Evaluation of Four Methods for Monitoring the Population of Desert Locust ***Schistocerca gregaria*** (Forskal) **in the Red Sea Coast, Sudan**

By

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Dedication

I have the pleasure to dedicate this effort to:

The soul of my parent,

my brothers,

my sisters,

my darling wife

and my daughter (Mohga)

It is the honor to dedicate this research for all of them.

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Abstract

The aim of this study is to develop an improved field survey technique for Desert Locust (solitary adults and hoppers); in comparison to the conventional method. Three methods (10m ×10, 20m×5 and 50m×2) were tested beside the conventional method (100m) in the Red Sea coast during the winter of 2012 and 2013. The study area extended from Tokar delta (N 18º 25´ 35.5″ /E 37º 43´ 52.3″) to Karora (N 17º 41´ 51.3″ E/38º 21´ 51.2″) and Oko area (N 20˚27´12″/ E 35º 48´32″) at one hundred and fourteen positions representing different Desert Locust habitats (plain, dunes and wadies).

The results show that the method designated as 20 m ×5 (means $62\pm^{a}$ in Tokar and $16.5\pm^{a}$ in Oko) was superior to the conventional method 100 m (means$36\pm^{b}$ in Tokar and $7.5\pm^{bc}$ in Oko), method 10 m × 10 (means$28.75\pm^{b}$ in Tokar and $6.0\pm^{c}$ in Oko) and method 50 m×2 (means $31.75\pm^{b}$ in Tokar and $11.0\pm^{b}$ in Oko) for detecting solitary adults at plain habitats with significant differences between the method designated as 20 m ×5 and other methods. But there was no significant difference between the four methods with regard to application time (mean application time for method designated as 20 m ×5 was $38.14\pm^{a}$ in Tokar and $13.48\pm^{a}$ in Oko, conventional method was $38.98\pm^{a}$ in Tokar and $11.5\pm^{a}$ in Oko, method designated as 10 m ×10 was $38.34\pm^{a}$ in Tokar and $6.0\pm^{a}$ in Oko and method designed at 50 × 2 was $38.69\pm^{a}$ in Tokar and $11.68\pm^{a}$ in Oko).

At wadi habitat The results show that the method designated as 20 m ×5 (means $48.25\pm^{a}$ in Tokar and $20.25\pm^{a}$ in Oko) was superior to the conventional method 100 m (means$27.0\pm^{b}$ in Tokar and $9.5\pm^{b}$ in Oko), method 10 m × 10 (means$23.5\pm^{b}$ in Tokar and$8.75\pm^{b}$ in Oko) and method 50 m×2 (means $23.25\pm^{b}$ in Tokar and $9.75\pm^{b}$ in Oko) for detecting solitary adults with significant differences between the method designated as 20 m ×5and the other methods.

But there was no significant difference between the four methods with regard to application time (mean application time for method designated as 20 m ×5 was 35.20$\pm^{a}$ in Tokar and 10.58$\pm^{a}$ in Oko, conventional method was 35.81$\pm^{a}$ in Tokar and 8.78$\pm^{a}$ in Oko, method designated as 10 m ×10 was 35.91$\pm^{a}$ in Tokar and 8.96$\pm^{a}$ in Oko and method designed at 50m × 2 was 40.56$\pm^{a}$ in Tokar and 8.39 $\pm^{a}$ in Oko)

At dunes habitat The results show that the method designated as 20 m ×5 (means 61.75$\pm^{a}$ in Tokar and 18.5$\pm^{a}$ in Oko) was superior to the conventional method 100 m (means31.75$\pm^{b}$ in Tokar and 8.0$\pm^{b}$ in Oko), method 10 m × 10 (means 28.25$\pm^{b}$ in Tokar and 8.5$\pm^{b}$ in Oko) and method 50 m×2 (means 29$\pm^{b}$ in Tokar and 8.75$\pm^{b}$ in Oko) for detecting solitary adults with significant differences between the method designated as 20 m ×5 and other methods. There was no significant difference between the four methods with regard to application time (mean application time for method designated as 20 m ×5 was 40.9$\pm^{a}$ in Tokar and 16.15$\pm^{a}$ in Oko, conventional method was 41.85$\pm^{a}$ in Tokar and 13.11$\pm^{a}$ in Oko, method designated as 10 m ×10 was 41.8$\pm^{a}$ in Tokar and 13.0$\pm^{a}$ in Oko and method designed as 50m × 2 was 41.19$\pm^{a}$ in Tokar and 13.4 $\pm^{a}$ in Oko).

When there were no solitary hoppers in the field charcoal was used to simulate hoppers and the four methods were applied to detect charcoal. Thus the charcoal detected and the application time for each method was recorded. The results show that method designated as 20 m ×5 (means 12.50$\pm^{a}$) was superior to the conventional method 100 m (means7.5$\pm^{b}$), method 10 m × 10 (means 9.0$\pm^{b}$) and method 50 m×2 (means 7.25$\pm^{b}$) for detecting simulated hopper at 50% levels of simulated hopper infestations with significant differences between the method designated as 20 m ×5 and other methods. There were insignificant differences between the methods with regard to the detection time (mean application time for method designated as 20 m ×5 was 1.17±^{a}, conventional method was 1.22±^{a}, method designated as 10 m ×10 was 1.11±^{a} and method designed at 50 × 2 was 1.11±^{a}).

At charcoal simulating 37.5% locust infestation the results show that method designated as 20 m ×5 (means 8.25±^{a}) was superior to the conventional method 100 m (means4.5±^{b}), method 10 m × 10 (means 3.50±^{b}) and method 50 m×2 (means 3.25±^{b}) for detecting simulated hopper with significant differences between the method designated as 20 m ×5 and other methods . There were no significant differences between the methods with regard to the detection time (mean application time for method designated as 20 m ×5 was 1.05±^{a}, conventional method was 1.07±^{a}, method designated as 10 m ×10 was 1.01±^{a} and method designed at 50m × 2 was 1.07±^{a}).

At charcoal simulating 25% locust infestation the results show that method designated as 20 m ×5 (means 6.75±^{a}) was superior to the conventional method 100 m (means 3.25±^{b}), method 10 m × 10 (means 1.75±^{c}) and method 50 m×2 (means 3.0±^{b}) for detecting simulated hopper with significant differences between the method designated as 20 m ×5 and other methods. Regard to the detection time there were no significant differences between the method 20 m ×5 (mean 1.09±^{a}), conventional method (mean1.07±^{ab}) and method 10m ×10 (mean1.02±^{ab}) but There were significant difference between method 50m × 2 (mean 0.95±^{b}) and the method 20 m ×5 (mean 1.09±^{a}).

When charcoal simulating 12.5% locust infestation the results show that method designated as 20 m ×5 (means 6.00±^{a}) was superior to the conventional method 100 m (means 2.00±^{b}), method 10 m × 10 (means 2.00±^{b}) and method 50 m×2 (means 2.75±^{b}) for detecting simulated hopper with significant differences between the method designated as 20 m ×5 and other methods.

Regard to the detection time there were significant differences between the method 20 m ×5 (mean 0.95±[b]) and method 10m ×10 (mean1.08±[a]). For the other methods (conventional method (mean1.05±[ab]), method 50 m×2 (means 1.07±[ab]) and method 10m ×10 (mean1.08±[a]) there is insignificant difference between them).

In 2013 there were solitary hoppers so the three proposed methods and conventional method used to detect solitary hoppers in different habitats (plain, wadi and dunes) at 34 position at Tokar Delta and Oko area, the result show that methods designated as 20 m ×5 (means 20 ±[a] in Tokar and 30 ±[a] in Oko) was superior to the conventional method 100 m (means10.75±[b] in Tokar and 14.5±[b] in Oko), method 10 m × 10 (means8.75±[b] in Tokar and 9.5±[b] in Oko) and method 50 m×2 (means 8.5±[b] in Tokar and 11.25±[b] in Oko) for detecting solitary hoppers at plain habitats with significant differences between the method designated as 20 m ×5 and other methods. There were significant differences between the four methods with regard to application time and method designated as 50m× 2 was record less application time than others methods (mean application time for method designated as 20 m ×5 was 12.44±[b] in Tokar and 8.5±[b] in Oko, conventional method was 17.66±[a] in Tokar and 14.52±[a] in Oko, method designated as 10 m ×10 was 19.28±[a] in Tokar and 13.87±[a] in Oko and method designed at 50m × 2 was 9.85±[c] in Tokar and 6.95±[c] in Oko)

At wadi habitat the result show that methods designated as 20 m ×5 (means 21.5 ±[a] in Tokar and 20.25 ±[a] in Oko) was superior to the conventional method 100 m (means10.25±[b] in Tokar and 9.5±[b] in Oko), method 10 m × 10 (means 9.75±[b] in Tokar and 8.75±[b] in Oko) and method 50m ×2 (means 10.75±[b] in Tokar and 8.5±[b] in Oko) for detecting solitary hoppers with significant differences between the method designated as 20 m ×5 and other methods. There were significant differences between the four methods with regard to application time and method designated as 50m× 2 was record less application time than others methods (mean application time for method designated as 20 m ×5 was $10.77\pm^{b}$ in Tokar and $6.76\pm^{c}$ in Oko, conventional method was $14.97\pm^{a}$ in Tokar and $11.76\pm^{a}$ in Oko, method designated as 10 m ×10 was $14.5\pm^{b}$ in Tokar and $11.03\pm^{b}$ in Oko and method designed at 50m × 2 was $8.07\pm^{c}$ in Tokar and $5.40\pm^{c}$ in Oko)

At dunes habitat the result show that methods designated as 20m×5 (means $18.75\pm^{a}$ in Tokar and $18.5\pm^{a}$ in Oko) was superior to the conventional method 100 m (means $8.50\pm^{b}$ in Tokar and $7.75\pm^{b}$ in Oko), method 10 m × 10 (means $8.00\pm^{b}$ in Tokar and $8.00\pm^{b}$ in Oko) and method 50 m×2 (means $7.75\pm^{b}$ in Tokar and $8.75\pm^{b}$ in Oko) for detecting solitary hoppers with significant differences between the method designated as 20 m ×5 and other methods. There were significant differences between the four methods with regard to application time and method designated as 50m×2was record less application time than others methods (mean application time for method designated as 20m×5 was $12.41\pm^{b}$ in Tokar and $9.99\pm^{b}$ in Oko, conventional method was $18.86\pm^{a}$ in Tokar and $17.66\pm^{a}$ in Oko, method designated as 10m×10 was $18.69\pm^{a}$ in Tokar and $16.95\pm^{a}$ in Oko and method designed at 50m × 2 was $9.90\pm^{c}$ in Tokar and $8.19\pm^{c}$ in Oko).

ملخص الأطروحة

هدفت هذه الدراسة الي تطوير وتحسين طرق مسح الجراد الصحراوي (انفرادي كامل وحوريات) مقارنة مع الطريقة التقليدية. اختبرت ثلاثة طرق (10م× 10 ، 20م×5 و 50م×2 بجانب الطريقة التقليدية (100م) في ساحل البحر الأحمر في الموسم الشتوي 2012 و2013م . منطقة الدراسة امتدت من دلتا طوكر (ع ″35.5 ′25˚18 / ط ً52.3 ´43˚37) حتى قرورة (ع ً51.3 41 º17/ ط ً51.2 ´21˚38) ومنطقة اوكو (ع ً12 ´27˚20 / ط ً32 ´48˚35) في 114 موقع مثلت مختلف بيئات الجراد الصحراوي (وادي، كثبان رملية وسهول).

اشارت النتائج إلي أن الطريقة المصممه علي 20م×5 (متوسط 62±[a] في طوكر و16.5±[a] في اوكو) تفوقت علي الطريقة التقليدية 100م (متوسط 36±[b] في طوكر و7.5±[bc] في اوكو)، الطريقة 10م×10(متوسط 28.75±[b] في طوكر و6.0±[c] في اوكو) و الطريقه 50م ×2 (متوسط 31.75±[b] في طوكر 11.0±[b] في اوكو) في اكتشاف الجراد الصحراوي الانفرادي الكامل في بيئة السهول مع اختلافات معنوية بين الطريقة المصممه علي 20م×5 والطرق الاخري. لاتوجد اختلافات معنوية بين الطرق الأربعة في زمن التطبيق (متوسط زمن التطبيق للطريقة المصممه علي 20م×5 كان 38.14±[a] في طوكر و 13.48±[a] في اوكو، الطريقه التقليديه كان 38.98±[a] في طوكر و 11.5±[a] في اوكو، الطريقة 10م×10كان 38.34±[a] في طوكر و 6.0±[a] في اوكو و الطريقه 50م ×2 كان 38.69±[a] في طوكر و 11.68±[a] في اوكو).

في بيئة الوادي اشارت النتائج إلي أن الطريقة المصممه علي 20م×5 (متوسط 48.25±[a] في طوكر و20.25±[a] في اوكو) تفوقت علي الطريقة التقليدية 100م (متوسط 27.0±[b] في طوكر و9.5±[b] في اوكو)، الطريقة 10م×10(متوسط 23.5±[b] في طوكر و8.75±[b] في اوكو) و الطريقه 50م ×2 (متوسط 23.25±[b] في طوكر و 9.75±[b] في اوكو) في اكتشاف الجراد الصحراوي الانفرادي الكامل مع اختلافات معنوية بين الطريقة المصممه علي 20م×5 والطرق الاخري. لاتوجد اختلافات معنوية بين الطرق الأربعة في زمن التطبيق (متوسط زمن التطبيق للطريقة المصممه علي 20م×5 كان 35.20±[a] في طوكر و 10.58±[a] في اوكو، الطريقه التقليديه كان 35.81±[a] في طوكر و 8.78±[a] في اوكو، الطريقة 10م×10 كان 35.91±[a] في طوكر و 8.96±[a] في اوكو و الطريقه 50م ×2 كان 40.56±[a] في طوكر و 8.39±[a] في اوكو).

في بيئة الكثبان الرملية اشارت النتائج إلي أن الطريقة المصممه علي 20م×5 (متوسط 61.75 ±[a] في طوكر و18.5±[a] في اوكو) تفوقت علي الطريقة التقليدية 100م (متوسط 31.75±[b] في طوكر و8.0±[b] في اوكو)، الطريقة 10م×10(متوسط 28.25±[b] في طوكر و8.5±[b] في اوكو) و الطريقه 50م ×2 (متوسط 29±[b] في طوكر و 8.75±[b] في اوكو) في اكتشاف الجراد الصحراوي الانفرادي الكامل مع اختلافات معنوية بين الطريقة المصممه علي 20م×5 والطرق الاخري. لاتوجد اختلافات معنوية بين الطرق الأربعة في زمن التطبيق (متوسط زمن التطبيق للطريقة المصممه علي 20م×5 كان 40.9±[a] في طوكر و 16.15±[a] في اوكو، الطريقه التقليديه كان 41.85±[a] في طوكر و 13.11±[a] في اوكو، الطريقة 10م×10 كان 41.8±[a] في طوكر و 13.0±[a] في اوكو و الطريقه 50م ×2 كان 41.19±[a] في طوكر و 13.4±[a] في اوكو).

عند عدم وجود العتاب الانفرادي في الحقل، استخدم الفحم لتمثيل العتاب. طبقت الاربعه طرق لاكتشاف الفحم. اشارت النتائج الي ان الطريقة المصممه علي 20م×5 (متوسط 12.50±[a]) تفوقت علي الطريقة التقليدية 100م (متوسط 7.5±[b])، الطريقة 10م×10(متوسط 9.0±[b]) و الطريقه 50م ×2 (متوسط 7.25±[b]) في اكتشاف العتاب الممثل علي مستوي اصابه 50% مع اختلافات معنوية بين الطريقة المصممه علي 20م×5 والطرق الاخري. لاتوجد اختلافات معنوية بين الطرق الأربعة في زمن التطبيق (متوسط زمن التطبيق للطريقة المصممه علي 20م×5 كان 1.17±[a] ، الطريقه التقليديه كان 1.22±[a]، الطريقة 10م×10كان 1.11±[a] و الطريقه 50م ×2 كان 1.11±[a]).

في مستوي اصابه 37.5% للعتاب الممثل، اشارت النتائج الي ان الطريقة المصممه علي 20م×5 (متوسط 8.25±[a]) تفوقت علي الطريقة التقليدية 100م (متوسط 4.5±[b])، الطريقة 10م×10(متوسط 3.5±[b]) و الطريقه 50م ×2 (متوسط 3.25±[b]) في اكتشاف العتاب الممثل مع اختلافات معنوية بين الطريقة المصممه علي 20م×5 والطرق الاخري. لاتوجد اختلافات معنوية بين الطرق الأربعة في زمن التطبيق (متوسط زمن التطبيق للطريقة المصممه علي 20م×5 كان 1.05±[a] ، الطريقه التقليديه كان 1.07±[a]، الطريقة 10م×10كان 1.01±[a] و الطريقه 50م ×2 كان 1.07±[a]).

في مستوي اصابه 25% للعتاب الممثل، اشارت النتائج الي ان الطريقة المصممه علي 20م×5 (متوسط 6.75±[a]) تفوقت علي الطريقة التقليدية 100م (متوسط 3.25±[b])، الطريقة 10م×10(متوسط 1.75±[c]) و الطريقه 50م ×2 (متوسط 3.0±[b]) في اكتشاف العتاب الممثل مع اختلافات معنوية بين الطريقة المصممه علي 20م×5 والطرق الاخري. في مايخص زمن التطبيق لاتوجد اختلافات معنوية

بين الطريقة المصممه علي 20م×5 (متوسط $1.09\pm^{a}$) ، الطريقه التقليديه (متوسط$1.07\pm^{ab}$) و الطريقة 10م×10(متوسط $1.02\pm^{ab}$) بينما هناك اختلافات معنوية بين الطريقه 50م ×2 (متوسط $0.95\pm^{b}$) و الطريقة المصممه علي 20م×5 (متوسط $1.09\pm^{a}$).

في مستوي اصابه 12.5% للعتاب الممثل، اشارت النتائج الي ان الطريقة المصممه علي 20م×5 (متوسط $6.00\pm^{a}$) تفوقت علي الطريقة التقليدية 100م (متوسط $2.00\pm^{b}$)، الطريقة 10م×10(متوسط $2.00\pm^{a}$) و الطريقه 50م ×2 (متوسط $2.75\pm^{b}$) في اكتشاف العتاب الممثل مع اختلافات معنوية بين الطريقة المصممه علي 20م×5 والطرق الاخري. في مايخص زمن التطبيق توجد اختلافات معنوية بين الطريقة المصممه علي 20م×5 (متوسط $0.95\pm^{b}$) و الطريقة 10م×10(متوسط $1.08\pm^{a}$). بالنسبة للطرق الاخري (الطريقة التقليديه (متوسط$1.05\pm^{ab}$) ،الطريقه 50م ×2 (متوسط $1.07\pm^{ab}$) و الطريقة 10م×10(متوسط $1.08\pm^{a}$) لا توجد اختلافات معنوية بينهم).

في 2013 م هناك حوريات انفرادية لذا الطرق المقترحة والطريقة التقليدية استخدمت لاكتشاف الحوريات الانفرادية في بيئات مختلفه (السهول ، الكثبان الرملية والأودية)، في 34 موقع في منطقة دلتا طوكر ومنطقة اوكو. اشارت النتائج إلي أن الطريقة المصممه علي 20م×5 (متوسط $20.0\pm^{a}$ في طوكر و$30.0\pm^{a}$ في اوكو) تفوقت علي الطريقة التقليدية 100م (متوسط $10.75\pm^{b}$ في طوكر و$14.5\pm^{b}$ في اوكو)، الطريقة 10م×10(متوسط $8.75\pm^{b}$ في طوكر و$9.5\pm^{b}$ في اوكو) و الطريقه 50م ×2 (متوسط $8.5\pm^{b}$ في طوكر و $11.25\pm^{b}$ في اوكو) في اكتشاف العتاب الانفرادي في بيئة السهول مع اختلافات معنوية بين الطريقة المصممه علي 20م×5 والطرق الاخري. هناك اختلافات معنوية بين الطريقه 50م ×2 والطرق الاخري فيما يخص زمن التطبيق والطريقه 50م ×2 سجلت اقل زمن تطبيق (متوسط زمن التطبيق للطريقة 20م×5 كان $12.44\pm^{b}$ في طوكر و $8.5\pm^{b}$ في اوكو، الطريقه التقليديه كان $17.66\pm^{a}$ في طوكر و $14.52\pm^{a}$ في اوكو، الطريقة 10م×10كان $19.28\pm^{a}$ في طوكر و $13.87\pm^{a}$ في اوكو و الطريقه 50م ×2 كان $9.85\pm^{c}$ في طوكر و $6.95\pm^{c}$ في اوكو).

في بيئة الوادي اشارت النتائج إلي أن الطريقة المصممه علي 20م×5 (متوسط $21.5\pm^{a}$ في طوكر و$20.0\pm^{a}$ في اوكو) تفوقت علي الطريقة التقليدية 100م (متوسط $10.25\pm^{b}$ في طوكر و$9.5\pm^{b}$ في اوكو)، الطريقة 10م×10(متوسط $9.75\pm^{b}$ في طوكر و$8.75\pm^{b}$ في اوكو) و الطريقه 50م ×2 (متوسط $10.75\pm^{b}$ في طوكر و $8.5\pm^{b}$ في اوكو) في اكتشاف العتاب الانفرادي مع اختلافات معنوية بين الطريقة المصممه علي 20م×5 والطرق الاخري. هناك اختلافات معنوية بين الطريقه 50م ×2

والطرق الاخري فيما يخص زمن التطبيق والطريقه 50م ×2 سجلت اقل زمن تطبيق من الطرق الاخري (متوسط زمن التطبيق للطريقة 20م×5 كان 10.77±^{b} في طوكر و 6.76±^{c} في اوكو، الطريقه التقليديه كان 14.97±^{a} في طوكر و 11.76±^{a} في اوكو، الطريقة 10م×10كان 14.5±^{b} في طوكر و 11.03±^{b} في اوكو و الطريقه 50م ×2 كان 8.07±^{c} في طوكر و 5.40±^{d} في اوكو).

في بيئة الكثبان الرمليه اشارت النتائج إلي أن الطريقة المصممه علي 20م×5 (متوسط 18.75±^{a} في طوكر و18.5±^{a} في اوكو) تفوقت علي الطريقة التقليدية 100م (متوسط 8.50±^{b} في طوكر و7.75±^{b} في اوكو)، الطريقة 10م×10(متوسط 8.00±^{b} في طوكر و8.00±^{b} في اوكو) و الطريقه 50م ×2 (متوسط 7.75±^{b} في طوكر و 8.75±^{b} في اوكو) في اكتشاف العتاب الانفرادي مع اختلافات معنوية بين الطريقة المصممه علي 20م×5 والطرق الاخري. هناك اختلافات معنوية بين الطرق الاربعة فيما يخص زمن التطبيق والطريقه 50م ×2 سجلت اقل زمن تطبيق من الطرق الاخري (متوسط زمن التطبيق للطريقة 20م×5 كان 12.41±^{b} في طوكر و 9.99±^{b} في اوكو، الطريقه التقليديه كان 18.86±^{a} في طوكر و 17.66±^{a} في اوكو، الطريقة 10م×10كان 18.69±^{a} في طوكر و 16.95±^{a} في اوكو و الطريقه 50م ×2 كان 9.90±^{c} في طوكر و 8.19±^{c} في اوكو).

CHAPTER ONE

INTRODUCTION

Man has interacted with the Desert Locust (*Schistocerca gregaria Forskål*) since ancient times as reflected in the decorations of the 6th dynasty Egyptian tombs (2420 BC) , Greek, Roman, Rabbinical, Biblical and Koranic literature, (Cressman and Hodson**,** 2009). It is a serious insect pest of agricultural crops and pastures mainly due to the vast area infested, the huge size of the swarms and its most voracious feeding habitat (Adeyemo and Longe, 2008). Its geographical range varies from a recession area of 16 million km² covering more than 25 countries, when locust densities are low, to an invasion area of 29 million km² covering over 65 countries, when locust densities are high (Van Der Werf *et al*, 2005). This is more than 20% of the total land surface of the world. During plagues the Desert Locust has the potential to damage the livelihood of a tenth of the world's population (Steedman, 1990).

When in the solitary phase, locust density remains low and poses no economic threat, but under favourable breeding conditions, population increases very fast and gregarious swarms are formed leading eventually to plagues. Locust outbreaks do not follow cyclical patterns but rather depend on weather conditions, as wind, rainfall and plant growth that encourage migration. (Despland, 1999).

There were nine major plagues between 1860 and 1997, 75% of which occurred between 1860 and 1963, but only 12% in the years since then. Plagues varied in duration from one to 22 years (Cressman, 1987) and the last one occurred during 1987-89 which required about $275 million to partly suppress its spread, that plague was followed by local upsurges during 1992 – 1994, 1997 – 1998 and 2004 (Lecog, 2003).

From 1963 till now FAO adopted strategy called preventive control strategy in which Desert Locust breeding areas are surveyed and monitored regularly to detect and control locust before swarming. Monitoring of locust breeding areas needs reliable sampling methods to detect solitary adults and hoppers early before they gregarize. Studies were therefore carried out to improve the sampling methods. In 2002 Ghaemain proposed a method called **M** pattern which was good but needed some improvement because it was rather complicated and needed four locust officers besides it leaves uncovered area of a Hectare by surveyors and required more time to perform. Another method was proposed by Mahmoud in 2006 which was called **A** pattern. This method also needs at least three locust officers to perform. There is also an uncovered area of a Hectare and it takes a long time to perform.

Therefore the objective of this study is to develop and test an improved ground survey method for estimation of populations of solitary Desert Locust and hoppers at the recession and breeding areas in Sudan taking note of the problems encountered in the **M** and **A** patterns described above.

CHAPTER TWO

LITERATURE REVIEW

2-1- Economic importance of Desert Locust:

The Desert Locust, *Schistocerca gregaria* (Forskal) is the most economically important locust. It is highly mobile, invade large area in a short period, its multiplication rate is very high when the conditions are favourable for breeding and it eats about its weight of fresh vegetation each day (Doranton and Lukok, 1990). This amount increase from 20mg for the first instar up to 2 – 3 g for the adult, however Wilps and Diop (1994) believe that the species feed less than the above mentioned amount, recently study at ICIPE revealed feeding rate up to three times of its body weight (Taha, 2000).

Desert Locust is capable of causing starvation in any country that lies in its invasion zone during major plagues. This actually happened in Ethiopia during 1958 plague when the loss was estimated by 167000 tons of grain. In Sudan 1954 about 55000 tons of grain was lost (Taha, 2000).

Abd El Rahman (1999) mentioned the following examples of crop losses caused by the desert locust:

Year	Country	Crop or estimated value of crops lost (£sterling)
1944	Libya Sudan	7000000 vines £ 390000
1950	India	£ 2000000
1952	Pakistan	£ 3850000
1953	Somalia	£ 600000

1954	Sudan	55000 tons grain
1955	Morocco	£ 4780000
1957	Senegal Guinea Tunisia	16600 tons millet and 2000 tons other crops 6000 tons orange £ 900000
1962	India	4000 ha (10000 acres) cotton

For the 9 year period 1949 – 57 the FAO estimate of total value of crop damage in 12 countries, from some 40 subject to invasion, was £ 15 million. The other 28 suffered no appreciable damage in these years. Little damage occurred since the end of the plague in 1963, due to the efforts of national and regional organizations established to prevent plagues (Abd El Rahman, 1999).

2-2- Morphology:

Meinzingen (1993) mentioned that Male is 60-75 mm long and female is 70-90 mm long. In the solitarious phase, adults are pale yellow, grey or beige in the older forms, only mature males show a slight yellowing of the hind wings. Solitary hoppers are usually green or brown, without any black marking. Lecog and Balmat (2007) indicate that In the gregarious phase, adults undergo considerable colour changes. Immature adult are pinkish in colour, when immaturity is prolonged (imaginal quiescence) due to unsuitable breeding conditions (shortage of rainfall and/or inadequately low temperatures), hoppers become progressively dark red or brown. This phenomenon is noted in quiescent populations of the Mediterranean region under cold weather conditions. Sexual maturity is attained when ecological conditions become suitable for breeding. Locusts then gradually turn to a highly characteristic bright yellow. For a certain period of time, locust populations can be composed of a mixture of red and yellow coloured locusts. Symmons and Cressman (2001) showed that gregarious hoppers are black at first instar and typically yellow and black from second to fifth instars, the extent of blackness depends on the degree of gregarisation. The transiens form the solitarious phase to the gregarious and vice versa is called the transient phase. Lecog and Balmat (2007) said that wing colours are transparent, pale yellow, pinkish or reddish. No brown or blackish spots or crescents. Male cerci are square, which is highly characteristic and distinguishes them from *Anacridium spp.*, whose cerci are cone-shaped and pointed at the end. Desert Locust hoppers can be easily confused with those of *Anacridium spp.* which have many highly characteristic small white tubercles on the hind part of the pronotum.

2-3- Life cycle:

2-3-1- Mating:

Mackean and Ian Mackean (2011) mentioned that during mating the male locust mounts the back of the female, applies the tip of his abdomen to hers and passes sperms into her reproductive tract. The sperms are stored in a sperm sac in the female's abdomen, and as the eggs pass down the oviduct during laying, the sperms are released and so fertilize the eggs.

2- 3-2- Eggs:

Roffey and Magor (2003) indicated that after mating, the female lays her eggs in warm, moist sand following a rainy spell. It pushes her abdomen down into the sand, extending the membranes between the segments, and burrowing to a depth of 50 or 60 mm. In this burrow, 50 to 100 eggs are laid and mixed with a frothy fluid, which hardens slightly and may help to maintain an air supply round the eggs. Egg needs to absorb approximately their own weight of water to complete their development.

Steedman (1990) Showed that duration of incubation is 10-14 days in summer breeding areas of Africa, Arabia, India and Pakistan where mean air temperatures exceed 25 ^{o}C. Roffey and Magor (2003) reported that in the winter-spring breeding areas of Arabia and the Middle East temperatures decrease to a minimum in January. Between November and February, reported incubation periods increased from 15 to over 60 days and then decreased markedly to 11-15 days between March and June. In the Eastern Region, breeding on winter rains is confined to the coastal areas of southern Iran and western Pakistan and incubation reports vary from 15 to 22 days. Laying occurs further north and at higher altitudes between February and March and incubation periods shorten as temperatures rise. They are highly variable ranging from 10 to 40 days. By May, laying would cease in coastal areas, temperatures would rise and incubation periods would be mainly between 14 and 21 days. Steedman (1990) said that in the winter-spring breeding area of Northwest Africa incubation periods is 10 – 60 days. Laying in the coldest month, January is restricted to the western coast of Morocco and the northwestern coast of Libya. From February as temperatures rise, laying is more widespread and occurs at greater altitudes.

2- 3-3- Hopper development

Hatching usually occurs within two to three hours after dawn (Steedman, 1990). Symmons and Cressman (2001) said that during hatching, the emerging hoppers work their way up through the froth plug to the surface. They immediately moult to the first instar. The hoppers then pass through five instar (gregarious phase) or six instar (solitary phase), moulting between each.

Most studies on the duration of hopper development concerned the effects of temperature and humidity. Laboratory and field cage studies showed a linear relationship between temperature and development that can be used to estimate hopper durations (Roffey and Magor, 2003). The correlation with air temperature is less clear than with egg because the hoppers can control their body temperature to considerable extent by basking or seeking shade (Symmons and Cressman, 2001). Meinzingen (1993) indicted that in the summer and monsoon breeding areas (West Africa, India and Pakistan), most hopper development periods lay within the range 27-36 days. Hopper development periods during the short rains in eastern Africa were between 31 and 45 days. On the long rain in Eastern Africa, coastal plains around the Red Sea and Gulf of Aden, development periods were between 27 and 47 days. The hoppers development periods at the winter-spring breeding areas in Arabia, the Middle East and the Eastern Region is 25 – 57 days, and in the Northwest Africa varied from 28 - 49 days.

2-3-4-Egg and hopper mortality:

2-3-4-1- Egg mortality:

Symmons and cressman (2001) showed that the proportion of egg that survives to hatching varies widely according to habitat condition and the presence of egg parasites. Egg can dry especially if exposed by wind, and can also be destroyed by persistent flooding; however such events are not common. High mortality may occur if soil temperatures are above 35Cº. Estimation of total loss is varries from about 5 – 65 percent because of inviability (less than 10%), failure to hatch (3-4%), predation (less than 40 percent), mould, bacteria and desiccation(less than 10%). Generally the average loss in solitary is 13% and in gregarious 33%.

2-3-4-2- Hopper mortality:

Greathead (1966) summarized data on parasitism and predation among hoppers. He noted that rates varied greatly. Whilst agreeing with Dempster (1963) that rainfall was a major factor affecting survival, he disagreed with the assumption that natural enemies would be unable to breed throughout the year and thus could never be effective in controlling hopper populations. In support of this view, he cites the importance of natural enemies in Red Sea habitats close to wadi cultivations where they caused high mortality. In addition, he notes that rates of predation can be high in seasons and places where locust and bird migrations coincide. He concluded, after estimating the rates of mortality from other factors, that natural enemies would have little effect on reducing large gregarious populations but could hasten the decline of diminishing populations.

Roffey and Magor (2003) said only two complete studies on hopper mortality exist for solitarious populations. Both took place on the coast of Eritrea near or in seasonally cultivated areas on parts of dissociated populations. In addition, these habitats are not typical of many solitarious breeding areas because they contain considerable areas of perennial vegetation. In both studies, unexplained mortalities were high in early instars, recording the highest mortality of first instars (76 percent) in open parts of the habitat. Stower and Greathead (1969) found an unexplained loss of 50 percent in the first two instars and attributed it to the elimination of unsuitable genotypes. They also noted that these early losses were so widely observed, that they may be universal.

2-3-5- Adults:

2-3-5-1- Fledglings and immature adults:

It takes about ten days after fledging for the adult’s wings to harden sufficiently so that it is capable of sustained flight. The adults then remain immature until they encounter conditions that stimulate maturation. This period is highly variable, depending on habitat conditions, and it may involve migration to another area where more favourable conditions exist. (Symmons and Cressman, 2001).

2-3-5-2- Maturation:

Steedman (1990) reported that Desert Locust may become sexually mature in few days or a few months, according to environmental circumstances. In unfavourable weather and food condition, as for instance when they are subjected to low temperature and drought maturation may take as long as six month. If they have the right kind of food and weather, maturation can take place rapidly in 2 – 4 weeks. The exact conditions that cause locust to mature are not known but the process is usually associated with the start of the rainy season. Male locusts start to mature first and then give off from their skin a chemical substance the odour of which cause maturation to start in females, and in any males in which it has not already begun.

2-3-5-3- Swarming:

Mackean and Ian Mackean (2011) mentioned that if food is in adequate supply and the hoppers are not forced to crowd together when they emerge from the eggs, the locusts live their lives separately as do other grasshoppers. If, however, the hoppers are crowded together for one reason or another, they enter a gregarious phase of activity. The hoppers tend to keep together in a band and move forward together. The crowding effect also results in a change of colour from the normal green, buff or brown to a striking black and yellow (or orange) coloration. There are also structural differences from the solitary form. Steedman (1990) showed that the bands of hoppers vary in size from hundreds to millions, covering a few square metres or several square kilometers, depending partly on the age of the hoppers and how many bands have combined. Mackean and Ian Mackean (2011) indicated that hoppers migrate only a few kilometres each day, basking in the early morning sun until their body temperature rises to a level which allows them to move off and eat all the vegetation in their path. When the temperature drops at night they climb bushes and plant stems and remain immobile. After the final ecdysis, the adult locusts take to the wing and after a few days of short flights set off on extensive migrations, settling at night and in the middle of the day when it is hottest. Symmson and Cressman (2001) showed that medium-sized swarm may contain million locusts and cover an area of 20 square kilometers. Such a swarm will consume some 3000 tones of vegetation per day; and so if a swarm lands on agricultural crops, the locusts will strip them of every vestige of leaf and edible stem. The swarms may travel many hundreds of kilometers from their place of origin, e.g. from Africa to India, and the females will lay eggs during their journey, so leaving the nucleus of successive swarms within a few weeks.

2-4- Ecology and behavior:

Desert Locusts change phase in response to population density: ‘solitarious’ insects avoid one another, but when crowded they shift to the gregarious phase and aggregate. This individual-level process is the basis for population- level responses that may ultimately include swarm formation. (Despland *et al*, 2000).

Desert Locusts breed in areas that have received enough rain (usually at least 25-50 mm) which provides moisture for egg development and for vegetation to grow or regenerate and provide food and shelter for hopper development (Roffey and Magor, 2003). It has a high requirement for food nitrogen or protein and selectively feeds on host plants with high nitrogen content. (Van Huis *et al*, 2008).

Lecog and Balmat (2007) Indicated that this species mainly gathers in dry environments with open steppe vegetation, including *Panicum turgidum* and *Acacia ehrenbergiana* or ephemeral formations of *Tribulus mollis* and *Shouwia thebaica*. Solitary locusts fly at night during calm periods when temperatures are above 25°C and can be captured by light traps at such times. In contrast, swarms migrate during the day and colonize areas thousands of kilometres away.

2- 4-1- Gregarzation:

Locusts occur in two different form called phases: solitarious and gregarious. When locusts are present at low densities, the individuals stay solitarious. But when numbers increase, they cluster into dense groups and become gregarious (Symmons and Cressman, 2001).

Gregarization is a complex phenomenon, including morphological and behavioral changes. (Despland *et al*, 2000). Maeno and Tanaka (2011) mentioned that a typical example afforded by the Desert Locust is continuous variation in hatchling characteristics. Hatchlings at low population densities (solitarious phase) are typically green in colour, whereas those under crowded conditions (gregarious phase) are darker and longer in size. However, a few hatchlings, intermediate in size and colouration are also observed. These density-dependent differences, which influence subsequent development, morphology and body colouration in Desert Locusts, are caused by the crowding conditions experienced by the female parent. In *Schistocerca gregaria*, the maternal determination of hatchling characteristics plays an important role in the trans-generational changes in phase characteristics. The details of the underlying mechanism controlling progeny gregarization remain largely unknown.

Le Kang, *et al* (2004) explained that the gregarious traits and behavior are regulated by pheromones, also artificial physical stimulation on the hind legs of the Desert Locust can trigger phase transformation. In addition, foam from the reproductive glands of the crowded female encourages gregarious behavioral features and even affecting the color of young hoppers.

Maeno and Tanaka (2011) explained that during the nymphal stage, behavioural gregarization is induced most strongly by mechanical stimulation perceived by the legs. The maternal determination of progeny body size and colouration depends on tactile stimuli from other individuals. However, these stimuli are perceived by the antennae.

Despland *et al* (2004) indicated that Desert Locust outbreaks are generated by three co-occurring and mutually interdependent processes: concentration, multiplication and gregarisation. Concentration occurs when habitat availability forces locusts to aggregate in certain areas, multiplication is reproduction then population growth and gregarisation is the process by which individual locusts change phase and form cohesive groups.

Magor *et al* (2008) showed that outbreaks and upsurges form successive stages in the continuum of plague development. Outbreaks occur when rains make areas favourable for breeding and the numbers and density of the background population increase sufficiently for bands and swarms to form. Only rarely are seasonal rains sufficiently widespread, heavy and prolonged to give rise to many concurrent outbreaks. Symmons and Cressman (2001) showed that upsurges are a result of successful breeding over a number of generations by an initially small population. With successive generations, the proportion of the total population in bands and swarms increases until few scattered locusts remain; the total number of locusts increases as does the size and coherence of the bands and swarms. Several outbreaks that occur at the same time followed by two or more generations of transient-to-gregarious breeding can lead to an upsurge. Magor *et al* (2008) indicated that finally, the area infested falls dramatically as swarms and bands replace the extensive areas of less dense non gregarious infestations. Symmons and Cressman (2001) said that plague can occur when favourable breeding conditions are present and control operations fail to stop a series of local outbreaks from developing into an upsurge that cannot be contained.

Meinzingen (1993) mentioned that the transition from recession to major plague takes about two year during which overall numbers may rise by a factor of about 1000. If the sequence of widespread and heavy rain interrupted, an upsurge will be halted before it becomes a plague.

2-4-2- How and why do swarm form?

The weather plays a critical role in locust population growth and swarm formation, because it promotes growth of host plants and provides soil moisture for egg development. (Symmons and Cressman, 2001). Simpson (2006) mentioned that individual-based computer simulations, laboratory and field experiments have shown that the fine-scale spatial distribution and quality of resources in the habitat can either promote or deter contact among individuals, and hence influence the probability of locusts entering the gregarious phase. Clumping of food plants or areas of favourable condition encourages solitarious locusts to come into contact and gregarise, despite their initial tendency to be repelled by one another. In contrast, more dispersed resources allow solitarious locusts to avoid one another and inhibit gregarisation.

2-4-3- Migration:

Symmons and Cressman (2001) mentioned that temperature and wind influence the migration of both solitary adults and swarms. Solitary adults fly for only a few hours at night. Cressman (1987) showed that swarms generally take off several hours after sunrise in warm weather and fly throughout the day until just before or just after sunset. On especially hot days, swarms may settle around midday and take off again in the afternoon. Temperature limits the height of flight. Swarms are thought to fly between 1,500 and 1,800 meters above the surface of the ground. All major swarms travel downwind. In sunny warm weather, swarms tend to fly about 10 hours, but they have the ability to fly continuously for 13-20 hours. A swarm is displaced at some fraction of the wind speed because many of the adults spend some time on the ground. The ground speed of a swarm is usually about 20-50% of the wind speed. The average daily rate of net displacement of swarms varies from 5 km in cool weather to 200 km in warm weather with a consistent wind direction. Steedman (1990) reported that desert Locust adults can migrate great distances in a short time. They can stay in the air for long periods, for example, they regularly cross the Red Sea, a distance of more than 300 km, and in October 1988 a large number crossed the atlantic Ocean to the west Indies, a distance of nearly 5,000 km.

2-5-Distribution:

The Desert Locust is one of about a dozen species of short horned grasshoppers that can form adult swarms or, bands of wingless nymphs called hoppers. (Ibrahim *et al*, 2000).

The total area subject to invasion by Desert Locust swarms is the greatest known among all locusts, and cover the whole of west and north Africa, Eastern Africa, all countries of the Middle East up to Turkey and the southern of most Soviet Republics, Iran, Afghanistan, Pakistan and the northern half of India (Uvarov, 1955). Desert Locust have been record in the Atlantic Ocean (In 1989 the swarm reached the Caribean and the northern part of south America) the British Isles, the Mediterranean, Italy, Greace, the Red Sea, the Gulf of Aden, the Arabian Sea and Arabian Gulf (Meinzingen, 1993).

2-6-Desert locust survey

Surveys are undertaken to collect information in order to clarify whether locusts are present or not, estimate the infested area, estimate the locust density, describe locust behavior and describe the state of habitat (Taha, 2000). Based on the results of a survey, the need for further surveys or the initiation of control operations can be determined. During surveys, control targets may be identified so that decisions can be made on the most suitable control method. Additional information can be collected during surveys from villagers, nomads and travelers (Cressman, 2001).

Woldewahid, *et al* (2004) mentioned that monitoring the build-up of solitarious locusts to deploy timely control effort before development of upsurges or plagues is the currently favoured strategy, but this is problematical because the area to be monitored is large and difficult to access. Many outbreaks in the past were not detected until they had become too large. Ground surveys are the principal means for monitoring the build-up of solitarious Desert Locust populations. Ground survey teams focus on places that are considered harbour substantial numbers of locusts; these are areas of green vegetation. Taking into consideration the limited resources for sampling and the vast areas to be surveyed, it is crucial that sampling is optimally targeted.

2-6-1- Survey types:

Cressman (2001) explained the following types of survey:

2-6-1- 1- Assessment survey:

The purpose of assessment surveys is to (1) monitor locust populations and assess the suitability of the habitat for breeding, and (2) determine whether significant populations are present that may require control. Assessment surveys are conducted in areas that have a history of locust breeding or presence, or where rain has recently been reported or thought to have occurred, or where reports of locusts have been received from locals, nomads, scouts or agricultural extension agents. Estimates of locust densities made at each survey stop can be used to identify those areas where significant numbers of locusts are present.

2-6-1-2- Search survey:

Search surveys are conducted in areas known to contain significant populations in order to (1) estimate the total infested areas, and (2) delimit the areas that require control. Results from searching will allow decisions on if, when and how control should be conducted.

2-6-2- Survey methods:

There are three survey methods: feet transect, vehicle transects and aerial transect. These methods can be used for assessment or search surveys (Cressman, 2001).

2-6-2-1-Ground survey:

Ground surveys are the principal means for monitoring the build-up of solitarious Desert Locust populations (Woldewahid, *et al* 2004).

Cressman (2001) said that the amount of time spent at each stop during a ground survey session will determine how many stops can be made in a day

.Usually 15-20 minutes at a single stop are enough to collect the required information and still allows about six to ten stops to be made during a morning or afternoon of survey. The locusts counted during foot and vehicle transects can be used to compare the relative numbers of locusts seen at different stops made during this or other surveys.

Cressman (2001) explained the following type of ground survey:

2-6-2-1- 1- Foot transect:

A foot transect consists of walking a certain distance (maximum 400 m) in an open area collecting data about locusts, rainfall, vegetation and soil.

2-6-2-1-2- Vehicle transect:

Vehicle transect is a useful method to determine the presence of adults over a large area, such as a sandy plain or within large areas of green vegetation. By counting the adults, an estimate can be made of how many are present in the transect.

Estimates of adult number can be made from a vehicle by looking out of the wind shield and counting adults that fly up in front of the vehicle in a strip equal to the width of the vehicle (about 1.5 m in most cases). The vehicle must be driven at a walking pace in low gear. It should be driven a distance of one kilometer and upwind or crosswind to reduce the number of adults that are counted more than once.

2-6-2-2- Aerial survey:

Taha (2000) explained that flying low in a fixed-wing aircraft with an experienced observer can get a quick overview of large area and have an idea about location of recent rains and green vegetation, this help in directing the ground teams to conduct detailed investigation in the located areas. Helicopter is ideal mean for aerial survey, because it can land where ground investigations are necessary. Generally the aerial survey is very expensive and requires supporting by the ground teams.

The most suitable fixed-wing aircraft for green vegetation and hopper band surveys are those with high wings to allow better visibility.

Cressman (2001) showed that surveys for vegetation should be undertaken at the beginning of the rainy season to identify those areas that are first becoming green. Surveys may be repeated midway through the season and once again at the end of the season. Surveys of flying swarms should be undertaken when they are most likely to be seen; the pilot should fly about 50 m above the ground so that the maximum number of locusts are above the horizon and will look similar to smoke cloud. In order not to miss swarms, the same area should be surveyed every three to four days and adjacent areas checked on successive days. Hopper band surveys should be undertaken in the early morning and in late afternoon. Bands are easy to see from the air if they are in dense groups; bands should be visible up to about 500 m or more from the aircraft when there is little ground vegetation or in areas of scattered trees and shrubs.

Van Der Werf, *et al* (2005) mentioned that knowledge about the habitats of the desert locust is partly based on reports of reconnaissance surveys such as those in which remote desert areas were traversed by vehicles for weeks or months at a time. By necessity, such surveys are selective, focusing on habitats where locusts are expected or reported to be present by word of mouth. As a consequence, the information obtained in such surveys gives an incomplete and potentially biased estimate of the likelihood of finding solitarious Desert Locusts in different habitats.

2-7-Desert locust control

The original locust control strategy assumed that plagues arose when swarms escaped from outbreak areas and bred successfully in the surrounding invasion area (Magor, *et al* 2008).

Cressman (1987) said over the years, strategies of Desert Locust control have evolved from curative efforts to an emphasis on prevention that is finding and treating infestations before they form large hopper bands and swarms. This requires regular monitoring of locust breeding areas and the ability to quickly mount small scale control operations in many of the 60 countries affected by the desert locust. Currently, about 18 countries in Africa, the Middle East and southwest Asia maintain a regular survey program for monitoring the desert locust these are countries that are frequently infested and have therefore established specialized anti-locust units responsible for survey and control. These units are usually part of the Ministries of Agriculture under the supervision of the Plant Protection Departments. Some units are autonomous while others are incorporated into the national plant protection or agricultural extension programs.

Latchininsky and Sivanpillai (2010) showed that under the preventive mode, locust control specialists also need information on elevation (or topography), soil moisture, temperature and rainfall, in addition to the vegetation type, status and growth. Specialists use this information to set up effective surveys to assess locust egg-pod or nymphal distribution.

Davis et al (1998) showed that there are two views on locust control strategies - preventing the problem at source or trying to deal with locust swarms when they are in the air. These different approaches arise as a result of the locust’s life-cycle and the habitat in which it breeds. The preventive approach seeks to monitor locust breeding areas and spray as gregarising populations of locusts are identified. This is difficult in practice, as many of the principal breeding zones are difficult to reach. The cost and effort of infrastructure and communications required is considerable. In many areas (Mali, Niger, Chad, Ethiopia and Sudan) there is or has been until recently civil war. The other approach aims to identify and deal with the result of the exponential increase in the gregarised population that eventually leads to a plague or swarm. This involves aerial spraying of the swarm in flight, or trying to prevent crop damage in areas in the path of a swarm. This requires resources that can be extensively deployed at short notice. Swarms often dissipate as a result of wind, rain and lack of food, making the role of chemical control in ending the swarm unclear. The most appropriate control will therefore depend on whether prevention at source, or destruction of swarms, is the objective.

Meinzingen (1993) showed that gregarious groups of nymphs are called hopper bands and large groups of adults are called swarms. Locusts may also be in a transiens phase – somewhere between solitarious and gregarious phases. Adults may either be sexually mature i.e. ready to mate and lay eggs or immature.

Dobson (2001) indicated that if control is necessary, the factors which determine the methods used include the following:-

- Size of infestation:

If the targets are small and few in number, they can be controlled using low speed, simple methods. However, if the infestation is heavy and widespread, is required to treat large areas quickly.

- The stage of locusts:

If adults are encountered, a quick response and fast work rate are usually required to prevent them migrating to other areas, especially if they are sexually mature.

- The location of infestation:

If bands or swarms are close to crops, there is even greater need for a method that can start quickly and give rapid results. There is also the opportunity for valuable assistance from the farming community.

- The resources available for control:

Sometimes the most appropriate equipment or materials are not available at the right place at the right time but control must be carried out with whatever is available.

2-7-1- Control methods:

2-7-1-1- Mechanical control

Methods such as digging trenches for hoppers to fall into, beating hoppers with branches, burning and tillige are sometimes used as a last resort to try to protect crops (Yagoub, 1999). In some societies people believe on a magician man that he can drive away swarm of locust from their crops (Khalaf-Alla, 2004).

Cressman (1987) said that mechanical control may prevent some crop damage if the locust infestation is light, but they have little effect on the overall population in the region and can fail to protect crops when there are locusts continuously invading the fields. Locust eggs in the ground are sometimes dug or ploughed up but this is a laborious work and it is difficult to find many of the locust egg beds without very good information on previous swarm laying sites.

2-7-1-2- Baiting

Meinzingen (1993) indicate that bating involves the mixing of the insecticides, supplied as dust, with carrier normally bran, ground nut or similar food material. The insecticide dust usually contains a small amount of active ingredient (a. i.). The bait may be applied by hand or shovel from bag/sacks or from the vehicle in the path of hopper bands. The disadvantage are logistic involve in the transport/ re-transport of large quantity of the bait and it application. It is not effective for large scale control. Steedman (1990) mentioned that the advantage of bait is: it require no machinery and it can be carried out by relatively unskilled labour.

2-7-1-3- Dusting

Dusting involves mixing pesticide dust with a material such as powdered chalk or talc and scattering it on the locusts. Like baiting, insecticide dusting has the advantage that it can be carried out without specialist application equipment – a hessian bag of dust beaten with a stick has commonly been used

(Dobson, 2001).The experience has shown that the best result are obtained when dusting is carried out under moist condition and target is first instar hoppers particularly as they hatch (Steedman, 1990). However, many countries have given up dusting because of the large quantities of product to be transported and applied (up to 10 kg/ha), and to the fact that control is sometimes poor, especially with later instar hoppers and adults. There is also a health risk to operators who may accidentally inhale the dust (Dobson, 2001).

2-7-1-4- Spraying

Spraying is the most commonly used method for locust control. It involves using a sprayer to atomize a liquid pesticide, i.e. to break it into droplets, which are then distributed over the target area (Dobson, 2001).

2-7-1-4-1- Spray type:

Some different types of spraying are described by Dobson (2001):-

2-7-1-4-1-1-Water-based spraying:

Water-based spraying is common in conventional agricultural crop protection. It usually involves applying hundreds of litres of insecticide/water mixture per hectare. The insecticide formulation, i.e. the mixture supplied by the manufacturer, is usually an emulsifiable concentrate (EC), but may also be a wettable powder (WP) or other type of formulation. Water-based spraying is rarely carried out on a large scale against Desert Locust because the work rate (number of hectares treated per hour) is low and the large volumes of clean water are difficult to find in most desert locust habitats.

2-7-1-4-1-2-Ultra low volume (ULV) spraying:

A technique using much smaller volumes of spray liquid, called ultra low volume (ULV) spraying, was initially developed in the 1950s for use against the Desert Locust, and is now the most efficient and commonly used method. It is defined as applying between 0.5-5.0 litres of spray liquid per hectare, although between 0.5 and 1.0 l/ha is preferred for ULV locust control. This small quantity of concentrated insecticide is not mixed with water or any other liquid; the special formulation, known as a ULV (or UL) formulation, is usually supplied ready to spray.

2-7-1-4-1-2-1-Type of spraying used in ULV formulation:

Meinzingen (1993) explain the following type of spraying used in ULV formulation:

2-7-1-4-1-2-1-1- Drift spraying:

It is technique require the use of specialized equipment. It relies on complete coverage of target block with very low volume of insecticide.

The advantage of drift spraying are that relatively large areas can be treated using either vehicle or aircraft and low cost per unit area. The disadvantage the problem associated with the maintenance of relatively sophisticated equipment, the need for good logistic support and the requirement that wind in excess of 2m/s must be present.

2-7-1-4-1-2-1-2- Barrier spraying:

It does not aim for an even coverage of insecticide over the target area. The technique was successfully used for the treatment of very large locust infestation. The advantage of the method is the effective control of very large area of hopper bands in a relatively short time.

2-7-1-4-1-2-1-3- Air-to-air spraying:

It is used only against flying swarms of locust. The aircraft flies just above the swarm, spraying across the wind direction.

2-7-1-4-1-2-1-4- Direct band spraying:

It is involves spot spraying of small band or concentrations of hoppers. Control is best carried out when nymph are roosting with the wind to kill by direct contact. The disadvantage of the technique is the dangers of severe overdosing by excessive chemical use. The technique is only suitable for small scale control.

2-7-1-5- Biological control:

Steedman (1990) said that biological control includes breeding bacteria or fungus spores in great quantity and release them on locust swarms. Unfortunately, this would be ineffective in most case because special weather condition is need for these diseases to develop. Similar difficulties apply to the possibility of using other natural enemies, notably insect parasites and predator to kill locust.

Stolz (1999) Showed that Fungi were identified as the most promising agents, and a mycopesticide based on spores of *Metarhizium anisopliae* (Metsch.) Sorokin (=*flavoviride*) Gams and Rozsypal var. *acridum* (Deuteromycotina: Hyphomycetes) was developed. More than thirty isolates from different acridoid hosts were identified and screened for pathogenicity and virulence to locusts and grasshoppers. The strain IMI (International Mycological Institute) 330189, isolated from *Ornithacris cavroisi* Finot (Orthoptera: Acrididae), discovered in Niger, was selected by LUBILOSA as the standard isolate for experimental testing. According to Peveling *et al.* (1999), IMI 330189 is the most widely tested fungal strain in Africa. A series of experimental products based on this isolate were provisionally named Green Muscle, and in 1998 the product achieved registration in South Africa.

The efficacy of this entomopathogenic fungus against several African locust and grasshopper species was demonstrated in various laboratory and field experiments in several African countries (Kooyman and Abdalla, 1998).

However, there were only a few data available concerning the possible side-effects of the mycopesticide on non-target organisms (Peveling *et al.*, 1999).

Green Muscle® is designed for use with ULV sprayers, and should be suspended in an oil formulation. A reasonable volume application rate is 0.5 - 2 L/ha. The spore application rate is 100g/ha, so makes up 100g in 0.5 - 2 L.

2-7-1-6- Other methods:

Taha (2000) showed that other methods under research and development include the use of insect Groth Regulator (IGRs) which have some potential for use in barrier strip treatment as replacement for insecticides. Another approach is using locust pheromones. Also natural product especially those of plant origin (Neem powder) have been used for locust control.

CHAPTER THREE

MATERIALS AND METHODS

3-1- The study sites:

The study was conducted during the winter months of 2012 and 2013 at two locations along the Red Sea coast of Sudan mainly at Tokar delta in the south and Oko in the north.

Four methods for counting locusts at different habitats were compared as well as the duration needed for performing the counting process by each method. The methods were tested at wadi, plain and dunes habitat and each method was replicated four times at each habitat.

The survey methods used in the study were:

3-2- The conventional method for Desert Locust survey:

In this method the locust officer walks hundred meters crosswind or upwind(Figure: 1) at the area to be surveyed, counting locust along the pathway of an area two meters wide (one meter to the left and one meter to the right) then calculates the number of locusts in a hectare as follows:

Locusts per hectare = (number of locusts in transect) × (10000 ÷ 200).

One hectare =10000 square meters.

3- 3- The proposed alternative methods:

Method designed as 10m × 10:

In this method the locust officer performs the following steps:

a- Stops in the area to be surveyed.

b- Walks ten meters across wind, with a pathway two meters wide and counting the Desert Locust in this area.

c- Repeats step b, ten times, (crosswind and upwind). Figure (2)

d- Calculates the average number of locusts observed.

e- Calculates number of locusts in a hectare = (number of locusts in transect ÷ 10) × (10000 ÷ 20). One hectare =10000 square meters. 20 = 2×10 (because the locust officer walks ten meters across wind, with a pathway two meters wide and counting Desert Locust in this area).

Method designed as 20m × 5:

In this method the locust officer performs the following steps:

a- Stops in the area to be surveyed.

b- Walks twenty meters across the wind, with a pathway two meters wide and counts Desert Locust in this area.

c- Repeats step b, five times, (cross wind and upwind). (Figure (3)).

d- Calculates the average number of locusts observed.

e- Calculates locusts in a hectare = (number of locusts in transect ÷ 5) × (10000 ÷ 40). One hectare =10000 square meters. 40 = 2 × 20 (because the locust officer walks twenty meters across the wind, with a pathway two meters wide and counts Desert Locust in this area)

Method designed as 50m × 2:

In this method the locust officer performs the following steps:

a- Stops in the area to be surveyed.

b- Walks fifty meters cross the wind, with a pathway two meters wide and counts Desert Locust in this area.

c- Repeats step b, twice. (Cross wind and upwind). (Figure (4))

d- Calculates the average number of locusts.

e- Calculates locusts in a hectare = (number of locusts in transect÷ 2) × (10000 ÷ 100). One hectare =10000 square meters. 100 = 2× 50 (because the locust officer walks fifty meters cross the wind, with a pathway two meters wide and counts Desert Locust in this area).

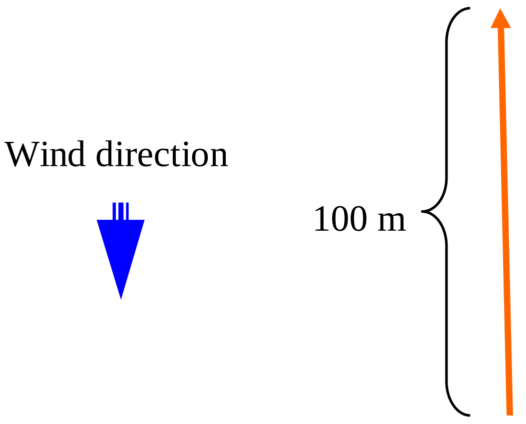

Figure (1): The locust officer walks 100 m up or crosswind

(Conventional method)

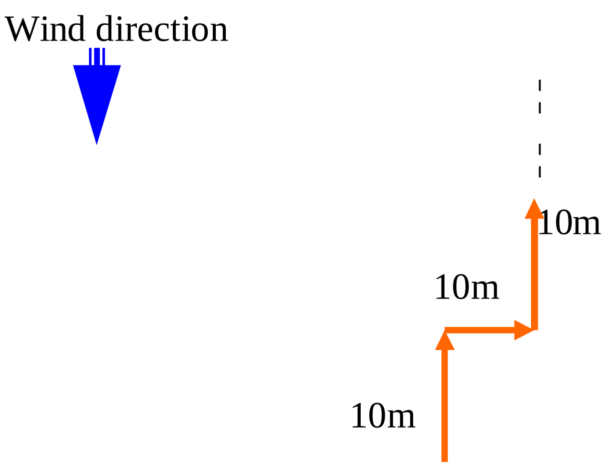

Figure (2): The locust officer walks 10 meters upwind and crosswind

Method designed as 10m× 10

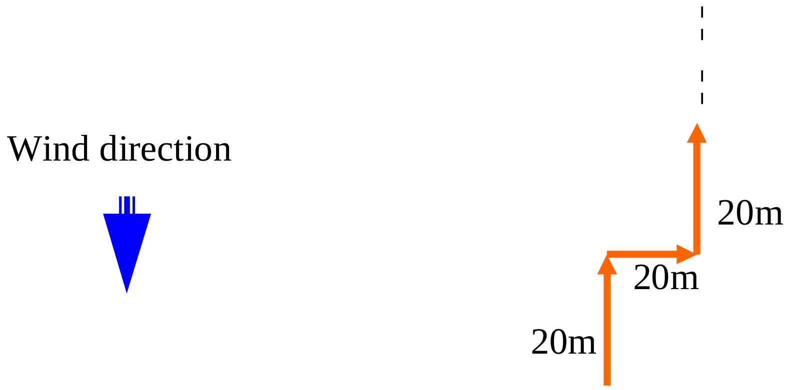

Figure (3): The locust officer walks 20 meters upwind and crosswind

(Method designed as 20m× 5)

Figure (4): The locust officer walks 50 meters up and cross wind

(Method designed as 50m × 2)

The above mentioned methods were used in detecting hoppers. In the conventional method, the locust officer walks ten meters then stops and counts the hoppers in a square meter, he repeats this ten times in straight line(Figure: 5), after that he calculates the average number of hoppers in $10m^2$.

In the Method designed as 10 m × 10 the locust officer stops after ten meters and counts hoppers in a square meter, he repeats this 10 times (upwind and crosswind) (Figure: 6), then he calculates the average number of hoppers in $10m^2$.

In the Method designed as 20 m × 5 the locust officer stops after twenty meters and counts hoppers in a square meter, he repeats this five times (upwind and crosswind) (Figure: 7), then he calculates the average number of locusts in $5m^2$.

In the Method designed as 50 m × 2 the locust officer stops after fifty meters and counts hopper in a square meter, he repeats this two times (up and cross wind) (Figure: 8), then he calculates the average number of locusts in $2m^2$.

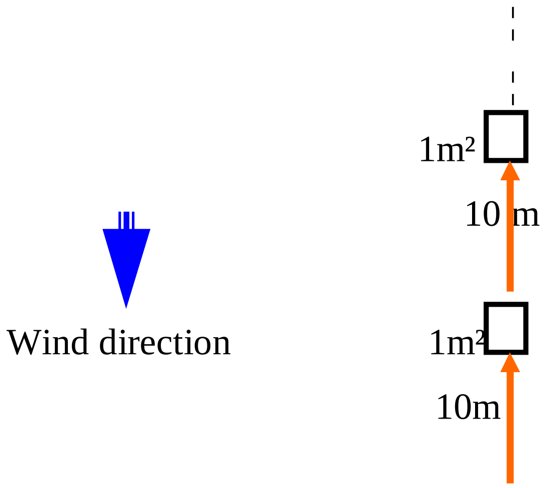

Figure (5): Counting hoppers after locust officer walks 10 meters along straight line (repeat counting ten times). Conventional method

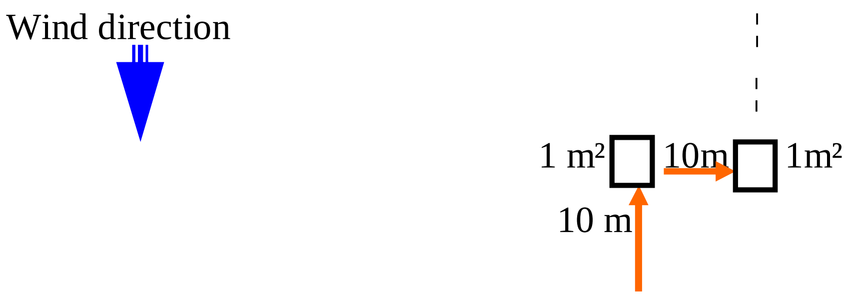

Figure (6): Counting hoppers after locust officer walks 10 meters upwind and crosswind (repeat counting ten times) .Method designed as 10m × 10

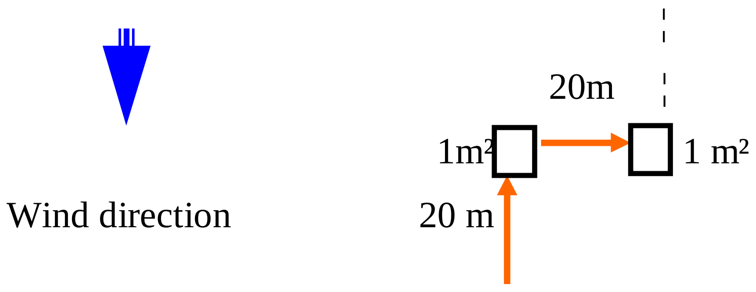

Figure (7): Counting hoppers after locust officer walked 20 meters upwind and cross wind (repeat counting five times). Method designed as 20m × 5

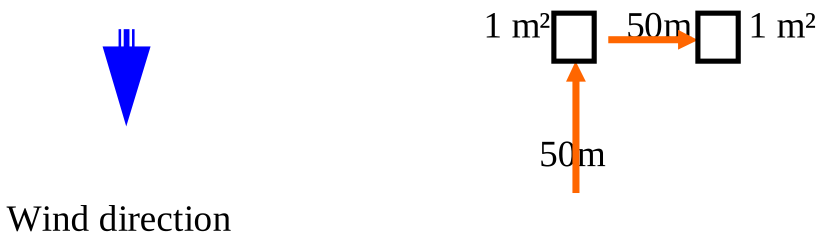

Figure (8): Counting hoppers after locust officer walks 50 meters upwind and cross wind (repeat counting two times). Method designed as 50m × 2

Due to lack of rain in winter of 2012 and absence of hoppers charcoal was used to simulate hoppers, at one area 100m long and 50 meters wide. It was divided into 200 units, each 5m². Charcoal was distributed in this rectangle randomly, with different levels of infestation as follows:-

1- 50 % infestation. (Figure 9)
2- 37.5 % infestation. (Figure 10)
3- 25% infestation. (Figure 11)
4- 12.5% infestation. (Figure 12)

The four survey methods were applied with four replicates to detect charcoal and the time of application for each method was recorded.

*SPSS programme was used to analysis the data with Duncan's Multiple Range Test.

*Error Mean Square range from 0.09 to 8.38.

CHAPTER FOUR

The RESULTS

4-1- Evaluation of four methods for detecting locusts in plain habitat:

When method designed as 20m × 5 was compared with the other three methods in the plains habitat it was found to be superior to the three methods with regard to the number of locusts detected. There were significant differences between method designed as 20m × 5 and the other three methods but there were no significant differences between conventional method 100m, method designed as 10m × 10 and method designed as 50m×2 regard locust number. The time of application of four methods was almost the same with no significant differences between the four methods. (Table: 1).

4-2- Evaluation of four methods for detecting locust in wadi habitat:

The results in Table (2) indicated that Method designed as 20m × 5 was superior to the conventional method and the other proposed methods with regard to the number of locusts detected and there were significant differences between method designed as 20m × 5 and other three methods. As for the time of the application there was no significant difference between the four methods.

4-3- Evaluation of four methods for detecting locust in dunes habitat:

Table (3) show that Method designed as 20m × 5 was better than the other three methods in detecting locust numbers in dunes habitat and there were significant differences between method designed as 20m × 5 and other three methods. There were no significant differences between the methods with respect to the time of the application of the four methods.

4-4- Evaluation of four methods for detecting charcoal simulating 50% infestation:

The result in Table (4) show that Method designed as 20m × 5 was superior to the other three methods for detecting charcoal with significant differences between Method designed as 20m × 5 and other three methods. As regards the application time there was no significant difference between the four methods.

4-5- Evaluation of four methods for detecting charcoal simulating 37.5% locust infestation:

Table (5) show that the Method designed as 20m × 5 was superior to the other methods in detecting charcoal with significant differences between Method designed as 20m × 5 and other three methods. The application time varied but there were no significant differences between the four methods.

4-6- Evaluation of four methods for detecting charcoal simulating 25% locust infestation:

The result in table (6) show that Method designed as 20m × 5 was superior to the other three methods for detecting charcoal with significant difference between Method designed as 20m × 5 and other three methods. There were insignificant differences between conventional method 100m, Method designed as 10m × 10 and method designed as 50m × 2. Regard to the time of application; method designed as 50m × 2 was performed in less time than the other three methods although there was significant difference between method designed as 50m × 2 and method designed as 20m ×5 only, Table: (6).

4-7- Evaluation of four methods for detecting charcoal simulating 12.5% of locust infestation:

Table (7) show that Method designed as 20m ×5 was superior to the other methods for detecting charcoal simulating locust with significant difference between Method designed as 20m ×5 and other three methods. Application time was shorter for Method designed as 20m ×5 in comparing to the other three methods and that there was significant difference between Method designed as 20m ×5 and method 10m × 10.

4-8- Assessment of population of solitary hoppers:

4-8-1- Evaluation of four methods for detecting hoppers Desert Locust at plain habitat at Tokar and Oko area :

The results in Table (8) show that Method designed as 20m ×5 was superior to other three methods in detecting hoppers at both locations with significant differences between Method designed as 20m ×5 and other three methods , but Method designed as 50m ×2 recorded less time in comparing with the other three methods with significant different. Method designed as 20m ×5 recorded less application time than Method designed as 10m ×10 and conventional method.

4-8-2- Evaluation of four methods for detecting number of hoppers at wadi habitat at Tokar and Oko areas:

At wadi habitat in Tokar and Oko areas method designed as 20m ×5 was superior to the other three methods in detecting the number of hoppers with significant different between method designed as 20m ×5 and other three methods. Method designed as 50m ×2 was carried out at much less time than the other three methods with significant differences between Method designed as 50m ×2 and other three methods.

4-8-3- Evaluation of four methods for detecting the number of hoppers at dunes habitat at Tokar and Oko areas

The result in Table (10) show that method designed as 20m ×2 was superior to the other three methods for detecting solitary hoppers at dunes habitat at Tokar and Oko areas with significant different between method designed as 20m ×5 and other three methods. Method designed as 50m ×2 was performed at less time than the other three methods with significant differences between it and other three methods.

Method designed as 20m ×2 recorded less time than Method designed as 10m ×10 and conventional method 100m with significant differences between them.

Table (1): Mean locust numbers detected and survey time for each of four methods in plain habitat at Tokar and Oko areas:

Tokar area			**Oko area**		
Methods	Mean Locust numbers detected	Mean survey time (Minutes)	Methods	Mean locust numbers detected	Mean survey time (Minutes)
Method 20m×5	**62.00 ±a**	38.14± a	Method No.2	**16.50 ±a**	13.48± a
Conventional method	36.00 ±b	38.98± a	Conventional method	7.50 ±bc	11.50± a
Method 10m×10	28.75± b	38.34± a	Method No.1	6.00± c	11.07± a
Method 50m×2	31.75± b	38.69± a	Method No.3	11.00± b	11.68 ±a

Table (2): Mean locust numbers detected and survey time for each of four methods in wadi habitat at Tokar and Oko area:

Tokar area			Oko area		
Methods	Mean detected Locust numbers	Mean survey time (Minutes)	Methods	Mean locust numbers detected	Mean survey time (Minutes)
Method 20m×5	**48.25 ±a**	35.20± a	Method No.2	**20.25±a**	10.58± a
Conventional method	27.00 ±b	35.81± a	Conventional method	9.50± b	8.78 ±a
Method 10m×10	23.50± b	35.91± a	Method No.1	8.75± b	8.96 ±a
Method 50m×2	23.25± b	40.56± a	Method No.3	9.75 ±b	8.39 ±a

Table (3): Mean locust numbers detected and survey time for each of four methods in dunes habitat at Tokar and Oko areas:

Tokar area			**Oko area**		
Methods	Mean locust numbers detected	Mean survey time (Minutes)	Methods	Mean locust numbers detected	Mean survey time (Minutes)
Method 20m×5	**61.75 ±a**	40.90± a	Method No.2	**18.50± a**	16.15±a
Conventional method	31.75± b	41.85± a	Conventional method	8.00± b	13.11±a
Method 10m×10	28.25± b	41.80± a	Method No.1	8.50 ±b	13.00± a
Method 50m×2	29.00± b	41.19± a	Method No.3	8.75± b	13.40± a

Table (4): Charcoal detected by the four methods and the application time, at 50% level of infestation:

Methods	Mean number of detected charcoal	Mean survey period (minute)
Method 20m×5	**12.50± *a***	1.17± *a*
Method 10m×10	9.00± *b*	1.11± *a*
Conventional method	7.50± *b*	1.22± *a*
Method 50m×2	7.25± *b*	1.11±*a*

Table (5): Charcoal detected by four methods and the application time for 37.5% level of simulated infestation:

Methods	Mean number of detected charcoal	Mean survey period (minute)
Method 20m×5	**8.25 ±*a***	1.05± *a*
Conventional method	4.50 ±*b*	1.07± *a*
Method 10m×10	3.50± *b*	1.01 ±*a*
Method 50m×2	3.25± *b*	1.07± *a*

Table (6): Charcoal detected by four methods and the application time, for 25% level of locust infestation:

Methods	Mean number of detected charcoal	Mean survey period (minute)
Method 20m×5	**6.75± *a***	1.09±*a*
Conventional method	3.25± *b*	1.07 ±*a b*
Method 50m×2	3.00± *b*	0.95± *b*
Method 10m×10	1.75± c	1.02± *a b*

Table (7): Charcoal detected by four methods and application time, at 12.5% level of infestation:

Methods	Mean number of detected charcoal	Mean survey period (minute)
Method 20m×5	**6.00** ±***a***	0.95± *b*
Method 50m×2	2.75 ±*b*	1.07± *a b*
Method 10m×10	2.00± *b*	1.08± *a*
Conventional method	2.00± *b*	1.05± a *b*

Table (8): Mean number of hoppers detected and survey time for each of four methods in plain habitat at Tokar and Oko area:

Tokar area			**Oko area**		
Methods	Mean number of hoppers detected	Mean survey time (Minutes)	Methods	Mean number of hoppers detected	Mean survey time (Minutes)
Method 20m×5	**20.00± a**	12.44± b	Method No.2	**30.00 ±a**	8.50± b
Conventional method	10.75± b	17.66± a	Conventional method	14.5± b	14.52± a
Method 10m×10	8.75± b	19.28± a	Method No.1	9.50± b	13.87± a
Method 50m×2	8.50± b	**9.85± c**	Method No.3	11.25 ±b	**6.95± c**

Table (9): Mean number of hoppers detected and survey time for each of four methods in wadi habitat at Tokar and Oko areas.

Tokar area			**Oko area**		
Methods	Mean number of hoppers detected	Mean survey time (Minutes)	Methods	Mean number of hoppers detected	Mean survey time (Minutes)
Method 20m×5	**21.50± a**	10.77 ±b	Method No.2	**20.25± a**	6.76± c
Conventional method	10.25± b	14.97±a	Conventional method	9.50± b	11.76± a
Method 10m×10	9.75± b	14.50± a	Method No.1	8.75± b	11.03± b
Method 50m×2	10.75 ±b	**8.07± c**	Method No.3	8.50± b	**5.40± d**

Table (10): Mean number of hoppers detected and survey time for each of four methods in dunes habitat at Tokar and Oko area.

Tokar area			**Oko area**		
Methods	Mean number of hoppers detected	Mean survey time (Minutes)	Methods	Mean number of hoppers detected	Mean survey time (Minutes)
Method 20m×5	**18.75± a**	12.41±b	Method No.2	**18.50± a**	9.99 ±b
Conventional method	8.50± b	18.86± a	Conventional method	7.75± b	17.66 ±a
Method 10m×10	8.00± b	18.69± a	Method No.1	8.00± b	16.95±a
Method 50m×2	7.75 ±b	**9.90± c**	Method No.3	8.75 ±b	**8.19 ±c**

CHAPTER FIVE

DISCUSSION

The objective of this study is to find a new method which is easy to apply and avoid the obstacles that company application of conventional method, ***M*** pattern and ***A*** pattern. Hence the conventional method is modified by divided into equal parts in order to calculate the average number of locust in these parts which are applied at different directions rather than one straight direction. This will enable the locust officer to avoid obstacles that occur in the conventional method.

The conventional method is divided into parts. The first consists of, ten parts each 10 meters long (Method designed as 10m × 10), the secondly consist of five part each 20 meters long (Method designed as 20m × 5) and the third consist of, two part every one 50 meters long (Method designed as 50m × 2).

The results indicated that Method designed as 20m × 5 was better than the conventional method 100m, Method designed as 10m × 10 and Method designed as 50m × 2 for detecting solitary adult and hoppers at all desert locust habitat in two locations (Tokar delta and Oko) with significant differences between Method designed as 20m × 5 and other methods. This is because during applying the conventional method the locust officer walks 100m in a straight path and counts the locusts along only one line. In performing Method designed as 20m × 5 the officer counts the locust in different directions at five lines. In Method designed as 10m × 10 the locust officer count the locusts at different directions as in Method designed as 20m × 5 but the counting areas of Method designed as 10m × 10 was smaller than in the area of Method designed as 20m × 5. In Method designed as 50m×2 the locust officer counts the locust in two directions while in Method designed as 20m × 5 he counts the locust in five directions.

This result is agree with result that achieved by Ghaemain (2002) when he proposed ***M*** pattern and Mahmoud (2006) when he used ***A*** pattern for detecting solitary adult because all methods(Method designed as 20m × 5, ***M*** pattern and **A** pattern) were better than conventional method100m for detecting solitary adult. But Method designed as 20m × 5 was best than ***M*** pattern and ***A*** pattern because it was easy during application, it can performing by one locust officer while **M** pattern and ***A*** pattern were need at least three locust officer for performing. Also during application of ***M*** pattern and ***A*** pattern there were angles between locust officer and wind direction to be measure. In addition, the ***M*** pattern and ***A*** pattern were performing at more time than conventional method while there was insignificant difference between Method designed as 20m × 5 and conventional method regard performing time.

During application of Method designed as 50m ×2 for detecting hoppers at different hopper habitat it was recorded less application time than Method designed as 20m ×5, Method designed as 10m ×10 and conventional Method because during the application of Method designed as 50m ×2 the locust officer stops two time while during application of Method designed as 20m ×5 the locust officer stops five time and count hoppers at 5m² and during application of Method designed as 10m ×10 and conventional method locust officer stops ten times and count hopper at 10m².

The number of locusts detected in Tokar area was higher than at Oko area probably because the abundance of plants which prefer for locust (particularly *Pennisetum typhoideum* (Woldewahid, 2003)) in Tokar lead to increase of locust number than Oko area (Table 1).

The time of application of the survey methods in the Tokar area was longer than at Oko area because of the higher plant density at Tokar which impeded the movement of the survey officer (plate 7).

CONCLUSION

After testing the conventional method, Method designed as 10m ×10, Method designed as 20m ×5 and Method designed as 50m ×2 for detecting desert locust (solitary adult and hoppers) at Tokar delta and Oko area at different desert locust habitat (dunes, wadi and plain). The result show that Method designed as 20m×5 was best than conventional method, Method designed as 10m ×10, and Method designed as 50m×2 for detecting desert locust (solitary adult and hoppers) with significant differences between Method designed as 20m ×5 and other three methods for detecting solitary adult and hoppers. Regarding application time there were no significant differences between four methods during survey solitary adult. For detecting solitary hoppers method designed as 50m×2 recorded less application time than all methods with significant differences between method 50 × 2 and other methods but there were insignificant differences between Method designed as 20m×5 and conventional method.

RECOMMENDATION

- For monitoring solitary adult in habitat of dunes, plain and wadies, the locust officer should used Method designed as 20m ×5 for foot transect.
- To detect solitary hoppers in different locust habitat (dunes, wadi and plain) during recession period, Method designed as 20m ×5 was highly recommended.
- The locust officers advised to focus on these plant species (*Pennisetum typhoideum, Dipterygium glaucum, Schouwia thebaica, Tephrosia nubica, Tribulus terrestris and Helitropium spp)* when they carried out desert locust survey.
- Studies of estimation of infested area of desert locust (solitary adult and hoppers was highly recommended in order to know exactly infested area.

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APPENDIXES

Appendixes: 1

Plant associated with existence of solitary Desert Locust:

Plate: (1) *Pennisetum typhoideum*

Plate: (2) *Dipterygium glaucum*

Plate: (3) *Schouwia thebaica*

Plate: (4) *Tephrosia nubica*

Plate: (5) *Tribulus terrestris*

Plate: (6) *Helitropium spp*

Appendix: 2

Habitat of two locations (Tokar and Oko areas):

Plate: (7) Tokar habitat

Plate (8): Oko habitat

Appendix: 3

Infestation level of simulating charcoal:

191	192	193	194	195	196	197	198	199	200
181	182	183	184	185	186	187	188	189	190
171	172	173	174	175	176	177	178	179	180
161	162	163	164	165	166	167	168	169	170
151	152	153	154	155	156	157	158	159	160
141	142	143	144	145	146	147	148	149	150
131	132	133	134	135	136	137	138	139	140
121	122	123	124	125	126	127	128	129	130
111	112	113	114	115	116	117	118	119	120
101	102	103	104	105	106	107	108	109	110
91	92	93	94	95	96	97	98	99	100
81	82	83	84	85	86	87	88	89	90
71	72	73	74	75	76	77	78	79	80
61	62	63	64	65	66	67	68	69	70
51	52	53	54	55	56	57	58	59	60
41	42	43	44	45	46	47	48	49	50
31	32	33	34	35	36	37	38	39	40
21	22	23	24	25	26	27	28	29	30
11	12	13	14	15	16	17	18	19	20
1	2	3	4	5	6	7	8	9	10

Figure (9) Distribution of charcoal in 100 squares (50% infested area)

191	192	193	194	195	196	197	198	199	200
181	182	183	184	185	186	187	188	189	190
171	172	173	174	175	176	177	178	179	180
161	162	163	164	165	166	167	168	169	170
151	152	153	154	155	156	157	158	159	160
141	142	143	144	145	146	147	148	149	150
131	132	133	134	135	136	137	138	139	140
121	122	123	124	125	126	127	128	129	130
111	112	113	114	115	116	117	118	119	120
101	102	103	104	105	106	107	108	109	110
91	92	93	94	95	96	97	98	99	100
81	82	83	84	85	86	87	88	89	90
71	72	73	74	75	76	77	78	79	80
61	62	63	64	65	66	67	68	69	70
51	52	53	54	55	56	57	58	59	60
41	42	43	44	45	46	47	48	49	50
31	32	33	34	35	36	37	38	39	40
21	22	23	24	25	26	27	28	29	30
11	12	13	14	15	16	17	18	19	20
1	2	3	4	5	6	7	8	9	10

Figure (10) Distribution of charcoal in 75 squares (37.5 % infested area)

191	192	193	194	195	196	197	198	199	200
181	182	183	184	185	186	187	188	189	190
171	172	173	174	175	176	177	178	179	180
161	162	163	164	165	166	167	168	169	170
151	152	153	154	155	156	157	158	159	160
141	142	143	144	145	146	147	148	149	150
131	132	133	134	135	136	137	138	139	140
121	122	123	124	125	126	127	128	129	130
111	112	113	114	115	116	117	118	119	120
101	102	103	104	105	106	107	108	109	110
91	92	93	94	95	96	97	98	99	100
81	82	83	84	85	86	87	88	89	90
71	72	73	74	75	76	77	78	79	80
61	62	63	64	65	66	67	68	69	70
51	52	53	54	55	56	57	58	59	60
41	42	43	44	45	46	47	48	49	50
31	32	33	34	35	36	37	38	39	40
21	22	23	24	25	26	27	28	29	30
11	12	13	14	15	16	17	18	19	20
1	2	3	4	5	6	7	8	9	10

Figure (11) Distribution of charcoal in 50 squares (25% infested area)

191	192	193	194	195	196	197	198	199	200
181	182	183	184	185	186	187	188	189	190
171	172	173	174	175	176	177	178	179	180
161	162	163	164	165	166	167	168	169	170
151	152	153	154	155	156	157	158	159	160
141	142	143	144	145	146	147	148	149	150
131	132	133	134	135	136	137	138	139	140
121	122	123	124	125	126	127	128	129	130
111	112	113	114	115	116	117	118	119	120
101	102	103	104	105	106	107	108	109	110
91	92	93	94	95	96	97	98	99	100
81	82	83	84	85	86	87	88	89	90
71	72	73	74	75	76	77	78	79	80
61	62	63	64	65	66	67	68	69	70
51	52	53	54	55	56	57	58	59	60
41	42	43	44	45	46	47	48	49	50
31	32	33	34	35	36	37	38	39	40
21	22	23	24	25	26	27	28	29	30
11	12	13	14	15	16	17	18	19	20
1	2	3	4	5	6	7	8	9	10

Figure (12) Distribution of charcoal in 25 squares (12.5% infested area).

Appendix: 4

Survey equipment:

Plate: (9). Hygrometer

Plate: (10). TwoTallycounters

Plate: (11) Compass and Stop watch

Plate: (12) Windmetr and Hygrometer

Plate: (13) GPS map 600

Appendix:5

Tokar delta map:

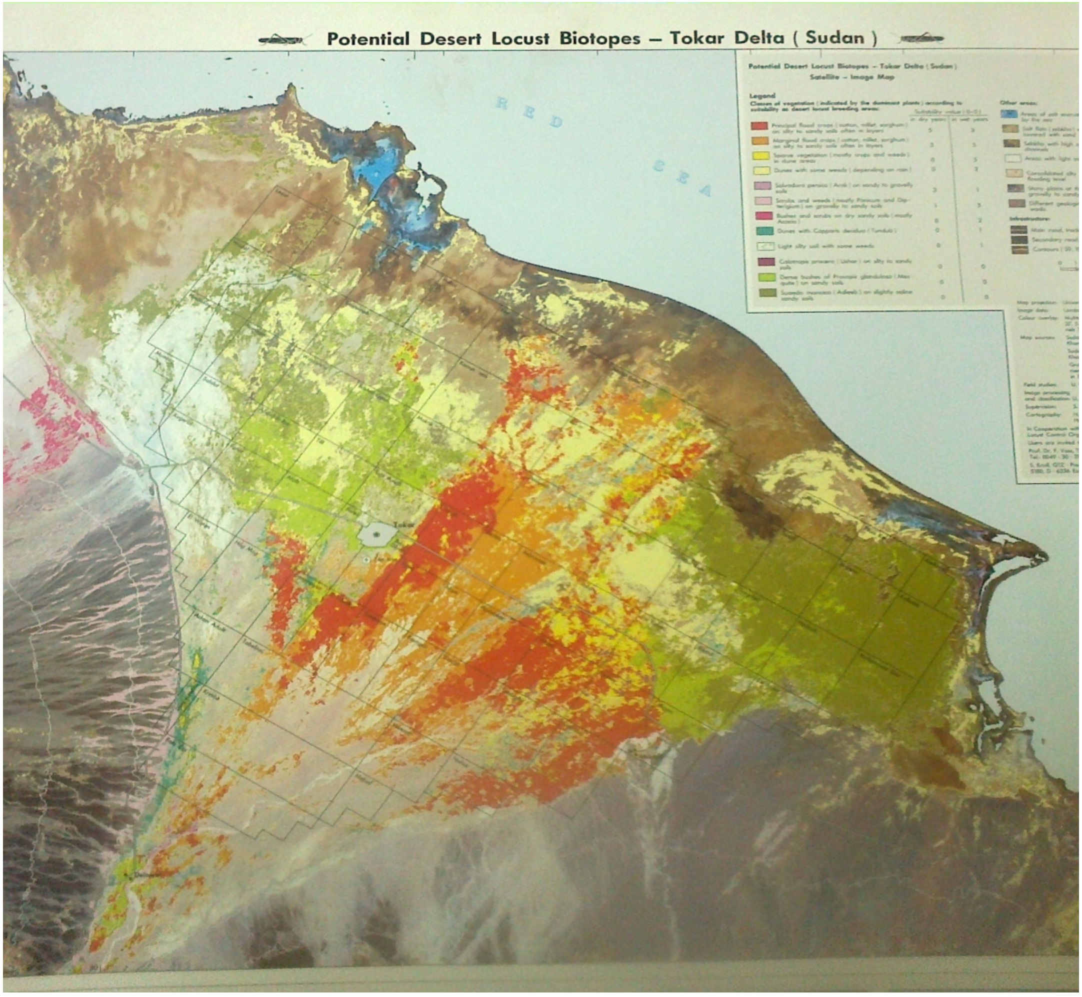

Plate: (14) Tokar Delta map (satellite image) (krall, 1989).