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The Senegalese grasshopper *Oedaleus senegalensis* (Krauss, 1877): Dynamics and socio-economic impact in Senegal

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Abstract

This study, conducted in Senegal between July and October 2021, investigated the population dynamics and economic impact of the Senegalese grasshopper *Oedaleus senegalensis*, as well as the effectiveness of a community-based pest control strategy. A total of 250 farmers across four regions (Fatick, Kaffrine, Thies, and Saint-Louis) each managed one fertilized and one non-fertilized (control) millet field of one hectare, using the Souna III variety. Fertilized fields received 150 kg each of Nitrogen-Phosphorus-Potassium (NPK) and urea.

Grasshopper densities and development stages were monitored through extensive field sampling and transect observations. Damage was evaluated by estimating leaf and ear attacks, and yield differences between field types were analyzed. In total, 500 hectares were surveyed 1,500 times.

Three grasshopper generations were found in most regions, except in Saint-Louis, where only two were recorded. Densities and movement patterns followed the rainfall gradient, decreasing from Kaffrine to Saint-Louis. Control fields showed higher grasshopper densities (20.25 individuals/are) and attack rates (15%) than fertilized fields (8.5 individuals/are; 2% attack). Correspondingly, fertilized fields yielded 813.95 kg/ha, nearly double the 435.30 kg/ha from control fields.

The results suggest that fertilization, possibly by enhancing millet's protein content, helps reduce grasshopper infestation and damage.

Keywords: *Oedaleus senegalensis*; Density; Damage; Millet; Control

1. Introduction

The agricultural sector is one of the pillars of Senegal's economy, contributing an estimated 15% to the gross domestic product (GDP) in 2020. A significant portion of the population continues to rely on it for their livelihood [1]. Most of Senegal's agricultural production comes from rainfed crops, totaling 8,771,559 tonnes, including 3,640,545 tonnes of cereals. These cereals, mainly rice, maize, fonio, and millet, account for 31.4%, or 1,144,855 tonnes [2]. Millet cultivation is particularly important for food security and nutrition, and its by-products serve as a source of income for farmers,

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especially in the Groundnut Basin (Fatick, Kaffrine, etc.). Millet is the second most cultivated cereal, with an average production of 1,529 kg per rural household [3].

One of the main constraints to optimal food production is losses caused by various crop pests, particularly locusts.

Grasshoppers and locusts (Orthoptera: Acrididae) are among the most destructive agricultural pests. They can cause severe damage to food crops, disrupting farming systems and local economies. For millennia, people have faced devastating locust and grasshopper outbreaks. Under favorable climatic conditions, Acridid populations can increase rapidly, resulting in local outbreaks or even regional and continental swarms ([4] ; [5] ; [6]). In many tropical regions, only a small number of the approximately 6,700 valid Acrididae species pose a serious threat to food security, especially in Africa ([7] ; [8] ; [9]; [10] ; [11]).

These insects exhibit morphological plasticity depending on whether they are in solitary or gregarious phases ([12] ; [13]). *Oedaleus senegalensis* (OSE) (Krauss, 1877), commonly known as the Senegalese grasshopper, is one of these pests. It is widely distributed across the Sahel, from the southern Sudano-Sahelian zones to the northern Sahelo-Sahelian zones [14]. Seasonal movements occur along a north–south gradient, ranging between the 1000 mm isohyet (latitude 11–12°N) and the 150–200 mm isohyet (latitude 17–18°N), following the Intertropical Convergence Zone (ITCZ).

This species poses a significant threat to food security, particularly in fragile regions like the Sahel. Damage caused by *O. senegalensis* is substantial and has led to the loss of thousands of tonnes of millet in Senegal. Launois and Launois-Luong [15] and Krall [16] reported yield losses of up to 40% in the Sahel in 1980 due to this species. In Niger, losses of 20–40% of millet, sorghum, and rice have been reported [17], while in Mali, crop losses ranged from 70–90% over five years [18]. In India, damage was estimated at 30% of crops [19]. Cissé [20] also reported damage in Senegal and Mali. *O. senegalensis* is considered the most economically important grasshopper species in West Africa ([21] ; [22]).

In 2003, *O. senegalensis* infestations severely impacted crop prospects in sorghum, maize, and millet fields in Senegal [23]. Every year, this species swarms in the Groundnut Basin, an area traditionally known for producing food crops and groundnuts. For instance, in October 2005, locust outbreaks caused a 25% loss in the Mbar rural community (Gossas Department, Fatick Region) [24]. Later, in 2006, infestations were recorded in the Matam region, followed by outbreaks in 2007 in Ndiassane (Thies Region) and in 2008 in the Noto rural community [25].

Various methods are employed to control crop locust pests: mechanical, thermal, chemical, biological, ecological, and integrated approaches ([26] ; [27]). Among these, chemical control has traditionally been the most widely used and effective ([28] ; [29]). However, it carries serious environmental and health risks ([30] ; [31]). In the United States, for example, the widespread use of insecticides has led to the destruction of pollinator populations, resulting in annual yield losses of approximately $1.5 billion due to poor pollination [32]. Some insecticides, especially those in the chlorinated cyclopentadiene group, are suspected of having carcinogenic effects ([33] ; [34]).

Sustainable agriculture that protects the environment, human health, and food safety must include preventive strategies for grasshopper and locust control ([8] ; [35] ; [36]). Many countries affected by locust swarms have developed monitoring and early-warning systems, supported by regional and international institutions [37]. Preventive control relies on surveillance [28] and requires in-depth knowledge of the insects' biology and ecology ([38] ; [39]) to detect phase transitions ([40] ; [37]). Monitoring and early warning enable timely interventions that are more effective and less costly [41]. Mapping dynamics using satellite imagery is also essential in the development of control strategies ([42] ; [43]).

Biopesticides have emerged as the most promising sustainable alternative. The use of fungal conidial formulations has shown great success worldwide in managing agricultural pests ([44] ; [45] ; [46]).

Effective management during both invasion and remission periods is key to controlling grasshopper and locust populations [47]. These insects are best identified by their density-dependent phase polymorphism, which can lead to spectacular migratory swarms [48]. Over the past 30 years, significant progress has been made in understanding the ecology of the Senegalese grasshopper, monitoring its population, and predicting the risk of invasion.

Control strategies are now shifting toward more realistic and sustainable alternatives to chemical pesticides. Efforts must be strengthened by improving monitoring, increasing the number and quality of surveys, and identifying outbreak hotspots and diapause egg fields during the dry season [49].

Locust feeding preferences based on plant nutrient content (e.g., nitrogen, carbon, phosphorus) represent a promising area for control [50]. Human modifications to ecosystems, whether biological or chemical, inevitably influence locust behavior [51].

The main objective of this study is to investigate the population dynamics of the Senegalese grasshopper, assess its economic impact, and evaluate the implementation of a community-based control strategy in Senegal.

2. Study area

2.1. Groundnut basin

The research was conducted in the groundnut basin, specifically in the administrative regions of **Fatick** and **Kaffrine** (Fig. 1).

2.1.1. Fatick Region

In this region, fieldwork was carried out in the rural communes of Mbar and Gossas.

Mbar (latitude 14°31′ N, longitude 15°45′ W) is located in the Fatick region, within the Gossas department, Colobane arrondissement. The area has a tropical sub-Saharan climate with irregular rainfall ranging from 300 to 800 mm annually. Monthly temperatures vary significantly, from around 24°C in January to 39°C in May. The soils are tropical ferruginous, and the vegetation is mainly shrub savannah. These soils are well-suited to agriculture, particularly the cultivation of millet, cowpeas, and, to a lesser extent, groundnuts. The presence of fallow land (used as pasture) reflects the area's traditional farming practices.

Gossas (latitude 14°30′ N, longitude 16°04′ W) has a tropical-Sudanian climate, with annual rainfall between 300 and 900 mm. The vegetation is diverse, and the soils are classified as dior or tropical ferruginous. Agriculture is the dominant activity, focused mainly on millet, groundnuts, and cowpeas.

2.1.2. Kaffrine Region

In Kaffrine, research was conducted in the communes of Gniby, Boulel, and Nganda: Gniby (latitude 14°25′ N, longitude 15°39′ W), Boulel (latitude 14°17′ N, longitude 15°32′ W), and Nganda (latitude 13°83′ N, longitude 15°42′ W)

These communes lie within the Kaffrine department, at distances of approximately 43 km, 22 km, and 35 km, respectively, from Kaffrine, the regional capital [59] (DRDR Kaffrine, 2012 Annual Report).

The region experiences a Sudano-Sahelian climate, with high temperatures from April to July (ranging from 15–18°C minimum to 35–40°C maximum). The year is divided into two main seasons: a dry season (November to May) and a rainy season (June to October). The area, located between the 800 and 900 mm isohyets, receives relatively favorable rainfall.

The soils are mainly of the dior type. Vegetation includes shrub and tree savannahs, pseudo-shrub steppes, and patches of open forest. Agriculture is the primary livelihood for approximately 75% of the regional population. The main crops grown include millet (souna), sorghum, and maize, with groundnuts and market gardening also widely practiced.

2.2. Central Senegal

For the central zone, the study was conducted in the rural commune of Touba Toul (latitude 14°49′ North, longitude 16°40′ West), located in the Thieneba arrondissement of the Thiès department and region (Fig. 1). This rural area, like the urban zones, has a Sahelian-type climate (dry and hot) shaped by maritime trade winds from the north and northeast, as well as continental harmattan winds that bring dry, hot easterly air during the dry season. In contrast, humid westerly winds are associated with the monsoon, marking the rainy season.

The dry season lasts from October to June, while the rainy season extends from July to October, characterized by the presence of monsoon rains.

In the Touba Toul area, the soils are predominantly of the *dior* type, with low clay content, making them well-suited for crops such as groundnuts, millet, and cowpeas. There are also *deck* soils, known for being moist, rich, and highly fertile.

Vegetation is diverse, comprising a variety of species arranged in three strata: trees, shrubs, and herbaceous plants.

Agriculture plays a central role in the local economy, employing around 80% of the working population.

2.3. Northern zone

Saint-Louis lies within the Sahelian zone, between 16°02′ North and 16°30′ West (Fig. 1). The region has a Sahelian-type climate, characterized by hot, dry continental trade winds (Harmattan) and maritime trade winds from the west. Average annual temperatures are relatively high, with the continental interior experiencing extreme heat year-round, occasionally exceeding 40°C in the Podor department.

Rainfall has been low in recent years, though it can reach up to 346 mm annually. Nevertheless, the moderating influence of the nearby ocean to the west is favorable for crop cultivation.

The sandy soil is often subject to wind erosion, leading to sandstorms that can last for several days, particularly during the Harmattan period (December to May), which originates in the Sahara Desert. During the rainy season, a thin layer of grass emerges, and bushes begin to regain their foliage.

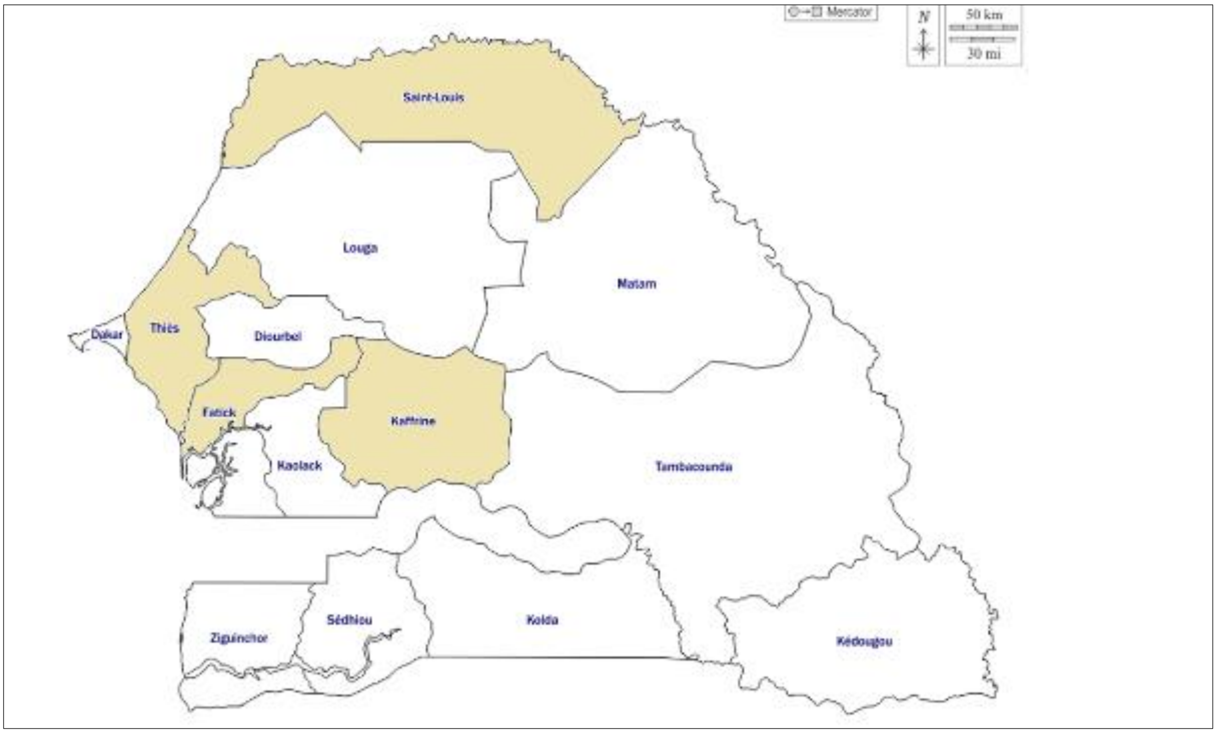

Figure 1 Regions of the study zone in Senegal

3. Material and methods

3.1. Material

Two hundred and fifty (250) farmers, each with a one-hectare fertilized field and a one-hectare control field, were selected in the regions of Fatick, Kaffrine, Thies, and Saint Louis. The Souna III millet variety was sown in both types of fields. The fertilized fields received 150 kg of NPK fertilizer applied once, followed by 150 kg of urea applied in two doses spaced 15 days apart.

The farmers sowed millet in June, well before the rains, to strengthen the crop against pest attacks and to hasten emergence.

The target pests were locusts, primarily the Senegalese grasshopper, *Oedaleus senegalensis*, which can be either brown or green in color in both the larval and adult stages.

3.2. Methods

3.2.1. Study of population dynamics

For this study, we conducted 1,500 surveys over 500 hectares, divided into three missions during the 2021 wintering period from July to September. For each mission, we recorded locust density in the fields, locust damage, date, time, temperature, humidity, and vegetation cover.

3.2.2. Densities

To assess the density of *Oedaleus senegalensis* (OSE), we used both the quadrat method and the pedestrian transect method.

3.2.3. Quadrat method

This method, used during the first mission, involves randomly placing a 1 m² quadrat in the field and counting the number of locusts found inside, carefully inspecting all the vegetation within the square. Approximately fifty repetitions are performed, and the average count represents the density for the given field. We calculated the locust density for each field using the following formula:

$$dlocusts = 2Nlocusts$$

- $\boldsymbol{d}_{\text{locusts}}$: locust density (number of locusts/100m²)
- $\boldsymbol{N}_{\text{locusts}}$: total number of locusts in fifty replicates

Senegalese grasshopper density is obtained after correcting locust density for net sampling.

3.2.4. Pedestrian transect method

This method involves walking through the field along a 100 m long and 1 m wide path, counting any grasshoppers that take flight. The surveyor performs about 50 repetitions and calculates the average, which corresponds to the density of the surveyed field.

The actual density of Senegalese grasshoppers is obtained by adjusting this value using the percentage derived from net sampling.

3.2.5. Net sampling

The purpose of net sampling is to determine the instantaneous population structure of the locusts. Repeated sampling over time and space allows us to study the population dynamics. We thoroughly search the surveyed fields and capture grasshoppers spotted jumping or resting on the ground using a sweep net. After identifying individuals of *Oedaleus senegalensis* (Krauss, 1877), we calculate the percentage of Senegalese grasshoppers, which is then used to correct the densities obtained during the surveys. The following formula is applied:

$$dOSE = xdlocusts$$

- $\mathbf{d}_{OSE}$: Senegalese grasshopper density,
- **x**: percentage of OSE density at sampling,
- $d_{locusts}$: density of all locusts at survey.

3.2.6. Developmental stages of generations

For each survey mission, we identified the generations of *O. senegalensis* populations present in the study areas. During the week, three sampling sessions were conducted by six surveyors between 7:00 and 8:30 a.m. The samples were collected and their composition analyzed. The captured Senegalese grasshoppers were examined, and the different developmental stages were characterized using an identification key. From July to September 2021, we established the generations and larval stages present in the four surveyed regions of Senegal.

3.3. Socio-economic impact

3.3.1. Assessment of attack rate

Over a ten-meter length of millet field, which normally contains about 10 tiller clumps, we first counted the number of tillers, then the total number of leaves, and finally the number of leaves damaged by locusts. For the last mission, when the millet was at a very advanced heading stage, damage was assessed on the ears. Fifteen repetitions were conducted for each field.

3.3.2. Recording production

After harvesting, farmers threshed the millet in front of our supervisory team, who recorded the yields from both fertilized and control fields. The harvest data allowed us to assess the socio-economic impact of grasshopper attacks.

All results were processed using R software (version 4.2.3, dated March 15, 2023). We examined whether there were any effects of region and field fertilization on the observed densities. An ANOVA was conducted for each mission, followed by a comparison of group means using the Tukey Honest Significant Difference (TukeyHSD) test. The ANOVA test was used to analyze differences between regions and field types. The TukeyHSD test assessed the significance of mean differences in OSE densities based on field type and region.

4. Results

4.1. Population dynamics

4.1.1. OSE density

Monitoring of fertilized and control fields throughout the rainy season showed that Senegalese grasshopper densities were similar during the first mission. Only in Kaffrine did the fertilized fields have fewer locusts than the unfertilized ones during this mission. Significant differences were observed between regions, mainly driven by Kaffrine (Fig. 2).

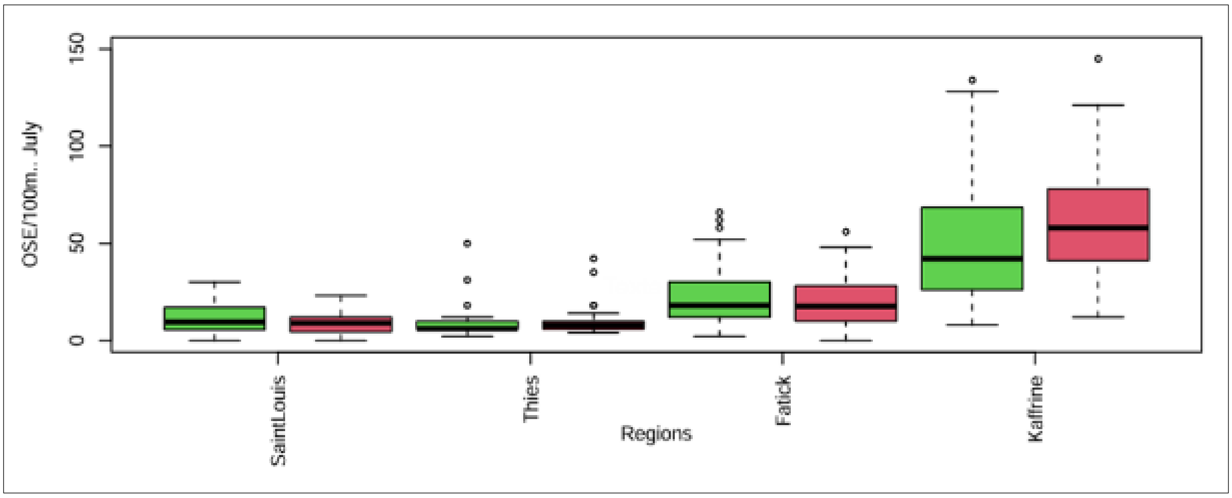

Figure 2 Senegalese grasshopper density in fertilized (green)and control (red) Fields during mission 1

Subsequent missions revealed a clear difference between the two types of fields. Fertilized fields had fewer *Oedaleus senegalensis* (OSE), with densities almost half those of unfertilized fields across all regions. However, during the second mission, the Kaffrine region was the only one showing no significant difference between fertilized and unfertilized fields (Figs. 3 and 4).

The highest density was recorded in unfertilized fields in Kaffrine at 40.35 OSE/are, while the lowest was in fertilized fields in Saint Louis at 7.57 OSE/are. This indicates that Senegalese grasshoppers tend to prefer fields not enriched with nitrogen.

The results also showed that *Oedaleus senegalensis* movements and densities decreased along the rainfall gradient from Kaffrine, Fatick, Thies to Saint Louis (Table 1). The species was more abundant in unfertilized fields, with an average density of 20.25 insects per year, compared to 8.5 insects per year in fertilized fields.

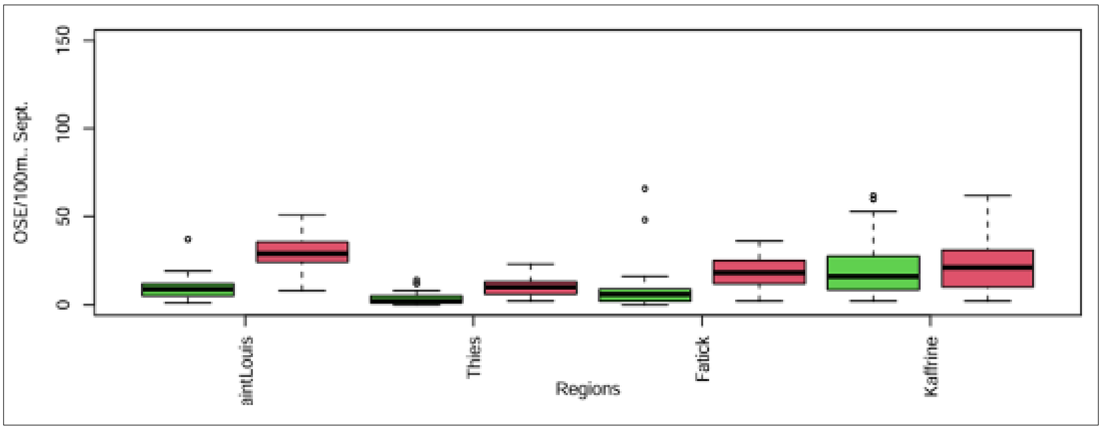

Figure 3 Senegalese grasshopper density in fertilized (green) and control (red) fields during mission 2

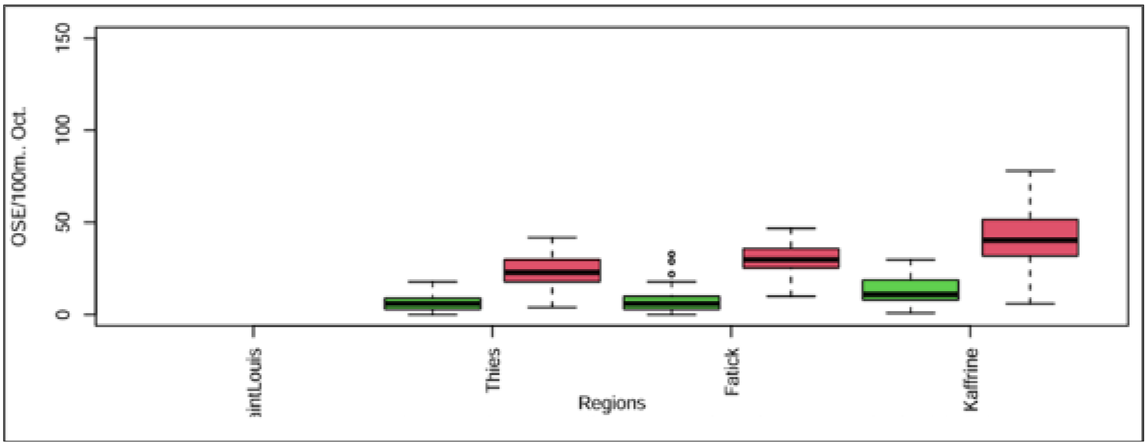

Figure 4 Senegalese grasshopper density in fertilized (green) and controls (red) fields during mission 3

Table 1 Annual average density of Senegalese grasshoppers by region and filed type

Regions	Saint Louis	Thies	Fatick	Kaffrine
Fertilized fields	7.57	9.97	12.28	26.81
Control fields	13.34	18.74	22.68	40.35

The presence of vegetation plays a crucial role in grasshopper distribution. For the same percentage of plant cover, Senegalese grasshoppers are more abundant in control fields than in fertilized fields. However, the highest number of insects is observed when vegetation cover ranges between 50% and 60% across all the regions studied (Fig. 5).

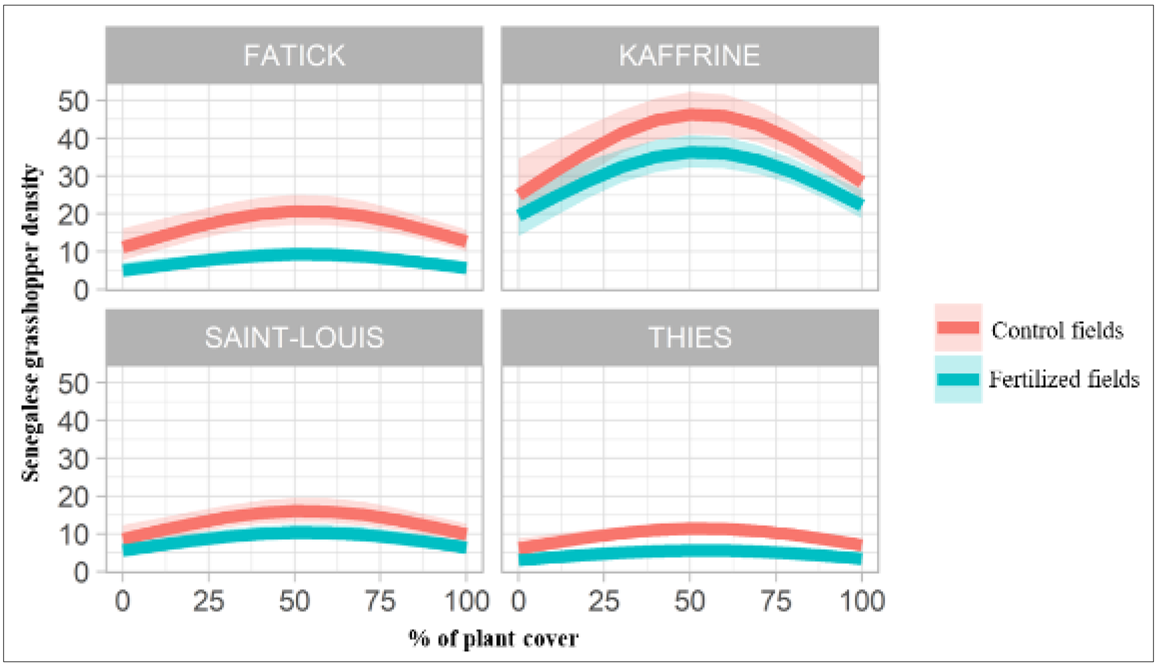

Figure 5 Senegalese grasshopper density as a function of plant cover

4.1.2. generations and development stages

Locust captures and identifications during the surveys enabled us to determine the developmental stages and generations of *Oedaleus senegalensis* present during each mission. We identified three generations of OSE (G1, originating from the eggs of the previous season's last generation, and G2 and G3 indigenous) in the Thies, Fatick, and Kaffrine regions. In Saint Louis, only the G1 and G2 generations were observed. All developmental stages were identified, from eggs (hypogeal stage), through larvae (epigeal stage), to adults (imago) (Table 2).

Table 2 Development stages and generation during mission (A. adult, G generation, L larva, O egg, Example L1G1, stage 1 larva of first generation)

Regions	**Mission 1 (in july)**	**Mission 2 (in august)**	**Mission 3 (in september)**
Saint Louis	L1G1 L2G1	AG1 OG1 L1G2	AG2 OG2
Thies	AG1 OG1 L1G2	AG1 OG1 L1G2	AG2 OG2 L1G3 L2G3
Fatick	L4G1 L5G1 AG1 OG1	AG1 OG1 L1G2	AG2 OG2 L1G3 L2G3
Kaffrine	L4G1 L5G1 AG1 OG1	AG1 L1G2 L2G2	AG2 L4G2 L5G2 L1G3

4.2. Socio-economic impact

4.2.1. Damage to millet

Attacks were observed at all stages of millet development, but those on young seedlings and ears caused much more severe damage (Figs. 6 and 7). Damage on young seedlings was primarily caused by the G1 generation, while the G3 generation was responsible for damage to the ears.

During the first mission, the difference in attack levels between fertilized and unfertilized fields was not statistically significant ($p = 0.0683$). However, subsequent missions showed a highly significant difference in millet damage between the two field types ($p = 0.0367$).

Damage rates recorded were 24.85% in unfertilized fields compared to 5% in fertilized fields. More attacks were observed during the first and last missions than during the second.

Figure 6 OSE damage on millet leaves

Figure 7 OSE damage on millet ears

4.2.2. Millet yields

Yields varied significantly according to field type. The yields recorded in fertilized fields were 138,734 Kg compared to 55,808 Kg for the unfertilized fields, i.e. 2.5 times more. Average yields were 813.95 kg/ha in fertilized fields compared to 435.30 kg/ha in control fields. Standard deviations for fertilized and control fields are 394.50 and 275.39 respectively. Depending on the region, we observed variations in harvests. Fertilized fields produced 61%, 63%, and 72% more than control fields in Fatick, Kaffrine, and Thies, respectively. Comparison of production by region, we have seen that for fertilized fields, the Fatick region showed the highest average production (856.86), followed by Thies (803.08), and Kaffrine (781.89).

For non-fertilized fields, Fatick again recorded the highest average production (537.23), followed by Kaffrine (449.58), and finally Thies (319.10).

Harvesting did not take place in Saint Louis because the millet failed to mature due to an early cessation of rainfall.

5. Discussion

Unfertilized fields are more vulnerable to locust attacks, despite some of these fields having low locust populations, particularly in July. After the first rains, millet germination coincides with the massive hatching of Senegalese grasshopper eggs, which had been in embryonic diapause during the dry season. Thus, rainfall triggers the resumption of *Oedaleus senegalensis* development. The water factor is a complex element that acts directly on the species and indirectly on its environment. The Senegalese grasshopper is an acridid species found in semi-arid zones, with a distribution range located in areas receiving between 250 mm of annual rainfall in the north and 1000 mm in the south.

The environment is optimal for the species' survival when monthly rainfall ranges between 25 and 50 mm. Between 50 and 100 mm, conditions remain compatible with the insect's normal development. Below 50 mm or above 100 mm, the environment becomes respectively too dry or too wet for the species [15].

It is observed that the Kaffrine region records the highest monthly and cumulative rainfall, followed by the regions of Fatick, Thies, and finally Saint-Louis.

The density of Senegalese grasshoppers follows this rainfall gradient: the insect is more abundant in the most humid areas (Kaffrine and Fatick) and less numerous in the least rainy regions (Thies and Saint-Louis).

During this period, we observed a substantial density of larvae representing an indigenous population, but we did not witness the arrival of southern-born adults, i.e., an allochthonous population, as reported by Lecoq [14]. The northward shift of the inter-tropical convergence zone at the onset of the rainy season leads to a gradual increase in biotope humidity [52], partly explaining the high densities observed during the first mission. Movements are influenced by variations in rainfall from southern to central Senegal as a consequence of climate change. Nevertheless, major locust invasions and outbreaks, often favored by climate change, continue to occur worldwide [53].

The results from the first mission in July showed little difference in *O. senegalensis* density between fertilized and control fields. This is likely because many fields had not yet been fertilized at that time, and in those that had, millet had not yet assimilated nutrients sufficiently to produce a visible difference in leaf density. Leaf analysis results from the two field types, taken at the beginning, middle, and end of the rainy season, confirm this difference.

Following fertilizer application, significant differences in insect presence were observed between control and fertilized fields. *O. senegalensis* densities were higher in unfertilized fields than in fertilized ones. Overall, locust presence declined in fertilized fields during the last two missions compared to the first. According to several authors, herbivores can cope with nitrogen deficiency ([54] ; [55] ; [56] ; [57]). Le Gall and colleagues found that Senegalese grasshoppers prefer plants with lower protein and higher carbohydrate content, and that the protein-to-carbohydrate ratio has a decisive impact on their reproduction, lifestyle, and development ([7] ; [58]). Fertilizers supply nutrients to plants to improve or accelerate growth. Nitrogen, a key element in plant nutrition, is involved in synthesizing proteins, chlorophyll, and other major compounds essential to plant metabolism. Nitrogen addition to the soil results, after 18 days, in increased protein levels and decreased carbohydrate levels in millet leaves, due to carbon mobilization for protein synthesis. Increasing nitrogen inputs can actually reduce herbivore performance, challenging the universality of the nitrogen limitation hypothesis [59].

Following is a practice used to improve soil fertility in agroecosystems. Plants in grazed or fallow fields tend to be richer in carbohydrates due to soil nitrogen depletion, creating a preferred habitat for locusts [25]. Therefore, the considerable locust densities observed in unfertilized fields are likely due to the low nitrogen content of the plants.

Plant cover also influences insect presence. The ecological optimum for vegetation cover was found to be around 60%. *O. senegalensis* density increased with plant cover in both fertilized and control fields but began to decline beyond this threshold. This contrasts with findings by Lawton et al. [50], who reported the highest locust densities at 80% vegetation cover.

Population dynamics were clearly evident in this study. We recorded three generations: G1, derived from eggs laid by the last generation of the previous season; G2, from the oviposition of G1; and G3, originating from G2 in the Fatick, Kaffrine, and Thies regions. In the Saint Louis region, only two generations (G1 and G2) were identified, as rainfall was lighter and of shorter duration, preventing completion of all developmental stages. Variations in the dominant developmental stage were noted across regions and survey periods. During the first mission, G1 adults were more numerous in Fatick and Kaffrine, while in Thies, first-instar larvae of G2 (L1G2) predominated, and in Saint Louis, first-instar larvae of G1 (L1G1) were most abundant. These differences correspond to the timing of initial rainfall, as all missions occurred on the same date across locations. Thies, which received its first rainfall earlier, showed more advanced developmental stages than the other regions. Only during mission three were G3 individuals at various larval stages observed. Egg hatching rates varied across regions and even within localities, as described by Lomer [60].

Oedaleus senegalensis (Krauss, 1877), the main millet pest, is abundant and migratory, causing significant damage throughout millet development and resulting in substantial yield losses. In August and September, although locusts remained present in unfertilized fields, the damage they caused was minor compared to that in fertilized fields. Attacks were most severe at two particularly vulnerable phenological stages: seedlings and milky ears, targeted by G1 and G3 generations respectively. Other stages (tillering, leafing, and flowering) were less susceptible, due to the plant's greater regenerative capacity and because these stages coincide with locust migration northward from the Sahelian crop zone [25]. There was a clear correlation between insect density and damage: control fields with higher locust densities sustained more damage, consistent with findings by Bal et al. [10].

Post-harvest yields confirmed the uneven distribution of Senegalese grasshoppers between fertilized and control fields, despite late germination in some plots. Fertilizers played a crucial role in achieving higher yields. Thus, *O. senegalensis* densities, observed damage, and yields were closely linked: fields with the highest locust densities (control fields) suffered more damage and produced lower yields.

This method of controlling Senegalese grasshoppers heavily involves local communities, who play a direct role in fertilization. This community-based strategy relies on the active participation of the farmers themselves in the control efforts.

However, the availability of fertilizer can be a barrier, as farmers do not always have the means to purchase it. That is why we have considered using organic fertilization with compost, which farmers can produce locally from crop residues and certain household waste. Studies are currently underway, and we will soon be able to compare these results with those obtained using the chemical fertilizer applied here.

6. Conclusion

This study provides new insights into the dynamics of the Senegalese grasshopper and the management of this millet pest in Senegal. *Oedaleus senegalensis* adopts a strategy to persist as long as possible under environmental conditions suitable for its reproduction, including an embryonic diapause during the dry season to survive unfavorable periods.

A comparative study of *O. senegalensis* densities across various localities in Senegal revealed distribution patterns dependent on both region and field type. The data collected allowed us to establish grasshopper densities within the study areas. The insect was more abundant in the Kaffrine region, which has the highest rainfall among the areas studied. The highest densities were consistently found in unfertilized fields.

Although the gregarization threshold was never reached in our surveys, the densities observed were sufficient for *O. senegalensis* to cause significant damage to millet crops. One factor explaining the high densities in unfertilized fields is the lower protein content of the plants, as grasshoppers prefer plants with low nitrogen and thus low protein content. In fact, the protein-to-carbohydrate ratio contributes to the heterogeneous distribution of *O. senegalensis* even within similar environmental conditions.

The population dynamics study showed larvae of all developmental stages present in both fertilized and control fields. The G1, G2, and G3 generations were observed in nearly all regions except Saint Louis.

Fertilization, which increases the protein content of millet, is an effective and environmentally friendly method to control the Senegalese grasshopper. he absence of harvest in Saint-Louis does not have a significant impact on the study results. We confirmed that the presence of the insect has a negative effect on millet yields.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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