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Review

Elements for the sustainable management of acridoids of importance in agriculture

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Acridoidea is a superfamily within the Orthoptera order that comprises a group of short-horned insects commonly called grasshoppers. Grasshopper and locust species are major pests of grasslands and crops in all continents except Antarctica. Economically and historically, locusts and grasshoppers are two of the most destructive agricultural pests. The most important locust species belong to the genus *Schistocerca* and populate America, Africa, and Asia. Some grasshoppers considered to be important pests are the *Melanoplus* species, *Camnula pellucida* in North America, *Brachystola magna* and *Sphenarium purpurascens* in northern and central Mexico, and *Oedaleus senegalensis* and *Zonocerus variegatus* in Africa. Previous studies have classified these species based on specific characteristics. This review includes six headings. The first discusses the main species of grasshoppers and locusts; the second focuses on their worldwide distribution; the third describes their biology and life cycle; the fourth refers to climatic factors that facilitate the development of grasshoppers and locusts; the fifth discusses the action or reaction of grasshoppers and locusts to external or internal stimuli and the sixth refers to elements to design management strategies with emphasis on prevention.

Key words: Acridoidea, grasshoppers, locusts, acridoid control, sustainable management.

INTRODUCTION

The Orthoptera order encompasses a heterogeneous group of insects characterized by gradual metamorphosis, mouthparts made for chewing, and two pairs of wings, the anterior pair being thick and leathery and covering the folded second pair. The posterior legs have enlarged hind femora adapted for jumping. Two representatives of this order are grasshoppers and crickets. Most are herbivores, but some are omnivores or even carnivores (Hoell et al., 1998). The superfamily Acridoidea includes temperate and tropical species of short-horned grasshoppers, some of which can cause economically relevant amounts of damage to pastures and agriculture across the world (Anaya et al., 2000). More than 11,000 species of these insects in approximately 2,400 genera have been described to date (Otte, 1995). Outbreaks occur when the population densities grow abnormally high in response to weather conditions or food availability. Once the grasshoppers become abundant, there are few options for their suppression other than chemical insecticides.

Although farmers attempt to combat these plagues, when such outbreaks occur, their proportions are beyond the farmer's capacity (Lockwood, 2004). Plagues of locusts and grasshoppers originate from outbreak areas, which are natural habitats where the insects multiply and gregarize (Toleubayev et al., 2007). A preventive control strategy often aims to control locusts in restricted, remote, and improperly monitored outbreak areas (van Huis et al., 2007). However, monitoring and controlling acridoids in these areas require more than simply

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checking grasshopper populations; a close analysis of weather and vegetation in outbreak areas is required. In this paper, the physical characteristics of the natural habitats of the main species of the Acridoidea superfamily are discussed in relation to the biology of these insects in order to clarify the critical periods in which to apply control measures. While considering the above, this review also describes common characteristics of the main grasshopper and locust species, such as their biology, geographical distribution and physiological response to abiotic factors, in order to identify strategic elements for the design of a sustainable management program for these insect populations.

ACRIDOIDS AS IMPORTANT PESTS IN THE WORLD

Locusts and grasshoppers

The superfamily Acridoidea belongs to the suborder Caelifera and the order Orthoptera. Grasshoppers and locusts are acridoids, which have large hind legs for jumping, antennae that are generally shorter than their body, tympana that are present on the first abdominal segment and a short ovipositor. The term grasshopper refers to insects of small to medium size (2 to 7 cm), and the term locust refers to insects of large size (more than 10 cm) (Steedman, 1988; Launois and Luong, 1991; Barrientos, 1992). Locusts change color and behavior at high population density, forming swarms of adults or bands of wingless nymphs called hoppers. Adults can migrate over hundreds or even thousands of kilometers. True grasshoppers form neither bands nor proper swarms. However, the distinction between locusts and grasshoppers is not entirely clear (Cressman, 1997). There are some species, such as *Oedaleus senegalensis* and *Melanoplus sanguinipes,* that occasionally form small, loose swarms. Locusts such as the Tree Locust (*Anacridium* sp.) rarely form bands (Cressman, 1997; Pfadt, 1994a). Some locust species, such as the Australian Plague Locust (*Chortoicetes terminifera*), do not change shape or color in response to changes in population density (Creesman, 1997).

Locusts: The important species of locusts in the world are classified into three subfamilies of Acrididae: Cyrtacanthacridinae, Oedipodinae, and Gomphocerinae. Even within a genus, some species exhibit the swarming habits of locusts, while others lack the habit and never swarm. This is most obvious in the genera *Schistocerca*, in which a majority of the American species are non-swarming, and *Dociostaurus*, which has many non-swarming Asian species. *Locusta migratoria*, which extends from Australia and eastern Asia to Europe and West Africa, has a number of subspecies that differ in their propensity for swarming. The species usually regarded as locusts and their distributions are given in Table 1 (Steedman, 1988; Walton et al., 2003). In the subfamily Cyrtacanthacridinae, *Schistocerca* is the largest genus, containing about 50 species (Dirsh, 1974; Song, 2004).

Grasshoppers: According to several authors in the Table 2 shows the distribution of several important grasshopper species. For example Camnula pellucida, which is distributed in North America; Brachystola magna and Sphenarium purpurascens, located in northern and central Mexico; and Oedaleus senegalensis and Zonocerus variegatus, located in Africa (Kevan, 1977; Champman et al., 1986; Pfadt, 1994e, Pfadt, 1999;Cerritos and Cano, 2008).

GEOGRAPHIC DISTRIBUTION OF ACRIDOIDS

According to Latchininsky et al. (2011), grasshoppers and locusts are found on all continents except Antarctica (Figure 1). These insects live in diverse habitats, including the tropics, temperate grasslands, deserts and mountains (Latchininsky et al., 2011).

BIOLOGY AND LIFE CYCLE OF ACRIDOIDS

Acridoids are hemimetabolous insects that pass through three stages: 1) egg, 2) nymph and 3) adult (Evans, 1984; Symmons and Cressman, 2001). The nymphs and adults of hemimetabolous insects are usually similar in shape and habits (Coronado and Marquez, 1986). The number of nymphal instars is different between acridoids, depending on the species, sex and in some cases, the individuals (Pfadt, 1988; Luong and Balanca, 1999). Some species of Acridoids have one generation per year, while others have two or more (Ando, 1993; Alvarez et al., 2003) (Table 3). However, other species, such as *Brachystola,* complete one generation in two years (Burleson, 1974; Lozano and España, 1997). These insects have a dormancy, a state of suppressed development, which is either quiescence, an immediate and direct response to a limiting factor (e.g., temporary cessation of development if the temperature falls below a developmental threshold), or diapause, a more profound interruption that re-routes the metabolic program of the organism into an organized break in development that is not simply controlled by the direct action of environmental factors (in nature, diapause often precedes the advent of adverse conditions) (Danks, 1987). Dormancy is geared to the timing of the life cycle (egg, nymph and adult) in relation to the seasons. Some species of grasshopper, such as *Arphia conspersa* and *Arphia simplex*, exhibit diapause in the nymphal stage (Carpintera and Sechrist, 1999). Some acridoids can exhibit diapause or quiescence; for example, *C. terminifera* avoids dry periods with an embryonic diapause and survives dry periods as quiescent eggs or adults (Hunter et al., 2001). Female acridoids lay eggs in batches called egg pods, which are usually deposited in the soil, but some species prefer to

Table 1. Distribution of the most important locust species.

Subfamily	Scientific name	Common name	Distribution	Reference
Cyrtacanthacridinae	*Anacridium melanorhodon*	Sahelian tree locust	Sahel, eastern Africa, southwestern Arabian peninsula	Steedman, 1990
	Anacridium wernerellum	Sudanese tree locust	Sahel, eastern Africa	Steedman, 1990
	Nomadacris septemfasciata	Red locust	Central, eastern and southern Africa	Bahana and Byaruhanga, 1991; Steedman, 1990
	Nomadacris succincta	Bombay locust	Southwest Asia,	Roffey, 1979; COPR, 1982; Steedman, 1990
	Schistocerca cancellata	South American locust	South America	Roffey, 1979
	Schistocerca gregaria	Desert locust	Northern Africa, Arabia, Indian subcontinent	Steedman, 1990; Van Der et al., 2005
	Schistocerca piceifrons	Central American locust	Mexico and Central America	Harvey, 1983
Oedipodinae	*Chortoicetes terminifera*	Australian plague locust	Australia	Walton et al., 2003
	Locusta migratoria	Migratory locust	Southern Europe, sub-Saharan Africa, Malagasy Republic. Southern Russia, China, Japan, Philippines, Australia.	Steedman, 1990; Walton et al., 2003
	Locustana pardalina	Brown locust	Republic of South Africa, Mozambique	Steedman, 1990
Gomphocerinae	*Dociostaurus maroccanus*	Moroccan locust	Mediterranean countries, Middle Eastern countries east of Kyrgyzstan	Latchininsky, 1998

oviposit within the roots of plants. Grasshopper egg pods commonly contain 4 to 40 eggs. Females may produce 4 to 25 egg pods, and total egg production is often around 100 to 200 but can reach 500 eggs or more (Criddle, 1933; Carpintera and Sechrist, 1982). In the laboratory, experiments with *Melanoplus differentialis*, the maximum number of eggs deposited by a single female was 645, and the maximum number of egg pods deposited by a single female was 6 (Pfadt, 1994d). Table 4 presents the reproductive capacity of some species of Acridoidea considered to be important pests in the world.

CLIMATE FACTORS THAT FAVOR THE DEVELOPMENT OF LOCUSTS AND GRASSHOPPERS

The proliferation of insects is determined to a large extent by climate because temperature, light and water are major components of their growth and development (Iglesias and Rozensweir, 2007).

Temperature

Temperature is arguably the most important abiotic factor that insects experience because it affects their life processes at all levels of biological organization (Stillman and Somero, 2000). Therefore, laboratory studies have been performed to find temperature thresholds and determine the degree days (DDs) of insect development (Gregg, 1983; Fisher, 1994; Guzman, 1999; Chuanhong et al., 2008). A DD is a measurement of heat units over time, calculated from daily maximum and minimum temperatures. DDs are based on the rate of an insect's development at temperatures between the upper and lower limits of adaptation. The minimum temperature at which insects first start to develop is called the "lower developmental threshold," or baseline.

The maximum temperature at which insects stop developing is called the "upper developmental threshold," or cutoff. The lower and upper thresholds vary among species and have been determined for many, but not all, major insect pests (Logan et al., 2005). According to Ganwere (1991), the temperature range for the development of acridoids is between 16 to 40°C. Table 5 shows temperature thresholds, and Table 6 shows degree days for some species. This information can be used as a support tool for insect control; it allows knowledge of the distribution and the appearance of insects on crops and the susceptible stages of the insects. However, more information needs to be collected.

Rainfall

Rainfall is the main factor influencing the onset of

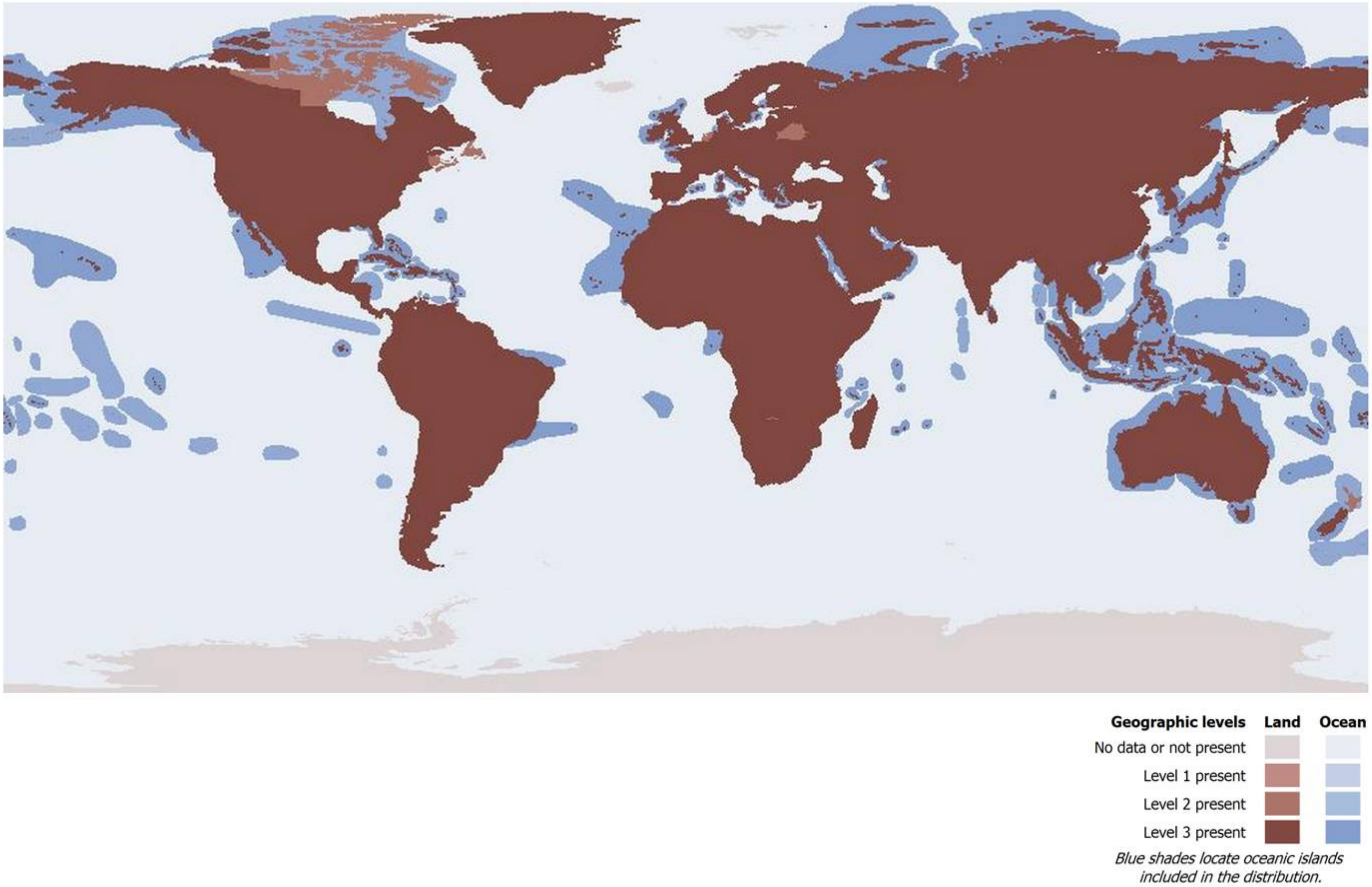

Figure 1. Worldwide distribution of grasshoppers and locusts (Eades et al., 2011).

insect development (Frith and Frith, 1990; Sabu et al., 2008). Rain is necessary for eggs to hatch in grasshopper species, such as *M. differentialis*, *M. sanguinipes*, *S. purpurescens* and *O. Segenalensis,* and in locust species, such as *C. terminifera*, *Locustana gregaria*, *Locustana pardalina*, *Sanicula gregaria* and *Sanicula piceifrons* (Rainey, 1963; Barrientos, 1992; Pfadt, 1994 a,b,d; Symmons and Cressman, 2001; Walton et al., 2003). Studies have been conducted to determine the minimum quantity of rain needed for breeding and egg hatching.

Bennett (1974) found that a minimum of 25 mm of rain was required for the successful breeding of *S. gregaria* and that more than 20 mm of rainfall was necessary for the development of *C. terminifera* (Phelps and Gregg, 1991; Walton et al., 2003). However, heavy rainfall can negatively affect the insect population. In a study of the relationship between monsoon rainfall and the population dynamics of *S. gregaria*, Chandra (1990) determined that heavy monsoon rainfall led to a decline in locust plagues and high locust mortality, especially at the egg stage, which was caused by excessive soil moisture.

ACRIDOID BEHAVIOR

Acridoids have two modes of behavior: 1) recession and 2) activity.

In a period of recession

The insects remain solitary and maintain low populations in favorable habitats. In this period, the insects do not cause damage, and the threat to crops and food security of the host country is insignificant. The duration of the recession period is from less than a year to several years (Cressman, 1997). During this period, acridoid outbreaks may occur. According to van Huis et al. (2007), recession periods of *S. gregaria* may last up to seven years.

An activity period

This occurs when the environmental conditions are appropriate for acridoid development and breeding.

Table 2. Distribution of several important grasshopper species.

Subfamily	Scientific name	Common name	Distribution	Reference
Melanoplinae	*M. bivattatus*	Two-striped grasshopper	Northern North America (In the United States extending from the Atlantic to the Pacific Ocean, in Canada extending from Nova Scotia to British Columbia).	Pfadt, 1994b
	M. femurrubrun	Red-legged grasshopper	North America (All of the United States and southern Canada and extending south through most of Mexico).	Pfadt, 1994c
	M. differentialis	Differential grasshopper	North America (central and western United States, northern Mexico, in Canada occurring in southern Saskatchewan and British Columbia).	Pfadt, 1994d
	M. sanguinippes	Migratory grasshopper	North America (Every state in the continental United States plus Alaska and every province in Canada).	Perez and Otte, 2003
	C. pellucida	Clear-winged grasshopper	North America (United States and Canada).	Pfadt, 1994e
Romaleinae	*B. magna*	Plains lubber grasshopper	Western plains of the United States and Mexico.	Pfadt, 1999
Pyrgomorphidae	*S. purpurascens*		Northern and central Mexico and Guatemala	Kevan, 1977; Cerritos and Cano, 2008
	Z. variegatus	Variegated grasshopper	Western and central Africa	Chapman et al., 1986; Idowu and Akinsete, 2001; Kekeunou et al., 2006
Oedipodinae	*O. senegalensis*	Senegalese grasshopper	Africa north of the equator, the Middle East, and the Indian sub-continent	Batten, 1969

When the population increases, outbreaks occur, resulting in migration to cultivated areas and heavy damage (Cressman, 1997). The majority of acridoids decrease their activity due to the environmental conditions. This occurs when winter comes and the dry seasons are present. It can occur in the egg, nymph and adult stages, depending on the species (Scott, 2006).

ELEMENTS OF DESIGN MANAGEMENT STRATEGIES

Concerns over the use of toxic pesticides in agriculture have driven the development of alternative strategies to reduce grasshoppers and locust populations (Skinner, 2000; van Huis et al., 2007). Integrated pest management (IPM), which aims to maximize pest control and plant health while minimizing cost and environmental impact, involves the use of a full spectrum of control measures in a coordinated, integrated and foresighted manner (Hill et al., 2002). Following these principles, strategies for the development of sustainable management programs for acridoids are discussed as follows:

1) A preventive scope: IPM is a concept that promotes preventive actions to preclude a pest problem instead of waiting for pests to arrive and then eradicating them. It implies treatment only when and where necessary. This means only applying when the above action thresholds have been exceeded. For the last 120 years, entomologists have looked for practical ways to prevent grasshopper damage. The geographical distribution, life cycles, behavior and diets of pest species have been described in detail in an effort to provide the knowledge to control their populations. Early researchers noted relationships between grasshopper abundance and various environmental factors, particularly the weather

Table 3. Number of generations per year of acridoids.

Insect	Specie	Number of generations/year	Reference
Grasshopper	*M. femurrubrun*	1	Pfadt, 1994c
	M. differentialis	1	Pfadt, 1994d
	M. sanguinippes	1	Pfadt, 1994a
	C. pellucida	1	Pfadt, 1994e
	S. purpurascens	1	Guzman, 1999
	O. senegalensis	3	Gehrkena and Ousamane, 1996
	Z. variegatus	1	Page, 1980
Locust	*A. melanorhodon*	1	Steedman, 1990
	A. wernerellum	1 to 2	Steedman 1990
	N. septemfasciata	1	Steedman, 1990
	N. succincta	1	Steedman, 1990
	S. cancellata	1 to 3	Hunter and Conzenso, 1990
	S. gregaria	3 to 6	Symmons and Cressman, 2001
	S. piceifrons p	2	Barrientos, 1992
	C. terminifera	2-4	Walton et al., 2003
	L. migratoria	2 to 4	Hong and Kang, 2004
	L. pardalina	2 to 4	Ando, 1993
	D. maroccanus	1	Alvarez et al., 2003

(Skinner, 2000). The best approach to grasshopper management is to avoid problem populations through cultural manipulation of their habitat. This is not always possible due to the highly dispersed nature of some species, and thus, chemical insecticides are commonly used (Capinera, 1999).

2) Monitoring populations in their natural habitats: Grasshopper management involves treating areas outside of cropping systems, and recommended strategies depend not only on the grasshopper population but also the time of year and location of the population. Locust and grasshopper survival and reproduction are dependent on exogenous biotic and abiotic factors in their environments (Matheson, 2003; van Huis et al., 2007). The complexity of these interactions makes the prediction of locust and grasshopper outbreaks very difficult. The most frequent condition is recession, in which populations remain at low levels without threatening agricultural zones (Capinera et al., 1999). Like other insect species, grasshoppers have the capability to produce more progeny than the environment can sustain. A state of dynamic equilibrium is achieved by an interaction between the biotic potential of the species and the resistance of biotic and abiotic factors in the environment. Biotic and abiotic control factors usually act together to limit population growth by reducing birth rates and increasing mortality or dispersal; thus, small modifications of some elements of the environment can cause exponential population growth (Hoy, 2008). An example of this was the swarm registered in June 1939 of 180 to 300 million locusts within a 60-square km area in Wadi Botha, South Africa (van Huis et al., 2007).

Surveying insect populations to identify reproduction periods and changes in density is essential to prevent outbreaks (Cressman, 2001). Most grasshopper species are univoltine, and the first nymphal instars have little mobility; thus, a good strategy to reduce population densities is the use of control measures against these immature stages, which also are more susceptible to chemical and biological insecticides (Barrientos and Almaguer, 2009). Nevertheless, a major complication in controlling the immature insects is that they are highly dispersed and spraying all individuals would be impossible or impractical (van Huis, et al., 2007). In the case of locusts and grasshoppers that complete two or more generations in a year, the control of the first generation's population is essential to maintain a low rate of reproduction in subsequent generations and to minimize the probability of an outbreak at the end of summer (Barrientos, 1992; Queensland, 2000; Ramírez and Romero, 2008).

3) Modeling insect growth, development and dispersal: Modeling is a fundamental and quantitative way to understand and analyze complex phenomena, such as insect populations and weather interactions. Mathematical models complement theory and experiments and have become widespread in sciences such as physics, chemistry, mechanics, materials, and biology

Table 4. Reproductive capacity of several species of acridoids considered to be important pests.

Insect	Species	Eggs per pod	Pods per female	Reference
Grasshopper	*B. magna*	20-35		Pfadt, 1999
	M. femurrubrun	50-150		Pfadt, 1994c
	M. differentialis	50-150	6 to 8	Pfadt, 1994d
	M. sanguinippes	20	20	Pfadt, 1994a
	C. pellucida	15-25	8	Pfadt, 1994e
	S. purpurascens	15-39	1 to 2	Serrano and Romero, 1990; Castellanos, 2001; Cerritos and Cano, 2008
	O. senegalensis	8 to 37	2 to 3	Steedman, 1990
	Z. variegates	17-98	6	Steedman, 1990
Locust	*A. melanorhodon*	150	3	Steedman, 1990
	N. septemfasciata	Mean 100 (20-195) solitarious, (20-100) gregarious	**5** under favorable conditions	Symmons, 1978; Steedman, 1990
	S. cancellata	73+- 18		Sanchez et al., 1997
	S. gregaria	20-100	2 to 3	Symmons and Cressman, 2001
	S. piceifrons	42-93, mean 68	1 to 4	Barrientos, 1992
	C. terminifera	30-60	4	
	L. migratoria	65 solitarious, gregarious less	1-2 (cool season); 3-5 (hot season)	Farrow, 1975
	L. pardalina	Mean 37 (solitarious), 47 (gregarious)	Mean 4-5, up to 11 in laboratory	Steedman, 1990
	D. maroccanus	20-30	Maximum 2 (solitarious), 5 (gregarious)	Skaf, 1972

Table 5. Temperature thresholds of various species of acridoids.

Species	Threshold (Temperature °C)							Reference
	Minimum						Maximum	
	Egg hatch	N1	N2	N3	N4	N5		
M. femurrubrun	9.8						42	Fisher, 1994
M. differentialis	8.8						42.3	Fisher, 1994
M. sanguinippes	10.4						43	Fisher, 1994
S. purpurascens		16.5	16.7	16.7	11.9	15.9		Guzman, 1999
S. piceifrons p.	13 and 16.5						38.5	Uvarov, 1935; Rodríguez et al., 2009
S. gregarea								
C. terminifera	19.8	12.23	11.13	19.27	16.78	21.45		Gregg, 1983
D. maroccanus	9						31	Quesada and Santiago, 2000
L. migratoria	14.17	15.84	16.64	16.8	16.35	15		Chuanhong et al., 2008

Table 6. Degree days of several species of acridoids.

Species	Degree day							Reference
	Egg hatch	N1	N2	N3	N4	N5	N6	
S. purpurascens	205.6	67.4	66.5	64.8	115	109		Guzman, 1999
S. piceifrons p.	405-432	110-114	137-143	137-144	151-157	166-173		Retana, 2000
L. migratoria	179.14	67.55	61.07	62.09	71.16	91.2		Chuanhong et al., 2008

(Thornley and France, 2007). Efforts to model insect biology, ecology, or dynamics must focus either on a single species or on a generalized grasshopper model to predict the dynamics of a community or a single grass-hopper species (*Melanoplus spretus*, *O. senegalensis* and *Z. variegatus*) or locust species (*L. pardalina, Nomadacris septemfasciata* and *C. terminifera)* (Skinner, 2000; Aagaard, 2009). Prediction of pest population changes over time and space is a strategic goal in pest management, and mathematical modeling is the major tool for this (Sharov, 1996). Some of the most important processes subject to locust and grasshopper modeling are: 1) patterns of spatial dispersal of insect populations, 2) suitability of weather and vegetation conditions for breeding, 3) suitability of weather conditions (mainly wind) for flight, and 4) development of eggs and hoppers as a function of temperature.

Modeling can complement field data on insect growth and development in order to gain a better understanding of population dynamics and to identify the most appropriate periods to perform surveys or control actions (Quijano et al., 2010). Several models have been used to integrate decision support systems to help with locust management (Holt, 1996; Cressman, 1997a; Deveson, 2002; Dutta et al., 2003). Tilch and Hanrahan (2000) reported a model for Brown locusts with the aim of understanding the mechanisms driving population fluctuation. Klass et al. (2007) published a model for evaluating the effects of environmental temperature and thermal behavior on the biological control of locusts (*L. pardalina, N. septemfasciata* and *C. terminifera*) and grasshoppers (*O. senegalensis* and *Z. variegatus*) using pathogens (*Metarhizium anisopliae* var. *acridum*). The ecosystem model published by Aagaard (2009) simulates the ecosystem dynamics of the Senegalese Grasshopper (*O. senegalensis*, Krauss). Currently, modeling efforts are directed toward predicting the effects of climate change on locust behavior (Tratalos et al., 2010).

4) Using weather and vegetation indexes as indicators of insect activity: Indexes based on agrometeorological variables help to determine the beginning and rate of nymph development and adult fecundity (Pickford, 1970; Hewitt, 1985). Also, vegetation can be used as an indicator of changes in grasshopper and locust behavior (Glogoza and Weiss, 1997). The FAO-supported Desert Locust Information Service (DLIS) analyzes rainfall data to identify areas that may be suitable for breeding or where green vegetation and locusts may be present. The DLIS utilizes temperature data to estimate the development rate of eggs and hoppers as well as to indicate whether it is warm enough for adults to take off. Wind and synoptic data are useful during periods when adults are likely to be migrating or if there is an invasion threat from a neighboring country (Cressman, 2001).

Van Der Werf et al. (2005) found that desert locust densities varied according to the amount and distribution of rainfall and the longevity of the annual green vegetation in the Red Sea coastal plain of Sudan, with virtually no locusts being observed in the dry season. They observed that locusts were prevalent only in the millet–Heliotropium plant community, which is found at sites with a fine, sandy soil texture and a comparatively high and long-lasting soil moisture in wadi deltas. These sites constitute less than 5% of the area of this part of the plain. Therefore, the authors concluded that surveys for early detection and control of desert locusts in this region could focus on millet cropping areas. The results suggest that the efficiency of monitoring migratory pest outbreaks in remote areas could be enhanced by using associations between plant communities and herbivorous insects to predict at-risk areas and target survey efforts.

5) Use of biological controls: Biological control relies on natural enemies to avoid or reduce the effects caused by a pest. This approach has proven to be effective in the management of locusts and grasshoppers, although control must focus on the first nymphal stages (Barrientos and Almaguer, 2009). The most well-known biological control agent for grasshoppers is the pathogen *Nosema locustae* (Canning). Extensive research and field testing were done to investigate the feasibility of using *N. locustae* as a long-term solution for grasshopper outbreaks. This pathogen is now available commercially, but its use and success in the field have been limited (Skinner, 2000). Laboratory research has been conducted by Kodjo (2007), who inoculated immature stages of *S. gregaria* and *O. zenegalensis* in Africa with *Paranosema locustae*; the results showed that mortality was significantly higher in the first, second and third instars.

Another organism utilized to control Acridoidea populations is *M. anisopliae acridum* (Driver & Milner).

Metarhizium is a naturally occurring fungus specific to locusts and grasshoppers. It will only infect and kill insects belonging to these groups. Although these alternatives are more expensive than chemical control, they are safer to use and preserve human and animal health and the environment (Mena-Covarrubias, 2009). According to Thomas (2000), a myco-insecticide (made with the entomopathogenic fungus *M. anisopliae* var. *Acridum*) has been used for the control of Brown and Red locusts in Africa with an effective control of 90%.

CONCLUSION

Grasshoppers and locusts share many biological and physiological characteristics. Both have the capability to rapidly increase their populations in response to suitable weather and vegetation conditions. When this happens, an outbreak begins, and these acridoids can leave their natural habitats and invade agricultural zones, devastating crops. Weather and vegetation conditions that initiate outbreaks are not always present, but they must be monitored every year with a combination of field surveys and population dynamics modeling to identify the events leading to an extraordinary increase in the insect population. Survey campaigns and control measures can be planned in effective ways to locate these events in space and time. The combination of these elements with biological control can help to regulate grasshopper and locust populations most effectively, preventing economically relevant damage to agricultural production.

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