were studied in April in the southern *Locusta* sites and in May in the (northern) *Dociostaurus* sites.

Data analysis.—The relationship between anthropogenic impact and locust population level was estimated in the following three ways:

1) By determination of the influence of overgrazing on the density changes in the Moroccan locust.

Grazing impact at the two sites (S1, S2) was assessed during each of our trips to the locales, as the frequency of passage of flocks of sheep and goats. Our observations of the Maroccan locust were obtained between March and September, indications of adults being numerous in the month of June. We undertook two trips per week to each station between 10:00 and 15:00 h.

We calculated Morisita's index (Southwood 1978), as a measure of dispersion of individuals inside the plots at each study site, according to the following formula:

$$I_s = N \sum_{i=1}^{i=n} \frac{n_i\,(n_{i-1})}{x\,(x-1)}$$

Where N= total number of squares per quadrat.

n_i= number of the individuals in the *i* (th) quadrat.

x= sum of all the individuals inside the quadrat.

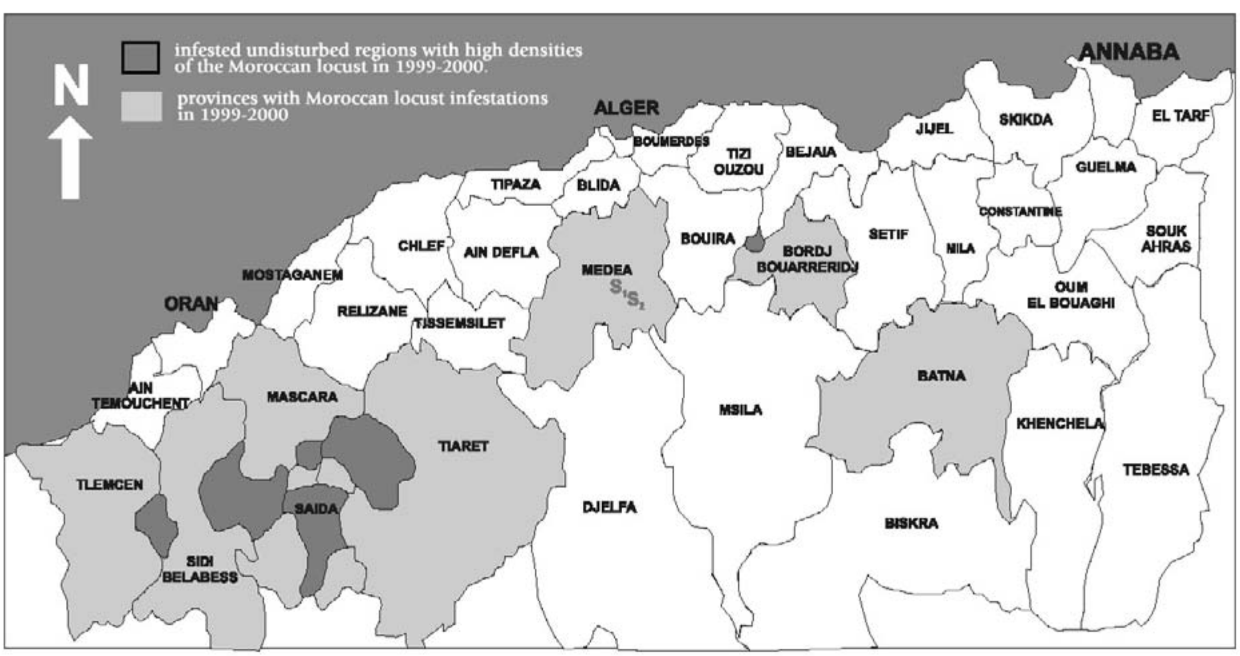
I_s= Morisita's index.

The distribution of the individuals is regular if $I_s<1$, random if $I_s=1$ and clumped if $I_s>1$.

2) By establishment of a correlation matrix between the *L. migratoria* population densities and the weed cover rates.

3) By using the Mc Nemar test (χ^2) to make 36 cross-comparisons of the vegetation cover and the densities between the two sites. The Mc Nemar test is a significance test for two dependent samples, used when two groups being compared are paired (Cohen 1988).

Fig. 1. Location of the Moroccan Locust infested areas in the central, western and eastern highlands; S_1, S_2: study sites of the Moroccan Locust southeast of Medea, affected by grazing.



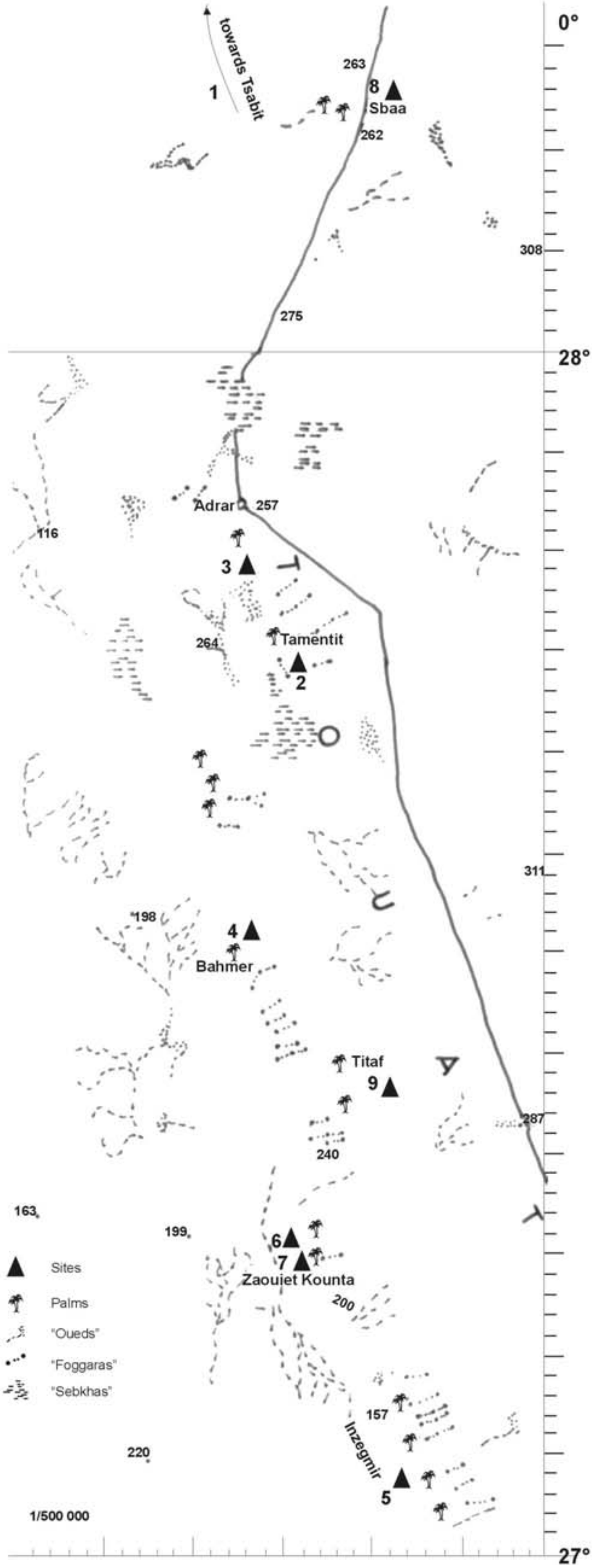


Fig.2. Locations of the *L. migratoria* study sites in the Touat region (Adrar, Central Sahara).

Results

Moroccan locust

Floristic composition.— The vegetation in the two sites (S1 and S2) consisted of 62 and 64 plant species respectively, belonging to 62 families overall. The commonest species are *Poaceae* (11 to 14 species) occupying 30 to 40% of the ground cover and represented by *Poa bulbosa* and *Dactylis glomerata*; also common are the *Asteraceae*, *Fabaceae* and *Lamiaceae* (Doumandji-Mitiche *et al*. 1993, Benfekih & Doumandji-Mitiche 1996). The floristic richness at site 2 is greater. We found in particular 6 *Asteraceae* species of which *Sonchus oleraceus*, *Crepis vesicaria* and *Scolymus hispanicus* were very abundant. Twenty six other species of 19 different families form continuous plant groups of approximately 15 to 20 cm height. By themselves these plants occupy 30% of the vegetation cover at site 2. The eastern and western Moroccan locust sites are situated in degraded areas near croplands. They are composed of a similar mosaic vegetation, dominated also by *Poa bulbosa*.

Population density.—Table 2 shows the adult densities of the Moroccan locust in June 1992 in the study sites southeast of Medea. At the El Bénia site (S1), adult numbers per hectare were 3 times greater than those at Aïn Sefra. Even though the floristic composition of the two sites is very similar, site 1 presents a dried and overgrazed vegetation cover as a result of the frequent passage of sheep. On each of our trips the passings of flocks of sheep were more frequent at S1 (El Bénia) than at S2 (Aïn sefra): of 8 trips in June, 7 flocks at S1 but only 4 at S2. The number of grazing animals was estimated as about 70 at S1 and several dozen at S2.

The different plant groups at site 1 are often interrupted by rocks and the proportion of bare soil is 45%. Site 2 is more steeply sloped, and so less accessible to sheep than site 1; it shows a denser, more or less continuous, vegetation cover of 74.5% (Table 2). Plants are taller at site 2 and the proportion of bare soil is only 25%. The Morisita index indicates a clumped locust distribution at site 1, where gravid females gather in bare spots to lay their eggs. Adult insect density and plant cover differed significantly ($p = 0.05$) between the two sites (χ^2= insect densities = 794.34; χ^2, plant cover = 36.83). On the other hand, table 3 data indicate that *D. maroccanus* has proliferated during the two last campaigns (1999 and 2000) in the eastern and western highlands of Algeria, particularly in Sidi Bel Abbes and Saïda regions (Fig.1). Swarming levels of the Moroccan locust exceeded 100 young hoppers m^{-2} and 15 to 25 adults m^{-2} in more than 20,000 ha at Sidi Bel Abbes and more than 15,000 ha at Saïda were infested by the Moroccan locust between April and June 2000 (Anonymous 2000). Most of these zones are degraded terrains, forest edges and barren desert or ungrazed fallow. In the croplands zone, the locusts inflicted severe damage, notably to barley and soft wheat.

Migratory locust

Floristic composition.—The 9 *Locusta* sites are all irrigated areas bordering on monospecific introduced cereal crops. The annual flora consists of various plant families: the most represented are the *Fabaceae*, *Asteraceae*, *Cucurbitaceae*, *Liliacea*e, *Cruciferaceae*, *Ombelliferaceae*, *Plantaginaceae* and Solanaceae. Others, *Asclepiadaceae* (*Pergularia tomentosa*), *Cyperaceae* (*Cyperus rotundus*), *Polygonaceae* (*Silene setacea*, *Emex spinosa*), *Caryophyllaceae* (*Vacaria pyramidata*), *Euphorbiaceae* (*Euphorbia dracunculoïdes*), *Boraginaceae* (*Lithospermum*

Table 1. Characteristics of study sites of *L. migratoria* in the Touat region (Central Sahara).

Site	Common name	Location (latitude, longitude)	Vegetation type	Dominant crop	Area (ha)
1	Tsabit	28°18′N, 0°12′W north of Adrar.	cereals under palms	*Triticum durum*	5
2	Tamentit	27°45′N, 0°15′W 264m, east of Adrar.	oasis	*Phoenix dactylifera*	5
3	Adrar	27°49′N, 0°18′W 257m, 8km south of Adrar.	crops under palms	*Hordeum vulgare*	3
4	Bahmer	27°30′N, 0°17′W 250m, south of Adrar.	irrigated cereals under pivots	*Triticum durum*	20
5	In Zegmir	27°04′N, 0°08′W 199m, 80km SE of Adrar.	irrigated cereals under pivots	*Triticum durum*	50
6	Zaouiet Kounta	27°15′N, 0°13′W 199m, 70km SE of Adrar.	irrigated cereals under pivots	*Triticum durum*	40
7	Zaouiet Kounta	27°15′N, 0°12′W 199m, 70km SE of Adrar.	irrigated cereals under pivots	*Triticum durum*	50
8	Sbaa	28°13′N, 0°09′W 230m, NE of Adrar.	irrigated cereals under pivots	*Triticum durum*	40
9	Titaf	27°24′N, 0°10′W 250m, SE of Adrar.	irrigated cereals under pivots	*Triticum durum*	20

Table 2. Observations of the Moroccan locust in June 1992 in study sites southeast of Medea.

Sites	Vegetation cover %	Density/ha	Grazing	Bare soil %	Morisita index
S1	55.99	2.720	severe	45%	1.07
S2	74.50	1.000	moderate	25%	0.95

Table 3. Observations of the Moroccan locust in 1999-2000 in western and eastern regions of Algeria.

Region	Infested area (ha)		Density (m^{-2})		Site
	1999	2000	1999	2000	
S.B.Abbes	10, 000	20, 108	40-60	80-100	degraded, fallow
Tiaret	600	19, 550	15-20	60-70	fallows, cereals
Saïda	13, 000	15, 625	50-70	80-100	fallows, forest edges
Tlemcen	.	950	.	5-10	fallow
Mascara	.	1. 705	.	10-20	degraded, fallow
B.B.Arreridj	3, 500	2, 350	30-40	50	fallow

appulum) and *Plombaginaceae* (*Limonium thouini ssp blondueli*) are less important. Sites 1 and 3 are crops under palms: essentially *Triticum durum*, *Allium cepae*, *Daucus carota*, *Lactuca sativa* and *Vicia fabae*. Site 2 is an ancient oasis. Sites 4 to 9 are cereals irrigated by pivoting sprayers. Sites 5, 6 and 7 are the most grassy, with a weed proportion varying from 16% to 26%: 10 to 20% are adventitious grasses. The oasis S2 is a natural habitat with only 6% weeds (Table 4).

Population density.— In the very different conditions of the arid zone and the Central Sahara desert, the presence of *L. migratoria* in the 9 study sites appeared to be important in those areas where there is weed cover, especially when one of the adventitious grasses was abundant (Table 4, Figs 3,4). Thus, 78% of the sites with the proportion of weeds <10% had *L. migratoria* densities between 125 and 3,000 individuals ha^{-1} (Fig. 5), whereas more than 6,000 to approximately 15,000 specimens colonized sprayer-irrigated areas, with 25% of cover grasses. When only 2 to 4 wild-grass species formed the grass stand and a dominant one had a cover percentage varying from 47 to 67%, total numbers of *L. migratoria* became high (Table 4, Figs 3,5). The insects were very strongly attracted by *Avena sterilis* and *Sorghum vulgare* in particular, even when the proportion covered by these plants was very low— not more than 4% (Fig. 4). Correlation was highly significant between the two types of vegetation cover and the locust population density ($0.68 < r < 0.89$) as well as for the locust density and *Avena sterilis*/ *Sorghum vulgare* cover ($0.68 < r < 0.99$). For the 36 cross comparisons between the two sites, the Mc Nemar test reveals significant data at the threshold of $\alpha = 5\%$, (df= 7). The spatial distribution was clumped in all sites except the oasis (Site 2, Table 4).

Discussion and conclusions

According to our results, it appears that both locust species can be negatively or positively affected by anthropogenic disturbance. In the Algerian semiarid area, the swarming risk of the Moroccan locust becomes possible in two situations. First, swarms can develop progressively in regions affected by a certain degree of sheep grazing (disturbed habitat, site 1, southeast of Medea). Skaf (1972) similarly reports the close association of sheep and cattle with *D. maroccanus* in breeding areas in Syria. Second, the swarming migratory form of the species arises through desertion of fallow areas situated at the bottom of mountains and also, since 1994, through abandonment of nearby marginal croplands by agriculturalists. These human actions lead to the installation of solitarious Moroccan locusts in the abandoned zones, (undisturbed habitat, western and eastern sites). Upsurges which occured in 1999 mainly in the western zones of the country, had thus originally been initiated 3 or 4 y earlier. The absence of phytosanitary measures in the adjacent areas, and the important spring precipitation that appeared in 1999 after several seasons of low rainfall, generated a striking population increase in the Moroccan locust in, notably, the Sidi Bel Abbes region.

Morphometrical measurements based upon many individuals, show characteristic features of the gregarious phase: respectively E/F3= 1.70 and F3/P= 2.59, (E= first pair of wings, F3= posterior femur, P= pronotum). Human impacts were also responsible for the upsurge of *D. maroccanus* during military conflicts in Tajikistan, at the beginning of 1990 (Latchininsky 1998). The increase of fallow area and drought in the same period in Hungary contributed as well to produce an outbreak necessitating chemical treatments, as mentioned by Nagy (1995).

Agricultural practices in the Central Sahara are another part of the anthropogenic impact on the dynamics of migratory locust populations. In the arid desert zone, *L. migratoria* has a tendency to concentrate in the Touat region (Fig. 2) where the cropped area has dramatically increased by more than 60% from 1984 to 1989 (Anonymous 1990). This region is a 'corridor' of flat land, characterized by rough-texture soils, more or less high in salt content. In this area, humans cultivated cereals under irrigation by pivoting sprayers, and one can find nearby truck and other traditional crops under palms. Most of the irrigated fields are concentrated in the

Table 4. Observations of the migratory locust in April 1996 in irrigated study fields of Adrar region.

Sites	Adult Density / ha	Morisita index	Total weed cover %	% cover due to adventitious grasses (*)	Dominant adventitious grass**, (***)	% total weed cover due to dominant grass sp.
1	393	1.26	13.10	8.00 (2)	Sve (70)	5.60
2	125	0	6.80	2.65 (3)	.	.
3	1.384	3.66	12.85	4.60 (1)	Hvu (100)	4.60
4	1.202	1.47	13.92	4.80 (2)	Tvu (46)	2.20
5	14.327	1.26	25.85	19.08 (10)	Ast,Svu 23.5	4.50
6	6.157	1.05	23.99	9.73 (8)	Ast (25.6)	2.50
7	2.161	1.47	15.90	5.58 (4)	Sru (39)	2.20
8	1.782	2.40	13.04	6.40 (2)	Ast (67)	4.30
9	2.014	2.30	14.36	5.05 (3)	Hvu (47.5)	2.40

*Numbers from 1 to 10 represent the number of grass species in the study sites.
** Sve: *Setaria verticillata* ; Hvu: *Hordeum vulgare* ; Ast: *Avena sterilis* ; Svu: *Sorghum vulgare* ; Tvu: *Triticum vulgare* ; Sru: *Sorghum rubens*.
***% adventitious grass cover due to species within parentheses.

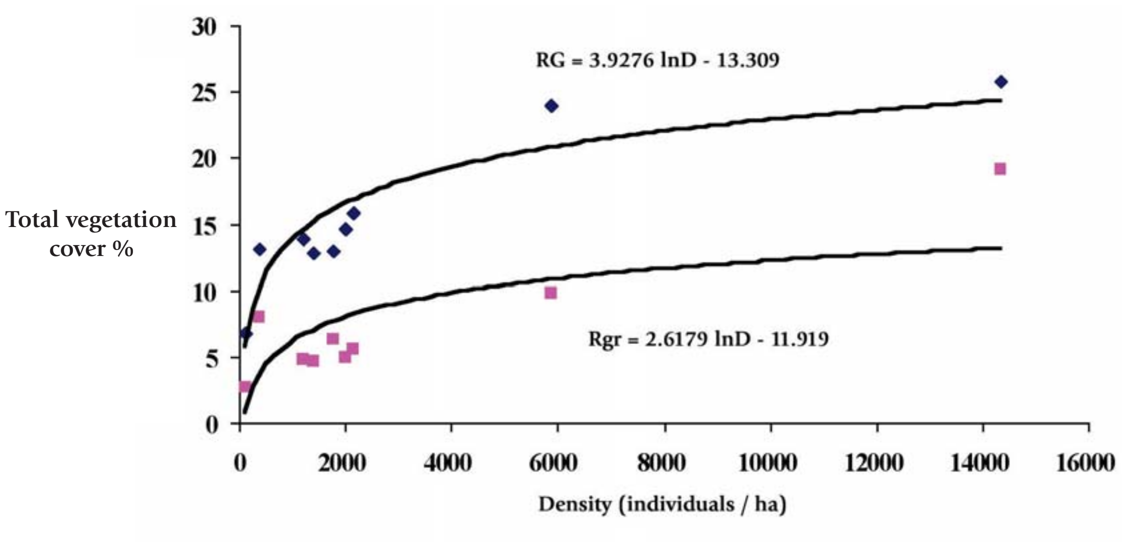


Fig. 3. Relation between *L. migratoria* population density, the total vegetation cover (RG) and the adventitious grasses cover (Rgr). RG: squared multiple correlation coefficient R = 0.8466, α = 0.05, df = 7; Rgr: squared multiple correlation coefficient R= 0.5513, α = 0.05, df = 7.

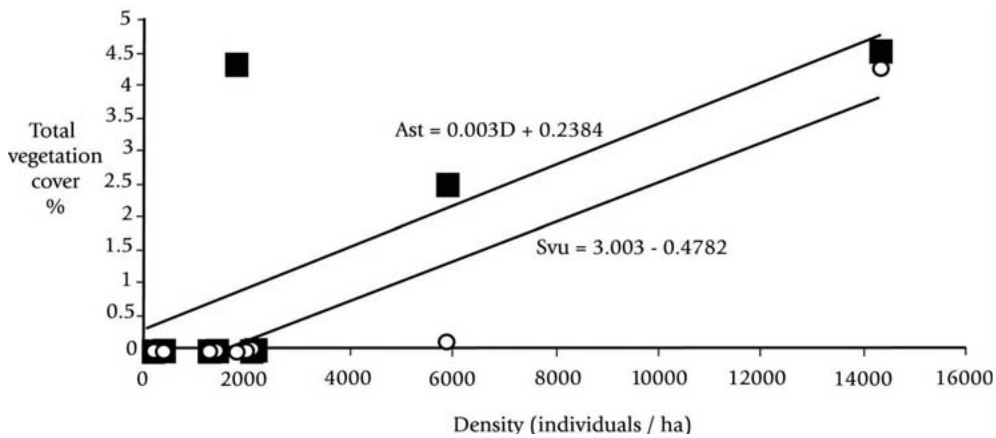


Fig. 4. Relation between *L. migratoria* population density and the percentages of *Avena sterilis* (Ast) and *Sorghum vulgare* (Svu) cover. Ast: squared multiple correlation coefficient R = 0.5086, α = 0.05, df = 7; Svu: squared multiple correlation coefficient R = 0.8767, α = 0.05, df = 7.

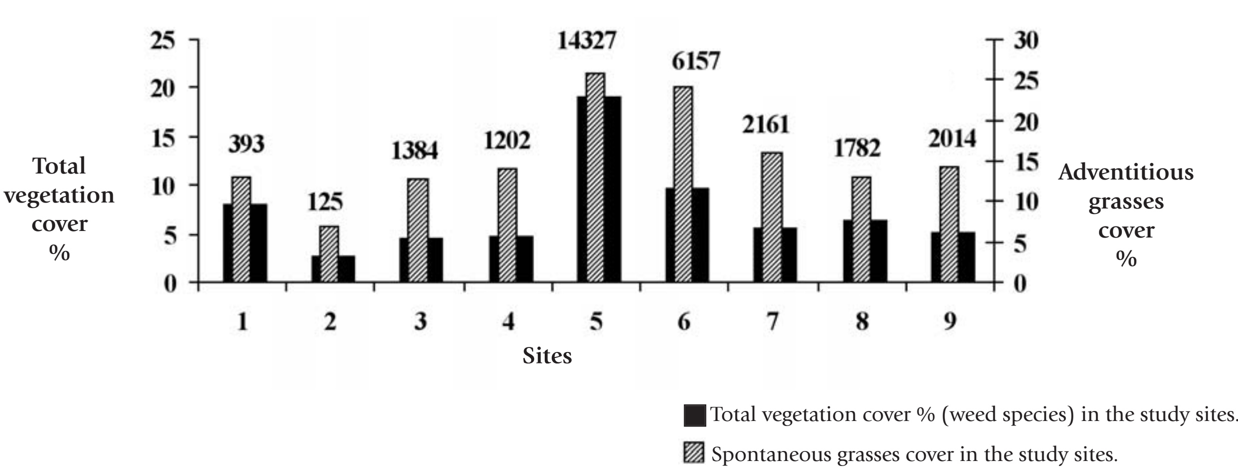


Fig. 5. Vegetation cover rates and densities (numbers atop bars) of *L. migratoria* in the study sites.

'Azzi' plateau, 70 km south of the Touat region (Fig. 2).

Plant protection specialists found localized but quite dense populations of *L. migratoria* on irrigated cereals in both the summer and winter of 1994. These populations were not morphologically gregarious in form and color. According to our observations from 1995 to 1997, the activity of the migratory locust was strictly correlated, as expected, with the level of weeds in proportion to crops. Population density went up, when almost 20% of the vegetation cover was represented by adventitious grasses. But the population of *L. migratoria* only continued to rise beyond this threshold of 20% if *Avena sterilis* and *Sorghum vulgare* were present. Damage to plants of *Sorghum* was noticed at field edges, close to the cereals irrigated by pivot sprayer systems; and as well damage was observed in the region south of Ghardaïa, in the oazian zone, 600km north of the Central Sahara, again in the area of pivoting sprayers.

Taking into account the relation between *Zonocerus variegatus* populations and an imported weed, *Chromolaena odorata* (Boppré & Fisher 1994), and considering that locusts are attracted to grasses because these plants do not have deterrent chemicals which repel acridids (Bernays & Chapman 1994), it seems relevant to search for the significance of the relation between *Sorghum* and *Locusta* under our climatic and especially anthropogenic conditions. This phenomenon, the interaction of agricultural practice and migratory locust swarms, is unique to the Sahara desert. A similar impact was observed with the expansion of pivot irrigation in Lybia in the 1980s. However, up to now, no research has addressed the problem of *L. migratoria* in the Algerian Sahara.

As a result of Launois' observations in the Lybian desert, the pest species seems to be *L. migratoria migratorioïdes* (Reiche & Fairmaire 1850), (Duranton, pers. comm). This locust represents a single nondiapausing and polymorphic subspecies from the tropics and the southern hemisphere (Farrow and Colless 1980). *Locusta migratoria capito* (Saussure 1884) is another migratory locust subspecies, whose outbreaks in Madagascar (Lecoq 1975) depend on a monthly rainfall of 50 to 100mm. Heavy swarms of *L. migratoria* were also linked to the extent of rainfall in southwestern Chad during 1988-1989 and early 1997 as mentioned by Chara (1989) and Balança *et al.* (1999). Studes by Verdier (1972) on the North African *Locusta* indicate that it is *Locusta migratoria cinerascens* Fabricius. The bibliography also reveals the presence of this species in the oasis as well as the scrubs and the humid zones (Chara pers. comm). Moreover, it is useful to emphasize that the *Locusta* of the Adrar region, when reared under laboratory conditions (T= 30°C, photoperiod= 12/12 hours), reproduce continuously, and there is no sign of diapause. Immature *Locusta* females were also observed in the field 50 km from Adrar (Central Sahara) in December 1995 and January 1996.

Whereas deforestation and drought are factors originally considered to be creating suitable habitats (for *L . migratoria manilensis* in Indonesia (Lecoq *et al.* 2000)), the colonization of new potentially favorable habitats by *L. migratoria* (Linnaeus 1758) in the Algerian Central Sahara, appears to result from the expansion of irrigated cereal crops. The use of local nonselected seeds, the absence of crop rotation and the increase in the proportion of weeds under pivoting sprayers are also, up to now, the main factors contributing to the maintenance of the species in this modified habitat, leading to a complete disappearance of this locust from its native habitat situated in the oasis. Determination of the risk of swarming by *L. migratoria* in the Central Sahara could be possible by following increasing population densities, which we could only understand in the long term after studying the extreme limit of the anthropogenic impact on this locust's population dynamics. Because the locust taxonomy under Algerian ecological and climatic conditions is not precisely known, it is too early to indicate a gregarization density threshold for the species.

In conclusion, we believe that independently of the spring rainfall, humans are creating suitable habitats for the Moroccan locust by overgrazing in the Algerian semiarid area. Consequently, this acridid remains a pest in this zone as was pointed out by Latchininsky (1998). As for the migratory locust, it can be a serious pest in the irrigated modified habitats of the central desert.

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