MANAGEMENT OF WITCHWEED (*Striga hermonthica* (Del.) Benth) IN PEARL MILLET (*Pennisetum glaucum* L.) R.Br. **WITH ORGANIC SOIL AMENDMENTS SOURCED FROM NEEM TREE** (*Azadirachta indica* A. Juss.)

BY

YAR'ADUA, ABDULLAHI AHMAD

B.Sc Microbiology (ABU, 1980), M.Sc Crop Protection (ABU, 1987)

A DISSERTATION SUBMITTED TO THE
POSTGRADUATE SCHOOL
AHMADU BELLO UNIVERSITY, ZARIA, NIGERIA
IN PARTIAL FULFILMENT FOR THE AWARD OF DOCTOR OF PHILOSOPHY IN CROP PROTECTION

DEPARTMENT OF CROP PROTECTION,
FACULTY OF AGRICULTURE,
AHMADU BELLO UNIVERSITY, ZARIA,
NIGERIA.

...

FEBRUARY, 2007

DECLARATION

I declare that the work in the dissertation entitled MANAGEMENT OF WITCHWEED (*Striga hermonthica* (Del.) Benth.) IN PEARL MILLET (*Pennisetum glaucum* L.) R.Br. WITH ORGANIC SOIL AMENDMENTS SOURCED FROM NEEM TREE (*Azadirachta indica* A. Juss.) has been performed by me in the Department of Crop Protection under the supervision of Professor A.D. Akpa, Professor A. M. Emechebe and Dr P.S. Marley

The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at any University.

Yar'adua, Abdullahi Ahmad		5/02/2007
(Student)	Signature	Date

The above declaration is confirmed

Professor A.D. Akpa	ADAkpa	February 05, 2007
(Chairman, Supervisory Committee)	Signature	Date

CERTIFICATION

This dissertation entitled MANAGEMENT OF WITCHWEED (*Striga hermonthica* (Del.) Benth.) IN PEARL MILLET (*Pennisetum glaucum* L.) R.Br. WITH ORGANIC SOIL AMENDMENTS SOURCED FROM NEEM TREE (*Azadirachta indica* A. Juss.) by Yar'adua, Abdullahi Ahmad meets the regulations governing the award of the degree of Doctor of Philosophy of Ahmadu Bello University, Zaria, and is approved for its contribution to knowledge and literary presentation.

Professor A. D. Akpa (Chairman, Supervisory Committee)	(Signature)	February 05, 2007 (Date)
Prof. A. M. Emechebe (Member, Supervisory Committee)	(Signature)	07/02/007 (Date)
Dr P.S. Marley (Member, Supervisory Committee)	(Signature)	(Date)
Dr (Mrs.) O. Alabi Head, Crop Protection	(Signature)	8/2/07 (Date)
Professor J.U. Umoh Dean, Post Graduate School	(Signature)	30/10/07 (Date)

ACKNOWLEDGEMENT

I would like to abundantly thank Professor A.D. Akpa, Chairman of the supervisory committee, Professor A.M. Emechebe, and Dr P.S. Marley, members of the supervisory team for stirring the course of this research. I would also like to thank the entire staff of the Department of Crop Protection, ABU Zaria, particularly, Dr (Mrs.) O. Alabi, the Head of Department, and Professor M.C. Dike, Deputy Dean, Faculty of Agriculture, for their assistances. The financial assistance from Hassan Usman Katsina Polytechnic and the Katsina State Government are greatly appreciated. The moral supports and encouragements offered, individually and collectively, by the Management Committee of HUK Polytechnic and the Katsina State Department of Higher Education, Dr Kabir Matazu, Rector HUK Polytechnic, A. Abdu Hallim Kafur, Registrar HUK Polytechnic and the entire staff of the Polytechnic, particularly A. Abdullahi Isa, Head of Department of Secretarial Administration, HUK Polytechnic and their entire staff College of Agriculture, HUK Polytechnic, Katsina, have been appreciated and hereby thankfully acknowledged. My regards to Alhaji Usman Musa (P.S., Governor's Office) , A. Iro Musa Anda (P.S., Deputy Governor's Office), A. Sani Abdu Funtua (Department of Higher Education), A. Aliyu Sani Muhammad, and Abdulaziz Yusuf Kankia for their assistances. To A. Armayau & Lawal, Safiya & Hajara, Bilkisu & Maryam, Fatima & Fatima, Ali & Ali, Hassan & Hussain, Zainab & Amina, Baba, Baba & Malama and Muhammad & Khadija, I say thank you all, again and again.

ABSTRACT

This research was conducted in order to investigate the potentials of managing *Striga hermonthica* (Del.) Benth., the noxious parasitic weed of cereal crops, with soil amendments derived from fruits of neem tree *(Azadirachta indica* A. Juss.). Effects of amending Striga-infested plots with the neem treatments (at 0, 0.5, 1.0, 2.0, 4.0, 6.0 and 8.0 kg/m^2) on emergence and biomass accumulation in S. *hermonthica,* on the germination, growth and grain yield of pearl millet grown on *Striga-i*nfested plots and on soil physico-chemical properties (short term effects) were investigated. Experiments were conducted using randomized block design with 4-5 replications, under field conditions at five locations in Katsina (13° 47'N & 7° 08'), Nigeria, during the 2001, 2002 and 2003 rainy seasons. Long term effects of neem residues on soil physico-chemical properties, and on the growth and grain yield of millet *(Pennisetum glaucum),* sorghum *(Sorghum bicolor)* (two common hosts of *Striga hermonthica),* cowpea *(Vigana unguiculata),* and groundnut *(Arachis hypogaea)* (two common mixed-cropping components in cereal-legume mixtures) were also compared with neem-free controls using student t-test at two locations in Katsina, during the 2004 rainy season, under field conditions. The neem treatments were found to completely inhibit *Striga* emergence at 8.0kg/m^2. However at 2.0-4.0kg/m^2, the neem treatments supported more *Striga* emergence than the control treatment, and at these concentrations neem appeared to have conferred tolerance to the neem-treated plants, as far as *Striga* syndrome and grain yield were concerned. Neem treatment at 8.0kg/m^2 was the most suppressive treatment

against S*trigs* emergence and germination of millet seeds that were sown at the time of amending the soil. However, millet seeds sown two weeks after amending the soil germinated and grew well in all the neem-amended plots, including 8.00kg/m^2. Yield and yield components of neem-treated millet plants at 6 -8kg/m^2 were significantly improved when compared with the control treatments, or other neem treated plots. Continuous deposition of neem residues into the 20 year old neem shelterbelts was not found to significantly affect the germination of the tested cereal and leguminous crop seeds. However, growth vigor of neem treated millet and sorghum seedlings were initially depressed, before stabilization of the rains, after which the entire test crop seedlings significantly (P=0.001-0.01) recorded accelerated growth and rapid biomass accumulation, at all locations. While neem treatment was significantly better than control in enhancing panicle biomass accumulation and grain yield in neem treated sorghum and millet (P= 0.001-0.5); the same treatment however, significantly suppressed pod-biomass accumulation and shelling percentage of neem-treated cowpea, while neem-treated groundnut was not significantly affected. Neem was also found to be significantly better than control in improving soil physico-chemical properties within a period of 2 0 years. Proportion of clay and silt, total nitrogen and organic matter in the neem treated soils were increased, while soil acidity was significantly reduced. Neem residues added to the soil through biomass transfer were not found to significantly affect soil physico-chemical properties within three month after application.

TABLE OF CONTENTS

CHAPTER	TOPIC	PAGE
	Title Page	III
	Declaration	IV
	Certification	V
	Acknowledgement	VI
	Abstract	VII
	Table of contents	IX
	List of Tables	XVI
	List of figures	XIX
	List of plates	XXII
	List of appendices	XXIII
1.0	**INTRODUCTION**	1
2.0	**LITERATURE REVIEW**	6
2.1	Parasitism in Plant Kingdom	6
2.2	Taxonomy and Nomenclature of *Striga*	12
2.3	Life cycle of *Striga*	15
2.4	Ecology and Distribution of *Striga*	25
2.5	Host Range of *S. hermonthica*	36
2.6	Economic Importance of *Striga hermonthica*	39
2.7	Management of *S. hermonthica*	45
2.7.1	Herbicide application in *Striga* management	47
2.7.2	Use of germination stimulants in *Striga* management	51

2.7.3	Use of resistant crop varieties in *Striga* management	52
2.7.4	Use of trap and catch crops in *Striga* management	58
2.7.5	Soil fertility management for *Striga* management	61
2.7.6	Biological control in *Striga* management	63
2.7.7	Hand pulling and hoe weeding in *Striga* management	64
2.7.8	Use of fumigants in *Striga* management	65
2.7.9	Use of bush fallow in *Striga* management	65
2.7.10	Action Program for *Striga* management in Africa	66
2.7.11	Integrated *Striga* management (ISM)	67
2.8	The Potentials of Neem Tree in *Striga* Management	68
2.8.1	Neem tree	68
2.8.2	Pesticidal principles in neem	74
2.8.3	Pest management with neem	75
2.8.4	Potentials of neem-based agroforestry systems for sustainable land management to mitigate *Striga* problems	76
3.0	**MATERIALS AND METHODS**	83
3.1	Effects of Neem Soil Amendments on *Striga hermonthica*, Pearl Millet and Soil Physico-chemical Properties to under Field Conditions	83
3.1.1	Aim	83
3.1.2	Collection and processing of neem fruits	83
3.1.3	Collection and preservation of *Striga* seeds	84
3.1.4	Experimental sites and plot size	84
3.1.5	Inoculation of experimental plots with *Striga*	84

3.1.6	Treatments and experimental design	85
3.1.7	Seed-bed preparation and sowing of millet seeds	86
3.1.8	Other management operations	86
3.1.9	Measurements and observations	86
3.1.9.1	*Striga* emergence	87
3.1.9.2	*Striga* biomass	87
3.1.9.3	Millet seed germination count (%)	87
3.1.9.4	Shoot height	87
3.1.9.5	Striga syndrome	88
3.1.9.6	Millet stalk biomass	88
3.1.9.7	Panicle length	88
3.1.9.8	Grain yield	88
3.1.9.9	Quality of grain yield	90
3.1.9.10	1000-Grain weights of grain yields	90
3.1.9.11	Proportion of marketable grain yield	90
3.1.9.12	Short term effects on soil physico-chemical properties	91

3.1.10	Data analyses	91
3.2	Effects of Prolonged Deposition of Neem Residues on Millet, Sorghum, Groundnut and Cowpea, and on Soil Physico-Chemical Properties	92
3.2.1	Aim	92
3.2.2	Treatments and experimental design	92
3.2.3	Measurements and observations	96
3.2.3.1	Germination count	96
3.2.3.2	Growth vigor	96
3.2.3.3	Plant biomass	98
3.2.3.4	Grain yield	98
3.2.3.5	Soil physico-chemical properties	98
3.2.4	Data analyses	98
4.0	**RESULTS**	99
4.1	Effects of Neem Soil Amendments on *Striga hermonthica*, Pearl Millet and Soil Physico-Chemical Properties to under Field Conditions	99
4.1.1	Effects of neem soil amendments on *Striga hermonthica*	99
4.1.1.1	Effects on *Striga* emergence	99
4.1.1.2	Effects of neem soil amendments on *Striga* biomass	102
4.1.2	Effects of neem soil amendments on pearl millet grown on *Striga*-infested soil	105
4.1.2.1	Effect on neem soil amendments on germination of millet seeds	105
4.1.2.2	Effects of neem soil amendments on severity of *Striga* syndrome on millet	109

4.1.2.3	Effects of neem soil amendments on plant growth parameters	117
	Height of millet plants	117
	Millet stalk biomass	120
4.1.2.4	Effects of neem soil amendments on yield components of millet	124
	Lengths of millet panicles	124
	Grain yield of millet	128
	Quality of grain yields	131
	1000-grain weights	143
	Proportion of marketable grain yield	156
4.1.3	Effect of neem soil amendments on soil physico-chemical properties	159
4.2	Long Term Effects of Neem Residues on Growth and Grain Yield of Millet, Sorghum, Groundnut and Cowpea and on Soil Physico-Chemical Properties	164
4.2.1	Long term effects of neem residues on germination of crop seeds	164
4.2.2	Effects of neem residues on growth vigor of treated crops	164
4.2.3	Long term effects of neem residues on shoot biomass	167
4.2.4	Long term effects of neem residues on crop yield and yield components	169
4.2.4.1	Long term effects of neem residues on pod and panicle biomass	169
4.2.4.2	Long term effects of neem residues on crop grain yield	171
4.2.5	Long term effects of neem residues on soil physico-chemical properties	171
5.0	**DISCUSSIONS**	176

5.1	Effects of Neem Soil Amendments on *Striga hermonthica*, Pearl Millet and Soil Physico-Chemical Properties to under Field Conditions	180
5.1.1	Effects of neem soil amendments on *Striga hermonthica*	180
5.1.2	Effects of neem soil amendments on pearl millet grown on *Striga*-infested soil	184
5.1.2.1	Effect on neem soil amendments on germination of millet seeds	184
5.1.2.2	Effects of neem soil amendments on severity of *Striga* syndrome	186
5.1.2.3	Effects of neem soil amendments on plant growth parameters	189
5.1.2.4	Effects of neem soil amendments on yield and yield components of millet	191
5.1.3	Short of neem soil amendments on soil physico-chemical properties	194
5.2	Long Term Effects of Neem Residues on Growth and Grain Yield of Millet, Sorghum, Groundnut and Cowpea and on Soil Physico-Chemical Properties	195
5.2.1	Long term effects of neem residues on germination of crop seeds	195
5.2.2	Long term effects of neem residues on growth parameters	196
5.2.3	Long term effects of neem residues on yield components	197
5.2.4	Long term effects of neem residues on soil physico-chemical properties	199
6.0	SUMMARY, CONCLUSIONS AND RECOMMENDATIONS	202
6.1	Summary	**202**
6.2	Conclusion	**204**

IBP

6.3	Recommendations	205
	REFERENCES	206
	APPENDICES	220
	BIOGRAPHY	236

LIST OF TABLES

TABLE	TITLE	PAGE
1	Families and genera of parasitic plants within the Plant Kingdom	8
2	Hosts and distribution of some parasitic weeds of agricultural importance	9
3	World distribution of some *Striga* species.	33
4	Host range of some *Striga* species	38
5	Estimated cropland area under *Striga* infestation in Sub-Saharan Africa	41
6	The impact of *Striga* on grain production in Africa	43
7	Loss of revenue in grain production in Africa due to *Striga*	44
8	Some crop varieties resistant to parasitic *Striga* spp.	57
9	Comparative chemical composition of neem-cake sourced from trees grown in India and Nigeria.	72
10	Types of agroforestry systems	81
11	Effect of amending *Striga*-infested plots, at four locations in Katsina, with neem organic soil amendments on Striga counts at harvests, during the 2002 and 2003 trials.	89
12	Visual assessment scale used for scoring plant growth.	97
13	Effect of amending *Striga*-infested plots, at four locations in Katsina, with neem organic soil amendments on *Striga* counts at harvests, during the 2002 and 2003 trials.	101
14	Effect of amending *Striga*-infested plots, at four locations in Katsina, with neem organic soil amendments on *Striga* biomass at harvests, during the 2002 and 2003 trials.	104

15 Effect of amending *Striga*-infested plots, at four locations in Katsina, with neem organic soil amendments on the germination of millet seeds, sown immediately (Day 0) and fourteen days after amending the soil at harvests, during the 2002 and 2003 trials. 107

16 Effect of amending *Striga*-infested plots, at four locations in Katsina, with neem organic soil amendments on *Striga*-syndrome scores on infested millet plants at harvests, during the 2002 and 2003 trials. 111

17 Effect of amending *Striga*-infested plots, at four locations in Katsina, with neem organic soil amendments on height of millet at harvests, during the 2002 and 2003 trials. 119

18 Effect of amending *Striga*-infested plots, at four locations in Katsina, with neem organic soil amendments on biomass of millet stalks at harvests, during the 2002 and 2003 trials. 122

19 Effect of amending *Striga*-infested plots, at four locations in Katsina, with neem organic soil amendments on lengths of millet panicles at harvests, during the 2002 and 2003 trials. 126

20 Effect of amending *Striga*-infested plots, at four locations in Katsina, with neem organic soil amendments on mean grain yields at harvests, during the 2002 and 2003 trials. 130

21 Effect of amending *Striga*-infested plots, at four locations in Katsina, with neem organic soil amendments on the % proportion of Grain Yields sieved and collected on 1.18mm sieve at harvests, during the 2002 and 2003 trials. 133

22 Effect of amending *Striga*-infested plots, at four locations in Katsina, with neem organic soil amendments on the % proportion of sieved grain yields collected on 1.70mm sieve at harvests, during the 2002 and 2003 trials. 136

23 Effect of amending *Striga*-infested plots, at four locations in Katsina, with neem organic soil amendments on the % proportion of sieved grain yields collected 2.00mm sieve at harvests, during the 2002 and 2003 trials. 140

24 Effect of amending *Striga*-infested plots, at four locations in Katsina, with neem organic soil amendments on the % proportion of sieved grain yields collected on 2.36mm sieve at harvests, during the 2002 and 2003 trials 142

25 Effect of amending *Striga*-infested plots, at four locations in Katsina, with neem organic soil amendments on 1000 grain-weights of sieved grain yields collected on 1.18mm sieve at harvests, during the 2002 and 2003 trials. 145

26 Effect of amending *Striga*-infested plots, at four locations in Katsina, with neem organic soil amendments on 1000 grain-weights of sieved grain yields collected on 1.70mm sieve at harvests, during the 2002 and 2003 trials. 147

27 Effect of amending *Striga*-infested plots, at four locations Katsina, with neem organic soil amendments on 1000 grain-weights of sieved grain yields collected on 2.00mm sieve at harvests, during the 2002 and 2003 trials. 149

28 Effect of amending *Striga*-infested plots, at four locations in Katsina, with neem organic soil amendments on 1000 grain-weights of sieved grain yields collected on 2.36mm sieve at harvests, during the 2002 and 2003 trials. 151

29 Effect of amending *Striga*-infested plots, at four locations in Katsina, with neem organic soil amendments on pooled 1000 grain-weights of sieved grain yields collected on 1.18, 1.70, 2.00 and 2.36mm sieves at Katsina, during the 2002 and 2003 trials. 155

30 Effect of amending *Striga*-infested plots, at four locations in Katsina, with neem organic soil amendments on % proportion of marketable grain yields sieved and collected on 2.00 and 2.36mm sieves at Katsina, during the 2002 and 2003 trials. 158

31 Effect of amending *Striga*-infested plots, at four locations in Katsina, with neem organic soil amendments on the % proportion of unmarketable grain yields sieved and collected on 1.18 and 1.70mm sieves at harvests, during the 2002 and 2003 trials. 161

32 Effect of amending *Striga*-infested plots in Katsina, with neem organic soil amendments on soil physico-chemical properties in 2001 162

33 Effect of neem residues on the germination of some cereal and leguminous crops at Katsina, during the 2004 trial. 165

34 Effect of neem residues on visually rated growth assessment scores of some cereal and leguminous crops at Katsina, during the 2004 trial. 166

35	Effect of neem residues on plant biomass of some cereal and leguminous crops at Katsina, during the 2004 trial.	168
36	Effect of neem residues on panicle and pod biomass of some cereal and leguminous crops at Katsina, during the 2004 trial.	170
37	Effect of neem residues on the shelled/threshed Grain Yields of some cereal and leguminous crops at Katsina, during the 2004 trial.	172
38	Effect of neem residues on the physico-chemical properties of host soil at two locations in Katsina, during the 2004 trial.	173

LIST OF FIGURES

FIGURES	TITLES	PAGES
1	*Striga*'s life cycle, with stages 1-5 totally dependant on chemical signals from host root exudates	16
2	The molecular structure of some germination stimulants	23
3	Distribution Map for *S. hermonthica* in Nigeria	35
4	World distribution map for *Striga hermonthica* (Del.) Benth, *S. asiatica* (L) Kuntze, *S. gesnerioides* (Willd.) Vatke	37
5	Patterns of tree planting in agroforestry systems drawn according to Young, 1997	82
6	Effect of amending *Striga*-infested plots in Katsina, with neem organic soil amendments on Striga counts at harvest in 2001 at Katsina	100
7	Effect of amending *Striga*-infested plots in Katsina, with neem organic soil amendments on *Striga* biomass at Katsina in 2001	103
8	Effect of amending *Striga*-infested plots in Katsina, with neem organic soil amendments on germination of millet seeds sown at 0 and 14 days after amending the soil in Katsina, during the 2001 trial	106
9	Effect of amending *Striga*-infested plots in Katsina, with neem organic soil amendments on *Striga* syndrome scores at Katsina, during the 2001 trial at Katsina	110
10	Effect of amending *Striga*-infested plots in Katsina, with neem organic soil amendments on height of millet plants at harvest in Katsina, during the 2001 trial.	118
11	Effect of amending *Striga*-infested plots in Katsina, with neem organic soil amendments on millet shoot biomass at Katsina, during the 2001 trial.	121
12	Effect of amending *Striga*-infested plots in Katsina, with neem organic soil amendments on mean length of millet panicles at Katsina, during the 2001 trial	125

13.	Effect of amending *Striga*-infested plots in Katsina, with neem organic soil amendments on grain yield of millet at Katsina, during the 2001 trial	129
14	Effect of amending *Striga*-infested plots in Katsina, with neem organic soil amendments on the proportion of grain yield collected on 1.18mm sieve at Katsina, during the 2001 trial	132
15	Effect of amending *Striga*-infested plots in Katsina, with neem organic soil amendments on the proportion of grain yield sieved and collected on 1.70mm sieve at Katsina, during the 2001 trial	135
16	Effect of amending *Striga*-infested plots in Katsina, with neem organic soil amendments on the proportion of grain yield sieved and collected on 2.00mm sieve at Katsina during the 2001 trial.	139
17	Effect of amending *Striga*-infested plots in Katsina, with neem organic soil amendments on the proportion of sieved grain yield collected on 2.36mm sieve at Katsina, during the 2001 trial.	141
18	Effect of amending *Striga*-infested plots in Katsina, with neem organic soil amendments on 1000 grain-weights of sieved grain yield collected on 1.18mm sieve at Katsina during the 2001 trial.	142
19	Effect of amending *Striga*-infested plots in Katsina, with neem organic soil amendments on 1000 grain-weights of sieved grain yield collected on 1.70mm sieve at Katsina during the 2001 trial.	146
20	Effect of amending *Striga*-infested plots in Katsina, with neem organic soil amendments on 1000 grain-weights of sieved grain yield collected on 2.00mm sieve at Katsina, during the 2001 trial.	148
21	Effect of amending *Striga*-infested plots in Katsina, with neem organic soil amendments on 1000 grain-weights of sieved grain yield collected on 2.36mm sieve at Katsina, during the 2001 trial.	150

22	Effect of amending *Striga*-infested plots in Katsina, with neem organic soil amendments on pooled 1000 grain-weights of sieved grain yield collected on 1.18, 1.70, 2.00 and 2.36mm sieves at Katsina, during the 2001 trial.	154
23	Effect of amending *Striga*-infested plots in Katsina, with neem organic soil amendments on proportion of marketable grain yield sieved and collected on 2.00 and 2.36mm sieves at Katsina, during the 2001 trial	157
24	Effect of amending *Striga*-infested plots0 in Katsina, with neem organic soil amendments on the proportion of unmarketable grain yield sieved and collected on 1.18 and 1.70mm sieves at Katsina, during the 2001 trial.	160

LIST OF PLATES

PLATE	TITLE	PAGE
I	Tiny *Striga* seeds being compared in size wit other seeds	17
II	Germinating *Striga* seeds with radicles issuing out of the seed coats	21
III	Germinating *Striga* seeds with developing haustoria at the radicles apex	25
IV	Attachment and penetration of young root of host by *Striga* haustoria	26
V	An enlarged underground *Striga* shoot attached to host root	28
VI	An emerged *Striga* shoot bearing flowers for seed formation, the stage in *Striga* life cycle	31
VII	The 20-year old neem shelterbelt used for testing long term effects of continuous and prolonged deposition of neem residues.	93
VIII	Natural deposition of neem leaves and fruits in a 20-year old neem shelterbelt	94
IX	Pruned neem trees in a 20-year old neem shelterbelt used for testing long term effects of continuous and prolonged deposition of neem residues	95
X	*Striga*-infested control plot not treated with neem soil amendment at 0.0kg/m^2 (T1) in replicate IV at Katsina during the 2001 trail	112
XI	*Striga*-infested plot treated with neem soil amendment at 0.5 kg/m^2 (T2) in replicate III at Katsina, during the 2001 trail	113
XII	*Striga*-infested plot treated with neem soil amendment at 1.0 kg/m^2 (T3) in replicate IV at Katsina, during the 2001 trail	114
XIII	*Striga*-infested plot treated with neem soil amendment at 2.0 kg/m^2 (T4) in replicate II at Katsina, during the 2001 trail	115

KASHIM IBRAHIM LIBRARY

XIV *Striga*-infested plot treated with neem soil amendment at 4.0 kg/m^2 (T5) in replicate V at Katsina, during the 2001 trail 116

XV *Striga*-infested plot treated with neem soil amendment at 8.0 kg/m^2 (T in replicate IV at Katsina, during the 2001 trail 117

XVI Effect of amending *Striga*-infested plots in combined replicates I-IV with neem soil amendments at 0, 4, 6, and 8kg/m^2 on air dried millet stalks produced at site 1 in Katsina, during the 2003 trial. 123

XVII Effect of amending *Striga*-infested plots in combined replicates I-IV with neem soil amendments at 0, 4, 6 and 8 kg/m^2 on millet panicle biomass at site 1 in Katsina during the 2003 trial. 127

List of Appendices

APPENDIX	TITLE	PAGE
1	The chemical structures of bioactively potent chemical compounds found only in neem tree	220
2	Analyses of variances on the effect of neem soil amendments on *Striga* and millet at Katsina, during the 2001 field trials	226
3	Allelophathy in neem, suppressing the growth of most weed	221
4	Allelophathy in neem residue deposits (a) and pruned neem trees (b) suppressing weeds.	232
5	Allelophathic neem trees (a) and neem deposits (b) selectively allow the germination and growth of their seeds and seedlings.	233
6	Neem trees on croplands at Katsina	234
7	Neem trees planted along highways, rural feeder roads, village paths, city streets and public buildings at Katsina.	217

CHAPTER ONE

1.0 INTRODUCTION

Witchweed is a common named for a group noxious parasitic weeds called *Striga* (Anonymous, 2005g). These parasitic weeds include *Striga hermonthica* (Del.) Benth., *Striga asiatica* (L.) Kuntz, *Striga aspera* (Willd.) Benth., *Striga forbesii* Benth., and *Striga* gesnerioides (Willd.) Vatke (OISAT, 2006). They cause staggering crop yield losses, worth over US$7 billion/annum, to resource poor peasant farmers throughout Africa, south of the Sahara. Consequently, they adversely affect the livelihood of some 300 million people in 52 countries, in addition to several others in Asia (Lagoke *et al.*, 1994a; Emechebe, 1994; M'Boob, 1986). Mean crop yield losses due to *Striga*, suffered by both sorghum and millet throughout Africa, were estimated at 25.5% of the potential yield, and it ranged between 5-90% (Obilana, 2003). *S. hermonthica* is the most important parasitic weed of cereals in West Africa, (Sauerborn *et al.*, 1991). Yield losses due to this parasite in Nigeria ranged between 10-100% (Lagoke *et al.*, 1994b). In this way, *Striga* threatens food security in seriously affected countries like Nigeria, and incites food scarcity, inflation, hunger, malnutrition and poverty, particularly among the resource-poor peasant farmers (Blade, 2006). Economically, they are considered as the single most important biotic factor militating against cereal cultivation in Africa (Lagoke, 1998) and they are considered as the 18th most important natural disasters in the continent (Okonkwo, 1994). *Striga* are root parasites of cereals, fodder grasses and leguminous crops. *S. hermonthica* is parasitic mainly to *Sorghum*

bicolor (L.), maize (*Zea mays* L.), upland rice (*Oryza sativa* L.), sugarcane (*Saccharum officinarum* L.), pearl millet (*Pennisetum glaucum* L.) and several other wild grasses (Wilson *et al.*, 2000). In addition to *S. hermonthica*, cereals are also attacked by *S. aspera*, *S. asiatica* and *Striga passargei* Engl., (Lagoke *et al.*, 1991). *S. gesnerioides* is parasitic mainly to leguminous crops (Emechebe, 1994).

These weeds are widely distributed weeds in Africa, and Asia, from where they are believed to have evolved and dispersed to other parts of the world. The parasites are considered as the most difficult weeds to control in Africa (Lagoke, 1998). In Africa, *Striga* is said to have infested over two thirds of 73 million hectares of cereal farmlands, and are rapidly infesting more areas (Lagoke, 1998 and Gworgwor *et al*, 2001).

Resource-poor subsistence farmers in most parts of Africa, including Nigeria, cannot sustainably adopt most of the techniques commonly recommended for *Striga* management (M'Boob, 1994; Chikoye, *et al.*, 2006 and Franke, *et al.*, 2006). Management techniques include herbicide application, use of resistant crop varieties, hand pulling/hoe weeding of emerged *Striga*, and soil fertility management through application of high doses of inorganic-nitrogen fertilizers or manures etc (M'Boob, 1986; Gworgwor and Weber, 1991 and Anonymous, 2005b). Consequently, *Striga* defies these control measures throughout the continent, as single-method control strategies (M'Boob, 1994). The need, therefore, to evaluate new resources and techniques, with good potential for sustainable *Striga*

management, in Africa is not only imperative and necessary, but is also timely and most apt. One such resource, with high potential for circumventing *Striga* endemics in Africa is neem tree (*Azadirachta indica* A. Juss.), a pesticidal tree crop, dubbed as the "Tree for solving global problems" (National Research Council, 1992).

Neem tree is widely distributed in Africa, and it grows well in all drier parts of northern Nigeria, where *Striga* is endemic. In these areas, neem is widely grown in farms as single dispersed stands or in boarder planting. Neem is not only important for desertification in neem plantations and shelterbelts, they also important in soil fertility management, and for the provision of shade, neem oil and firewood. Neem extracts have also been reported to be bioactive and potent against over 400 insect species and several other species of nematodes, snails, bacteria and fungi (National Research Council, 1992). Though neem tree is important in soil fertility management, the tree has not, apparently, been reported to be useful in *Striga* management under field conditions. This is so despite the fact that it has a potential for being important in suppressing the growth of the parasitic weeds. There exist some bits and pieces of evidences to suggest that neem may prove useful in sustainable *Striga* management under low input subsistence agriculture, typical in Africa. Bearing in mind that neem extracts are fungicidal (National Research Council, 1992; Yar'adua, 1987; Yar'adua, 2000; Yar'adua, 2002; Schmutterer and Ascher, 1987; Obagwu *et al.,* 1997), and *Striga,* at certain points in its life cycle, physically resembles fungi, gives us some suggestive evidence to suspect that neem may be potent against *Striga* too. Germinating *Striga* dust-seeds (measuring

300 x 200 μ) and their germ-tubes are microscopic (Berner, *et al.,* 1997), and they physically resemble fungal spores and hyphae, respectively. Neem's inhibitory effects on fungal mycelium may perhaps similarly affect conditioning/germination of *Striga* seeds, and growth of *Striga* germ tubes. Second suggestive evidence, is the fact that neem residues, particularly, the neem-cake and leaves are useful in Asia for soil fertility management (Neem Foundation, 1997a), and in improving soil physicochemical properties under agroforestry systems (Young, 1997). Hence, neem-based organic soil amendments may likely be useful in sustainable *Striga* management when used to sustainably fertilize nutrient deficient soils, since the parasite is exclusively a problem of nutrient deficient soils (Kranz, 1999 and Kranz *et al.,* 1998). Efficient *Striga* management strategies have been reported through soil fertility management with inorganic fertilizers and manure (Mabasa, 1994 and Gworgwor and Weber, 1991), and neem-based organic soil amendments may not likely be an exception. The other suggestive evidence is the fact that neem tree and its residues are allelophathic in nature, thereby suppressing or inhibiting the growth of nearby plants, and perhaps, *Striga* may not be an exception either. Lastly, the ability of neem residues to suppress *Striga* emergence on potted sorghum seedlings was reported by Kranz (1999). This research is, therefore, informed by these suggestive evidences that seem to indicate the potentials of using neem to manage *Striga* under field conditions.

This research work was, therefore, undertaken in order to investigate the potentials of managing *Striga*, under field conditions with neem organic soil amendments. The

research hoped to find answers to the following basic research questions: Does neem tree have any potential for suppressing *Striga* emergence, when used under field conditions in fertilizing nutrient deficient and *Striga*-infested plots? Under such circumstance, would neem improve crop yield and soil physico-chemical properties, without adversely affecting the growth and grain yield of treated cereals and/or other none-host crops that may be grown in crop mixtures with the neem protected cereal crops? In these answers perhaps we may find a new tool/technique for sustainable *Striga* management, through the use of the pesticidal neem tree and a new and additional option for integrated *Striga* management in Africa may be discovered.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Parasitism in Plant Kingdom

The Plant Kingdom comprises of mainly autotrophic green plants that are capable of manufacturing their own food through photosynthesis, from atmospheric carbon dioxide, water and sunlight. There, however, exist within the Kingdom, a group of unique plants that are not autotrophic in their mode of nutrition. They can not photosynthesize all or part of their food requirements, and alternative or supplementary sources of manufactured foods must have to be sourced from the autotrophs, which they parasitize (Anonymous, 2005a). Parasitism in plants, according to Schlauer (1996), is an association between two plants, the parasitic plant and the autotrophic host plant, in which the parasite survives at the expense of the host. A heterotrophic parasitic plant is a dicotyledonous angiosperm that is nutritionally dependant on its vascular plant host (Anonymous, 2005a). Over the centuries, the parasitic plants have evolved heterotrophic parasitism as their sole mode of nutrition, and they are dependant on autotrophs for all or part of their nutritional requirements (Anonymous, 2005a).

About 20% of the known parasitic plants in the Plant kingdom do not posses green chlorophyll, hence they cannot manufacture any of their food requirements. These kinds of pests are called obligate holoparasites, and they include *Cuscuta* and *Orobanche*. Though hemiparasites, which constitute 80% of the known parasitic

plants, do posses green chlorophyll, yet they can only photosynthesize part of their own food requirements, and they have to be partially dependant on their hosts for their survival. *Striga* is an obligate holoparasite during it subterranean growth phase, and an obligate hemiparasite after shoot emergence. An obligate parasite is one that must attach to a host to complete its life cycle, while a facultative parasite can as well grow independent of its host (Nickrent and Musselman 2004). About 60% of the known parasites in the Plant kingdom are root parasites that get attached to the roots of their hosts which they parasitize, while the rest are stem parasites that get attached to the stems of their hosts which they parasitize (Anonymous, 2005c). All parasitic plants attach themselves to their hosts via a root-like structure called haustorium (plural: haustoria), through which they penetrate vascular tissues and strands of their hosts and siphon away manufactured foods, mineral nutrients and water. Haustorium is common to all parasites within the Plant Kingdom (Anonymous, 2005c; Walker, 2004).

This group of plants is parasitic, and constitutes about 1% of the plant population in the Plant Kingdom, or about 3,000-5,000 varied plants species. According to Nickrent and Musselman (2004) Anonymous (2005a) the Plant Kingdom comprises of 4,100 parasitic flowering plant species distributed in 277 plant genera of 17-20 taxonomic families. These parasitic taxonomic families include Balanophoraceae, Convolvulaceae, Hydnoraceae, Loranthaceae, Lennoaceae, and Lauraceae. Others include Orobanchaceae, Rafflesiaceae, Santalaceae, Scrophulariaceae, and Viscaceae etc (Anonymous, 2005a and Walker 2004) (Table 1). Of the 17-20

Table 1: Families and genera of parasitic plants within the Plant Kingdom

Family	Parasitic Genera
Balanophoraceae	*Balanophora, Chlamydophytum, Corynaea, Cynomorium, Dactylanthus, Ditepalanthus, Exorhopala, Hachettea, Helosis, Langsdorffia, Lathrophytum, Lophophytum, Mystropetalon, Ombrophytum, Rhopalocnemis, Sarcophyte, Scybalium, Thonningia*
Hydnoraceae	*Hydnora, Prosopanche*
Lennoaceae	*Lennoa, Pholisma*
Rafflesiaceae	*Apodanthes, Bdallophyton, Berlinianche, Botryocytinus, Cytinus, Hypolepis, Mitrastema, Pilostyles, Rafflesia, Rhizanthes, Sapria, Phoradendron, Arceutobium*
Convolvulaceae	*Cuscuta*
Lauraceae	*Cassytha*
Santalaceae	*Okoubaka, aubrevillei, Thesium*
Orobanchaceae	*Rhinatheae, Tozzia, Aeginetia, Boschniakia, Christisonia, Cistanche, Conopholis, Epifagus, Gleadovia, Kopsiopsis, Mannagettaea, Necranthus, Orobanche, Phacellanthus, Phelypaea, Platypholis, Xylanche, Striga, Alectra.*
Loranthaceae	*Dendrophtoe, Tapinantus, Amyema*
Viscaceae	*Viscum,* mistletoes
Scrophulariaceae	*Alectra , Harveya, Hyobanche, Lathraea, Tozzia, Buchnera, Rhamphicarpa, Odontites, Melampyrum, Rhinanthus, Seymeria, Parentucellia, Pedicularis, Balladry*

(Sources: Anonymous, 2005a; Anonymous, 2005d; Anonymous, 2005e; Anonymous, 2005f; Musselman, 1987; Schlauer, 1996; Walker, 2004).

parasitic families in the Kingdom, only less than half that number is of economic importance as agricultural weeds that parasitize crops (Anonymous, 2005m) and they include Lauraceae (Laurel Family), Convolvulaceae (Morning Glory Family), Orobanchaceae (Broomrape/Witchweed Family), Loranthaceae (Showy Mistletoe Family), Santalaceae (Sandalwood Family), and Viscaceae (Christmas Mistletoe Family) (Table 2).

Reviews on families of parasitic plants include those of Musselman, 1987; Schlauer, 1996; Parker and Riches, 1993; Walker, 2004; Nickrent and Musselman, 2004 and Anonymous, 2005a). *Balanophoraceae* is a little known family of parasitic plants, some of which are known to be root parasites of trees in the humid tropics (Anonymous, 2005a; Anonymous, 2005d and Schlauer, 1996). Convolvulaceae (Cuscutaceae) are stem parasites of agricultural importance. The most prominent genus is this family is *Cuscuta*, with 279 parasitic species that have very broad host range, attacking both dicots and monocots, though the former are preferred (Anonymous, 2005d; Schlauer, 1996). Hydnoraceae is a family of two parasitic genera, *Hydnora* and *Prosopanche* having four and three parasitic genera, respectively (Schlauer, 1996). Lauraceae is a family of 30 parasitic species in a single genus, *Cassytha*, which is capable of literally covering the foliage of an entire tree with its filaments, before eventually killing it (Anonymous, 2005a; Anonymous, 2005d; and Schlauer, 1996). The family Lennoaceae is said to contain two parasitic genera, *Lennoa*, and *Pholisma*, each having 2-3 parasitic plant species (Schlauer, 1996; Anonymous, 2005d). Loranthaceae is a family of tropical herbaceous stem

Table 2: Hosts and distribution of some parasitic weeds of agricultural importance

Family	Parasitic species	Hosts	Distribution
Convolvulaceae	*Cuscuta campestris*	Mostly legumes	Worldwide
Lauraceae	*Cassytha filiformis*	Woody plants	Pantropical
Orobanchaceae	*Aeginetia indica*	Sugarcane	India, Philippines, Indonesia
	Alectra vogellii	Cowpea	Africa
	Christisonia wightii	Sugarcane	Philippines
	Orobanche ramosa	Mostly *Solanaceae*	Mostly in Mediterranean areas
	Orobanche crenata	Mainly legumes; carrots	Mostly Mediterranean areas
	Orobanche minor	legumes, carrots, tobacco, etc	Mostly temperate regions.
	Rhamphicarpa fistulosa	G/nut & rice	Africa
	Seymeria cassioides	pine (*Pinus* spp.)	Southern USA
	Striga hermonthica	Cereals	Semi-arid Africa
	Striga asiatica	Cereals	Africa, N & S Carolina
	Striga gesnerioides	Legumes	Africa, & Florida USA
Loranthaceae	*Agelanthus* spp.	Shea butter	Burkina Faso
	Amyema spp.	*Eucalyptus*	Australia
	Tapinanthus bangwensis	Cacao etc.	Africa
	Dendrophthoe spp.	Kapok etc.	Asia
	Phthirusa spp.	rubber & teak	Central & South America
	Psittacanthus spp.	*Citrus*	Mexico
	Struthanthus spp.	*Coffea, Citrus*, etc	Central & South America
Santalaceae	*Acanthosyris paulo alvimii*	Cacao	Brazil
	Exocarpos spp.	*Eucalyptus*	Australia
	Osyris alba	Grape (*Vitis*)	Yugoslavia
	Pyrularia pubera	Fir (*Abies fraseri*)	West Virginia, USA
	Thesium spp.	Sugarcane barley	Australia, Spain, Africa, US
Viscaceae	*Arceuthobium* spp.	Pinaceae & Cupressaceae	North America, Europe, Asia, Africa

Source: Nickrent and Musselman (2004)

parasites found in 70 taxonomic genera. The family comprises about 900 parasitic species, includeing *Dendrophtoe*, *Tapinantus*, and *Amyema* spp. (Anonymous, 2005a; Anonymous, 2005d). Santalaceae, which comprises of *Okoubaka, aubrevillei, Thesium* spp., is a family of parasitic herbaceous and woody trees that parasitize the roots of other trees (Anonymous, 2005d). Viscaceae is a family of seven genera of herbaceous temperate parasitic plants comprising of 500 parasitic species including *Viscum* and Mistletoes. They are stem parasites of temperate trees (Anonymous, 2005a and Walker, 2004). Scrophulariaceae is an economically very important family of herbaceous root parasites, comprising of 500 parasitic plant species in several parasitic genera, including Harveya and Hyobanche having 41 and 7 parasitic species, respectively (Musselman 1987; Anonymous, 2005a; Anonymous, 2005c; Anonymous, 2005e and Anonymous, 2005f). Other genera within the family include *Buchnera*, *Rhamphicarpa*, *Odontites*, *Melampyrum*, *Rhinanthus*, *Seymeria*, *Parentucellia*, *Pedicularis*, and *Bellardia* (Schlauer, 1996).

Orobanchaceae is one of the most important and the largest of the families of parasitic plants in the Plant Kingdom, with 85 constituent parasitic genera and 1,650 parasitic species, including *Aeginetia, Boschniakia, Christisonia, Epifagus, Gleadovia* and *Kopsiopsis*. Other genera include *Mannagettaea, Necranthus, Orobanche, Phacellanthus, Xylanche, Rhinatheae* and *Tozzia* (Anonymous, 2005d). This family also includes all the hemiparasites that were earlier classified into the family Scrophulariaceae (the figwort family), that includes the genera *Striga* and *Alectra*. *Striga* species are major pests of cereals and legumes throughout semi-arid

AHMADU BELLO UNIVERSITY

Africa and parts of Asia, and they are believed to have co-evolved with their principal hosts, mainly millet and sorghum in Africa. *Striga* asiatica and *S. hermonthica* are parasitic, almost entirely to grasses including cereals. *S. gesnerioides* prefers dicot hosts, particularly cowpea (Anonymous, 2005a). The two, economically, most important genera in the family Orobanchaceae are *Striga* (witchweed) and *Orobanche* (broomrape). They are also parasitic to the members of the families *Asteraceae*, *Fabaceae* and family Lamiaceae (Anonymous, 2005a).

Agronomically, the most destructive parasitic families in the Plant Kingdom are Convolvulaceae, Orobanchaceae and Scrophulariaceae, (Parker and Riches, 1993; Raynal-Roques, 1996), while the most destructive parasitic genera in these noxious families are Mistletoes, *Orobanche*, *Cuscuta*, and *Striga* (Schlauer, 1996).

2.2 Taxonomy and Nomenclature of *Striga*

Taxonomically, *Striga* weeds have been classified under the genus *Striga* in the family Orobanchaceae (Parker, 2003; Nickrent and Musselman, 2004). They were earlier classified under the family Scrophulariaceae. Transferring the hemiparasitic members of the family Scrophulariaceae to the family Orobanchaceae was informed by the recent molecular phylogenetic evidences that showed that all the holoparasitic genera in the family Orobanchaceae and the hemiparasitic genera of the family Scrophulariaceae are monophyletic descendents of a common ancestry; a nonparasitic Scrophulariaceae, hence reclassified together under the family

Orobanchaceae. The genus *Striga* consists of about 40 parasitic species and the most important among them are *Striga gesnerioides* (Willd.) Vatke, *Striga asiatica* (L.) Kuntze, *Striga hermonthica* (Del.) Benth., and *S. forbesii* (Parker and Riches, 1993; Musselman and Parker, 2003).

Striga gesnerioides is one of the smallest *Striga* species, normally measuring up to 15 cm high with closely packed and branched stem at the ground level. The stems bear pale green scale-like leaves. Its flowers are usually purple in color, though variants may be white or yellow (Anonymous, 2005g; OISAT, 2006). *S. hermonthica*, formally known as *Striga senegalensis* Benth., is the most important parasitic weed of cereal crops in Africa, particularly in Nigeria (Lagoke *et al,* 1994a). It is a profusely branching weed, with a sturdy habit. It is usually robust in size, larger than all other *Striga* species, measuring up to 20-60 cm high. According to OISAT (2006) the stems of both *S. hermonthica* and *S. asiatica* are hairy, hard, quadrangle-shaped, and fibrous. Leaves are narrow and spear-head shaped and pointed at the tip, measuring 2.5-7.5 cm long and up to 2 cm wide, in case of *S. hermonthica*, and measures about 4 cm long and 1.5 -3.5 mm wide, in case of *S. asiatica*. *S. hermonthica* bears numerous pink colored flowers, which are found in dense spikes, each of which may bear 6-10 open flowers. Variant flower colors vary from bright pink, pale red, rose-red, and white. The flowers of *S. asiatica*, which are prominent and alternately arranged on apical spikes, are showy red, pink, orange, yellow, white, or purple, but are normally bright red. *Striga asiatica* is relatively smaller and more compact than the robust *S. hermonthica*. *S. aspera* closely

resembles *S. hermonthica*, but posses delicate and profusely branching stem that hadly grows more than 50 cm high. Its leaves are linear and oppositely arranged, usually measuring 1.0-3.5 cm long and up to 5 mm wide. Its flower resembles that of *S. hermonthica* (Parker and Riches, 1993; Musselman and Parker, 2003).

Floral characteristics, particularly shape and size of bracts and the length of calyx, are the main basis for the taxonomic identification of these *Striga* species. *S. hermonthica* is readily differentiated from *Striga aspera* and *Striga passargei*, which closely resemble it, by possessing a broad bract which subtends its pink colored large flowers and total absence of glandular hairs on the entire external portion of the corolla of its flowers. Musselman and Parker (1983) further added that broad lower leaves characterize *S. hermonthica* and its corolla tube near the terminal end of the flower calyx are set at a more abrupt angle than that of any of its close relatives that are often confused with it in addition, other than *S. aspera*, *S. hermonthica* is the only *Striga* species that was observed by Musselman and Parker (1983) to posses more than two open corollas per inflorescence and its flowers survive for more than one day. Corolla variation, according to the later report, distinguishes *S. hermonthica*, by possessing upper corolla lobe those varieties from entire to bifid, the throat of the corolla is white or pink, while the lower corolla lobes vary from deeply toothed to entire. *S. hermonthica* is reported to exist in two strains; one of which only attacks millet (*Pennisetum glaucum* (L.) R. Br.). The other strain attacks only sorghum. The two strains of *S. hermonthica* can not be differentiated from each other based on ornamentation of the surfaces of their seed coats, which

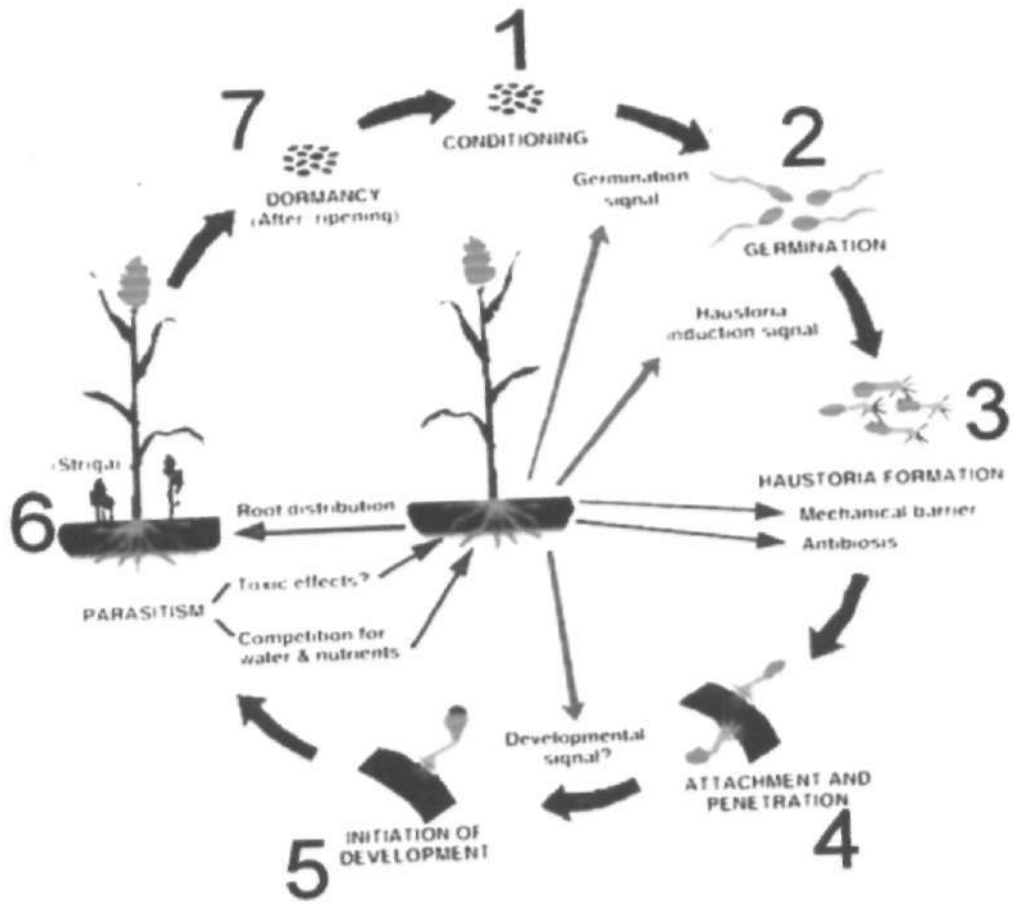
according to Musselman and Parker (1983) are aereolate, with prominent primary ridges that are ornamented at the crest by bi-lobed protuberances. *S. hermonthica* unlike all other *Striga* species is an obligate out breeder, producing viable seeds only by cross-pollination between neighboring plants of the same species.

2.3 Life cycle of *Striga*

Striga has a very complex life cycle (Figure 1), which is completely adapted to and dependant on its host (Anonymous, 2005m). The life cycle has 7 stages, with stages 1-5 totally dependant on chemical signals from the root exudates of the host. The life cycle has been extensively reviewed in the literature (Parker and Riches, 1993; Elzein, and Kroschel, 2006). It takes about 10-15 weeks to complete the cycle, from conditioning of the seeds to seed formation (Verkleij and Kuijper, 2000). The stages in *Striga* life cycle starts with conditioning of seeds, seeds germination, formation of haustorium, attachment, and penetration of host roots, subterranean growth of young *Striga* shoot, and then emergence and growth of shoot and finally seed formation and dispersal.

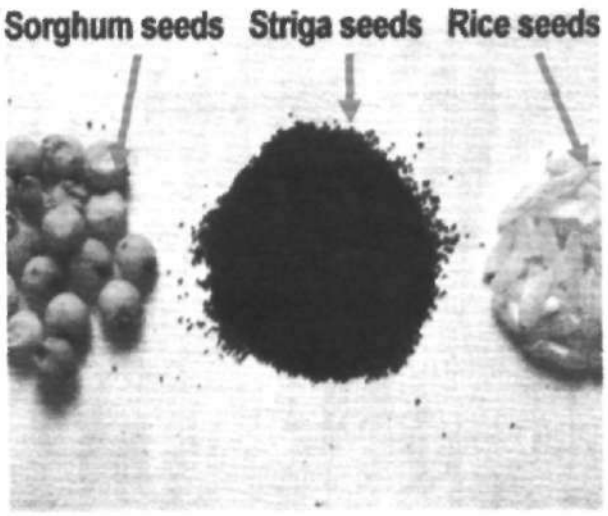
Striga seeds are extremely tiny and dust-like, each measuring about 200 x 300 μ in size, with characteristic crested seed coat (Plate I), which is believed to contain certain chemical germination inhibitors that would not allow the seeds to germinate during the first 6 months after their production, hence the well known primary seed dormancy in *Striga*. This is a stage in the life cycle of *Striga* in which fresh seeds can not germinate, and must remain dormant for at least 6 month. Dormancy is said

Figure 1: *Striga's* life cycle, with stages 1-5 totally dependant on chemical signals from host root exudates.

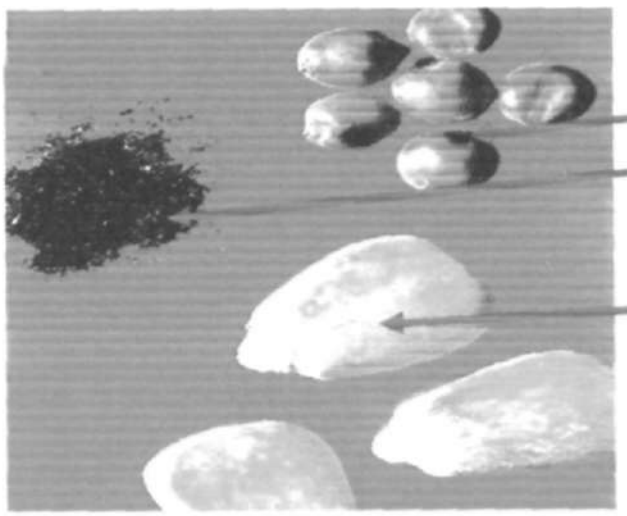


(Source: Ejeta *et al.* (1992)

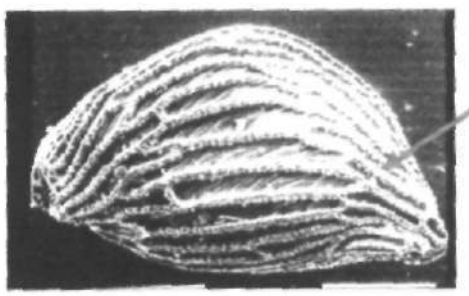
Plate: Tiny *Striga* seeds being compared in size with others



Source: Ejeta *et al*, 1992



Source: Anonymous, 2005a



Source: Parker and Riches, 1993

to be due to the presence of germination inhibitors on the seed coat and within the seed (Anonymous, 2005m). Dormancy is an evolutionary adaptation that ensures that seeds do not germinate at a time when host plants are not available in the field. Fresh seeds can only germinate after undergoing a process of preconditioning or an afterripening period, which lasts for about 6 weeks, after dispersal (Anonymous, 2006). Dormancy is broken just before the end of the dry season (Verkleij and Kuijper, 2000), after a period of storage under warm and dry conditions in the soil for 6 weeks at 31°C, or after 32 weeks at 4°C (Anonymous, 2006). In dry state, the seeds can remain dormant and viable for up to 14-20 years. During the preconditioning, *Striga* seeds do not respond to changes in the osmotic potential (0 to –1.5 MPa) (Dawoud and Sauerborn J. (1994), and so can not germinate, until the dormancy is broken.

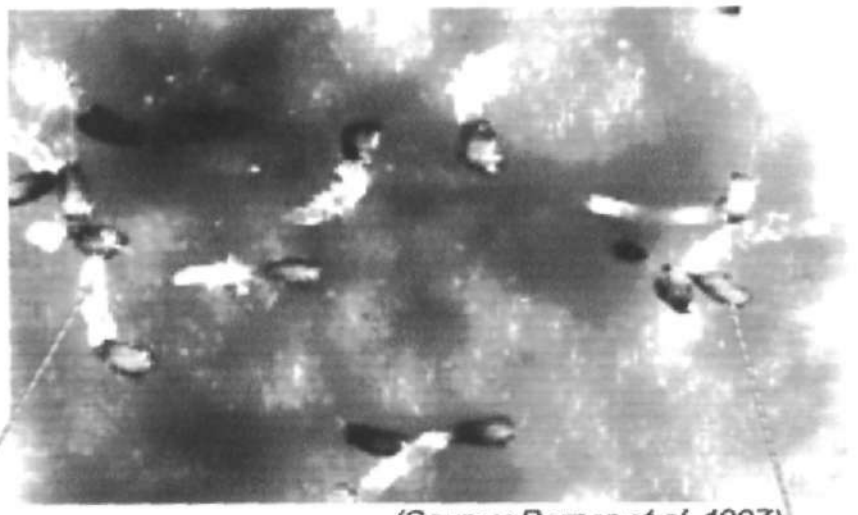
Once dormancy is broken, seeds start to respond to osmotic changes within their immediate environment, and can be conditioned to germinate. Like preconditioning, the necessity of conditioning seeds before they could be induced to germinate is an adaptation that ensures that seeds germinate at the right moment, at the commencement of the rainy season when the host seeds have germinated too (Anonymous, 2005m). Conditioning is the processing of storing the seeds in warm and moist environment, pre-requisites that are met under field conditions only in the rainy season or under irrigation. Seeds become effectively conditioned after storage in moist environment for 5-21days at 30-40°C (Verkleij and Kuijper, 2000), with an optimum temperature range of 23°C for seed conditioning (Anonymous, 2006 and

Anonymous, 2005m). Under favorable laboratory conditions, conditioning in sterile distilled water is achieved in 6-10 days (Anonymous (2006). During the process of conditioning *Striga* seeds, permeability of the seed coat to water is increased, while germination inhibitors are leached away from the seeds. The activities of endogenous germination inhibitors are minimized while those of endogenous germination promoters are increased. A number of complex biochemical pathways are triggered including those of tissue respiration, synthesis of deoxyribonucleic (DNA), proteins and hormones (Anonymous, 2005m). Adequate soil moisture in well drained and textured soil promotes conditioning of *Striga* seeds, which are suffocated under prolonged water logged conditions (Anonymous, 2005m).

Once a seed is adequately conditioned within 2-3 weeks, it must have to be immediately induced to germinate, else germination counts soon declines to zero, and this is called secondary or wet dormancy (Anonymous, 2006). It is a safety adaptation that ensures that limited food reserve in the seed is not wasted too soon in the absence of specific host, and the seed does not germinate too late, in the normally short rainy season of semi-arid savanna, as result of which life cycle might not be completed before the end of the rainy season (Anonymous, 2005m). In each rainy season only a little fraction of the conditioned seeds germinate, either because of the absence of specific host to induce their germination or the seeds are not situated close enough to be reached by the host root exudates. If conditioned seeds could not germinate in 3 weeks, they become dormant again (wet dormancy) in

order to preserve their food reserve until next rainy season, and like this they can retain their viability for up to 15 years (Elzein and Kroschel, 2006; Anonymous, 2006), until they come close enough to a host root to induce the conditioned seed to germinate.

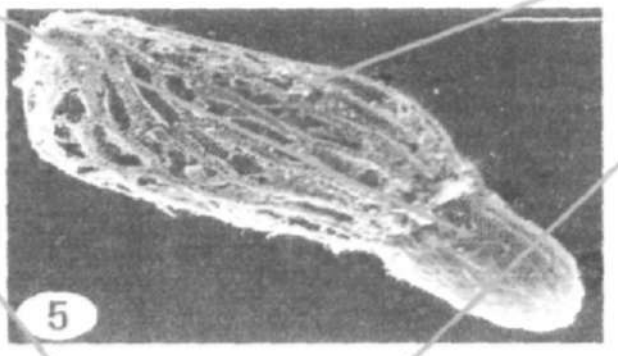
For angiosperm seeds to germinate they must have to be exposed to warm and moist environment for a couple of days, normally 7-14 days. In addition to that, conditioned *Striga* seeds must have to be exposed to certain chemical substances, germination stimulants, from the root exudates of a nearby host root before they could germinate. Under favorable field conditions, these seeds can be induced to germinate in 10 days after the commencement of the rainy season, when the young seedlings of the host crops become established. However, under favorable laboratory conditions they can be induced to germinate only in 1-2 days (Anonymous, 2006). Soon after germination, the germ tubes begin to elongate in the direction of the host root, by chemotrophy, until physical contact is made (Plate II). The optimum day and night temperatures for the germination of *Striga* seeds is 30°C and 20°C, respectively (Dawoud and Sauerborn, 1994; and Anonymous, 2005m), and deviation from these significantly retards germination rates (Dawoud and Sauerborn, 1994). Adequate soil moisture, in well drained and textured soil, promotes seed germination and it is inhibited by prolonged water logging (Anonymous, 2005m). Degree of germination decreases with increasing osmotic potential of the germination stimulant (Dawoud and Sauerborn, 1994). In some *Striga* species, light inhibits seed germination. This is another adaptation that



(Source: Berner *et al*. 1997)

***Striga* germ tubes or radicles**

Crested seed coats



(Source: Parker and Riches, 1993)



(Source: Parker and Riches, 1993)

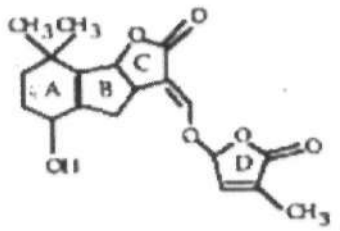
Plate II: Germinating *Striga* seeds with radicles issuing out of their seed coats.

ensures that seeds do not germinate in areas where they may be prone to desiccation under sunlight (Anonymous, 2005m). The necessity of germination stimulant from the host root, before a *Striga* seed germinates, is an evolutionary adaptation that ensures that seeds do not germinate where host root is not available. Only conditioned seeds located not more than 2 cm away from the tip of young host roots are induced germinate, and the germination stimulant is secreted only by a specific portion of the young roots, about 3-6mm behind the root tip or apex; old roots do not exude germination stimulant (Parker and Riches, 1993; Anonymous, 2005m). Seeds located too far (more than 2 cm) away from the host root may not perceive the germination stimulant, or their food reserves may run out before they could reach the host root. If contact with the root is not made in 5 days, the germtube ultimately dies of exhaustion (Anonymous, 2006).

Most of the natural germination stimulants of plant sources are sorgholactones and are active in extremely low concentrations (1 ppb to 1 ppm) (Verkleij and Kuijper, 2000). The stimulants from root exudates of specific hosts serve as host recognition factor to the parasites, though some other chemicals from root exudates of none-host crops such as cotton, groundnut, cowpea, bambara groundnut, and other chemicals such as kinetin, giberellic acid, abscisic acid, cumarin derivates, yeast extracts and ethylene can also induce conditioned *Striga* seeds to germinate (Anonymous, 2006). Other stimulants include strigol, and strigol analogues particularly GR-7 and GR-24 (Figure 2) (Anonymous, 2005m).

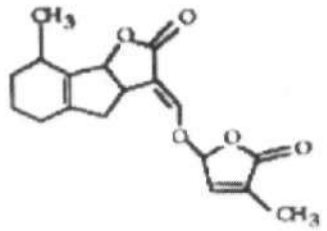
Figure 2: The molecular structure of some germination stimulants

a)



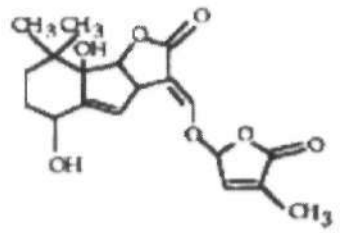
(a) Strigol

b)



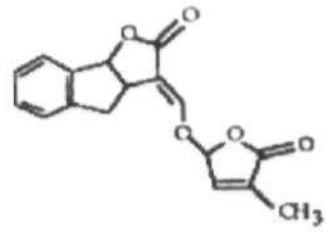
(b) Sorgolectone

c)



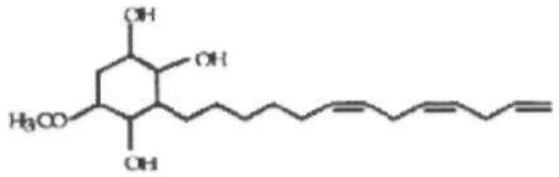
(c) Alectrol

d)



(d) GR-24

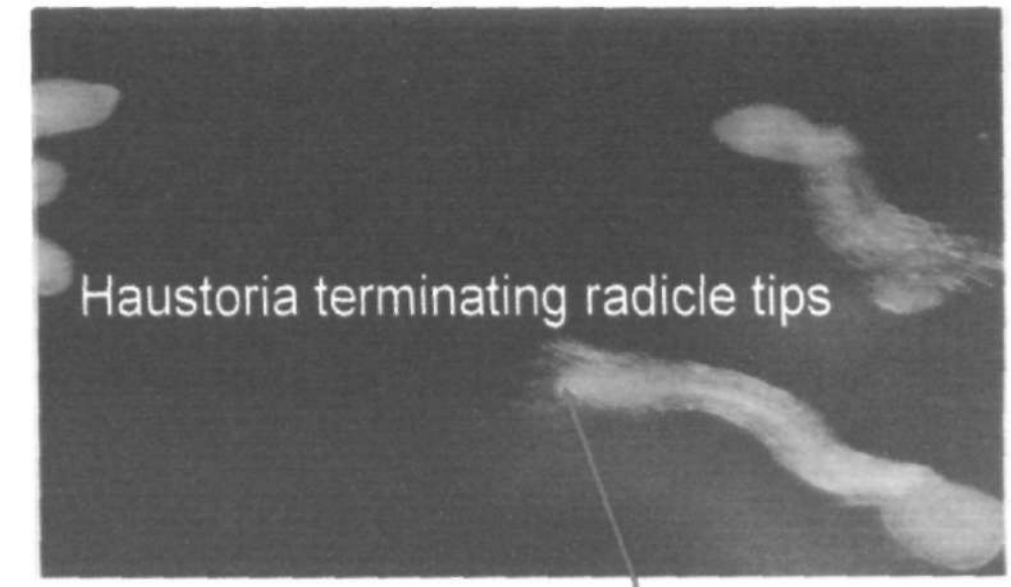
e)



(e) Dihydrosorgoleone

(Source: Anonymous, 2005m)

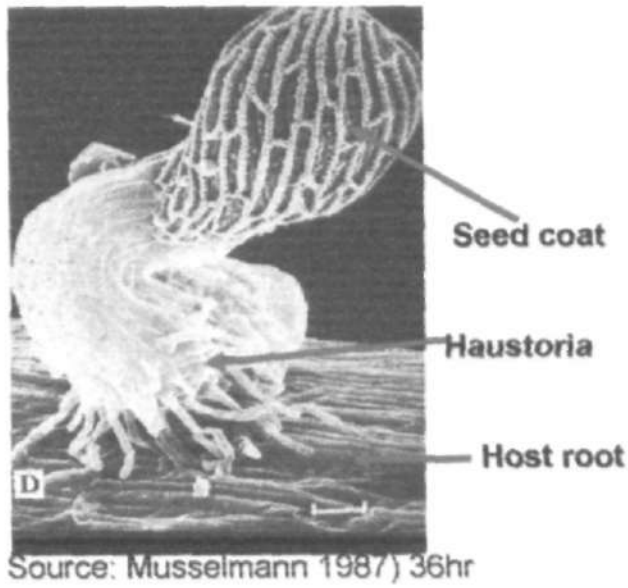
Striga seeds do not only require chemical stimulants from the host before they germinate, they also require specific chemical signals from the host root exudates to elongate in the direction of the host root, by chemotrophy, until contact is made. Soon as the germtube makes physical contact with the host root, an adhesive substance is secreted to firmly attach it to the surface of the host root. Further elongation is immediately stopped and development of haustorium soon commences (Anonymous, 2005m). The optimum day and night temperatures for the attachment of *S. hermonthica* germ tube to the host root are 35 and 25°C (Dawoud and Sauerborn, 1994). A third chemical signal contained only in the root exudates of the host serves not only as host recognition factor, but it also induces the formation of haustorium, once the germtube is in contact with the host root (Anonymous (2006). The tip of the pointed germ tube develops into a club-like structure that finally differentiates into several finger-like projections (Plate III). The haustorium, which is common to all parasitic plants in the Plant Kingdom, is the morphological and physiological bridge between the host and parasite. It firmly glues the parasite to the host roots on which it secretes hydrolytic enzymes that dissolve root tissues. This together with the mechanical pressure from the haustorium enables the parasite to penetrate the host root (Plate IV). Ultimately the host root is penetrated and only the xylems vessels of both the host and the parasite are directly connected together (Anonymous, 2006). In some *Striga* species the functions of the primary haustorium may be supplemented by about 100 other secondary haustoria that are developed starting from about 2 weeks after attachment (Anonymous, 2006; Anonymous, 2005m; Parker and Riches, 1993). The lateral secondary haustoria



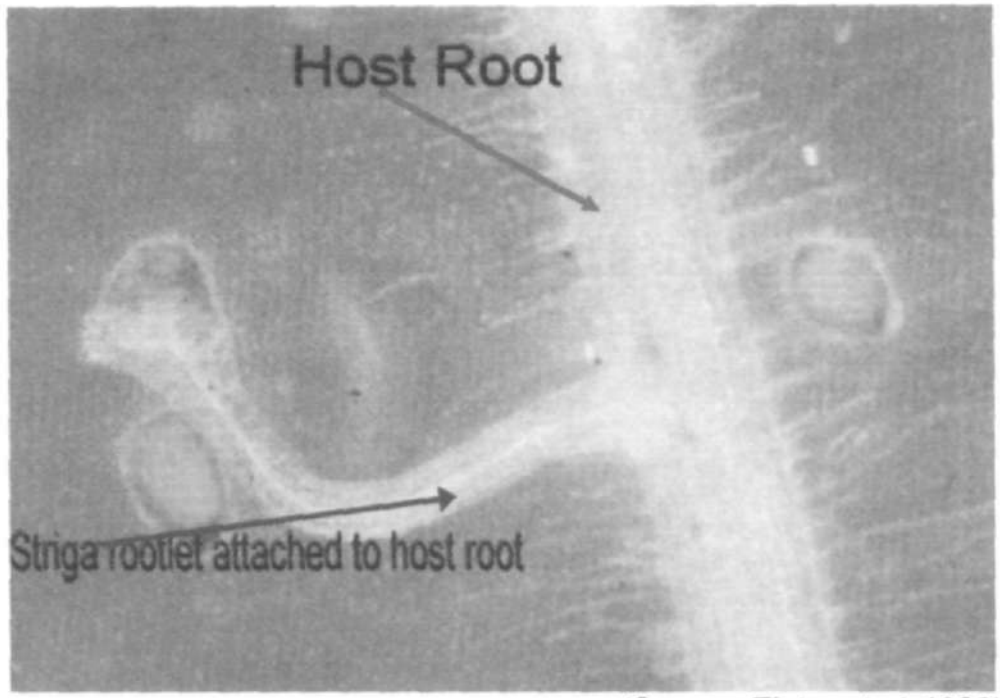
(Source: Ejeta *et al*, 1992)

(Source: Parker and Riches, 1993)

Plate III: Germinating *Striga* seeds with developing haustoria at the radicle's apex.



Source: Musselmann 1987) 36hr



(Source: Ejeta *et al*, 1992)

Plate IV: Attachment and penetration of young host roots by *Striga* haustoria

provide several points of attachment to the roots of the same host. In some parasitic plants, secondary haustoria may also elongate to ramify and penetrate the roots neighboring of hosts of the same (intraspecific parasitism) or different species (interspecific parasitism) at several points (Anonymous, 2006). The primary haustorium, with or without the lateral secondary haustoria, serve to augment the function of conventional root system, which is poorly developed in all parasitic plants. Apart from attachment and penetration of the host root tissues, the haustorium also serves as the sink through which the parasite siphons away, on continuous basis, manufactured foods, water, and mineral nutrients and solutes from the host (Anonymous, 2006; Anonymous, 2005m).

Soon after attachment, the extremely tiny germtube rapidly develops into an underground or subterranean parasitic shoot (Plate V). This shoot does not contain chlorophyll; thus it is holoparasitic and entirely dependant on the host, and therefore continues to drain away the host nutritionally. These actions, and perhaps the toxic effects of the parasites too, reigns the greatest havoc on the host, and make this stage as the most destructive stage in the life cycle of the parasite that greatly affects the physiology and morphology of the host (Verkleij and Kuijper, 2000; OISAT, 2006). Observable symptoms due the subterranean activities of underground *Striga* shoots becomes manifest several weeks before the emergence of the parasite above the ground. These symptoms include strong reduction of the shoot/root ratio manifested at least some 10 days after attachment of a single parasite to the host. (Verkleij and Kuijper, 2000). Other symptoms include

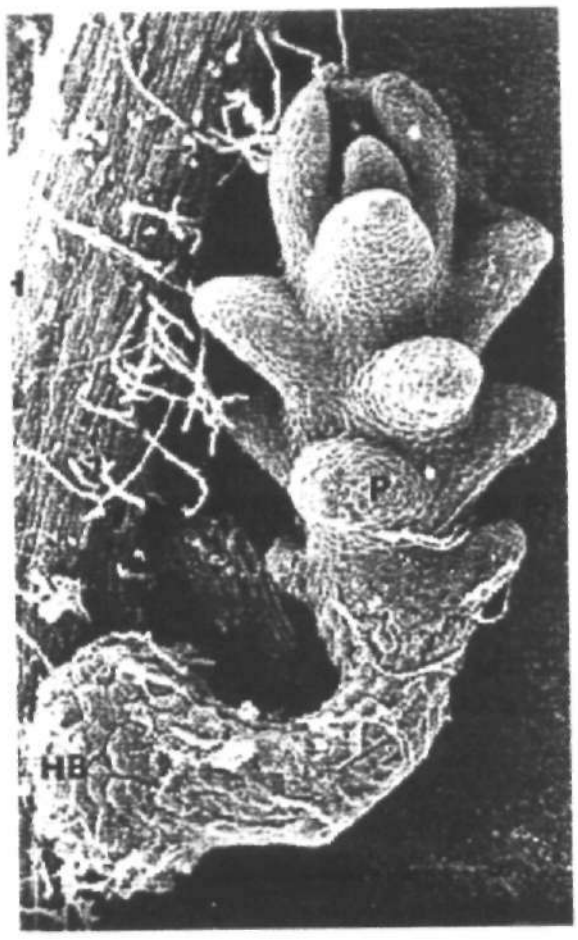


Plate V: An enlarged underground *Striga* shoot attached to a host root (Source: Parker and Riches, 1993).

manifestation of drought stress and wilting of the host, stunted shoot growth, and reduction of grain yield (Elzein and Kroschel, 2006). Unlike germination of *Striga* seed that can be induced by germination stimulant from hosts and some non-host crops and some other chemical substances, initiation of haustorium formation in *Striga* is exclusively triggered by haustorium initiation factors found only in the exudates of host crops. This is the principle of managing the parasite through trap cropping (Verkleij and Kuijper, 2000), since a non-host crop such as cotton and cowpea can induce the seeds to germinate, but thereafter cannot be attacked by the parasites, and in the absence of true host, this leads to suicidal germination.

Aerial *Striga* shoot begins to emerge above the ground some 4-5 weeks after seed conditioning. Emergence is followed by formation of chlorophyll and the parasite begins to photosynthesize, though still wholly dependant on the host as hemiparasite. The haustorium still continue draining water, nutrients and foods from the host, and this is further facilitated by preponderance of numerous stomata on both the upper and the lower side of the leaves of the parasite. Unlike the stomata found on the host leaves, the stomata on *Striga* leaves remain open day and night and they do not close even in times of harsh draught. This ensures continuous flow of water and other materials from the host to the parasite, via strong transpirational pull initiated from the numerous stomata on the leaves of the parasite (Verkleij and Kuijper, 2000; Anonymous, 2005m). After emergence of the parasite shoot, other additional symptoms include drought stress and wilting.

Flower formation commences about 2-4 weeks after emergence (Plate VI). Two weeks after pollination viable seeds are produced. A *Striga* plant may produce about 700 seeds/capsule, and about 60-70 capsules/plant (Anonymous, 2005m) or up to 20,000-100,000 (OISAT, 2006; Elzein and Kroschel, 2006) or 200,000 seeds/plant (Verkleij and Kuijper, 2000). A *Striga* life cycle lasts about 4 weeks from conditioning to formation of viable seeds. Seeds measure about 0.1-0.4mm in length and weigh about 3-15µg in weight (Anonymous, 2005m). They are extremely small and under specific soil conditions can retain their viability for up to 14 years. During the first 6 weeks the seeds remain dormant. After the dormancy period in warm dry conditions the seeds can be induced to germinate thus repeating the cycle.

2.4 Ecology and Distribution of *Striga*

Striga is native to grasslands of West and Central Africa, where it thrives best on nutrient deficient soils (Anonymous, 2005a), and *Striga* is an indicator plant for nutrient deficient soils (Kranz, 1999; Kranz *et al.*, 1998). Incidence and severity of parasitic *Striga* spp. (*S. asiatica*, *S. hermonthica*, *S. aspera* and *S. forbesii*) on cereals are particularly high in the savanna of Central, East and Southern Africa, and are worst in the savanna grassland of West Africa (Anonymous, 2005m). They are prevalent in both the tropics and sub-tropics particularly in the natural savanna or grassland of semi-arid zones with 400 to 1000 mm of annual rainfall (Gworgwor *et al.*, 2001), and in rain-forests (Anonymous, 2005m). They are major pests throughout semi-arid Africa and parts of Asia (Walker, 2004). Two-thirds of about 40



Plate VI: An emerged *Striga* shoot bearing flowers for seed formation; the final stage in *Striga* life cycle (Source: Anonymous, 2005g).

known *Striga* species in the world are believed to have originated and prevailed in Africa (Ramaiah *et al.*, 1983; Emechebe, 1994; Musselman, 1987; Raynal-Roques, 1987) (Table 3). Out of the listed 30 *Striga* species, 23 are said to have originated from Africa, out of which 16 are from West Africa (Anonymous, 2005m). In colonized and undisturbed natural habitats, a single host plant is hardly parasitized by more than a single parasitic plant; hence the parasite lives side by side with its hosts without causing much damage to it (Anonymous, 2005a). Similarly, *Striga* populations are kept in check in agricultural systems characterized with long fallow periods of 5-10 years, and crop rotation with non host crops. But in the last 20-30 years, the need to grow more foods to feed teeming human population in Africa and Asia have led to intensified land use that strongly favored *Striga* resurgence, with abundance of hosts. During this period the duration of fallow periods were grossly shortened or totally eliminated, thereby giving little or no time for nutrient-exhausted soils to regenerate under bush fallow system. In addition, successive monocropping of susceptible host crops (maize, sorghum, millet or faba bean, lentils, sunflower, cowpea) ensured abundance of alternative host sources, thereby aggravating the incidence, intensity, and spread of *Striga*. This have been further assisted by ease of dissemination of minute *Striga* seeds, and wide host range among cultivated cereals, legumes, fodder grasses and non-cultivated wild grasses, within the same habitat (Anonymous, 2005a; Anonymous, 2005h). Under such intensified land-use for accelerated food production a single host plant is most often simultaneously parasitized by one or more parasitic species (Anonymous, 2005a). *Striga* resurgence in Africa and Asia have also been seriously aggravated by the recent

Table 3: World distribution of some *Striga* species.

***Striga* species**	**Distribution Areas**
S. hermonthica	Sahel/semi-arid to sub-humid tropics of Africa including Madagascar and south-western parts of the Arabian Peninsula
S. asiatica	Semi-arid tropical & subtropical grasslands of Africa, Asia (including India, Burma), Australia, China, USA, Arabian peninsula, Philippines, Malaysia, Indonesia, Madagascar, and New Guinea
S. gesnerioides	West Africa, Indian subcontinent, Sri Lanka, Arabian peninsula, & USA
S. aspera	Africa, particularly in the West African savanna, and sporadically in Ethiopia, Sudan and Tanzania.
S. passargei & *S. brachycalyx*	Widespread in African savanna
S. forbesii	Found throughout Africa under fairly wet conditions particularly ir Zimbabwe, Madagascar and Tanzania
S. aequinoctialis & *S. dalzielii*	West Africa
S. angolensis	Angola
S. angustifolia	E. Africa, Asia, Indonesia
S. bilabiata & *S. latericea*	Africa
S. chrysantha	Central Africa
S. elegans Benth.	Angola, Malawi, S. Africa, Zimbabwe
S. gastonii A. Raynal	Chad and Central African Republic
S. gracillima Melch.	Tanzania
S. hallaei A. Raynal	Congo
S. junodii Schinz	S. Africa, Mozambique
S. klingii	Togo W. Africa, Nigeria, Ghana, Cameroon

(Sources: Anonymous, 2005a; Anonymous, 2005c; Anonymous, 2005g; Anonymous, 2005h; Anonymous, 2005i; Lagoke, 1998; Mohamed *et al.*, 2001; Musselman, 1987; and Musselman and Parker, 1983)

general global economic recession that forced many governments, to withdraw subsidies on agricultural farm inputs, thereby making inorganic fertilizers prohibitively expensive to resource poor peasant farmers who hardly purchase and apply enough fertilizers to maintain optimum soil fertility in their croplands (Anonymous, 2005a). It is strongly favored by soil moisture stress conditions, which led to less shading by poor growth of the host. As parasitic weeds, *Striga* species prefer permanently disturbed habitats, where they show great phenotypic variations, and exhibit a wide environmental tolerance and ubiquitous spatial distribution (Walker, 2004; Kiriro, 1991; Lagoke, 1998).

Striga are widely distributed mainly in Africa and Asia., and is endemic in the whole of Africa south of the Sahara, particularly in the Sahel and Savanna ecological zones, from latitude 5° S to 20° N (Figure 3). (Obilana, 1980; Parker, 1983; Hess, 1994; Butler, 1989; Lagoke *et al.*, 1986; Lagoke *et al.*, 1991; M'Boob, 1994; Musselman *et al.*, 1991). In Africa, an estimated 21 million hectares of farmlands have been reported to be infested with *Striga* (Sauerborn *et al.*, 1991). In other reports, two-thirds of about 73 million hectares of cereal farmlands in Africa have been reported to be infested with *S. hermonthica* (Anonymous, 2005c; M'Boob, 1986; Emechebe, 1994). The parasites have already infested about 40% of the total arable farmlands in Africa's Savanna ecological zones and their geographical distribution, incidence and severity are said to be on the increase (Orodopho and Kiriro, 1994; and Lagoke *et al.*,1994b, Gworgwor *et al.*, 2001). In Nigeria, where *Striga hermonthica* is the most widely distributed plant parasitic weed, 95% of some



Distribution map for *Striga hermonthica* (Del.) Benth



Distribution map for *Striga asiatica* (L) Kuntze



Distribution map for *Striga gesnerioides* (Willd.) Vatke

Figure 3: World distribution maps for three most noxious *Striga* species
(Source: Musselman *et al.*, 1991)

surveyed cereal farmlands in the Savanna ecological zones were said to have been infested by the parasites (Lagoke *et al.*, 1994a, Gworgwor *et al.*, 2001). Numerous *Striga* species attacking both cereal and leguminous crops in Nigeria are reported to be prevalent in areas extending from latitude 7-14°N (Obilana, 1980) (Figure 11). *S. hermonthica* is a serious pest in northern Cameroon, where 400,000 ha were severely infested, and in Togo (Tchemi, 1986), The Gambia (Carson 1986), and indeed throughout Africa south of the Sahara (Kim, 1991). It is the most widely *Striga* species in Africa (Lagoke *et al.*, 1991), and one third of the total land area in Nigeria, representing savanna and the Sahel ecological zones, were reported to have been infested by *Striga* (Lagoke, 1986). *S. hermonthica* is more important in drier northern parts of Nigeria, Togo and Republic of Benin (Parkinson, 1985), and it is also the most important pest of maize in Nigeria's northern Guinea savanna (NGS) and Sudan savanna (SS) (Lagoke, 1986). In Kenya *Striga* is prevalent in Lake Victoria basin particularly at Siaya, Kisumu, South Nyanza, Kisii, Busia and Kakamega districts, and in areas with both low rainfall and soil fertility (Kiriro, 1991).

2.5 Host Range of *Striga hermonthica*

Out of about 40 known *Striga* species at least 11 species including have been reported to be parasitic to other plants (Anonymous, 2005m) (Table 4), particularly maize, sorghum, millet, rice, and some to cowpea, groundnut and sweet potato and some fodder grasses (Nickrent and Musselman, 2004). However, currently only *S. hermonthica*, *S. asiatica and* S. *gesnerioides* are considered to be major problems in tropical agriculture. *Striga hermonthica* has a broad host range, but almost

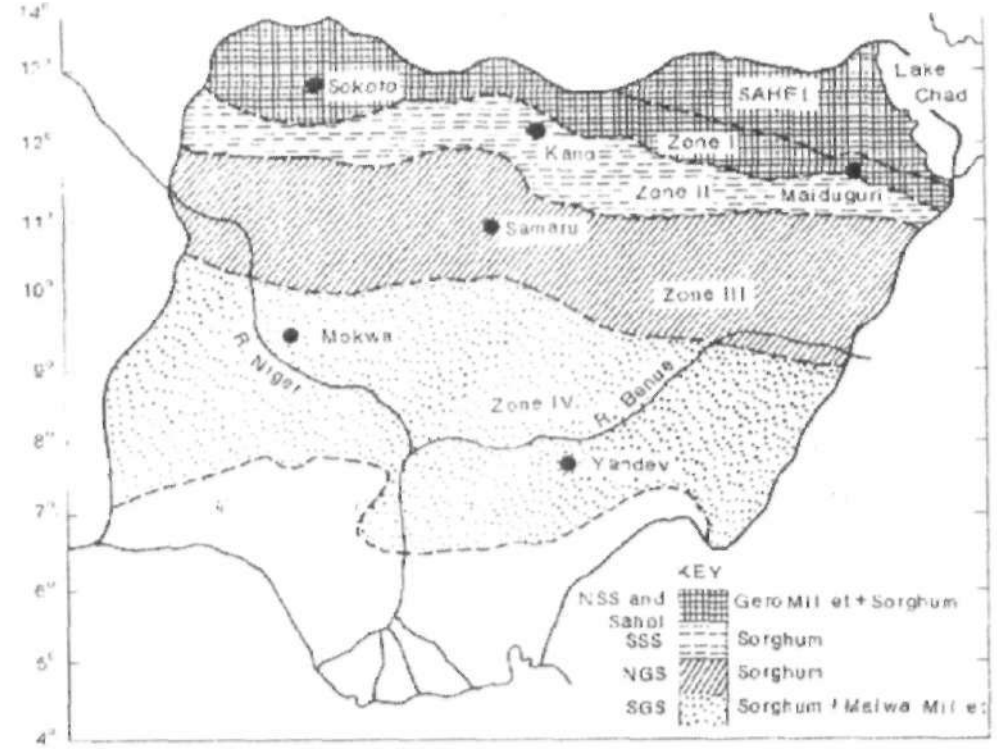


Figure 4: Distribution Map for *S. hermonthica* in Nigeria
(Source: Obilana, 1983)

Table 4: Host range of some *Striga* species.

PARASITE	HOSTS
S. hermonthica	Pearl millet (*Pennisetum glaucum* (*americanum* L.) finger millet *(Eleusine coracan* (L.) Gaertn). sugarcane (*Saccharum officinarum* L.), sorghum (*Sorghum bicolor* (L.) Moench), maize(*Zea mays* L.), upland rice(*Oryza sativa* L.), & several wild grasses, including: *Settaria incrassata*, *Sorghum arundinaceum*, *Rottboelia cochinchinensis*, *Eleusine indica*, *Paspalum scrobiculatum*, *Aristida*, *Brachiaria*, *Cymbopogon* and Digitaria species
S. asiatica	Cereals: sorghums, millet, maize, sugar cane, corn, sorghum, and weedy grasses, especially crabgrass (*Digitaria* spp.)
S. *gesnerioides*	Dicot hosts, mainly cowpea (*Vigna unguiculata* (L.) Walp.), tobacco (*Nicotiana tabacum* L.) and sweet potato (*Ipomea batatas* (L.) Lam.)
S. aspera	Maize, sorghum, upland rice, & wild grass species, as *Aristida*, *Brachiaria*, *Digitaria* and Loudetia species
S. passargei	Sorghum and maize occasionally
S. brachycalyx	several crops
S. forbesii	maize & sorghum

(Sources: Anonymous, 2005a; Anonymous, 2005c; Anonymous, 2005d; Anonymous, 2005g; Anonymous, 2005h; Anonymous, 2005i; Lagoke, 1998; WARDA, 1998; Ejeta *et al.,* 1992; and Mohamed *et al.*, 2001, Gworgwor *et al.*, 2001)

entirely restricted to sorghum, maize, upland rice, sugar cane, millet and several other wild grasses (Parker, 1983; Parkinson, 1985; Lagoke *et al.*, 1986; Carson, 1986; Butler, 1989; Emechebe, 1994; Hess, 1994; M'Boob, 1994; Johnson *et al.*, 2000; and Wilson *et al.*, 2000, Gworgwor *et al.*, 2001). Some of strains of *S. hermonthica* are specific to millet alone, while some parasitize sorghum alone (Musselman and Parker, 1983). In addition to *S. hermonthica,* cereals are also attacked by *S. aspera*, *S. asiatica* and *S passargei* (Lagoke *et al.*, 1991*) S. aspera* which commonly attacks wild grasses such as *Digitaria* spp, *Aristida kerstingii* and *Digitaria exilis,* was recently found attacking maize in The Gambia (Carson, 1986), sorghum, millet, maize and rice in Burkina Faso and Nigeria (Lagoke *et al.*, 1991; Gworgwor, personal communication). *S. asiatica* attacks mainly wild grasses such as *Digitaria* sp and *Dactylotenium aegyptum* in Cameron and sporadically sorghum (Lagoke *et al.*, 1991). Alternative hosts of *S. hermonthica* include *Pennisetum* spp, *Andropogon* spp, *Rottboelia cochinchinensis, Setaria palledifusca, Brachiaria* spp, *Digitaria* sp, *Dactyloctenium* sp *and aegyptum* sp (Lagoke, 1986). *S. gesnerioides* attacks cowpea (Lagoke *et al.*, 1991; Carson, 1986), wild legumes such as *Indigofera pricureana,* in The Gambia (Carson, 1986) *Tephrosia sp., Indigofera sp. and Desmodium sp.* in Cameroon and Nigeria and *Ipomoea* spp. (Lagoke, 1986; Lagoke *et al.,* 1991 and Gworgwor *et al.,* 2001).

2.6 Economic Importance of *Striga hermonthica*

Striga are obligate root parasites that are wholly dependant on their hosts for the supply of all or part of their nutritional requirements, which they siphon away from

the host through their haustoria that connect directly with the phloem tissues of the host roots (Walker, 2004; Press *et al.*, 1987; Gurney *et al.*, 2000). *Striga hermonthica* severely reduces photosynthetic rates in parasitized plants in addition to siphoning away manufactured food and absorbed water and mineral nutrients from the host, as a result of which the host crops encounter enormous amounts of yield losses, which directly correlate with the severity of *Striga* symptoms (Lagoke *et al.*, 1994a). Symptoms include stunted growth, chlorosis, necrosis, wilting, and eventual death of the host plants (Hess, 1994; Emechebe, 1994). The severity of *Striga* symptoms, and hence the enormity of the damage caused by the parasites, have always been compounded by moisture and nutrient stress in the soil, conditions which are said to commonly prevail in the semi-arid zones of Africa (Ejeta *et al.*, 1992).

In Africa, two thirds of about 73 million hectares of cereal farmlands is now infested with *Striga hermonthica* (Watson *et al.*, 1993). In East and Central Africa and Southern Africa, the amount of *Striga*-infested land planted with IR-maize was estimated at 604,000 and 643,000ha/annum respectively, while West in Africa and the whole of Africa the figure was put at 1,337,000 and 2,585,000ha/annum, respectively (Table 5) (Obilana, 2003; Anonymous 2005a). In this way, *Striga* becomes the single most important biotic factor affecting cereal cultivation in 42-59 African countries, including South Africa, Ethiopia, Kenya, Burkina Faso, Botswana, Niger, Mauritania, Zimbabwe and Nigeria (Anonymous, 2005a; Anonymous, 2005b; Anonymous, 2005m; M'Boob, 1994; Hess, 1994; Emechebe, 1994; Walker, 2004;

Table 5: Estimated area under *Striga* infestation in sub-Saharan Africa

Country	Maize area ('000s ha)	*Striga* infested area				Total potential area in *Striga* ('000s ha/yr)	Total potential IR-maize seed sales (T/yr)
		% total	'000s ha	% total	'000s ha		
		Season A		Season B			
Benin	607	15	91	20	18	109	2,732
Botswana	20	10	2	0	0	2	50
Burkina Faso	261	10	26	0	0	26	653
Cameroon	392	10	39	30	12	51	1,274
Cote d'Ivore	700	5	35	30	11	46	1,138
Ethiopia	1,606	5	80	0	0	80	2,008
Ghana	683	15	102	30	31	133	3,330
Kenya	1,502	10	150	50	75	225	5,633
Lesotho	134	5	7	0	0	7	168
Malawi	1,342	20	268	0	0	268	6,710
Mali	195	10	20	0	0	20	488
Mozambique	1,221	10	122	0	0	122	3,053
Namibia	39	10	4	0	0	4	98
Nigeria	4,111	20	822	10	82	904	22,611
Senegal	61	5	3	0	0	3	76
South Africa	3,691	1	37	0	0	37	923
Sudan	169	10	17	0	0	17	423
Swaziland	83	5	4	0	0	4	104
Tanzania	1,785	10	179	20	36	214	5,355
Togo	377	10	38	20	8	45	1,131
Uganda	615	10	62	10	6	68	1,691
Zambia	553	10	55	0	0	55	1,383
Zimbabwe	1,437	10	144	0	0	144	3,593
Subtotal ECA	5,677		487		117	604	15,109
Subtotal SA	8,520		643		0	643	16,079
Subtotal WA	7,387		1,176		161	1,337	33,430
TOTAL	21,584		2,307		278	2,585	64,618

ECA = East and Central Africa; SA = Southern Africa; WA = West Africa.

Source: Obilana, (2003

and Lagoke *et* al., 1994b). The parasites are prevalent both in East, West, Central, and South Africa. Crop yield losses due to *Striga* suffered by both sorghum and millet throughout Africa were estimated at 25.5% (or 8.44 million tons/annum) of the potential yield. For the said crops, yield losses/annum range between a minimum of 5%, each, in Cote d'Ivore, Rwanda and South Africa, to a maximum of up to 90% in Tanzania, or a minimum of less than 0.001 million tons/annum each in Botswana and Swaziland to a maximum of 3.15 million tons/annum in Nigeria (Table 5) (Obilana, 2003). In Africa, *Striga* accounts for annual crop yield losses estimated at 5 - 15% (Sauerborn *et al.*, 1991), 40% (Anonymous, 2005a; Anonymous, 2005b; and, M'Boob, 1994), and 70% (Watson *et al.*, 1993), and as high as 80% (Anonymous, 2005b). *S. hermonthica* is the most important parasitic weed of cereals in West Africa, (Sauerborn *et al.*,1991), and yield losses due to it in Nigeria ranged between 10-100% (Ogborn, 1972; Parkinson, 1985; Lagoke 1991; and Lagoke *et al.*, 1994a). *Striga* accounts for annual loss of 4.1 million tons/annum to cereals in Africa (Sauerborn *et al.*, 1991, and Watson *et al.*, 1993). In West Africa, general grain yield losses due to *Striga* range between a minimum of 10,000 tons/annum in The Gambia to 1,056,000 tons/annum in Nigeria (Table 6) (Anonymous, 2005a). In monetary terms a staggering 89.45% loss of revenue from corn, millet and sorghum, was reported pegging farmers' earnings to a mere US $311/annum out of the potential US $2949/annum (Table 7) (Anonymous, 2005a). Total loss of revenue across Africa on all crops due to all parasitic *Striga* species was estimated at over US $7 billion/annum (Anonymous, 2005a; Anonymous, 2005b and M'Boob, 1994).

Table 7: Loss of revenue in grain production in Africa due to *Striga*

Crop	Actual (million US $)	Potential (million US $)
Corn (76)	140	1513
Millet (73)	82	676
Sorghum (73)	89	760
Total	**311**	**2949**

Source: Anonymous, 2005a)

Food and Agriculture Organization (FAO) estimated that in Africa, *Striga* seriously affect the livelihood of some 300 million people (Anonymous, 2005a; Anonymous, 2005b; Anonymous, 2005m; M'Boob, 1994; and Walker, 2004), out of which about 100 million are from West Africa alone (Anonymous, 2005b). These parasitic weeds have also been reported to force peasant farmers into shifting cultivation, from heavily infested lands to uninfested ones (Ejeta *et al.*, 1992; M'Boob, 1994; Emechebe, 1994). In some badly hit areas, peasant farmers were forced by *Striga* to abandon cereal cultivation completely in favor of non-cereal crops that, otherwise, may not have been cultivated, or even entirely abandon the farmland (Anonymous, 2005b; Obilana, 2003). In Africa, farmers spend 40% of their time in the farm controlling weeds, including *Striga*, while less than 10% of it is spent in Western countries for effective weed control, mainly with chemical herbicides (Sand, 1987). In Ethiopia and many other parts of Africa and Asia, *Striga* entrenches poverty among the resource poor farmers.

2.7 Management of *S. hermonthica*

A number of techniques have been tested and found suitable for *Striga* management. These techniques have been broadly classified into preventive, cultural, host plant resistance, chemical, physical and biological management techniques (Anonymous, 2006). Preventive measures include national and international cooperation to limit the spread of *Striga*. Cultural techniques include crop rotation with trap and catch crops, planting dates, application of mineral fertilizer, flooding, use of organic materials and managed fallow. Host plant

resistance involves use of planting crop varieties that are resistant or tolerant to *Striga* attacks. Use of chemicals involves the use of herbicides, soil disinfectants and germination inducing compounds. Physical *Striga* management techniques involves the use of clean planting seeds, hand weeding, weeding after harvest, burning of weeded *Striga* shoots, deep ploughing, and soil solarization. Biological control techniques involve the use insects and fungi (Anonymous, 2006; Lagoke *et al.,* 1986, and 1991). Other tested techniques include soaking of cereal seeds in brine solution (Ogunremi and Olaniyan, 1994; Gworgwor *et al.*, 2002) and the use of arbuscular mycorrhiza (Gworgwor and Waber, 2003).

However, despite all the wide array of *Striga* management options, the parasites are still considered as some of the most difficult weeds to manage. The parasites have become noxious in Africa despite dedicated, concerted and coordinated research efforts in the last 80-90 years (Parker, 1983). Virtually all recommended *Striga* management techniques have proved ineffective, since peasant farmers cannot sustainably adopted most of them (Kiriro, 1994; Emechebe, 1994; Lagoke *et al.,*1994a), due to a myriad of socioeconomic problems (Parker, 1983; Okonkwo, 1994; Kiriro, 1994; Emechebe, 1994; Ejeta *et al.,* 1992; and Lagoke *et al.*, 1994b). In addition, this is partly because *Striga* are highly adapted to traditional cultural practices (Carson, 1986). *Striga* management is difficult because its seeds are capable of surviving in infested soil for up to 20 years (Lagoke *et al.,* 1991). Besides, conventional management techniques, such as use of herbicides,

stimulants, and breeding for resistance, have not been consistent in controlling *Striga* (Sauerborn *et al.*, 1991).

2.7.1 Herbicides application in *Striga* management

Various chemical herbicides, particularly dinitroanalines (trifluraline, benefine, flurchloraline, pendimethaline), diphenyl ethers (oxyfluorfen, fomesafen, chlobenil, DCPA), ametryn, linuron; lactofen and gramoxone, and salts of 2,4-dichlorophenoxy acetic acid (2,4-D), *etc* have been tested and found effective for the management of *Striga*, when used either as pre-emergence soil applied sprays or as post-emergence directed foliar sprays (Aggrawal, 1994; Ouedrago and Bani, 1994; Lagoke *et al.*, 1994b). Other herbicides reported by Anonymous (2006) to be useful in the management of parasitic weeds include Imazaquin (Trade name:Scepter), Imazethapyr (Pursuit, Pivot), Imazapyr (Arsenal, Assault), Glyphosate (Roundup), Dazomet (Basamid), Methylbromide (Haltox, Zedera, Terabol) Ethylenedibromide (Ethylenedibromid), Chlorpropham, Dicamba (Banvel) and Ethylene. However the most widely used herbicides for *Striga* management are dicamba and 2,4-D (Verkleij and Kuijper, 2000).

Herbicides are used in *Striga* management by applying them directly into the soil before planting crop seeds or before their emergence after sowing (pre-planting or pre-emergence herbicide application). Herbicides are also applied directly on to the crop or the parasite (post emergence herbicide application). They are also applied

directly to the weed after crop harvest (post harvest herbicide application). In both instances, the herbicides are applied in order to eradicate the vegetative shoot of the parasite and prevent it from producing seeds (Anonymous, 2006).

Pre-emergence application of herbicide is often used in *Striga*. According to Eplee *et al.* (1991) and Anonymous (2006) dinitroanilines (DNAs) (particularly trifluraline, benefine, flurchloraline and pendimethaline, metalachlor) and diphenyl ethers are pre-emergence herbicides widely used for the control of *Striga asiatica* in the US. DNAs are used at 0.5-0.7 kg a.i./ha, at 2.5-10 cm soil depth. Pendimethalin is a DNA with relatively higher vapor pressure applied to the soil in order to rid it free of *Striga* seed bank in the soil. The most effective DNA for *Striga* management is oxyfluorfen (Goal®). All these prevent *Striga* emergence. Other DNAs include fomessafen, dichobenil and DCPA (Eplee *et al.*, 1991). Pendimethalin (Prowl) at 1.7 kg a.i./ha is applied as pre-emergence herbicide to the soil surface, and metalachlor (Dual) at 2.2 kg a.i./ha is applied as pre-plant soil incorporated (PPI) herbicide to give 80-100% *Striga* control. They are carried into the soil by rain water (Eplee *et al.*, 1991). Post emergence application of herbicides, such as salt formulations of 2,4-dichlorophenoxy acetic acid (2,4-D), are applied after emergence of the parasite on the host. 2,4-D is applied in maize and sorghum, as directed foliar sprays to the emerged *Striga* at about the time of flowering or before, at the rate of 0.5-1.0 kg/ha, along with surfactants (0.12-0.25%) in order to aid the absorption of the herbicides and ensure effective control. 2,4-D is sprayed several times directly onto the parasite during the growing season (Verkleij and Kuijper, 2000; and Elzein and

pesticides are hazardous and are neither user nor environment friendly. Their application demands a farmer to acquire new knowledge, make additional investments, and observe a lot of precautions. Herbicide application is not compatible with mixed cropping system that is predominantly practiced in Africa (Lagoke *et al.*, 1991).

2.7.2 Use of germination stimulants in *Striga* management

Striga seed reserve in *Striga*-infested soil is depleted through the use of chemical stimulants such as ethylene gas, strigol and strigol analogues, which are injected into the soil to induce suicidal germination of the seeds in the absence to true host (Lagoke *et al.*, 1991; Verkleij and Kuijper, 2000). Synthetic strigol analogs, according to Butler (1989) and Eplee *et al.* (1991), could be used to diminish the number of viable seeds and reduce the degree of *Striga* infestation in the soil by causing premature seed germination before planting the true host. *Striga* seeds have receptor sites that recognize chemical stimulants from the root exudates of their specific hosts, and would not germinate without receiving such chemical stimulus (Butler, 1989). Ethylene gas is injected into the soil under pressure, to give a false signal to the seeds of the presence of a host, thus inducing suicidal germination of preconditioned *Striga* seeds. Seeds germinate within 2-4 days as the gas diffuses through the soil killing about 90% of the viable seeds. Similarly cotton, a false host of *Striga*, is capable of inducing suicidal germination of *Striga* seeds by way of producing strigol within its root exudates which induces suicidal germination of *Striga* seeds in the absence of true host. Synthetic strigol analogues

such as GR-7 and GR-24, too, are also capable of inducing suicidal germination of preconditioned *Striga* seeds in the absence of true host, thereby aiding in depleting soil seed-bank in *Striga*-infested soil (Eplee *et al.*, 1991). Nijmegen 1, and GR-24 are structurally similar to natural stimulant Strigolactone, and are the most potent and active synthetic germination stimulants for many *Striga* species at low concentration (10^{-}-10^{-} mol l^{-1}) (Elzein, and Kroschel, 2006).

Problems associated with the use of stimulants for *Striga* management in Africa have been highlighted by Lagoke *et al.* (1991), who reported that though chemical stimulants are highly efficient in the US for *Striga* management, the technique is not adoptable by small scale farmers in Africa because the technique is too expensive and highly technical. Besides, test results with strigol and ethylene generators in the tropics are not consistent and reliable, and since *Striga* seeds do not germinate at the same times and not all *Striga* seeds may be induced to germinate. Similarly, short and erratic rainy seasons may not permit adoption possible in the savanna and Sahel regions (Ogborn 1987; and Lagoke *et al.*, 1991). Application equipments (tractor mounted injectors, backpacks and hand applicators) are too expensive (Eplee *et al.*, 1991).

2.7.3 Use of resistant crop varieties in *Striga* management

Striga management through the use of tolerant or resistant crop varieties has been considered as the cheapest and the most effective solution to *Striga* problem,

particularly to resource poor farmers in developing countries (Anonymous, 2005a; Ramaiah, 1991; Lagoke *et al.,* 1991; Orodopho and Kiriro, 1994; Haussmann *et al.*,1999). Framida posses heritable resistance to *Striga hermonthica* under diverse conditions, and it also posses some other desirable traits including stability in high grain yield, good seedling establishment and resistance to grain mold and birds (Ramaiah, 1991). A number of other sorghum, maize, cowpea varieties and their wild relatives have been reported to be inherently resistant to *Striga*, and such varieties form the basis of breeding programmes that transfer resistance genes from such resistant varieties to susceptible elite, landrace or local varieties with desirable agronomic qualities (Anonymous, 2005b). *Striga* resistance in sorghum variety SRN 39 is controlled by a heritable single recessive gene (Hess *et al.,* 1992). Such naturally resistant varieties form the basis for pedigree breeding programmes, involving crossings between a *Striga*-resistant parent stock to donate resistance genes to susceptible elite or landrace crop variety, thereby improving the resistance of the latter. One or two back-crossings produce F_2 or F_3 generations that may exhibit desirable resistance trait from both the *Striga*-resistant parent and desirable agronomic qualities from the susceptible landrace. In one such studies for developing *Striga* resistant varieties, such as sorghum ICSV 1007 BF, genes for stable resistance to *Striga hermonthica* were transferred from *Striga*-resistant sorghum varieties, IS 9830 and SRN 39, to agronomically good, but susceptible elite sorghum varieties (Ezeaku and Gupta, 2004). In this study Framida, KSV 4, and CS 95 were confirmed resistant to *Striga*, since they exhibited lower *Striga* counts, lower *Striga* syndrome scores and higher grain yield than local checks.

Offspring of crosses between IS 9830 or SRN 39 and the susceptible elite sorghum varieties also produced susceptible but *Striga*-tolerant varieties that supported high *Striga* emergence, but exhibited comparatively lower *Striga* syndrome ratings scores and higher grain yields when compared with the susceptible elite parent stock. Such varieties include KSV 4, ICSV 400, ICSV 111, S 35, CS 54, ICSV 901 NG, and CS 95. The offspring that exhibited true resistance by supporting fewer *Striga* emergence included ICSV 1007 BF (low grain yield), SRN 39, IS 9830 (higher grain yield). These findings of Ezeaku and Gupta (2004) were also corroborated by works of Murty *et al.* (1995), who confirmed the similarity between the ICSV 111 with CSV 1007 BF, IS 9830, and Framida for resistance to *Striga*. Resistance of Framida red, and its high yield in *Striga*-infested soils, in that report, was also corroborated by the works of Ramaiah (1991), and Lagoke *et al.* (1999).

Evolutionary association between *Striga* and its hosts has enabled some crop varieties to acquire, as survival strategies, various complex mechanisms of avoiding or cushioning *Striga* menace, either through host avoidance, tolerance, or true resistance due to antibiosis. Resistance due to host avoidance is brought about by low or no production of germination stimulant and or haustorium inducing factor in the root exudates of the host, as in the case of sorghum against *Striga or* Faba beans against *Orobanche* spp (Anonymous, 2005a). This kind of resistance is manifested by low *Striga* count in infested plots (Musselman *et al.*, 1991). Tolerant varieties are susceptible to *Striga* attacks, but they are hardly devastated by the parasites despite heavy attacks. In this situation, resistance is not manifested by

low *Striga* emergence in infested plots, but rather by low *Striga*-syndrome crop reaction and high grain yield, despite heavy *Striga* emergence (Anonymous, 2005a). Tolerant varieties, according to (Ejeta *et al.*, 1991) are parasitized to the same extent as the susceptible varieties, but suffer comparatively less damage. Resistant varieties show less *Striga* incidence than susceptible varieties, and therefore suffer less damage than the susceptible varieties (Anonymous, 2005a). While susceptible crop varieties may readily loss up to 95% grain yield to *Striga*, resistant varieties may only loss as low as 5% (Obilana, 1983). Varieties with immunity against *Striga* are totally resistant to it, and they neither support any *Striga* emergence nor suffer yield loss (Anonymous, 2005a). True resistance could be due to the ability of the host to mechanically defy penetration by the parasite or its ability to suppress the growth of the parasite through antibiosis (Ramaiah, 1986). Root architecture that favors little branching at the top soil, as in the case of some resistant sorghum varieties, is associated with low *Striga* emergence since the top soil that houses the *Striga* seeds is not heavily ramified by the secondary roots from the host. This is responsible for resistance in Sorghum against *Striga* spp., or resistance in Faba bean against *Orobanche crenata*. Evidences in support of mechanical basis for resistance to *S. asiatica* were provided by Maiti *et al.* (1984) and Musselman and Dickson, (1975). Thickenings of the root pericycle and endodermis due to silica deposits and tyloses have been reported to be responsible for mechanical resistance in some resistant crop varieties. For instance, *Striga* resistance in SRN 39 is said to be due to a combination of low stimulant production and post-infection *Striga* growth inhibition. These complex mechanisms have

facilitated durable resistance of the cultivar in the field and it is currently being recommended for use in Sahel agro-ecological region of Western and Central Africa (Hess *et al.*, 1992). Some crop varieties resistant to *Striga* are shown in Table 8

Though effective and simple, the use of resistant crop varieties for *Striga* management, too, is marred with a number of shortcomings. Precise mechanism resistance to *Striga* is yet to be fully elucidated, therefore making breeding programmes for resistance particularly difficult, and restricted mainly to breeding for low stimulant production (Vaidya *et al.*, 1991). No sorghum variety is totally resistant to *S. hermonthica* (Lagoke *et al*, 1991), and no millet or maize variety is considered resistant to *S. hermonthica*, though some varieties hold some promises for resistance (Ramaiah, 1991) Thus the most resistant sorghum variety is sure to allow the germination and emergence of at least a few *Striga* plants that may perpetuate the problem and become a source of inoculums to other areas. Resistant crop varieties can not be relied alone for effective *Striga* management (Lagoke *et al.*, 1991). Besides that, a number of farmers reject the resistant varieties, and they prefer their susceptible local varieties because many of the resistant varieties, such as sorghum IS 16184, are of low grain yield and poor agronomic qualities (Ramaiah, 1986; Ramaiah, 1991). In addition, great genetic variability in developed resistant lines often leads to breakdown in resistance, thereby rendering a resistant variety susceptible to *Striga*. *S. hermonthica* is an obligate out-breeder, and so exhibits a high level of genetic diversity that results in frequent breakdown of resistance in developed lines (Ramaiah, 1986 and

Table 8: Some crop varieties resistant to parasitic *Striga* spp.

Crop	Parasite	Resistant/tolerant variety/line
Sorghum	S. hermonthica	16-3-4 BES (short season) Dobbs Framida, ICVS 1002, 1005, 1006, & 1007 BF IS 6961, 7777, 7739, 14928, 14825, 9830, 8140, 16184 L-187 (long-season) N 13 RZI (medium season) SAR 1,2,19,29, 33 & 35 SRN 39 Serena Seredo
	S. asiatica	YG5760 (medium season) SPV 103 SRN 39, & 4841 S-35
Cowpea	*S. gesnerioides*	IAR 81-27 IT82D-666, -667, -450-4 SR 322 IT830-226 IT82-479-1 IT81D-994 58-57 SIVITA-2 B 301
Millet	*S. hermonthica*	No resistant variety but promising lines from ICRISAT in Burkina Faso include: P449 P2627 Inbred 5258 Serere 2A-9 CVP-164 CSM-3, 3/4 HK-2-2
	S. asiatica	TF23A
Rice	*S. hermonthica*	IR-38547 & 47697
Maize	*S. hermonthica*	inbred lines 8322-13
	S. asiatica	Pioneer 3181TZ-300 (PR)

(Source: Anonymous, 2005a; Ramaiah, 1986; Carson, 1986; Lagoke, 1986; Kirlro, 1991; Ramaiah, 1991; Aggrawal, 1986; Lagoke *et al.*, 1991)

Musselman *et al.*,1991). Another problem is that low-stimulant producing resistant varieties do not permanently eliminate *Striga* problem from an infested field (Lagoke *et al.*, 1991). Such varieties may succeed in escaping detection by the parasite, yet they are incapable of disinfesting *Striga*-infested soil free of parasitic seeds. In semi-arid areas these seeds can retain their viability for up to 20 years in the soil (Musselman *et al.*, 1991), and during this period *Striga* resurgence may ensure if a susceptible crop or weed happens to be in the field, thus allowing the parasite to complete its life circle. Since a resistant variety may not be planted by all farmers within the same locality, the efforts of a concerned farmer using resistant varieties may be thwarted by *Striga* seeds dispersed from neighboring *Striga*-infested farms where susceptible varieties have been planted and allowed to flower. Sorghum varieties Framida, SRN 39 and many other crop varieties may have good resistance to *Striga*, and high grain yield, yet they have problems of adoption by farmers. Framida is rejected by farmers in West and Central Africa on account of its poor agronomic qualities, particularly its high tannin content and the brown seed color (Ramaiah, 1991). Some *Striga*-resistant varieties such as SRN 39, and IS 9830 have undesirable traits such as low grain yield, short stature, and small grains, that limit their acceptance by farmers (Ramaiah, 1991; Lagoke *et al.*, 1994a; and Ezeaku and Gupta, 2004).

2.7.4 Use of trap and catch crops in *Striga* management

Trap crops are non-host crops that are capable of inducing suicidal germination of *Striga* seeds, without themselves being parasitized (Lagoke *et al.*, 1991). Soybean,

cotton, and bambara groundnuts are used as false hosts of *S. hermonthica* when intercropped or rotated with susceptible crops in order to induce abortive germination of *Striga* seeds, thereby leading to reduced *Striga* emergence (Parkinson, 1985; Hudu and Gworgwor, 1999). Groundnut was rotated with sorghum in Togo, (Tchemi, 1986), and Cameroon (Lagoke *et al.*, 1991) and it was intercropped with sorghum in Nigeria (Gworgwor, 2000) in order to reduce *Striga* seed bank. In Kenya, beans (*Phaseolus* sp.), cowpea (*Vigna unguiculata*), cotton (*Gossypium* sp), sunflower (*Helianthus* sp.) and groundnut (*Arachis hypogaea*) are traditionally grown as trap crops or are intercropped with cereals in order to control *Striga* (Kiriro, 1991). Similarly in The Gambia, trap crops are intercropped or rotated with susceptible hosts in order to bring about low *Striga* infestation. This involved alternating cereals with groundnut in the same farm, or growing groundnut for 3 consecutive rainy seasons, followed by growing cereals in the 4th season in order to give low *Striga* emergence (Carson, 1986). A variant of trap cropping is catch cropping, a technique in which true host crops are planted to induce *Striga* seeds to germinate and attach to the host, and at an appropriate time of maximum *Striga* emergence, before flowering, both the hosts and the parasites are ploughed into the soil, thereby killing the emerged *Striga* and thus depleting *Striga* seed-bank in the infested soil (Lagoke *et al.*, 1991). Trap crops act by producing chemical stimulants within their root exudates that are perceived by conditioned and viable *Striga* seeds, as result of which the seeds are induced to germinate. However, since the germinating seeds can not penetrate the roots of the trap crops the germinating seeds ultimately die within 3-5 days (Lagoke *et al.*, 1991). There is little evidence to

prove induction of *Striga hermonthica* seed germination by groundnut or cowpea since they are rarely seen in the field to be parasitized (Lagoke *et al.*, 1991). However Ogborn (1972) and Parkinson (1985) reported instances of groundnut being attacked by *S. hermonthica*, thus making both cowpea and groundnut potentially unsuitable for trap cropping to reduce seed bank (Lagoke *et al.*, 1991). Some trap crops, particularly cowpea and sunflower, were reported to stimulate the germination of only a few *Striga* seeds, in an experiment in Kenya (Kiriro, 1991). In millet, sesame was found as an effective trap crop for *S. hermonthica* (Gworgwor, personal communication).

Trap and catch cropping is marred with a number of limitations. According to Lagoke *et al.* (1991) trap crops do not give 100% protection against infestation, hence require through research to determine the appropriate sowing dates of the component crops, plant arrangement, and plant population for effective control. Besides, effectiveness of managing *S. hermonthica* with trap crops is reduced if any of the alternative hosts such as *Rottboelia cochinchinensis, Pennisetum purpureum, Digitaria ciliaris, Andropogon gayanus, Brachiaria sp,. Setaria sp., Dactyloctenium aegyptum* are available within the same farm with *Striga*. Similarly multiple infestation of the field with *S. hermonthica* along with other parasitic weeds such as *S. gesnerioides* and *Alectra vogelli*, that are capable of attacking the trap crops, may reduce the effectiveness of the leguminous trap crops since their continuous cultivation may lead to build up in the population of their own parasites, particularly *S. gesnerioides and Alectra vogelli* (Lagoke *et al.*, 1991). Trap crops are not

spectacular in reducing *Striga* population or increasing grain yield in the immediate growth season, rather, remarkable decrease in *Striga* seed reserve in the soil or yield increases can only be manifested if they are used for at least three consecutive seasons. This is because not all germinable *Striga* seeds germinate all at once in a growth season (Lagoke *et al.*, 1991). In Kenya complete *Striga* seed reduction can not be achieved even in five years (Kiriro, 1991). In addition, trap and catch crops must have to be carefully selected from among the crops that are commonly grown in the specific locality and there is a good ready market for the products from the trap crops, otherwise the recommended trap crops and the technique may be rejected by the local farmers (Lagoke *et al.*, 1991). Erratic rainfalls may not allow farmers to sacrifice time and resources on catch crops without harvesting anything; hence the technique may not easily be adopted by a resource poor farmer (Lagoke *et al.*, 1991).

2.7.5 Soil fertility management for *Striga* management

Striga is a problem of nutrient deficient soils, (Kranz, 1999, and Kranz *et al.*, 1998). Any technique that improves soil fertility helps in checking *Striga* problem, and for this reason application of high dose of nitrogenous fertilizers or well decomposed manure is good for effective *Striga* management (Mabasa, 1994). *Striga* incidence and virulence are inversely related to soil fertility (Lagoke *et al.*, 1991). Manure, ash and inorganic nitrogen and phosphorous fertilizers are known to reduce *Striga* infestation, virulence and crop yield losses. Nitrogen was reported to delay *Striga* emergence, caused stunted growth of emerged *Striga* shoot, reduced flowering and

organic matter content in the parasitic weed (Agbawi and Younis, 1965, Gworgwor and Weber, 1991). Nitrogen is said to reduce germination stimulant production in the host's root exudates, retard *Striga* growth and increase crop growth and tolerance (Parkinson, 1985). Nitrogenous fertilizers have been reported to increase production of cytokinin and gibberellic acid in the host, which are depressed by *Striga*, and therefore increase host growth (Pesch and Pieterse, 1985). These fertilizers have also been reported to reduce germination stimulant production in the host's root exudates, retard *Striga* growth and increase crop growth and tolerance (Parker, 1984). Urea is a better source of nitrogen than CAN in *Striga* management, and nitrogenous fertilizers increase growth and biomass accumulation in both parasite and host, and the latter gives good yield despite being parasitized (Ogborn, 1972; Lagoke *et al.*, 1991). They also influence resource allocation between shoot and roots in the host (Parker, 1984). Pesch and Pieterse (1985) reported urea and ammonium sulphate to suppress *Striga* seed germination. High dose of nitrogen application at the rate of 150 kg N/ha has been recommended for effective *Striga* management in Africa (Mansfield, 1982).

Like all other *Striga* management techniques, high nitrogen application has a number of setbacks. Lagoke *et al.* (1991) noted that 150 kg N/ha is too high for cereal-legume mixtures for small scale farmer. Besides, the cost of control is too high, with 150 kg N/ha being equivalent to US$160/ha or about N20,400/ha. Inorganic fertilizers in Nigeria are not only prohibitively expensive but are not easily available in the local market, hence the technique may not be profitable. Despite all

these setbacks, urea cannot give 100% protection against *Striga* and so the technique has to be integrated with other compatible techniques in order to effectively keep *Striga* in check.

2.7.6 Biological control in *Striga* management

Use of mycoherbicides has been tested and found useful for biological *Striga* control, and could be a good component for integrated *Striga* management (Marley *et al.*, 2004). A soil bone pathogenic fungus (*Fusarium oxysporum*) (isolate M12-4A) in Mali was found to be naturally pathogenic to germinating *Striga* seeds and seedlings, and is capable of preventing *Striga* attachment to the host roots and is capable of aborting attached *Striga* seedlings, by way of suppressing the under ground growth of the parasite (Ciotola *et al.*, 1995). In a pilot study, sorghum straws or glumes were first soaked overnight in water, drained, and sterilized before inoculated with the *Fusarium oxysporum* (isolate M12-4A), and incubated from 7 days at 28°C. The colonized moist straws were then strategically inoculated into the *Striga*-infested soil at the rate of 350 kg/ha at the time of planting. The fungus infested the germinating *Striga* seeds and seedlings, at early growth stage, to suppress their growth and attachment to the host roots. The technique was found to reduce *Striga* incidence by 60-90%, increased grain yield of cereals by up to 75-100%, and the number of individual *Striga* plants reaching flowering-seed-setup was reduced by up to 80% (Anonymous, 2005j; Ciotola *et al.*, 1995, and Watson *et al.*, 1993). Another biological control technique that is potentially useful for *Striga* management is the use of ethylene-producing bacteria. Under laboratory condition

the technique was found to be as effective as commercial products in stimulating the germination of parasite seeds (Lagoke *et al.*, 1991). The technique is still being researched upon, and is too technical and too expensive for the resource poor farmers to adopt.

2.7.7 Hand pulling and hoe weeding in *Striga* management

The most common technique for *Striga* management used by small scale farmers is the hand pulling and hoe weeding of emerged *Striga*. It is good for long term reduction of soil seed bank if done before or during flowering, but before seed formation (Lagoke *et al.*, 1991). In The Gambia, second hoe weeding followed by hand pulling of emerged *Striga* towards crop harvest only resulted in slight increase in yield, and reduced net income for the farmer (Carson, 1986). Similarly in Guinea, hand pulling of emerged *Striga* is neither economical nor encouraging (Lagoke *et al.*, 1991). In Ghana, hoe weeding is the most common *Striga* management technique (Nyarko, 1986). Uprooting and burning is common in Benin Republic, Mali and Niger Repulic (Lagoke *et al.*, 1991). Benefits of this technique start to manifest after three years of continuous application (Verkleij and Kuijper, 2000).

The problem with this technique is that it is very tedious, labor intensive and expensive, and it does not prevent crop yield losses (Lagoke *et al.*, 1991). Unless destroyed completely uprooting a mature *Striga* cannot prevent its young capsules from developing to produce mature seeds. (Lagoke *et al.*, 1991). Hand pulling is effective only for controlling light infestations, which can as well be tolerated and it

stimulates emergence of more *Striga* shoots, and consequently more seed production (Pieterse, 1985).

2.7.8 Use of fumigants in *Striga* management

A highly technical and capital intensive technique commonly employed for *Striga* management in the US is by the use of highly volatile liquids, gaseous and often solid fumigants to fumigate *Striga*-infested soils, in order to kill *Striga* seeds in the soil. Fumigation, according to (Eplee *et al.*, 1991) is the only procedure presently available for killing *Striga* seeds in the soil. In the US, methyl bromide is used for the management of *S. asiatica* at the rate of 350kg/ha, which is equivalent US$2000/ha or N282,000/ha. Metham is a liquid fumigant for drenching *Striga*-infested soils in the US at the rate of 400-600 liters/ha, while dazomet are granular form of metham, used for broadcasting over *Striga*-infested soils (Eplee *et al.*, 1991).

Fumigants and their injectors are expensive and special training is required before application (Eplee *et al.*, 1991). The technique is too technical and too expensive for the resource-poor farmers in Africa.

2.7.9 Use of bush fallow in *Striga* management

Striga is a problem of nutrient deficient and exhausted soils, and any technique that helps to regain soil fertility helps greatly in reducing *Striga* problems. Bush fallow is one such technique through which an exhausted land is allowed to rest for some 5-

10 years without being cultivated. This has helped greatly in reducing *Striga* seed bank in *Striga*-infested nutrient deficient soil (Lagoke *et al.*, 1991). In the past, this technique used to be a common *Striga* management technique under subsistence agriculture, when abundant farmlands permitted shifting cultivation. During fallow periods neither the host crops nor alternative weed hosts such as *Tephrosia* sp., *Indigofera* sp., and *Desmodium* sp are be allowed to grow in the land under bush fallow, so that *Striga* seed production is prevented, while existing seeds within the soil are allowed to be degraded under natural conditions.

The gains of bush fallow can easily be spoilt by *Striga*'s wide host range, thereby allowing it to complete its life cycle on alternative hosts. Population explosion in Africa that demands for intensified land use for food production makes bush fallow difficult to adopt (Lagoke *et al.*, 1991).

2.7.10 Action Program for *Striga* management in Africa

Over 50 national and international research organizations, including Pan African *Striga* Control Network (PASCON), International Cereal Research Institute of Semi-Arid Tropics (ICRISAT), International Institute of Tropical Agriculture (IITA) and Institute for Agricultural Research (IAR), Samaru, Zaria, have been engaged in *Striga* management (Ayensu *et al.*, 1994; Trablousi *et al.*, 1994). Action program for Africa is a partnership of the System-wide Program on Integrated Pest Management (SP-IPM), the Pan African Network for *Striga* Control (PASCON), the Global IPM Facility (GIF), the African Union's Semi-Arid Food Grain Research, and

Development Program (SAFGRAD), Agricultural Departmental Group of the FAO Regional Office for Africa (FAOROFA) and Forum for Agricultural Research in Africa (FORA). The partnership works in close collaboration with other national and international agricultural research organizations in order to advance IPM objectives for controlling *Striga* in maize, sorghum, millet and cowpea in sub-Saharan Africa (Anonymous, 2005k). Other tactics recommended for *Striga* control include research, publicity campaigns, training and extension (Lagoke *et al.*, 1991).

2.7.11 Integrated *Striga* management (ISM)

ISM is the integration of two or more compatible management techniques for combating *Striga*. Such integration is necessary because no one technique is adequate enough for effective *Striga* management. ISM control options, currently being evaluated on farms in Nigeria, include a combination of clean seed and resistant crop varieties, measures to enhance the natural suppressiveness of soils, and the rotation of cereals with carefully selected cultivars of legume trap crops which stimulate the 'suicidal' germination of *Striga* seeds (Anonymous, 2005j). A good long term management of *S. hermonthica* is achieved if susceptible host crops are rotated with resistant cereal variety for 1-2 years, and with appropriate trap crop, such as cotton or groundnut, for 1-2 years, while emerged *Striga* are weeded out by hoe weeding, hand pulling or by herbicide application (Lagoke *et al.*, 1991). Other integrated management options include application of high urea dosage, selecting appropriate sowing dates, eradication of alternative weed hosts, and seed quarantine. Others are good hygiene in using farm implements, prevent

contamination of irrigation water with *Striga* seeds, use of well composted farmyard manure, prevent grazing on flowering *Striga* and sensitizing farmers, agricultural organizations and government agencies on *Striga* problems/control and the need for legislation to contain spread. Also important are train-the-trainer programmes, and extension on *Striga* problem/control and Action program for Africa (research, publicity, training & extension). Integrating *Striga*-resistant cultivar Samsorg 40, or *Striga* tolerant landrace with a bio-control technique using *Fusarium oxysporum* (isolate PSM 197)-based mycoherbicide in on-farm trials in the Sudano-Sahelian savanna of Nigeria significantly and profitably increased crop stands, and sorghum yields (49.6%). *Striga* emergence was reduced by about 95% (Marley *et al.*, 2004). One other integrated *Striga* management option is limiting dispersal of *Striga* seeds (Anonymous, 2005b). ISM also includes biological control option, and judicious use of techniques that are compatible with the use of biological control agents or minimize negative impact on *Striga* natural enemies. Integrated *Striga* management in sorghum using a *Striga*-tolerant sorghum variety, Seredo, together with modest fertilizer application (80kgN/ha), two hand weeding and intercropping sorghum with *Celosia argentia* significantly reduced *Striga* incidence and increased sorghum yield (Anonymous, 2005k).

2.8 Potentials of Neem Trees in *Striga* Management

2.8.1 Taxonomy of neem tree

Neem tree (*Azadirachta indica* A. Juss.) has been classified under the genus *Azadirachta* in the family Meliaceae, the family of mahogany trees. It is,

taxonomically, closely related to *Azadirachta siamensis* (Synonym *Azadirachta azadirachta* var. *siamensis*), the "edible neem" and *Azadirachta excelsa* (National Research Council, 1992). In Hindi, Urdu, Punjabi, and English languages, the tree is known as neem. In French language it is called azadira d'Inde, margousier, azidarac, and azadira. In Portuguese and Spanish languages it is called margosa. In Farsi language, the tree is called azad darakht i hindi, from which the *Azadirachta indica*, the botanical of the genus and the species name was derived. In Nigeria the tree is variously known as dogonyaro, bedi, dalbejiya, maina, charbi and nim etc (National Research Council, 1992). These are just but a few local names for *Azadirachta indica* A. Juss, suggesting that it is widely cultivated in the World.

However, neem tree is said to be a native of South and Southeast Asia, including Assam, Burma, the whole of Indian subcontinent, Pakistan, Sri Lanka, Thailand, Malaysia, and Indonesia, where they may be found commonly growing in the wild. In the last century, the tree has been introduced to other parts of the world and now it grows well in over 30 countries including Fiji, Mauritius, the Caribbean, and many countries in Central and South America, and Africa, where it is widely grown, particularly in regions along the Sahara's southern fringe. In Africa, neem is grown to combat desertification and desert encroachment in gigantic government neem plantations and shelterbelts. It is grown for the production of fuel wood and provision of shades in houses, public buildings, private woodlots and along street, roads, highways and village paths (National Research, 1992). The population of neem trees in India was estimated at about 20 million tree stands (Neem

Foundation, 2006), but in Nigeria, neem stands were estimated at about 100 million tree stands (Aminu Nahuce, President Neem Tree Development Association of Nigeria, personal communication), out of which a recent survey established the presence of about 13 million stands in Katsina State alone (Aminu Mamman Dee, General Manager, KTSG/FGN/EEC Afforestation Project, personal communication).

Neem is a broad-leaved rapidly growing tree with high biomass production rates. It grows profusely and coppices readily after repeated pollarding (National Research Council, 1992). Annual biomass production rate by a 10 year old neem tree was reported to be about 1 ton of organic matter/annum, out of which 500 kg are leaves, while fruits and firewood or timber account for 250 kg each (Neem Foundation, 1997b). The tree could measure as high as 30-50 m tall and 2.5 m in girth, at the trunk. Its branches have a spreading habit, and form a rounded crown that may be as wide as 20m. Neem is evergreen, shading its leaves only during extreme drought. The stem is usually straight and its bark is thick and strongly furrowed. It has a long tap root and extensive lateral roots. It grows profusely, thereby coppicing readily after repeated pollarding. Neem bears plenty of honey-scented small, white, bisexual axillary flowers that are born in clusters. The flowers readily attract honey bees, thereby making the tree good in apiary as a source of nectar. Neem fruits are small, smooth, and ellipsoidal drupes that are green when raw and yellow or greenish yellow when ripe. The fruit could be as long as 1.5-2.0 cm long. Ripe neem fruits are visited and readily dispersed by bats on account of their sweet pulp that covers the seeds, which may contain 2-3 kernels within a woody seed coat. The

kennels may constitute about 50% of the seeds by weight, and they are unique in containing group pesticidal compounds, mainly the limonoids. Neem fruits are rich in pesticidal oil. Neem-cake, the byproduct of oil extraction, is rich in some vital nutrients, and so used in fertilizing nutrient deficient soils. It is used in the industrial production of neem organic fertilizer. The material used in this research is the whole fruit that has been grinded into powder without removing the oil and the woody seed coat, which are not found in neem-cake.

The chemical composition of neem-cake varies, depending on the area the tree grows, as shown in (Table 9). National Research Council (1992) reported that neem fruits contain 13-35% crude protein, 26-50% carbohydrate, 8-26% crude fiber, 2-13% fat, 5-18% ash, 1-17% acid soluble ash. The chemical compositions of some vital nutrients in neem-cake was reported by Neem Foundation (1997a) to comprise of 3.56% nitrogen, 0.83% phosphorous, 1.67% potassium, 0.77% calcium, and 0.75% magnesium.

Neem is an economically important tree. In plantations, shelterbelts and woodlots the tree is important in sustainable land management, particularly in combating desertification, desert encroachment, and soil erosion (due to wind and water) (Young, 1997). In plantations and shelterbelts, neem produces dense and contagious canopies, with the aid of which it decelerates turbulent winds to combat wind erosion. It is also useful in the production of firewood, up to 103-169m^3/ha, in addition to other products, particularly timber, resin, honey, neem oil and cake etc

Table 9: Comparative chemical composition of neem-cake sourced from trees grown in India and Nigeria.

Chemical constituents in neem-cake	Nigeria Neem (%)	India Neem (%)
Dry matter	93.80	92-95
Nitrogen	7.40	4-5
Calcium as CaO	0.79	1-2
Phosphorous as P_2O_5	0.35	0.5-1.5
Potassium as K_2O	0.64	1-2
Organic Matter	80.10	72-75
Crude protein	46.13	13-35
Crude fiber	15.83	8-26
Ash content	6.12	1-17
Magnesium	0.051	0.75
N.F.E	5.15	0.75

Source NARICT (2004)

(National Research Council, 1992). Its litter is good for fertilizing nutrient deficient soils, either through biomass transfer or through agroforestry (Young, 1997). Neem based agroforestry system is important in diversifying land productivity into arable crop and firewood production. Self sufficiency in alternative sources of firewood saves fragile environments from deforestation, which predisposes it to accelerated land degradation. Neem is an important tree component in reclamation forestry for reclaiming and revitalizing degraded fields and wastelands (Young, 1997). Its deep and extensive root network enables neem to function well in patrolling deeper soil horizons to recover leached soil nutrients that are located deep beyond the reach of crop roots, some 20-100 m deep. These nutrients are reabsorbed and ultimately returned to re-fertilize the top soil after decomposition of tree litter (National Research Council, 1992; Young, 1997; SeaFriends, 2005). Its rapid growth enables it to produce large quantities of tree litter, ideal for biomass transfer, green manuring and mulching (Young, 1997). Its sweet scented flowers are favored by foraging bees that produce a special and highly prized neem-tainted medicinal honey (National Research Council, 1992 and Young, 1997). Neem fruits are rich in essential nutrients and are, therefore, used throughout Asia for soil fertility management (Neem Foundation, 1997c). Neem is rich in pesticidal compounds that are effective against over 400 insect pests, nematodes, bacteria, snails, crustaceans, fungi, plant viruses, and malarial parasites, but are not harmful to beneficial earthworms, honey bees and pollinator butterflies (National Research Council, 1992; Friend, 1995). Though these compounds have not apparently been reported to be pesticidal or microbicidal against *Striga*, they are likely to be

bioactively potent against it, since at a point in its life cycle *Striga* is microscopic, and neem extract do not appear to spare most microbes.

2.8.2 Pesticidal principles in neem

Neem is a pesticidal tree crop. The pesticidal properties of neem tree have been attributed to a group of chemically related compounds called triterpenes or the limonoids. These compounds have been shown to be capable of suppressing growth in insects, thereby affecting a wide range of insects, including some of the most deadly pests of agriculture and human health. The best known of these compounds include azadirachtin, salannin, meliantriol, and nimbin (Appendix 1). Concentration of azadirachtin in neem kernels is about 2-4% by weight (National Research Council, 1992).

According to Rembold *et al.* (1987) and National Research Council (1992), azadirachtin is the most important of all the limonoids. It has pesticidal and repellant properties against insects and nematodes. Neem extracts have antifeedant properties, it disrupts growth and reproduction in insects once consumed, even if in trace amounts. It slowly kills insects through its ability to repel away insects and some nematodes from treated plant leaf. Azadirachtin acts in such away as to disrupt life cycle in insects, by preventing larvae from transforming into pupa, and prevents it from feeding until it starves to death. Normally in insects, metamorphosis involves the transformation of larva to pupa and finally to adult, a process under the control of an organ called corpus cardiacum. The organ synchronizes the release of

the required growth hormones, ecdysones. Azadirachtin negatively affects corpus cardiacum, so that it can no longer synchronize release of the hormones. Besides, azadirachtin is structurally similar to ecdysones, so it easily blocks binding sites meant for ecdysones, thereby effectively blocking the hormones away from discharging their normal functions of controlling the process of metamorphosis in insects, such that insects can no longer molt (Rembold *et al.*, 1987). Both salannin and meliantriol are feeding inhibitors that deter insects from feeding on treated leaves, even in extremely low concentrations. They act in concert with azadirachtin in this regard. Salannin does not influence molting in insect.

Limonoids are not only insecticidal in nature, but they are also bioactively potent against a wide range of bacteria, fungi, nematodes, viruses and snails of agricultural, veterinary and medical importance. It is based on these bioactive potency of limonoids in neem, the tree has become the subject of intense research all over the world in order to evaluate the potentials of the tree in pest and disease management in agriculture, veterinary and human medicine.

2.8.3 Pest management with neem

Neem has been reported to be pesticidal against several pests including insects, bacteria, nematodes, viruses and fungi of agricultural importance, and is important in soil fertility management (National Research Council, 1992; Neem Foundation, 1997b, 2004 and 2005; Dreschsel *et al*, 1991). Neem extracts in water and alcohol have been reported to posses antifeedant, and insecticidal effects. They disrupt

growth and metamorphosis and deter insects from oviposition. Neem extracts are ovicidal, thus can influence fertility and reproduction in insects. They are also synergistic when mixed with insecticides, thereby increasing their efficacy (Parmar, 1986). Neem has not been reported to be pesticidal against *Striga* but a pot experiment showed the ability of neem to suppress *Striga* emergence (Kranz, 1999). The ability of neem to suppress *Striga* emergence may be due to its natural allelophathy, its pesticidal properties and its soil-fertilizing effects.

2.8.4 Potentials of neem-based agroforestry systems for sustainable land management to mitigate *Striga* problems

Striga is an ecological problem, facilitated by agricultural practices that deplete soil nutrients, thereby leading to revisible chemical land degradation. Any technique that manages soil fertility well is likely to affect *Striga* problem. Agroforestry systems are designed for sustainable land and soil fertility management, and hence are likely to manage *Striga*. Poor soil fertility status of agricultural lands predisposes them to colonization by *Striga*, in areas where the parasites are endemic (Kranz, 1999). Hence, dwindling soil fertility is one of the most important problems in degraded agricultural lands and the greatest factors militating against sustainable agriculture (Anonymous, 2005n). Causes of decline in soil fertility, according to Altieri (1995) and Young (1997) include successive crop harvests from farms, leaching of nutrients into deeper soil strata by rain water and soil erosion, which washes away fertile topsoil along with organic matter. Other causes include loss of biodiversity and retarded biological activities thereby stagnating nutrient recycling. Soil fertility

management to replace lost nutrients through addition of inorganic fertilizer is good (Mabasa, 1994), but is hardly sustainable. Fertilizers are expensive and are not readily available and must have to be used with a lot of precautions in order to prevent phytotoxicity, particularly in the Sahel, and semi-arid ecological zones. Fertilizer procurement and subsidy placed a lot of burden on the government, while withdrawal of fertilizer subsidy placed the resource poor peasant farmers in dilemma, and that predisposed the land to *Striga* infestation, on account of avoidable decline in soil fertility. Soil fertility management with neem-based agroforestry systems, offers a durable and sustainable solution to soil fertility problems, and perhaps to *Striga* problem.

KASHIM IBRAHIM LIBRARY

Neem has been listed among the common multipurpose trees (MPT) and shrubs used for improving soil fertility in agroforestry (Young, 1997). The ability of neem to fertilize nutrient deficient soils lies in its capability to produce large quantities of neem biomass, mainly leaves and fruits that are rich in plant nutrients, and its ability to encourage biodiversity in soils and recover lost nutrients from deep soil strata.

The parasitic weeds do not fare well on fertile lands. Artificial fertilization of nutrient deficient agricultural lands with organic and inorganic fertilizers has been reported to reverse the deficiency and consequently mitigate *Striga* problem (Mabasa, 1994; Lagoke *et al.*, 1991; Kranz, 1999; Kranz, *et al.*, 1998; Pesch and Pieterse, 1985; Pieterse, 1985). Agroforestry practice is one technique through which *in-situ* solution to various forms of land degradation in agricultural lands are achieved.

Though there are scanty reported cases, if any, on *Striga* management under agroforestry systems, the chances that such a system may be useful in *Striga* management are bright. One such evidence comes from the repots that *Faideherbia albida,* an important agroforestry tree component useful for sustainable land management in Africa (Young, 1997), is also useful in managing *Striga* in pearl millet (Gworgwor, 2006). Multipurpose trees, commonly grown under agroforestry systems, were reported to have potential for increasing soil fertility and induce suicidal germination of *Striga* seeds and thereby potentially helpful in reducing the level of *Striga* infestation in the soil (Oswald *et al.*, 1996)

Agroforestry refers to land-use systems in which trees are grown in association with agricultural crops (agroslyvicultural system), with pasture/livestock (sylvopastoral system) or honey bees (entomoforestry system) or with fish (aquaforestry system) (Young, 1997). Agroforestry systems, according to this report, are employed to conserve renewable land resources including soil fertility, to achieve sustainability in land management and productivity. These systems are good for sustainable maintenance of soil organic matter content and fertility status through decomposition of tree litter and prunnings. The system encourages maintenance of biodiversity and biological. Texture and porosity of soils are enhanced through agroforestry systems, thereby increasing percolation of rain water into the soil, thus discourage water run-off, and soil erosion, and augment availability of ground water. Agroforestry systems, according to Young (1997) are better known for controlling soil erosion due to water and wind, and for controlling desertification through

windbreaks, shelterbelts and plantations. But agroforestry systems are also excellent in reclaiming leached soil nutrients from deep soil horizons, thereby increasing nutrient inputs and ensure closed nutrient cycling within the system. Eroded and degraded lands are reclaimed and put back to agriculture through well designed agroforestry systems. One of the most important agroforestry tree components in semi-arid and dry humid zones of Africa and Asia is neem tree.

Neem is a multipurpose tree (MPT) widely used in agroforestry to check land degradation in its various ramifications, reclaim degraded and fragile lands, and diversify and sustain agriculture in semi-arid and dry sub-humid zones, where desertification, soil erosion, deforestation and degradation of pastures and water resources have been the major forms of land degradation (Young, 1997). Ability of well managed neem-based windbreaks and shelterbelts to control wind erosion and improve crop yields were tested and proven in Republic of Niger and India (Kort, 1988; Byington, 1990 and Vandenbeldt, 1980). Reports of occasional use of neem in agriculture, as hedgerow intercrop, were reported by Young (1997), and Tilander *et al.* (1995). The neem-based agroforestry systems are capable of maximizing land use, and sustainably improving soil fertility. The present land-use system, in which a cropland has to be stripped of all trees in order to pave way for crop production, is always associated with accelerated land degradation, due to soil erosion (water and wind) and minimum nutrient recycling. In *Striga*-infested areas in Nigeria, such a land-use system utilizes the land only once for 3-5 months every rainy season, after which the land is left bare. Such bare lands are left prone to several agents of land

degradation, particularly gushing rainfalls and wind blasts that carry away the fertile top soil. This accelerates desertification, desert encroachment and rapid loss in soil fertility. However, in neem-based agroforestry systems, about 30-40% of the cropland is committed to neem production, to shield the farm against land degradation, and for the production of firewood, and other useful neem products. The same land is also put to conventional use during the rainy season for crop production, with or without pollarding the trees, depending on the adopted agroforestry system or pattern.

Types of agroforestry systems include agrosylvicultural system, and sylvopastoral systems among others. Neem is particularly relevant to all forms of agrosylvicultural systems, plantation /woodlot forestry, and entomoforestry for the production of a special brand of medicinal neem-tainted honey. According to Young (1997) types of agroforestry systems and patterns of tree planting in agroforestry systems include hedgerow intercropping, woodlot forestry, shelterbelts, trees-on-cropland, rotational tree fallow, and boundary planting, as shown in Table 10 and Figure 5.

Table 10: Types of agroforestry systems

Agroforestry systems		Types
Agrosylvicultural system (A.S.)	Rotational A.S.	Shifting cultivation, managed tree fallow, Taungya
	Spatial mixed A.S.	Trees on cropland, perennial-crop combinations, multistrata (agroforestry)
	Spatial zoned A.S.	Boundary planting, trees on erosion control structures, windbreaks & shelterbelts, hedgerow intercropping, & biomass transfer
Sylvopastoral (S.P.)	Spatial mixed S.P.	Trees on pastures, perennial crops with pastures.
	Spatial zoned S.P.	Hedges and livestock fences, fodder banks
Trees predominant (woodlot forestry		Farm forestry, village forestry, reclamation forestry.
Special component present		Honey bees, fish Entomoforestry, aquaforestry

Source: Young (1997)

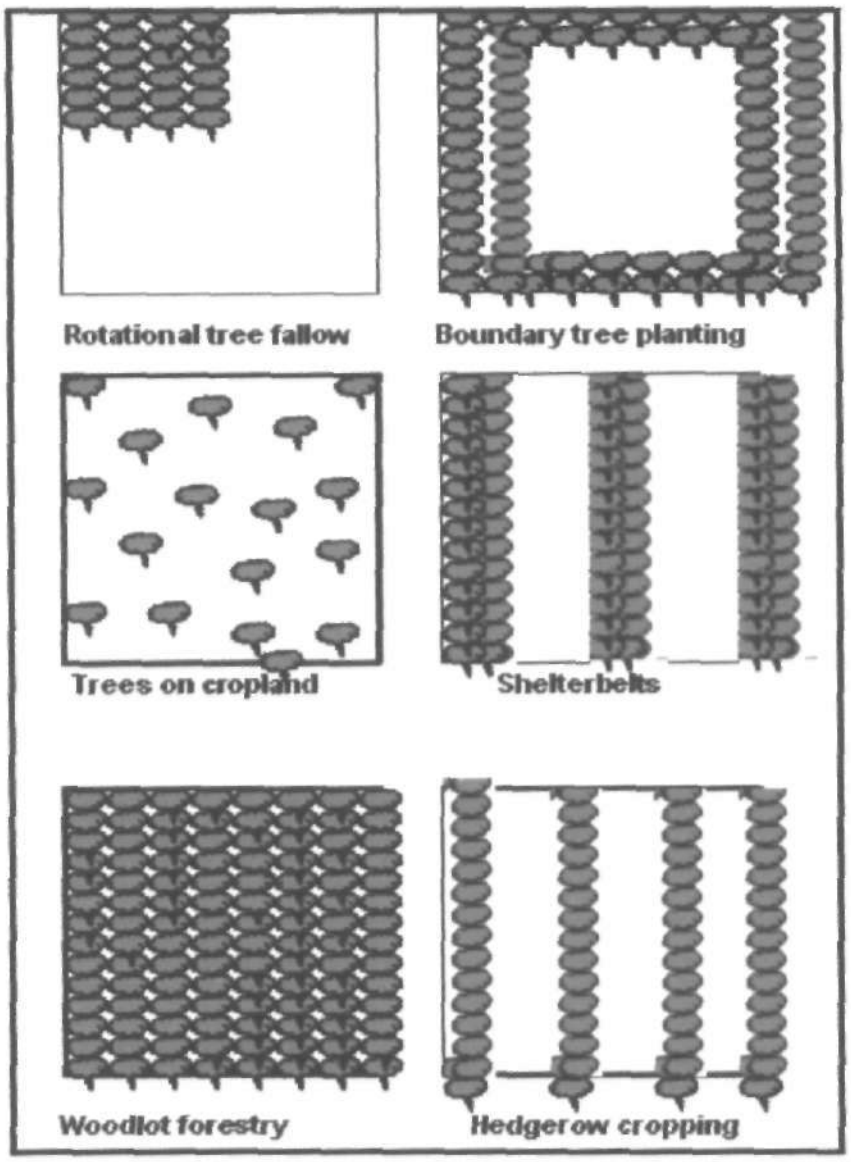


Figure 5: Patterns of tree planting in agroforestry systems drawn according to Young, 1997.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Effects of Neem Soil Amendments on *Striga hermonthica*, Pearl Millet and Soil Physico-chemical Properties under Field Conditions

3.1.1 Aim

The aim of this was to determine if amending *Striga*-infested soils with neem organic soil amendments would have any significant effect on emergence and biomass accumulation in *S. hermonthica* and on the growth and grain yield of pearl millet. Its short term effects on soil physico-chemical properties were also investigated.

3.1.2 Collection and processing of neem fruits

Ripe and dropped neem-fruits, collected from neem plantations in Katsina during the dry season, were spread on a large plastic mat and dried for one month under a shade. Whole fruits were lightly crushed using plate mill, before further drying for one week. Thereafter the dried crushed fruits were finally ground into fine powder using 30 HP cyclone hammer mill. Drying of crushed fruit aggregates for one week before grinding into fine powder was necessary in order to avoid caking. The powdered fruits were directly used in amending experimental plots as neem organic soil amendments.

3.1.3 Collection and preservation of *Striga* seeds

Mature *Striga* spikes were collected in paper bags from *Striga*-infested millet farms around Katsina metropolis. Spikes with ruptured or swollen capsules were avoided. Collected materials were sun-dried for one month on a wide polythene sheet in a screenhouse, before threshing to obtain seeds. Clean *Striga* seeds were collected on 150 µm sieve when threshed seed materials were sieved serially through a stack of 2.00 mm –150 µm sieves on test-sieve shaker (Endecott Laboratory Test Sieve Shaker, Endecotts LTD, London). for 10 minutes. Clean *Striga* seeds were stored on laboratory shelf in paper bags, and were used for all experiments at least 6 months after collection.

3.1.4 Experimental sites and plot size

Field experiments were conducted for 3 years on *Striga*-infested plots, during the 2001, 2002 and 2003 rainy seasons. Tests were conducted at one location in 2001, and a total of four locations in the years 2002 and 2003 at Katsina, (Latitude: 13° 47′ N, longitude: 7° 08′ E, altitude of 538 m above sea level; and mean annual rainfall of 8,880 mm). Each net and gross plot measured 2.0 m^2 and 3.0 m^2 respectively. Adjacent gross plots were set 3 m apart on either side.

3.1.5 Inoculation of experimental plots with *Striga*

Experimental plots at four test sites in Katsina were artificially infested with 6-8 month old, viable *Striga* seeds at the time of amending the plots with neem organic

soil amendments, in the year 2002 and 2003. In the year 2001 tests were conducted on naturally infested *Striga*-sick plots. Artificial inoculation of *Striga* seeds into the experimental plots involved evenly broadcasting a mixture of *Striga* seeds and sand (Berner *et a l.*, 1977), at the rate of about 1.5 kg *Striga* seeds/ha at least two to three weeks before the commencement of the rainy season (Vaidya *et al.*, 1991). Artificially infested plots were pulverized using hoe to mix up the soil with the seed inoculums up to a depth of about 20-30cm

3.1.6 Treatments and experimental design

This experiment involved amending *Striga*-infested soils with neem soil amendments. In the year 2001 tests were conducted at six neem soil amendment treatment levels, namely 0, 0.5, 1.0, 2.0, 4.0 and 8.0 kg/m^2 at Katsina, Nigeria. But in the year 2002 and 2003 tests were conducted at four sites, each at four treatment levels and they were: 0, 4.0, 6.0 and 8.0 kg/m^2. Randomized block design was adopted for all field-experiments with five replications in 2001, and four replications each at Sites I and II in 2002 and 2003, in accordance with Little and Hill (1978). At each of the five test sites *Striga*-infested soils were amended with the neem organic soil amendments at the commencement of the rainy season. This involved evenly broadcasting and thoroughly mixing the soil with the neem treatments up to a depth of about 20-30 cm using hoe. Control plots were not amended with the neem organic soil amendments, but were similarly pulverized with hoe.

3.1.7 Seed-bed preparation and sowing of millet seeds

Ridges were set about 65cm apart using hoe after thoroughly mixing up the neem amended soil. A widely cultivated, high yielding and early maturing susceptible local millet variety "dan-digali," sourced from a local market in Katsina, was used in this research. Millet seeds were sown at the rate of 10 seeds/hole about 75cm along the ridges. At all experimental sites, millet seedlings were thinned to three plants/stand 2 weeks after emergence (WAE) of the first millet seedlings. Thereafter all weeds were mechanically removed using hoe.

3.1.8 Other management operations

Experimental plots were carefully managed using recommended practices, except that no fertilizer or manure were added to the experimental plots, since soil fertilizing effects of neem soil amendments was being tested. After the first thinning and hoe weeding operations all emerged weeds were hand pulled in experimental plots as and when necessary until harvest. Insect pests, particularly stem borers (*Buseola fusca*) were controlled by fortnightly application of Sevin 85 (WP) (Cabaryl) at the rate of 1.12 kg a.i./ha in 255 liters of water. Birds were scared off using discarded magnetic video tapes hung over the experimental plots.

3.1.9 Measurements and observations

The following measurements and observations were recorded:

3.1.9.1 *Striga* emergence

At each site, records of *Striga* counts were taken once, at harvest, in each net plot.

3.1.9.2 *Striga* biomass (g)

At harvest, all emerged *Striga* plants in each net plot were hand pulled and air dried for 2 weeks. The dry biomass of all emerged *Striga* plants in each net plot, including those that died before harvest and those that were hand pulled at harvest, were measured using an electronic weighing balance (EL 582-552, 1999 Model, General Lab Equipment, London).

3.1.9.3 Millet seed germination count (%)

At each test site effects of neem soil amendments on millet seed germination were tested twice; once on millet seeds sown immediately after amending the soil (Day 0) and the other on seeds sown two weeks (Day 14) after amending the soil. Percentage germination count in each net plot was determined at 2 WAE.

3.1.9.4 Shoot height (cm)

At harvest, lengths of all harvestable millet stalks in each net plot were measured from the crown at the soil level to the panicle tips in each net plot using meter tape.

3.1.9.5 Striga syndrome

At harvest, severity of *Striga* syndrome on all millet plants, in each net plot, were collectively scored using *Striga* syndrome rating scale, recommended by International Board for Plant Genetic Resources (IBPGR) for maize (Berner *et al.*, 1997), adopted here for millet with slight modifications as shown in Table 11.

3.1.9.6 Millet stalk biomass (g)

All millet plants in each net plot were uprooted and freed of all soil clods 24 hours after harvest. Thereafter panicles were cut away and the remaining millet stalks were air-dried for four weeks on elevated stands, free from termites. Millet stalk air-dry weights were then recorded using a weighing balance (Hemel Hempstead Herts HP3 9RL England).

3.1.9.7 Panicle length (cm)

At harvest, lengths of all panicles harvested from each net plot were measured using meter tape.

3.1.9.8 Grain yield (g)

At harvest, harvestable panicles within each plot were harvested and sun dried for three weeks before threshing and winnowing out the grains. Grain weights were measured using an electronic weighing balance (EL 582-552, 1999 Model, General Lab Equipment, London). Grain yields/ha was calculated from the yield/2 m^2 by using the formula: **Grain yield (kg)/ha = [{(net plot yield) x 10,000)}/2]**.

Table 11: *Striga* syndrome rating scale used for scoring millet plants in experimental plots.

Visual assessment score point	Degree of manifestation of *Striga*-syndrome[a]
1	Normal millet plants; no visible syndrome
2	Scattered small and vague whitish leaf blotches visible otherwise normal millet plant growth
3	Blotching and streaking easily noticeable. Mild wilting, only a trace of scorching restricted to tip of leaves
4	Extensive blotching and streaking and mild wilting, only a trace of leaf scorching slight but noticeable stunting and reduction in panicle size
5	Extensive blotching and streaking, wilting. Leaf scorching on a small portion of the leaf area. Moderate stunting; panicle size reduction
6	Extensive streaking, now to scorching. Leaf scorching covering about a third of the leaf area. About one-third reduction in height. Reduced stem diameter and reduced panicle size
7	Extensive streaking/scorching turning gray and necrotic. About half of the plant surface is scorched. Severe stunting, about 50% reduction in height noticeable reduction in stem diameter and in panicle size. Some stalks breaking
8	Scorching on most of the leaf area. Stunting resulting in a 50% reduction in height stalks look thin and weak; many are broken
9	Virtually all leaf area scorched two-third or more reduction in height; most Stems collapsing; no useful panicle formed.

[a] Modified after Berner *et al.*, (1997)

3.1.9. 9 Quality of grain yield (%)

The quality of grain yield in each net plot was estimated by determining the relative grain sizes of the entire grain yield produced in each net plot. This was done by serially sieving the grain yield through a stack of sieves of 2.36, 2.00, 1.70 and 1.18 mm gauze sizes, in that order for 5 minutes using a test-sieve shaker (Endecott Laboratory Test Sieve Shaker, Endecotts LTD, London). The weight of seed lot fraction collected on each sieve was measured and expressed as percentage of the total weight of grain yield in that plot.

3.1.9.10 1000-Grain weights (g) of grain yields

The weight of 100 millet seeds, randomly selected from the seed aggregates collected on 1.18, 1.70, 2.00 and 2.36 mm sieve (see 3.1.9. 9) was determined for each net plot using an electronic weighing balance EL 582—552, 1999 Model, General Lab Equipment London. 1000-grain weights for the seed aggregates collected on each sieve were computed by multiplying the weight of 100 randomly selected seeds by 10 (Bala, 1997). For each net plot pooled 1000-grain weight for the grain yield obtained in it was computed, as the mean of the 1000-grain weights of the individual seed aggregates collected on each of the four sieves.

3.1.9.11 Proportion of marketable grain yield (%)

Sieved seed aggregates of the grain yield from each net plot collected on 1.18 and 1.70 mm sieves (see 3.19.9) were considered to be of low market quality value

therefore unmarketable on their own while those collected on 2.00 and 2.36 sieves were considered to be of high market quality, therefore marketable even on their own. The total weights of marketable and unmarketable grain weights in each net plot were expressed as percentage of the total weight of the grain yield in that net plot.

3.1.9.12 Short term effects on soil physico-chemical properties

At harvest, 200g of soil specimens were collected from each net plot, at the depth of about 0-20 cm of the top soil using auger (Rowell, 1996). Specimens were taken to Department of Soil Science, Faculty of Agriculture, Ahmadu Bello University Zaria for comprehensive soil analyses on soil physico-chemical properties, including soil texture, total nitrogen, exchangeable bases, cation exchange capacity and soil pH etc.

3.1.10 Data analyses

All data collected were analyzed according to Analysis of Variance (ANOVA) (Appendix 2), and treatment means comparison was carried out by Fischer's Least Significant Difference (LSD) test at 1-5% levels of significance. Data collected on soil physico-chemical properties were analyzed using student t-test at P = 1-5% level of significance, as in Little and Hill (1997).

3.2 Effects of Prolonged Deposition of Neem Residues on Millet, Sorghum, Groundnut and Cowpea, and on Soil Physico-Chemical Properties

3.2.1 Aim

The aim of this experiment was to determine possible long term effects of prolonged deposition of organic residues from neem trees planted in shelterbelts on soil physico-chemical properties, and on the germination, growth and grain yield of millet, sorghum, cowpea and groundnut, planted within the pollarded shelterbelt.

3.2.2 Treatments and experimental design

Tests were conducted at two locations in Katsina, at the commencement of the 2004 rainy season. Each test site was a 20-year old neem shelterbelt in which neem trees were, 20 years earlier, planted with a 5 x 5 m grid spacing (400 trees/ha), three rows wide and about 2 km long each (Plate VII). Within the 20 years period, the areas within the shelterbelt have not been cultivated for any crop production purposes. Neem residues particularly fruits, leaves and flowers have been dropping from the neem trees onto to the ground, where they ultimately decompose and gradually got incorporated into the soil (Plate VIII). Effect of continuous and prolonged deposition of neem residues into the neem shelterbelt soil on the soil's physico-chemical properties, and on the germination, growth, and grain yield of the millet, sorghum, cowpea, and groundnut were investigated after pollarding the neem trees, and incorporating the pruned leaves and fruits into the soil (Plate VI). Experiments were conducted at two locations, each between two treatments; neem-treated plots within the shelterbelt and the untreated plots located



Plate VII: The 20-year old neem shelterbelt used for testing long term effects of continuous and prolonged deposition of neem residues.

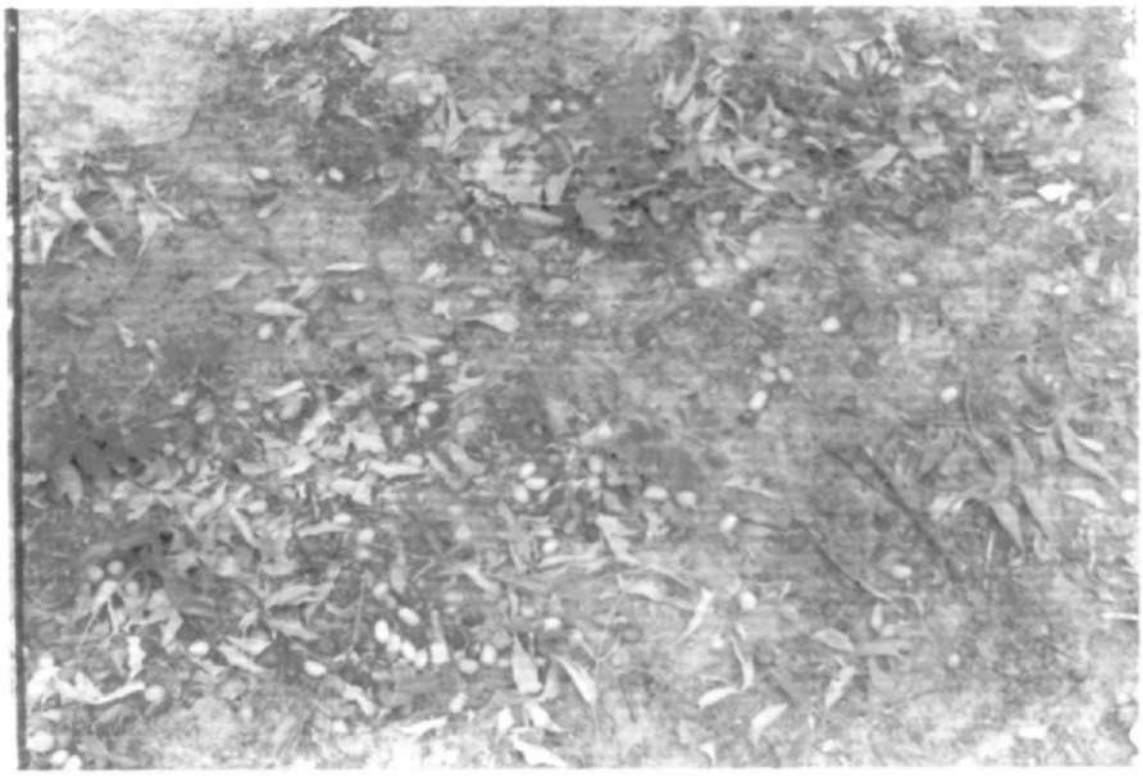


Plate VIII: Natural deposition of neem leaves and fruits in a 20-year old neem shelterbelt.



Plate VIII: Pruned neem trees in a 20-year old neem shelterbelt used for testing long term effects of continuous and prolonged deposition of neem residues.

outside the shelterbelt. In each case, separate experiments were conducted for millet, sorghum, cowpea and groundnut. In each experiment, 10 plots each within the shelterbelt and 10 control plots were planted with the same crop. In each experiment a gross plot measured 3 m^2 plot and the net plot measured $2m^2$. Hoe was used in setting the ridges about 65 cm apart. Control plots were located outside the shelterbelt zone and had neither neem trees nor neem residues in them or in their vicinity. In order to determine percentage germination counts 10 millet (dan-digali), sorghum (far-fara), groundnut (yar-jingila), and cowpea (dan-ila) seeds were sown per hole on the ridge, about 65, 65, 35, and 50 cm apart, respectively. In all cases local varieties were used for the experiments. After the first hoe weeding and thinning operations at 2 WAE all weeds were hand pulled as and when necessary.

Measurements and observations

3.2.3.1 Millet seed germination counts

These were recorded by counting the germinated seedlings with each net plot at 2 WAE. Thereafter millet seedlings were thinned to three seedlings per stand, while all other crops were thinned to 2 seedlings per stand, during the first hoe weeding operation at 2 WAE.

3.2.3.2 Growth vigor

Growth vigor of all plants in each net plot was collectively scored visually on a 1-5 growth vigor scale that was based on the goodness of plant growth as shown in Table 12.

Table 12: Visual assessment scale used for scoring plant growth.

Visual assessment score point	Degree of manifestation of vegetative growth
1	Very poor vegetative growth
2	Poor vegetative growth
3	Fair vegetative growth
4	Good vegetative growth
5	Very good vegetative growth

3.2.3.3 Plant biomass (g)

At the end of the rainy season plants in each net plot were harvested and air dried for three weeks. Air-dry weights were measured using a mechanical weighing balance (Hemel HP3 9RL, Hempstead Herts, England).

3.2.3.4 Grain yield

At harvest pods and panicles were harvested and sun-dried for three weeks after which air-dry weights were measured using an electronic weighing balance (EL 582-552, 1999 Model, General Lab Equipment, London). Pods and panicles were threshed and grain air-dry weights were similarly recorded after winnowing.

3.2.3.5 Soil physico-chemical properties

At end of the 2004 rainy season, 200g of soil specimens were collected from any three randomly selected net plots under the neem shelterbelt and the control plots, each at the depth of about 0-20 cm of the top soil using auger (Rowell, 1996). Specimens were taken to Department of Soil Science, Faculty of Agriculture, Ahmadu Bello University Zaria for comprehensive soil analyses on soil physico-chemical properties.

3.2.4 Data Analyses

All data collected were analyzed using student t-test at P=1-5% level of significance in accordance that described by Little and Hill (1997).

CHAPTER FOUR

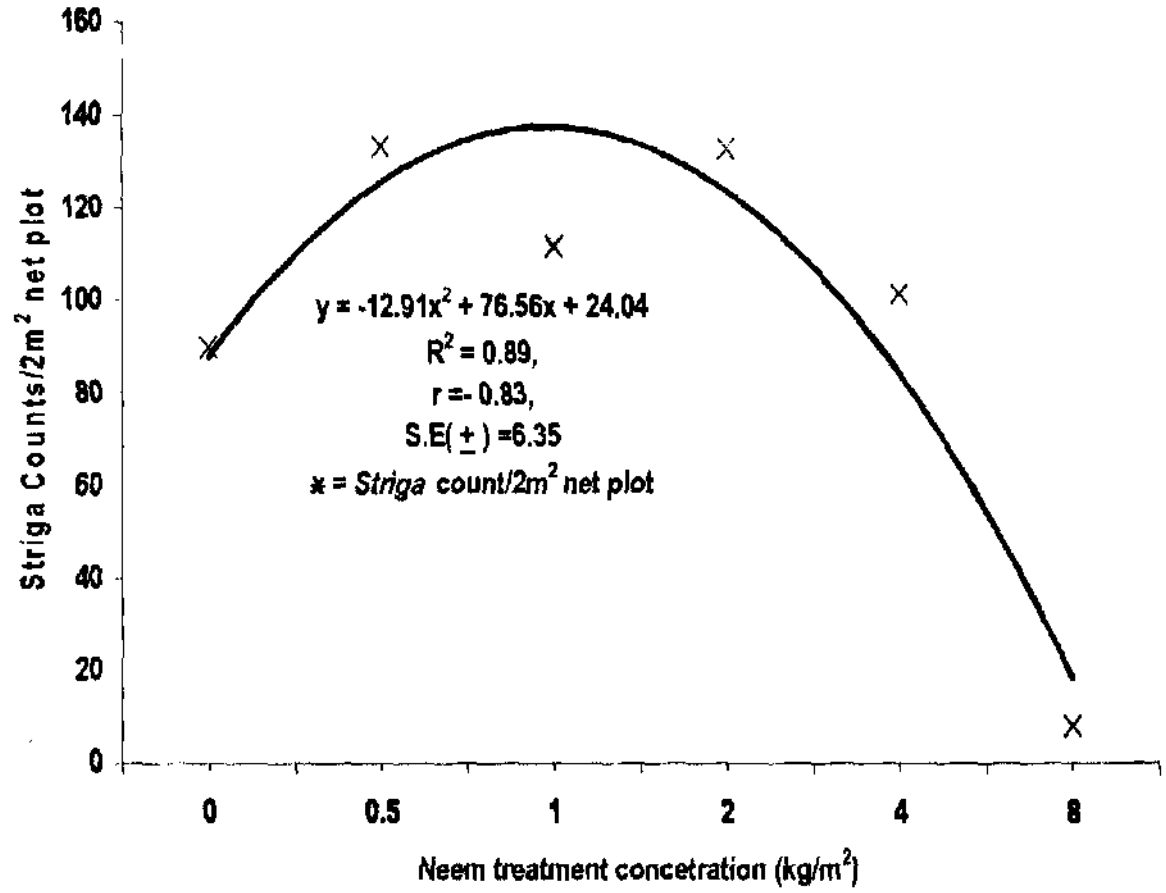
4.0 RESULTS

4.1 Effects of Neem Soil Amendments on *Striga hermonthica*, Pearl Millet and Soil Physico-Chemical Properties to Under Field Conditions

4.1.1 Effects of neem soil amendments on *Striga hermonthica*

4.1.1.1 Effects on *Striga* emergence

Amending *Striga*-infested soil with neem soil amendments at 0.5-8.0 kg/m^2 significantly (P=0.01) affected *Striga* emergence on millet (Figure 6 and Table 13). In the year 2001, the neem treatments at 0.5, 1.0, 2.0 and 4.0 kg/m^2 increased *Striga* emergence by 48.55, 24.28, 47.88 and 12.69% respectively compared with the control treatment, while 8.0 kg/m^2 suppressed emergence by 91.09% in relation to the control treatment. At the four other sites in the years 2002 and 2003, the neem treatments at 4.0 - 8.0 kg/m^2 suppressed *Striga* emergence by 44.44-100%, though *4.0kg/m^2 at site 1 in the year 2002, increased Striga emergence by* 355.56%. Neem treatments at 6.0 and 8.0 kg/m^2 were found to significantly suppress *Striga* count at harvest, and were consistently better than control treatments in this regard (P= 0.01) (Figure 6 and Table 13). At lower concentrations the neem treatments significantly supported more *Striga* emergence than the control treatments. Neem treatments at 4.00 kg/m^2, in two out of the five test sites, and neem treatments at 0.5-2.0 kg/m^2 in the year 2001 at Katsina, significantly (P=



LSD (P= 0.01) = 25.55

Figure 6: Effect of amending *Striga*-infested plots with neem soil amendments on *Striga* counts at harvest in the year 2001 at Katsina

Table 13: Effect of amending *Striga*-infested plots, at four locations in Katsina, with neem soil amendments, on *Striga* counts at harvests, during the 2002 and 2003 trials.

Neem Treatment Dose (kg/m^2)	Mean *Striga* Counts/plot			
	2002		2003	
	Site 1	Site 2	Site 1	Site 2
0	4.50	32.75	13.50	0.25
4	20.50	6.0	2.00	0.00
6	2.50	0.75	0.00	0.00
8	0.00	0.00	0.00	0.00
S.E. (+/-)	2.60	6.23	2.12	ns
LSD (P=0.01)	8.33	19.92	6.78	ns
r	-0.28	-0.25	-0.93	ns
R^2	0.98	0.52	0.98	ns

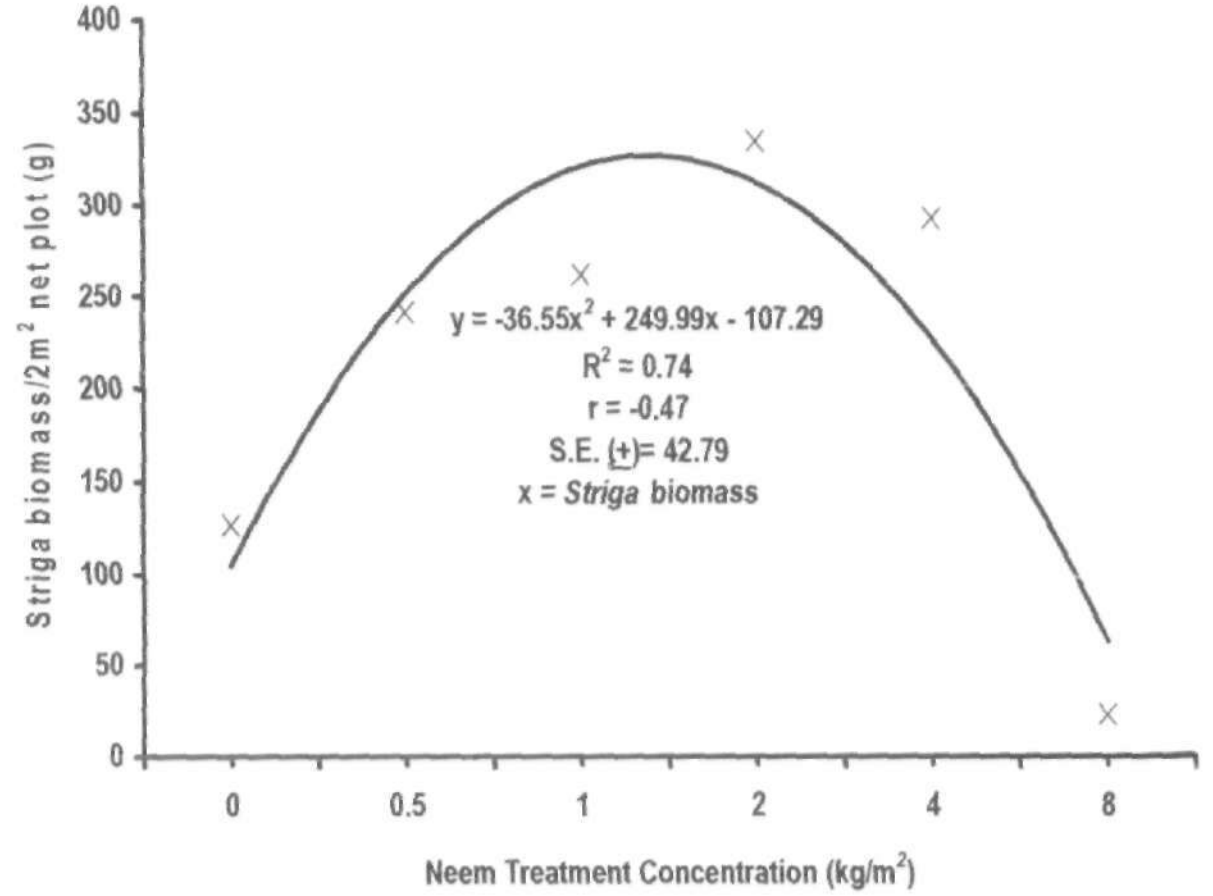
ns = not significant at P=0.05
r = coefficient of linear correlation
R^2 =coefficient of multiple determination

0.01) supported more *Striga* counts at harvest than the control treatments. *Striga* counts at site 2 in year 2003 appeared to have been affected by the frequent heavy rainfall that kept the experimental plots flooded, thereby affecting the growth performance of host millet and perhaps its parasite.

The tested concentrations of neem soil amendments were related, in these experiments, to *Striga* counts by statistically significant coefficients of multiple determinations, R^2, that ranged between 0.52 at site 2 in the year 2002 to 0.98 at both sites 1 in the year 2002 and 2003. The two variables were also related by coefficients of linear correlations, r, that ranged between -0.25 at site 2 in the year 2002 to -0.93 at site 1 in the year 2003. In Figure 6, the two variables were related and closely fitted by a polynomial quadratic equation, $y = -x^2 + 6x + 2$.

4.1.1.2 Effects of neem soil amendments on *Striga* biomass

Amending *Striga*-infested soil with neem soil amendments at 0.5-4.0 kg/m^2 significantly (P=0.01) affected *Striga* biomass (Figure 7 and Table 14). In the year 2001, the neem treatments at 0.5, 1.0, 2.0, and 4.0 kg/m^2 increased *Striga* biomass by 90.76, 107.15, 164.71 and 131.51%, respectively compared with the control treatment, while 8.0 kg/m^2 suppressed *Striga* biomass by 81.84%. At the four other sites in the years 2002 and 2003, the neem treatments at 4.0 - 8.0 kg/m^2 suppressed *Striga* biomass by 32.67-100%. Neem treatment at 8 kg/m^2, which was not significantly different from 6.0 kg/m^2, was the best treatment in suppressing *Striga* biomass at all sites and in all the years (Figure 7 and Table 14



LSD (P=0.01) =172.17

Figure 7: Effect of amending *Striga*-infested plots with neem soil amendments on *Striga* biomass at Katsina, during the 2001 trial.

Table 14: **Effect of amending *Striga*-infested plots, at four locations in Katsina, with neem soil amendments on *Striga* biomass at harvests, during the 2002 and 2003 trials.**

Neem Treatment Dose (kg/m^2)	Mean *Striga* biomass (g)/$2m^2$ net plot			
	2002		2003	
	Site 1	Site 2	Site 1	Site 2
0	36.0	36.55	5.03	0.11
4	24.24	9.40	0.29	0.00
6	5.39	0.06	0.51	0.00
8	0.00	0.13	0.00	0.00
S.E (+/-)	5.70	6.01	0.84	ns
LSD (P=0.01)	26.61	27.61	3.84	ns
r	-0.97	-0.95	0.90	ns
R^2	0.97	1.00	0.91	Ns

ns = not significant at P=0.05
r = coefficient of linear correlation
R^2 =coefficient of multiple determination

). Control treatment at all the test sites, other than at site 2 in the year 2003, were significantly better (P=0.01) than all the neem treatments in supporting *Striga* biomass accumulation, which at site 2, in the year 2003, appeared to have been affected by the frequent heavy rainfall that kept the experimental plots flooded, thereby affecting the growth performance of host millet and perhaps its parasite.

The tested concentrations of neem soil amendments were related, in these experiments, to *Striga* biomass by statistically significant coefficients of multiple determinations, R^2, which ranged between 0.74 in the year 2001 to 1.00 at site 2 in the year 2002. The two variables were also related by coefficients of linear correlations, r, that ranged between -0.47 in the year 2001 to -0.97 at site 1 in the year 2002. In Figure 7 the two variables were related and closely fitted by a polynomial quadratic equation, $y = -x^2 + 7x - 3$.

4.1.2 Effects of neem soil amendments on pearl millet grown on *Striga*-infested soil

4.1.2.1 Effect on neem soil amendments on germination of millet seeds

Amending *Striga*-infested soil with neem soil amendments at 0.5-8.0 kg/m^2 significantly (P=0.01) affected germination of millet seeds (Figure 8 and Table 15). In the year 2001, the neem treatments at 0.5-8.0 kg/m^2 suppressed germination of millet seeds, sown at Day 0, and Day 14 by 0.0-100%, and 0.0-57%, respectively, compared with the control treatment. At the four other sites in the years 2002 and

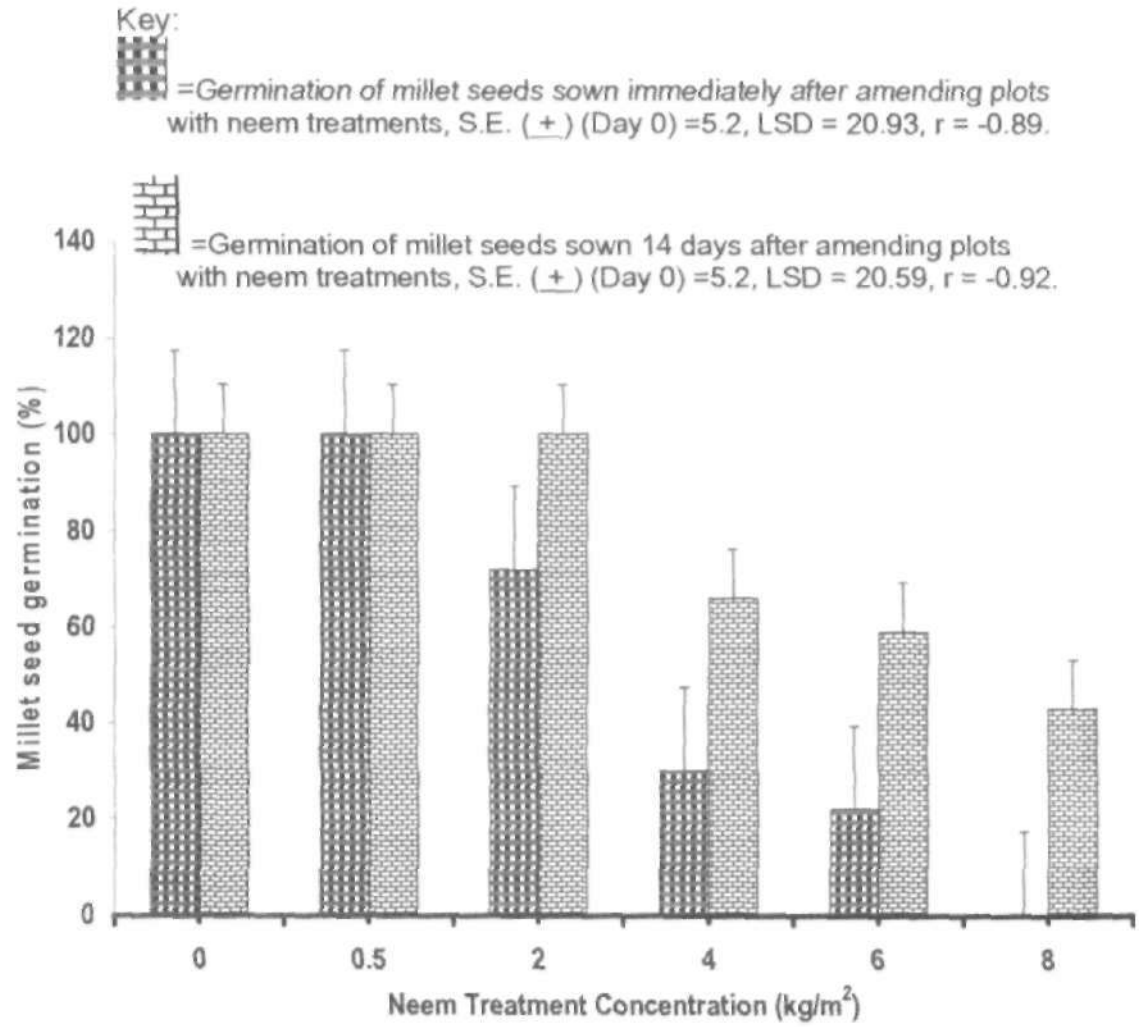


Figure 8: Effect of amending *Striga*-infested plots with neem soil amendments on germination of millet seeds sown at 0 and 14 days after amending the soil in Katsina, during the 2001 trial.

Table 15: Effect of amending *Striga*-infested plots, at four locations in Katsina, with neem soil amendments on the germination of millet seeds, sown immediately (Day 0) and fourteen days after amending the soil at harvests, during the 2002 and 2003 trials.

Neem Treatment Dosage kg/m^2	Germination count % (at Day 0)				Germination count % (at Day 14)			
	2002		2003		2002		2003	
	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2
0	100	100	100	100	100	100	100	100
4	32.5	35.0	62.5	57.5	65.6	55.0	77.5	80.0
6	27.5	27.5	47.5	42.5	50.0	52.5	67.5	67.5
8	0.0	0.0	5.0	15.5	35.0	40.0	45.0	47.5
S.E (+/-)	5.38	5.01	6.0	6.13	9.69	5.91	3.79	10.91
LSD (P=0.01)	17.2	18.9	19.2	19.6	24.6	18.9	12.1	34.9
r	-0.98	-0.98	-0.97	-0.99	-1.0	-0.96	-0.98	-0.99
R^2	0.93	0.94	0.97	0.96	0.99	0.93	0.98	0.99

r = *coefficient of linear correlation*
R^2 =coefficient of multiple determination

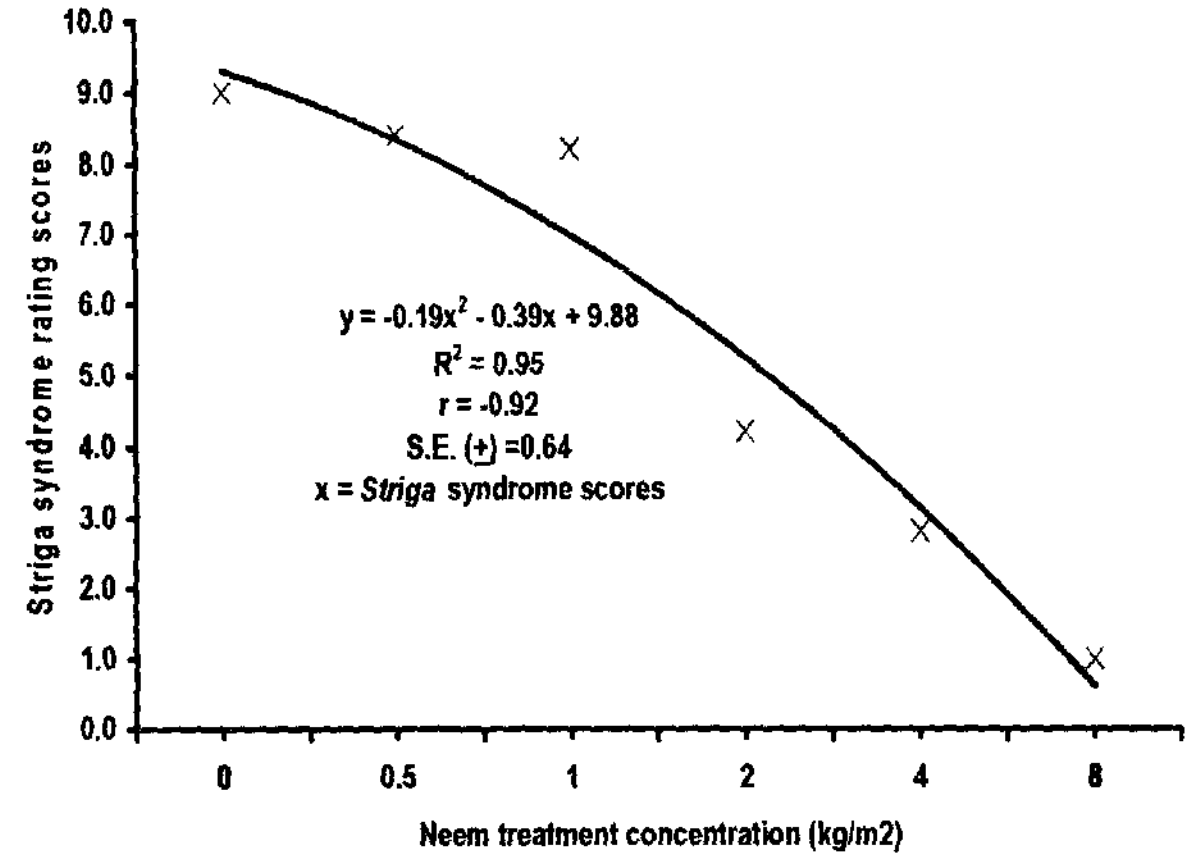
2003, the neem treatments at 4.0 - 8.0 kg/m^2 suppressed germination of millet seeds sown at Day 0, and Day 14 by 37.5-100% and 20-65%, respectively. The three-year results consistently showed that amending plots with neem soil amendments significantly (P=0.01) suppressed the germination of millet seeds that were sown immediately after amending the soil (Day 0) or two weeks (Day 14) later (Figure 8 and Table 15). For millet seeds sown on the Day 0, all the neem treatments, other than 0.5 kg/m^2, suppressed millet seed germination significantly (P = 0.01) higher than control treatment. For seeds that were sown at Day 14 all the neem treatments, other than 0.5 and 1.0 kg/m^2, suppressed millet seed germination significantly (P = 0.01) higher than the control treatment. The most suppressive of all the neem treatments was 8.0 kg/m^2, which suppressed germination of millet seeds by 84.5-100% and 52.5-65% for seeds sown at Day 0 and Day 14, respectively.

The tested concentrations of neem soil amendments were related, in these experiments, to percentage germination of millet seeds that were sown immediately after amending the soil (Day 0) by statistically significant coefficients of multiple determinations, R^2, which ranged between 0.93 at site 1 in the year 2002 and 0.97 at site 1 in the year 2003. However for seeds sown 14 days after amending the soil (Day 14), the R^2 values ranged between 0.93 at site 2 in the year 2002 to 0.99 at site 1 in the year 2002 and site 2 in the year 2003. The two variables were also related by coefficients of linear correlations, r, that ranged between -0.89 to -0.99 for seeds sown at Day 0, and ranged between -0.92 to -1.0 for seeds sown at Day 14.

4.1.2.2 Effects of neem soil amendments on *Striga* syndrome

Amending *Striga*-infested soil with neem soil amendments at 0.5-8.0 kg/m^2 significantly (P=0.01) affected *Striga* syndrome (Figure 9 and Table 16). In the year 2001, the neem treatments at 0.5-8.0 kg/m^2 suppressed *Striga* syndrome by 6.67-88.89%, compared with the control treatment. At the four other sites in the years 2002 and 2003, the neem treatments at 4.0 - 8.0 kg/m^2 suppressed *Striga* syndrome by 11.11-87.5%. Neem treatment at 2.0-8.0 kg/m^2 were found to have significant (P=0.01) effect on the severity of *Striga* syndrome at all the sites and in all the years. At 6.0 and 8.0 kg/m^2, the neem treatments were the best in reducing the severity of symptoms at both sites and in all the years. At 0.5 and 1.0 kg/m^2 the observed severity of symptoms was not different from that of the control treatment in the year 2001. Observed symptoms of *Striga* attack in pearl millet included severe stunted growth, thin stems with short or no panicles formed. Chlorosis and tattering of leaves were very evident, sometimes even before *Striga* emergence. However, as the concentrations of neem soil amendments were increased from the control treatment at 0.0 kg/m^2 to the highest treatment at 8.0 kg/m^2 *Striga* infection and severity of symptoms began to reduce dramatically (Plates X-XV).

The tested concentrations of neem soil amendments were related, in these experiments, to *Striga* syndrome by statistically significant coefficients of multiple determinations, R^2, which ranged between 0.63 at site 1 in the year 2003 to 1.00 at site 2 in the year 2002. The two variables were also related by coefficients of linear correlations, r, that ranged between -0.82 at site 1 in the year 2003 to -0.97 at site 1



LSD (P=0.01) = 2.57

Figure 9: Effect of amending *Striga*-infested plots with neem soil amendments on *Striga* syndrome scores at Katsina, during the 2001 trial at Katsina.

Table 16: Effect of amending *Striga*-infested plots, at four locations in Katsina, with neem soil amendments on *Striga*-syndrome scores on infested millet plants at harvests, during the 2002 and 2003 trials.

Neem Treatment Dose (kg/m^2)	Mean *Striga* -syndrome rating scores			
	2002		2003	
	Site 1	Site 2	Site 1	Site 2
0	8.0	8.75	6.0	6.75
4	4.00	3.25	1.75	5.50
6	1.00	1.00	3.50	6.0
8	1.00	1.00	1.50	4.25
S.E (+/-)	0.31	0.29	0.43	0.51
LSD	1.43 (P=0.01)	1.33 (P=0.01)	1.96 (P=0.01)	1.62 (P=0.05)
r	-0.97	-0.96	-0.82	-0.87
R^2	0.99	1.00	0.63	0.76

r = coefficient of linear correlation
R^2 =coefficient of multiple determination



Plate X: *Striga* infested control plot not treated with neem soil amendment (T1=0.0 kg/m^2) in replicate IV at Katsina during the 2001 trial.



Plate XI: ***Striga*** **infested plots treated with neem soil amendment at 0.5 Kg/m^2 (T2) in replicate III at Katsina during the 2001 trial**



Plate XII: *Striga*-infested plot amended with neem organic soil amendments at 1.0 kg/m^2 (T3) in replicate IV at Katsina during the 2001 trial



Plate XIII: *Striga* infested plots amended with neem organic soil amendments at 2.0 Kg/m^2 (T4) in replicate II at Katsina during the 2001 trial.



Plate XIV: ***Striga*-infested plots treated with neem organic soil amendments at 4.0 kg/m^2 (T5) in replicate II at Katsina during the 2001 trial.**



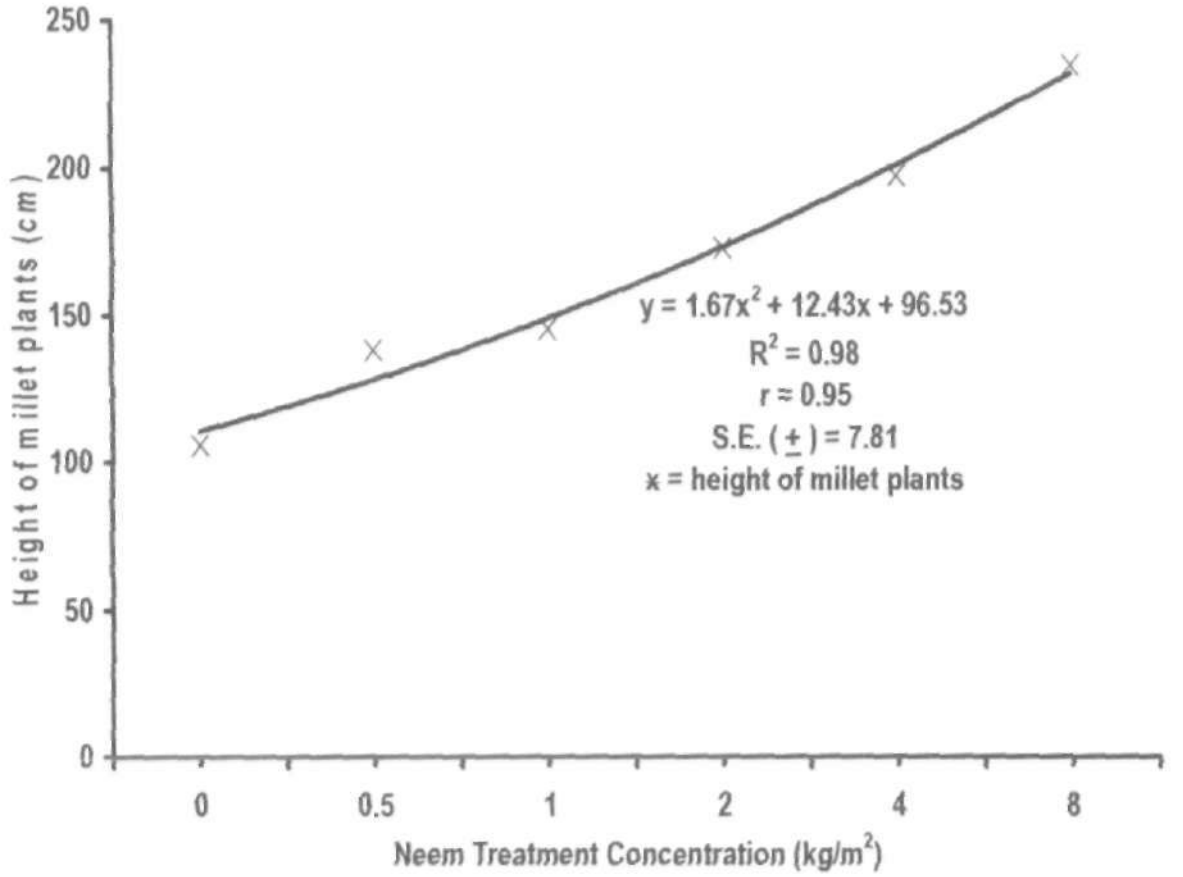
Plate XV: ***Striga*** **infested plots amended with neem organic soil amendments at 4.0 kg/m^2 (T5) in replicate IV at Katsina during the** 2001 trial.

in the year 2002. In Figure 9 the two variables were related and closely fitted by a *polynomial quadratic equation*, $y = -x^2 + 2x + 52$.

4.1.2.3 Effects of neem soil amendments on plant growth parameters

Height of millet plants: Amending *Striga*-infested soil with neem soil amendments at 0.5-8.0 kg/m^2 significantly (P=0.01) affected height of millet plants (Figure 10, Table 17 and Plates X-XV). In the year 2001, the neem treatments at 0.5-8.0 kg/m^2 increased height of millet plants by 27.14-235.71%, compared with the control treatment. At the four other sites in the years 2002 and 2003, the neem treatments at 4.0 - 8.0 kg/m^2 increased height of millet plants by 22.88-99.39%. The neem treatments were found to have significant effect (P=0.01) on the height of treated millet plants at all tested concentrations, compared with the control treatment in all years and at all sites. Neem treatments at 4.0, 6.0 and 8.0 kg/m^2 were the best treatments in significantly increasing plant height, compared with the control and neem treatments at 0.5, 1.0, and 2 kg/m^2 (Figure 10 and Table 17).

The tested concentrations of neem soil amendments were related, in these experiments, to height of neem-treated millet plants by statistically significant coefficients of multiple determinations, R^2, which ranged between 0.75 at site 2 in the year 2003 to 0.98 at site 1 in the year 2002 and during the 2001 trial. The two variables were also related by coefficients of linear correlations, r, that ranged between 0.85 at site 1 in the year 2002 to 0.98 at site 1 in the year 2002. In Figure 10 the two variables were related and closely fitted by a polynomial quadratic



LSD (P=0.01)= 31.41

Figure 10: Effect of amending *Striga*-infested plots with neem soil amendments on height of millet stalks at harvest in Katsina, during the 2001 trial.

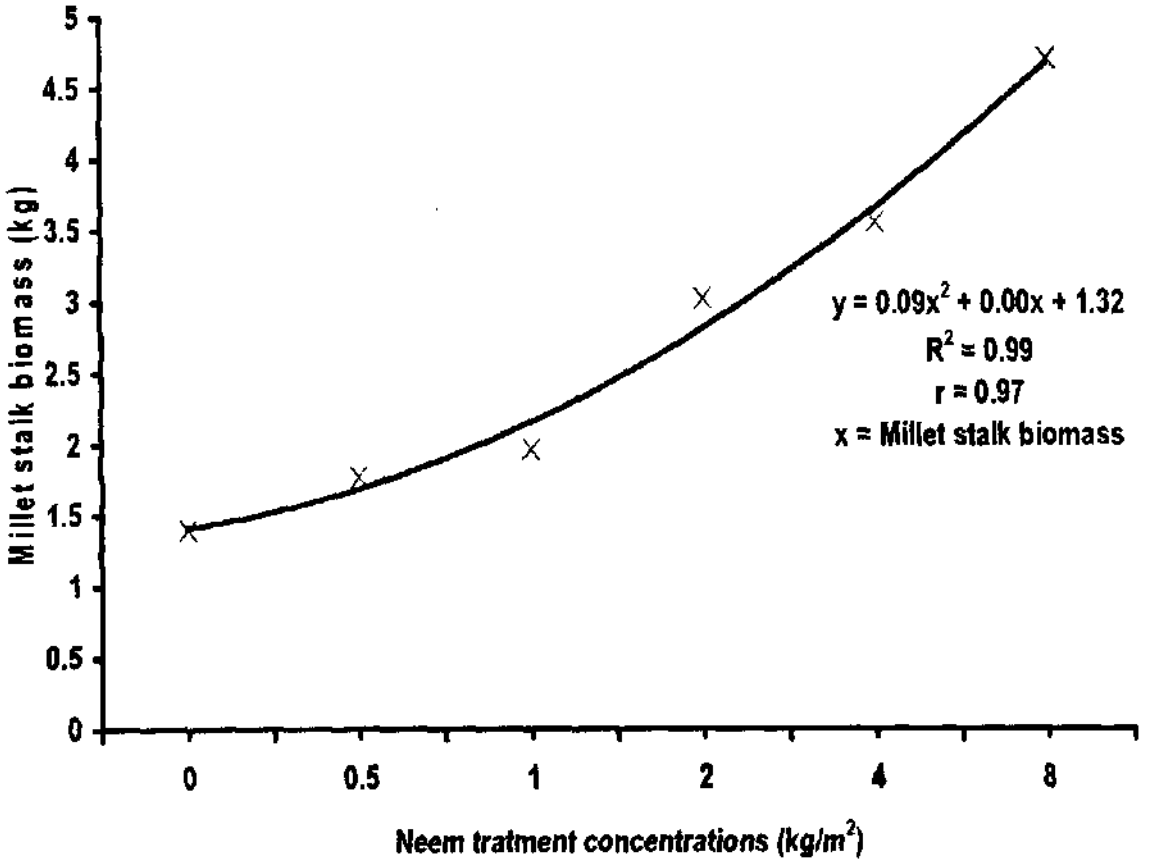
Table 17: ***Effect of amending Striga-infested plots, at four locations in Katsina, with neem soil amendments on height of millet at harvests, during the 2002 and 2003 trials.***

Neem Treatment Dose (kg/m^2)	Mean height of millet plants (cm)			
	2002		2003	
	Site 1	Site 2	Site 1	Site 2
0	110.50	114.00	163.58	112.13
4	135.78	205.60	217.34	175.42
6	171.13	211.96	215.50	159.13
8	182.60	225.02	213.14	181.06
S.E (+/-)	8.51	7.37	9.78	10.81
LSD(P=0.01)	39.11	33.88	44.93	49.68
r	0.98	0.94	0.85	0.87
R^2	0.98	0.95	0.92	0.75

r = coefficient of linear correlation
R^2 =coefficient of multiple determination

equation, $y = {}^{2} + 7x + 58$.

Millet stalk biomass: Amending *Striga*-infested soil with neem soil amendments at 0.5-8.0 kg/m^2 significantly (P=0.01) affected millet stalk biomass (Figure 11 and Table 18). In the year 2001, the neem treatments at 0.5-8.0 kg/m^2 increased millet stalk biomass by 90.76-164.71%, compared with the control treatment. At the four other sites in the years 2002 and 2003, the neem treatments at 4.0 - 8.0 kg/m^2 increased millet stalk biomass by 34.27-147.52% (Plates X-XV and XVII). The neem treatments significantly (P= 0.01) increased millet stalk biomass compared with the control. Neem treatments at 6.0 and 8.0 kg/m^2 had consistently the highest effect on millet stalk biomass at all the sites and in all the years. Control treatment was not significantly different from neem treatments at 0.5-2.00 kg/m^2 in the year 2001 in increasing millet stalk biomass. The control treatment was not also significantly different from neem treatments at 4.00-6.0 kg/m^2 in the year 2003 site 2, where frequent floods at the experimental site that year seriously affected the growth of the host plant and appeared to have hampered *Striga* emergence too. The tested concentrations of neem soil amendments were related, in these experiments, to millet stalk biomass by statistically significant coefficients of multiple determinations, R^2, which ranged between 0.75 at site 1 in the year 2003 and 1.00 at site 2 in the year 2002. The two variables were also related by coefficients of linear correlations, r, that ranged between 0.89 at site 1 in the year 2003 to 0.98 at site 1 in the year 2003. In Figure 11 the two variables were related and closely fitted by a polynomial quadratic equation, $y = x^2 + 15$.



LSD (P=0.01) = 1.05

Figure 11: Effect of amending *Striga*-infested plots with neem soil amendments on millet shoot biomass at Katsina, during the 2001 trial.

Table 18: Effect of amending *Striga*-infested plots, at four locations in Katsina, with neem soil amendments on biomass of millet stalks at harvests, during the 2002 and 2003 trials.

Neem Treatment Dose (kg/m^2)	Mean millet stalk biomass (kg)			
	2002		2003	
	Site 1	Site 2	Site 1	Site 2
0	2.40	2.86	1.41	1.04
4	3.33	3.22	3.08	1.55
6	3.63	3.84	2.61	1.43
8	4.56	4.54	3.49	2.00
S.E (+/-)	0.11	0.16	0.18	0.17
LSD (P=0.01)	0.52	0.75	0.85	0.80
r	0.98	0.95	0.89	0.90
R^2	0.97	1.00	0.75	0.82

r = coefficient of linear correlation
R^2 =*coefficient of multiple determination*

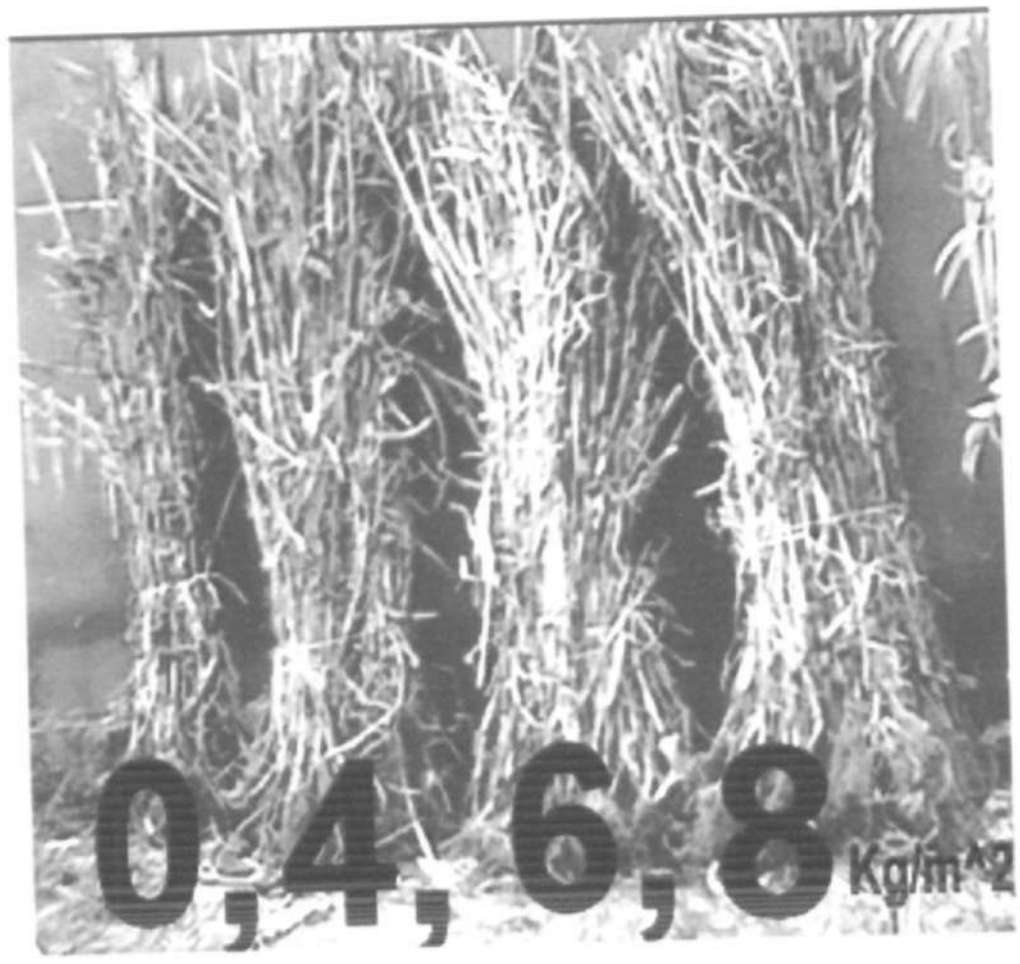


Plate XVI: **Effect of amending *Striga*-infested plots, in combined replicates I-IV with neem organic soil amendments at 0, 4, 6 and 8kg/m^2 at site 1 in Katsina during the 2003 trial.**

4.1.2.4 Effects of neem soil amendments on yield components of millet

Lengths of millet panicles: Amending *Striga*-infested soil with neem soil amendments at 0.5-8.0 kg/m^2 significantly (P=0.01) affected length of millet panicles (Figure 12, Table 19, Plate XVII). In the year 2001, the neem treatments at 0.5-8.0 kg/m^2 increased length of millet panicles by 23.79-54.14%, compared with the control treatment. At the four other sites in the years 2002 and 2003, the neem treatments at 4.0 - 8.0 kg/m^2 increased length of millet panicles by 12.32- 55.96%. Amending *Striga*-infested soils with neem soil amendments significantly (P=0.01) increased length of millet panicles. Neem treatment at 8.0 kg/m^2 was the best treatment in this regard. It was not significantly different from 2.00 and 4.00 kg/m^2 in the year 2001, from 6.0 kg/m^2 at site 2 in the year 2002 and from 4.00 and 6.0 kg/m^2 at site 1 in the year 2003. Control treatments produced significantly the shortest panicles. The neem treatments did not only significantly increased length of millet panicles, but they also consistently gave thicker panicles that were better filled with grains that these produced under the control treatment. Panicles produced under neem treatments were also consistently and significantly longer and bigger than those produced by control treatments, particularly in the year 2001. Panicle production was not severely hampered in plots treated with neem at 4.0 kg/m^2, despite the fact that the treatment supported more *Striga* shoot. The tested concentrations of neem soil amendments were related, in these experiments, to length of millet panicles by statistically significant coefficients of multiple determinations, R^2 that ranged between 0.95 in the year 2001 to 1.00 at site 1 in the year 2002. The two variables were also related by coefficients of linear correlations,

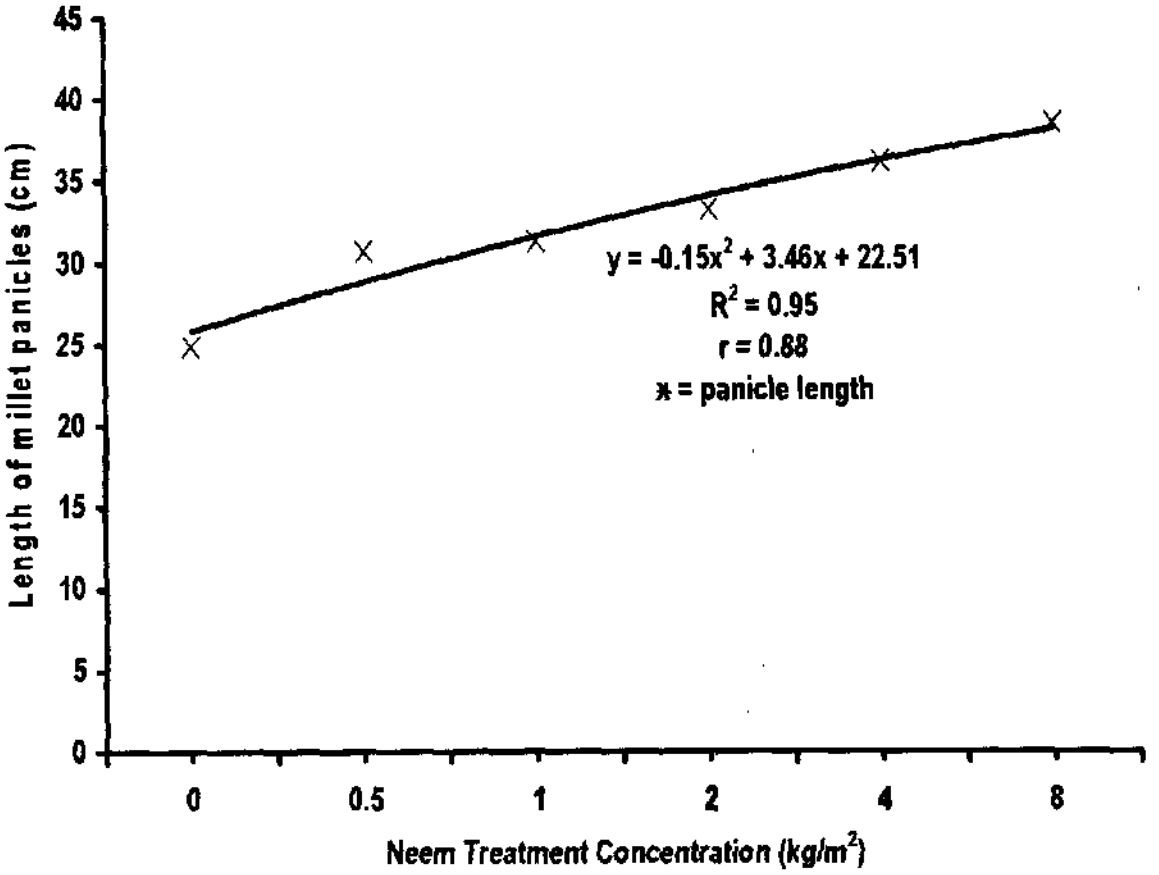


Figure 12: Effect of amending *Striga*-infested plots with neem soil amendments on mean length of millet panicles at Katsina, during the 2001 trial

Table 19: **Effect of amending *Striga*-infested plots, at four locations in Katsina, with neem soil amendments on lengths of millet panicles at harvests, during the 2002 and 2003 trials.**

Neem Treatment Dose (kg/m^2)	Mean panicle length (cm)			
	2002		2003	
	Site 1	Site 2	Site 1	Site 2
0	31.50	30.75	22.32	21.27
4	35.38	35.38	29.57	25.31
6	38.75	38.0	31.39	26.62
8	41.83	43.50	34.81	30.33
S.E (+/-)	1.23	1.54	1.80	1.4
LSD (P=0.01)	5.64	7.09	8.29	6.42
r	0.99	0.98	0.99	0.98
R^2	1.00	0.99	0.97	0.97

r = coefficient of linear correlation
R^2 =coefficient of multiple determination

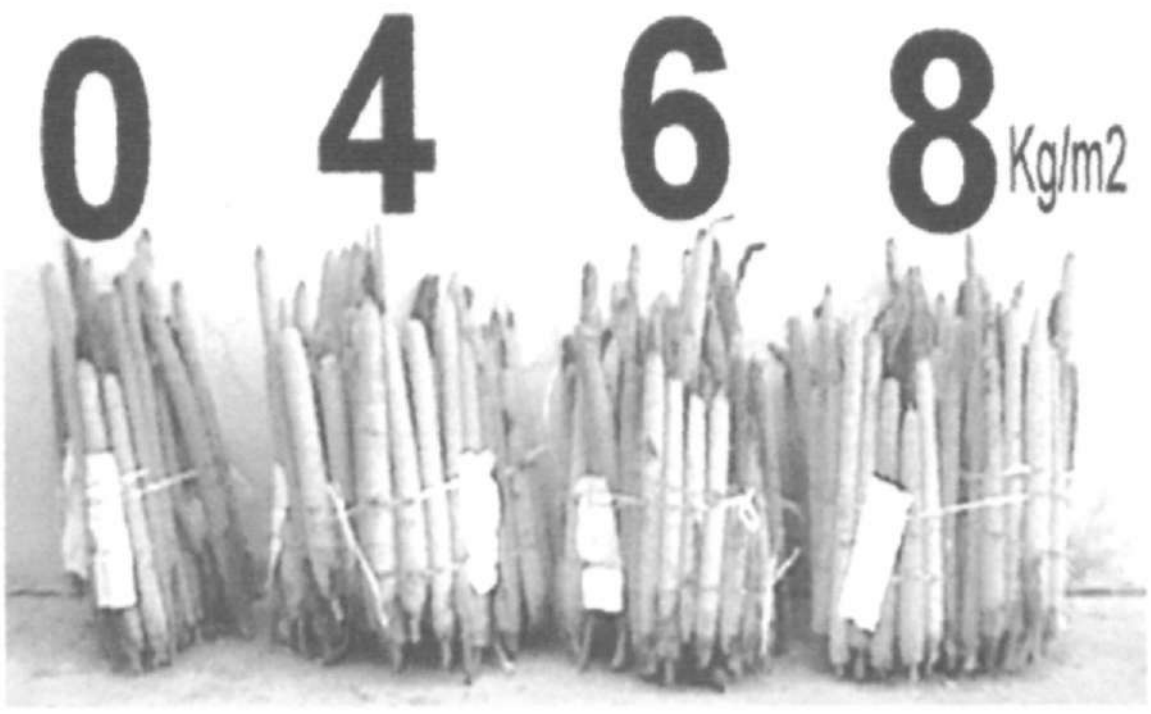
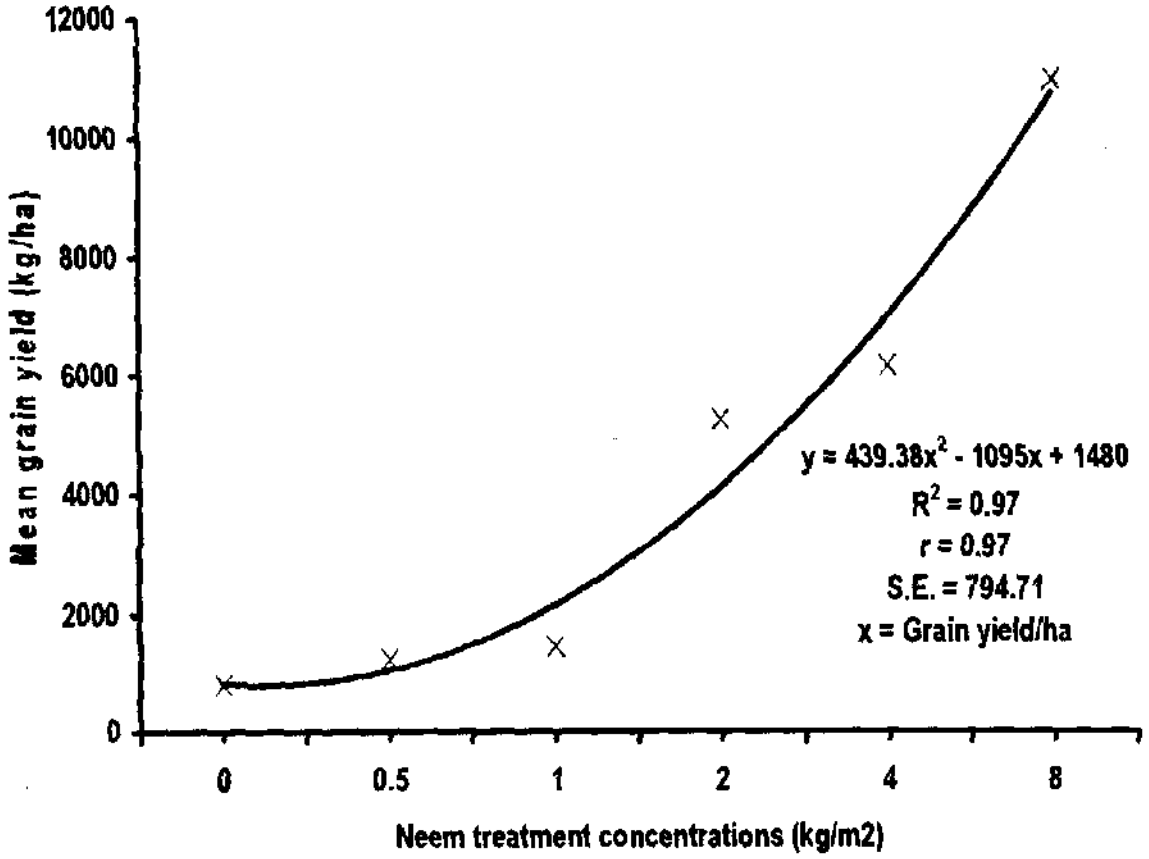


Plate XVII: Effect of amending *Striga*-infested plots in combined replicates I-IV with neem organic soil amendments at 0, 4, 4 and 8 kg/m2 on millet panicle biomass at site 1 in Katsina during the 2003 trial.

r, that ranged between 0.88 in the year 2001 to 0.99 at both sites 1 in the years 2002 and 2003. In Figure 12, the two variables were related and closely fitted by a polynomial quadratic equation $y = -x^2 + 23x + 150$.

Grain yield of millet: The three most spectacular observed effects of amending *Striga*-infested soil with neem soil amendments, in this research, were on accelerated vegetative growth of treated millet, suppressed *Striga* syndrome in millet despite boosted *Striga* emergence, and enhanced reproductive growth and grain yield of millet. Yield and yield components of the neem-treated millet in the *Striga*-infested plots were significantly improved ($P = 0.01$-0.05). Amending *Striga*-infested soil with neem soil amendments at 0.5-8.0 kg/m^2 significantly (P=0.01) affected grain yield of millet (Figure 13, Table 20). In the year 2001, the neem treatments at 0.5-8.0 kg/m^2 increased grain yield of millet by 51.82-1251.94%, compared with the control treatment. At four other sites in the years 2002 and 2003, the neem treatments at 4.0 - 8.0 kg/m^2 increased grain yield of millet by 115.99-545.58%. Neem treatments at 2.00-8.0 kg/m^2 significantly (P=0.01) better than the control treatment in increasing the grain yield of neem-treated millet plants. In the year 2001, neem treatment at 8.0 kg/m^2 was significantly better than 2.00 kg/m^2, which in turn was better than 0.0-1.0 kg/m^2. Similarly, in the year 2002 at both sites 1 and 2, neem treatment at 8.0 kg/m^2 was significantly better than 4.00 kg/m^2, but was not significantly better than 6.0 kg/m^2 in increasing grain yield. However, in the year 2003, at both sites 1 and 2, neem treatment at 8.0 kg/m^2 was significantly better than 4.00 and 6.0 kg/m^2 (Plate XVII). Grain yields were also noted to differ in



LSD (P=0.01) = 2836.28

Figure 13: ***Effect of amending Striga-infested plots with neem soil amendments on grain yield of millet at Katsina, during the 2001 trial***

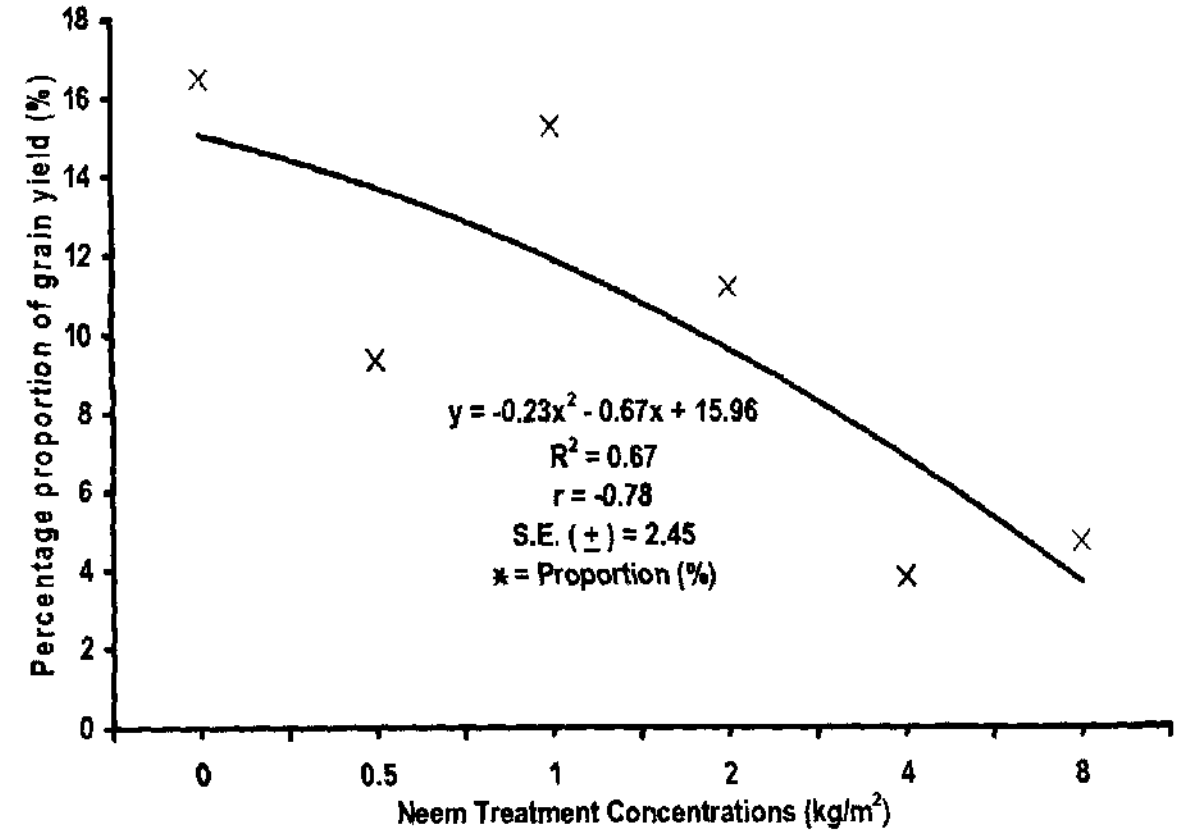
Table 20: Effect of amending *Striga*-infested plots, at four locations in Katsina, with neem soil amendments on mean grain yields at harvests, *during the 2002 and 2003 trials.*

Neem Treatment Dose (kg/m^2)	Mean grain yield (kg/ha)			
	2002		2003	
	Site 1	Site 2	Site 1	Site 2
0	1772.00	1619.75	3337.50	2137.50
4	4077.38	4456.00	9200.00	6862.50
6	6498.50	6868.13	9542.50	7412.50
8	10200.88	10424.3	10062.50	9575.00
S.E (+/-)	677.33	559.54	822.68	907.11
LSD (P=0.01)	3113.12	1700.91	2631.70	4169.25
r	0.96	0.97	0.93	0.98
R^2	1.00	1.00	0.95	0.94

r = coefficient of linear correlation
R^2 =coefficient of multiple determination

the quality of their grains. The tested concentrations of neem soil amendments were related, in these experiments, to grain yield by statistically significant coefficients of multiple determinations, R^2, that ranged between 0.94 at site 2 in the year 2003 to 1.00 at site 1 in the year 2002. The two variables were also related by coefficients of linear correlations, r, that ranged between 0.93 at site 1 in the year 2003 to 1.00 in the year 2001. In Figure 13 the two variables were related and closely fitted by a polynomial quadratic equation, $y = x^2 + 2x + 4$.

Quality of grain yields: Amending *Striga*-infested soils with neem soil amendments significantly affected the quality of grain yield. Relative grain sizes differed based on treatment concentration. At higher concentrations of the neem treatments, higher proportion of relatively bigger grains were noted, while at lower concentrations, particularly the control treatment, most of the seeds were relatively smaller, and most often shriveled. These kind of shriveled seeds readily float in water, while the relatively bigger grains from the neem treated plots at 4.00-8.0 kg/m^2 sink immediately after being poured in water. Amending *Striga*-infested soil with neem soil amendments at 0.5-8.0 kg/m^2 significantly (P=0.01) affected the proportion of sieved grain yield collected on 1.18mm sieve (Figure 14, Table 21). In the year 2001, the neem treatments at 0.5-8.0 kg/m^2 decreased the proportion of sieved grain yield collected on 1.18mm sieve by 7.52-71.56%, compared with the control treatment. At the four other sites in the years 2002 and 2003, the neem treatments at 4.0 - 8.0 kg/m^2 decreased the proportion of sieved grain yield collected on 1.18mm sieve by 6.31-75.13%. Between 14-48% of the grain yield



LSD (P =0.01) = 9.85

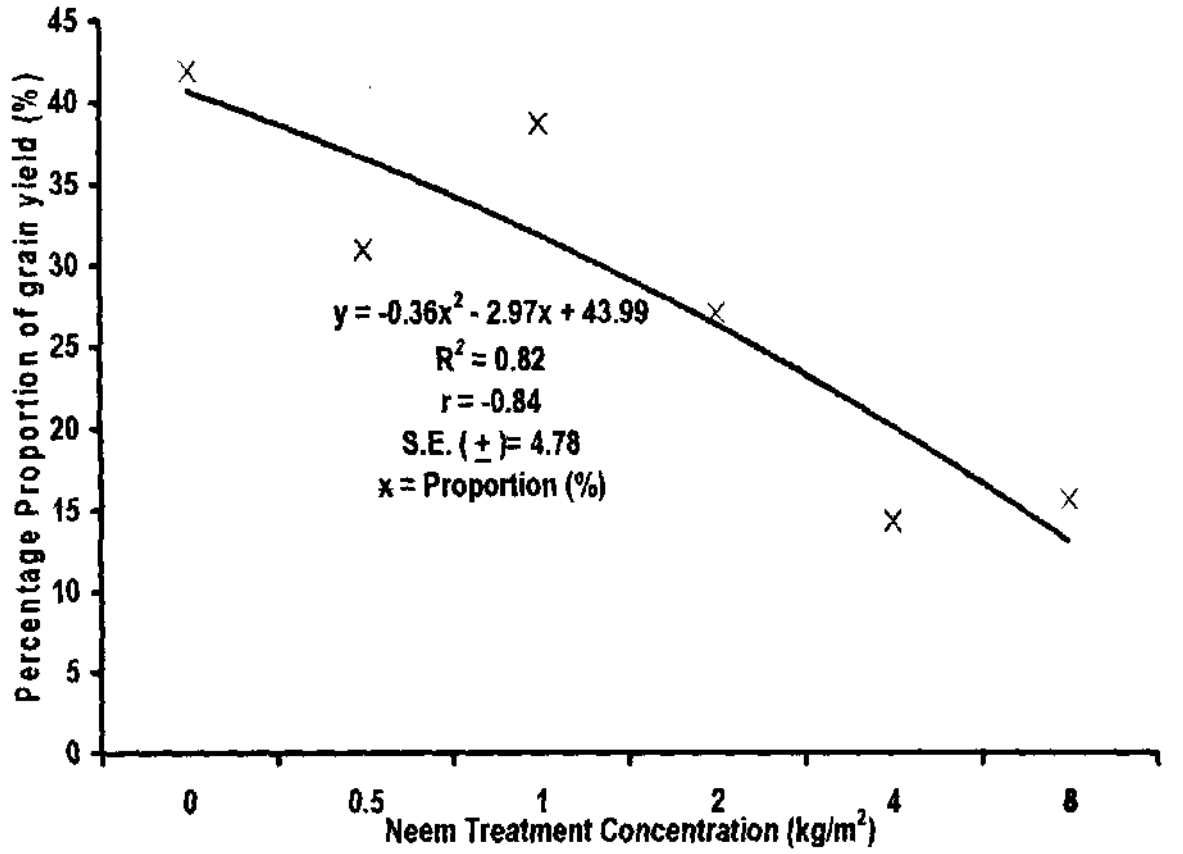
Figure 14: **Effect of amending *Striga*-infested plots with neem soil amendments on the proportion of grain yield collected on 1.18mm sieve at Katsina, during the 2001 trial**

Table 21: Effect of amending *Striga*-infested plots, at four locations in Katsina, with neem soil amendments on the % proportion of Grain yields sieved and collected on 1.18mm sieve at harvests, during the 2002 and 2003 trials.

Neem Treatment Dose kg/m^2	Mean percentage (%)			
	2002		2003	
	Site 1	Site 2	Site 1	Site 2
0	48.05	38.20	31.15	39.99
4	32.29	29.51	29.30	31.11
6	30.54	15.76	20.68	21.49
8	11.95	11.18	16.27	13.61
S.E(+/-)	3.09	3.03	1.33	1.36
LSD (P=0.01)	14.18	13.92	6.14	6.23
r	-0.96	-0.97	-0.92	-0.98
R^2	0.93	0.98	0.96	1.00

produced by the control treatments were collected on 1.18 mm sieve (Figure 14, Table 21). Most of these seeds were malformed and shriveled. They were light in weight, and most often remain afloat if -poured in water. However in neem treated plots at 8.0 kg/m^2 only between 4-15% of the total grain yield were collected on this sieve, and the observed differences were highly significant (P=0.01). Control treatment, however, was not significantly different from neem treatments at 0.5-2.0 kg/m^2 in the year 2001, and with 4.0 kg/m^2 at site 2 in the year 2002 and site 1 in the year 2003. The tested concentrations of neem soil amendments were related, in these experiments, to the proportion of grain yields sieved and collected on 1.18mm sieve by statistically significant coefficients of multiple determinations, R^2, that ranged between 0.67 in the year 2001 to 1.00 at site 2 in the year 2003. The two variables were also related by coefficients of linear correlations, r, that ranged between -0.78 in the year 2001 to -0.98 at site 2 in the year 2003. In Figure 14 the two variables were related and closely fitted by a polynomial quadratic equation, $y = -x^2 - x + 69$.

Similarly, significantly (P = 0.01) higher proportion of grain yield produced by control treatments were retained on 1.70 mm sieve than those retained from neem treated plots at 6.0-8.0 kg/m^2 (Figure 15 and Table 22). Amending *Striga*-infested soil with neem soil amendments at 0.5-8.0 kg/m^2 significantly (P=0.01) affected the proportion of sieved grain yield collected on 1.70mm sieve. In the year 2001, the neem treatments at 0.5-8.0 kg/m^2 decreased the proportion of sieved grain yield collected on 1.70mm sieve by 7.73- 62.73%, compared with the control treatment.



LSD (P=0.01) = 19.25

Figure 15: Effect of amending *Striga*-infested plots with neem soil amendments on the proportion of grain yield sieved and collected on 1.70mm sieve at Katsina, during the 2001 trial

Table 22: **Effect of amending *Striga*-infested plots, at four locations in Katsina, with neem soil amendments on the % proportion of sieved grain yields collected on 1.70mm sieve at harvests, during the 2002 and 2003 trials.**

Neem *Treatment* Dose kg/m^2	**Mean percentage (%)**			
	2002		**2003**	
	Site 1	**Site 2**	**Site 1**	**Site 2**
0	24.40	27.94	31.78	26.94
4	18.84	23.51	19.54	21.26
6	14.91	19.48	16.14	15.41
8	11.58	15.32	15.36	18.38
S.E (+/-)	2.26	1.49	2.10	2.19
LSD	7.22 (P=0.05)	6.84 (P=0.01)	9.63 (P=0.01)	7.0 (P=0.05)
r	-1.00	-0.99	-0.96	-0.92
R^2	1.00	1.00	0.99	0.97

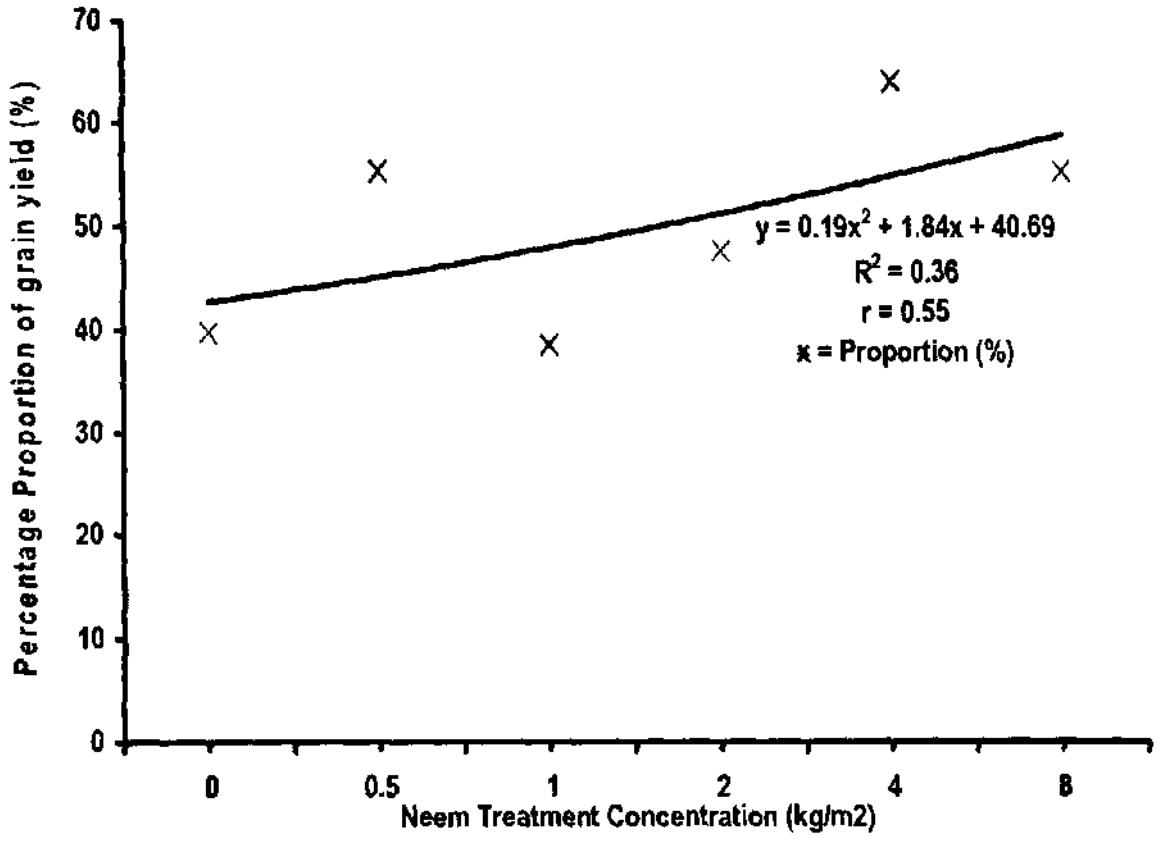
At the four other sites in the years 2002 and 2003, the neem treatments at 4.0 - 8.0 kg/m^2 suppressed the proportion of sieved grain yield collected on 1.70mm sieve by 15.86-52.54%. In the year 2001, the proportion of grain yield produced by the control treatment (at 0.0 kg/m^2) that were sieved and retained on the 1.70mm *sieved ranged between 36.52-47.53%, while that from neem treated plots at 8.0* kg/m^2 ranged only between 11.24-20.42%. The observed differences were highly significant (P=0.01). Similarly, in the year 2002 and 2003, at both sites 1 and 2, the proportion of sieved grain yield produced by the control treatment that were sieved and retained on the 1.70mm sieve ranged between 24.4-31.78% while that from neem treated plots at 8.0 kg/m^2 ranged between 11.58-18.38%. The observed differences were also statistically significant (P=0.01-0.5).

The tested concentrations of neem soil amendments were related, in these *experiments, to the proportion of grain yields sieved and collected on 1.70 mm* sieve by statistically significant coefficients of multiple determinations, R^2, that ranged between 0.82 in the year 2001 and 1.00 at all the test sites in the year 2002. The two variables were also related by coefficients of linear correlations, r, that ranged between -0.84 in the year 2001 to -1.00 at site 1 in the year 2002. In Figure 15 the two variables were related and closely fitted by a polynomial quadratic equation, $y = -x^2 - 8x + 122$.

There was no statistical difference between control and all the neem treatments with *regards to seed aggregates sieved and collected on 2.00 mm sieve, except in the*

year 2002 at site 1 and 2 with 6.0 and 8.0 kg/m^2 that had significantly more seed aggregates than the control (Figure 16 and Table 23). Amending *Striga*-infested soil with neem soil amendments at 0.5-8.0 kg/m^2 did not significantly affect the proportion of sieved grain yield collected on 2.00 mm sieve. In the year 2001, the neem treatments at 0.5-8.0 kg/m^2 increased the proportion of sieved grain yield collected on 1.70mm sieve by -3.12 to 60.68%, compared with the control treatment. The tested concentrations of neem soil amendments were related, in these experiments, to the proportion of grain yields sieved and collected on 2.00 mm sieve by coefficients of multiple determinations, R^2, that ranged between 0.36 in the year 2001 to 0.99 at site 2 in the year 2002. The two variables were also related in Figure 16 and closely fitted by a polynomial quadratic equation, $y = x^2 + 10x + 214$.

Between 24-42% of the grain yield produced in neem treated plots at 8.0 kg/m^2 were collected on 2.36 mm sieve, while only between 1.8-15% of the grain yield produced in control plots were retained by this sieve (Figure 17 and Table 24). Amending *Striga*-infested soil with neem soil amendments at 0.5-8.0 kg/m^2 significantly ($P=0.01$) affected the proportion of sieved grain yield collected on 2.36 mm sieve. In the year 2001, the neem treatments at 0.5-8.0 kg/m^2 increased the proportion of sieved grain yield collected on 2.36 mm sieve by 140.11-1257.75%, compared with the control treatment. At the four other sites in the years 2002 and 2003, the neem treatments at 4.0 - 8.0 kg/m^2 increased the proportion of sieved grain yield collected on 2.36 mm sieve by 42.68-392.37%. The observed differences

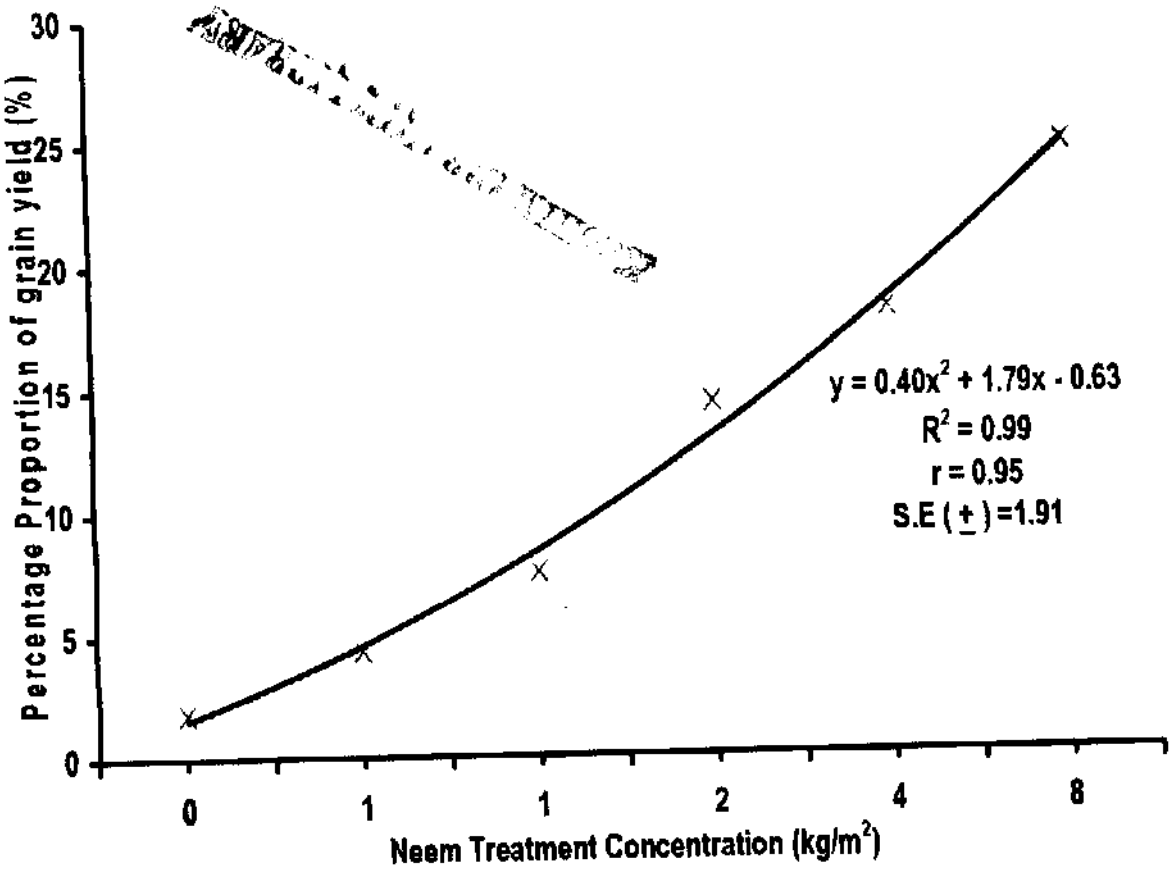


Calculated f not statistically significant

Figure 16: Effect of amending *Striga*-infested plots with neem soil amendments on the proportion of grain yield sieved and collected on 2.00mm sieve at Katsina, during the 2001 trial.

Table 23: Effect of amending *Striga*-infested plots, at four locations in Katsina, with neem soil amendments on the % proportion of sieved grain yields collected 2.00mm sieve at harvests, during the 2002 and 2003 trials.

Neem Treatment Dose kg/m^2	Mean percentage (%)			
	2002		2003	
	Site 1	Site 2	Site 1	Site 2
0	11.59	18.63	30.78	27.01
4	17.97	25.26	36.64	34.34
6	21.56	31.58	36.25	42.66
8	37.52	32.22	39.20	38.16
S.E (+/-)	3.33	2.91	ns	2.68
LSD	15.42 (P=0.01)	9.30 (P=0.05)	ns	8.58 (P=0.05)
r	0.91	0.98	ns	0.87
R^2	0.97	0.99	ns	0.92



LSD (P=0.01) = 7.70

Figure 17: Effect of amending *Striga* infested soil with neem soil amendments on the proportion of grain yield sieved and collected on 2.36mm sieve at Katsina during the 2001 trial.

Table 24: Effect of amending *Striga*-infested plots, at four locations in Katsina, with neem soil amendments on the % proportion of sieved grain yields collected on 2.36mm sieve at harvests, during the 2002 and 2003 trials.

Neem Treatment Dose kg/m2	Mean percentage (%)			
	2002		2003	
	Site 1	Site 2	Site 1	Site 2
0	15.96	15.23	6.29	6.06
4	30.90	21.73	14.53	13.30
6	33.00	33.20	26.94	20.45
8	38.90	42.26	29.18	29.85
S.E (+/-)	2.57	2.75	3.10	3.31
LSD (P=0.01)	11.82	12.65	14.25	15.22
r	0.98	0.96	0.97	0.97
R^2	0.95	0.99	0.97	1.00

were highly significant (P = 0.01). Quality wise, seeds collected on this sieve represent the best components of the grain yield. These, along with seed fractions collected on 2.00mm sieve were considered marketable, and they were abundantly collected on 2.00mm sieve were considered marketable, and they were abundantly produced mostly by the neem treated millet plants at 4.00-8.0 kg/m^2, irrespective of the degree of *Striga* emergence.

The tested concentrations of neem soil amendments were related, in these experiments, to the proportion of grain yields sieved and collected on 2.36mm sieve by statistically significant coefficients of multiple determinations, R^2, that ranged between 0.95 at site 1 in the year 2002 and 1.00 at site 2 in the year 2003. The two variables were also related by coefficients of linear correlations, r, that ranged between 0.95 in the year 2001 to 0.98 at site 1 in the year 2002. In Figure 17 the two variables were related and closely fitted by a polynomial quadratic equation, $y = x^2 + 5x - 2$.

1000-grain weights: Amending *Striga*-infested soil with neem soil amendments at 0.5-8.0 kg/m^2 did not significantly affected 1000-grain weights of sieved seed aggregates collected on individual test sieves, but significantly affected the pooled 1000-grain weights of all seed aggregates collected on all sieves. The neem soil amendments did not appear to significantly affect 1000-grain weights of seed aggregates sieved and collected on 1.18mm (Figure 18, Table 25), 1.70mm (Figure 19, Table 26), 2.00mm (Figure 20, Table 27) and 2.36 mm sieves (Figure 21, Table

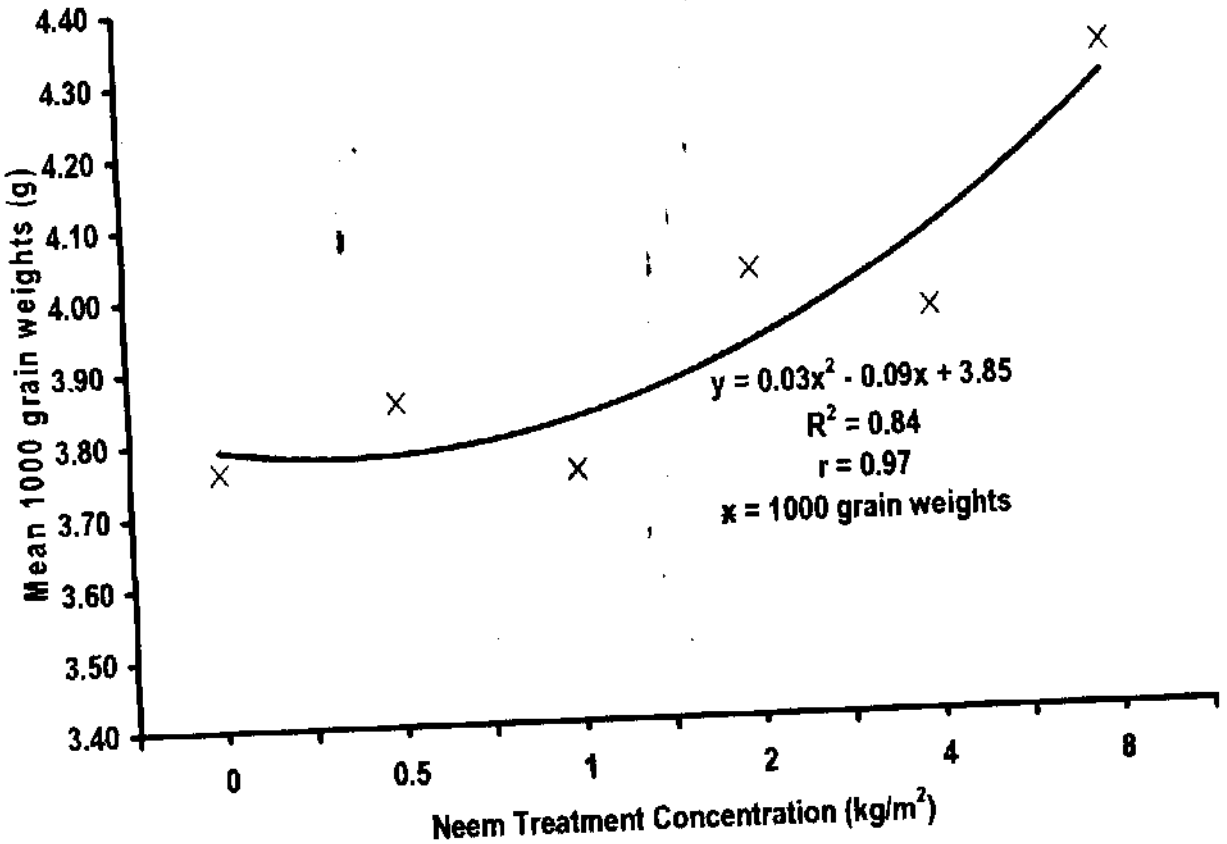


Figure 18: Effect of amending *Striga*-infested soil with neem soil amendments on 1000-grain-weights of sieved grain yield collected on 1.18mm sieve at Katsina during the 2001 trial.

Table 25: Effect of amending *Striga*-infested plots, at four locations in Katsina, with neem soil amendments on 1000 grain-weights of sieved grain yields collected on 1.18mm sieve at harvests, during the 2002 and 2003 trials.

Neem Treatment Dose $^{kg/m2}$	Mean 1000- grain weights (g)			
	2002		2003	
	Site 1	Site 2	Site 1	Site 2
0	3.26	3.65	3.88	3.77
4	3.78	4.26	3.86	3.79
6	4.28	4.27	3.78	3.39
8	4.03	4.86	3.88	3.73
r	0.89	0.96	-0.28	-0.37

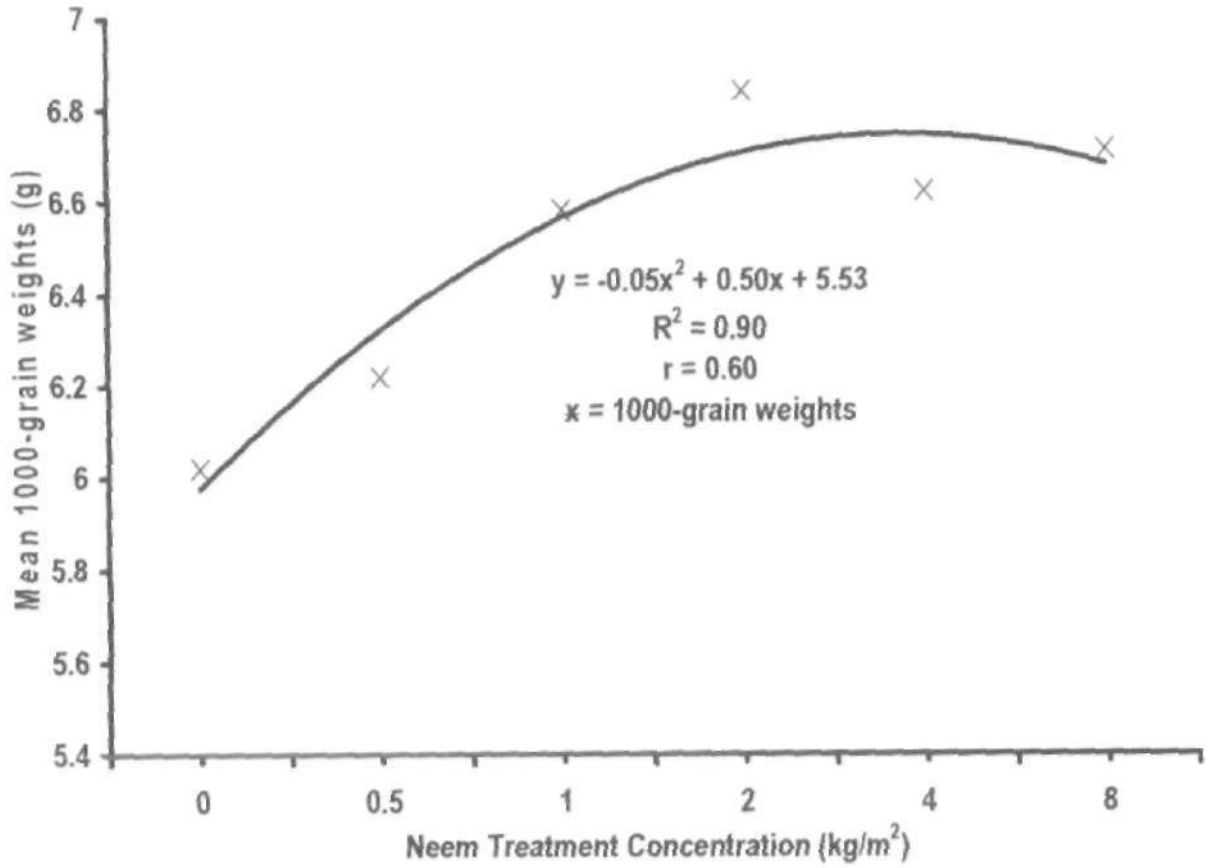


Figure 19: **Effect of amending *Striga*-infested plots with neem soil amendments on 1000 grain-weights of sieved grain yield collected on 1.70mm sieve at Katsina, during the 2001 trial.**

Table 26: Effect of amending *Striga*-infested plots, at four locations in Katsina, with neem soil amendments on 1000 grain-weights of sieved grain yields collected on 1.70mm sieve at harvests, during the 2002 and 2003 trials.

Neem Treatment Dose kg/m2	Mean 1000- grain weights (g)			
	2002		2003	
	Site 1	Site 2	Site 1	Site 2
0	5.98	6.59	7.68	6.29
4	6.32	6.76	7.04	6.69
6	6.54	7.40	7.64	6.81
8	6.92	7.56	8.11	7.13
r	0.98	0.93	0.39	0.99

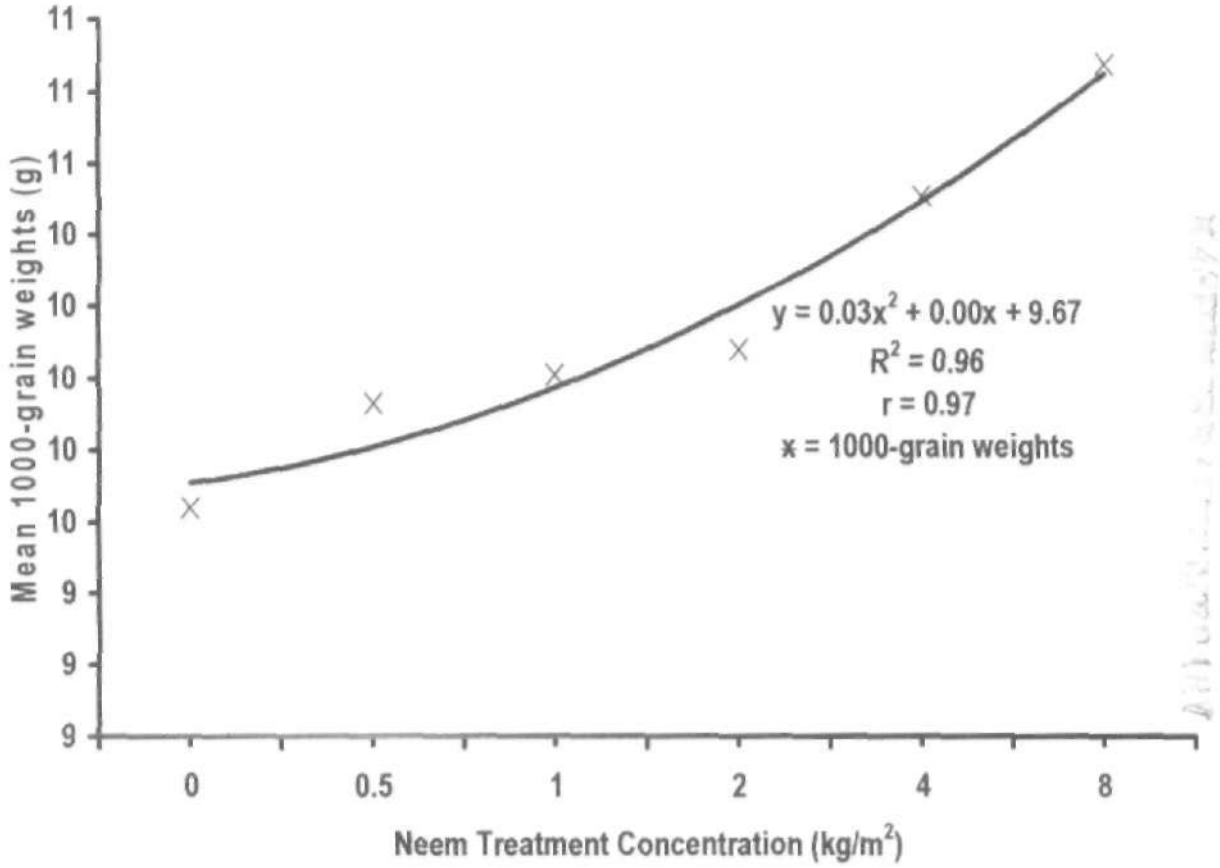


Figure 20: Effect of amending *Striga*-infested plots with neem soil amendments on 1000 grain-weights of sieved grain yield collected on 2.00mm sieve at Katsina, during the 2001 trial.

Table 27: Effect of amending *Striga*-infested plots, at four locations in Katsina, with neem soil amendments on 1000 grain-weights of *sieved grain yields collected on 2.00mm sieve at harvests, during* the 2002 and 2003 trials.

Neem Treatment Dose kg/m^2	Mean 1000- grain weights (g)			
	2002		2003	
	Site 1	Site 2	Site 1	Site 2
0	9.19	9.36	10.20	10.11
4	8.93	9.10	10.20	8.41
6	10.03	10.48	10.72	11.02
8	10.18	10.57	11.10	10.42
r	0.77	0.78	0.88	0.29

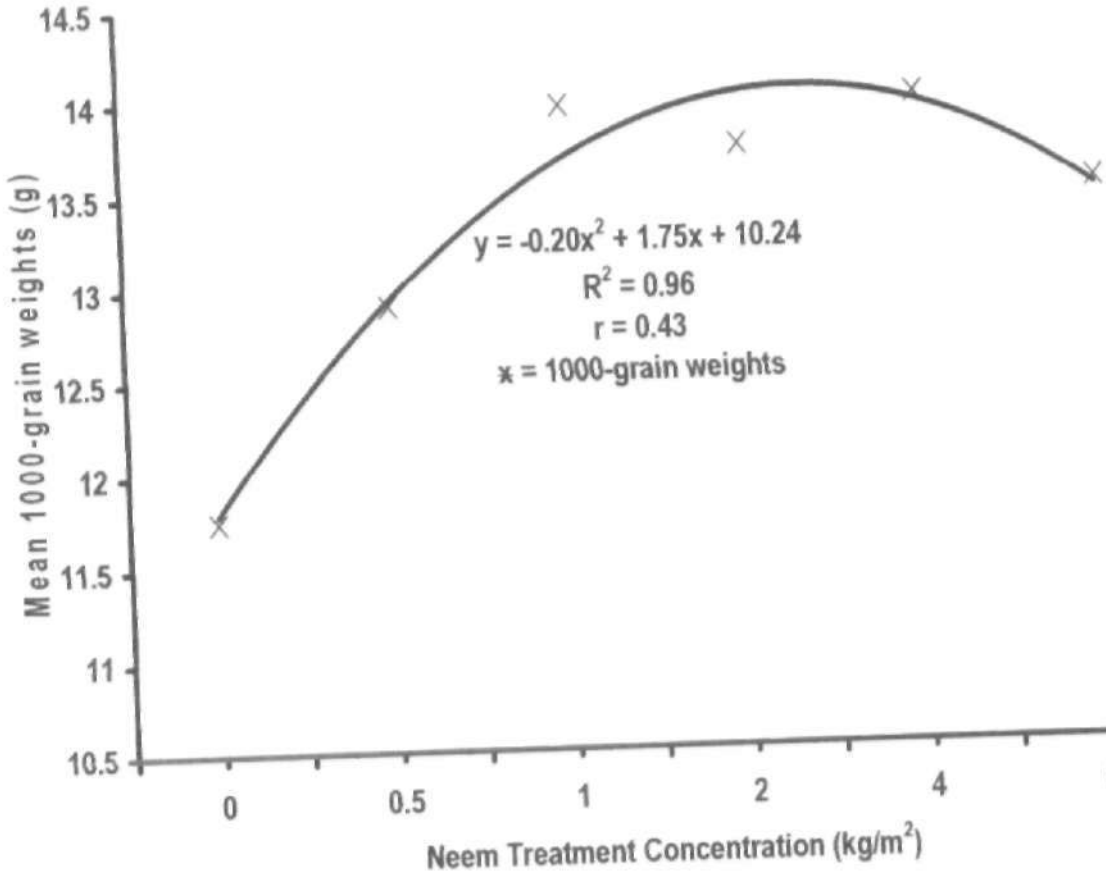


Figure 21: Effect of amending *Striga*-infested plots with neem soil amendments on 1000 grain-weights of sieved grain yield collected on 2.36mm sieve at Katsina, during the 2001 trial.

Table 28: Effect of amending *Striga*-infested plots, at four locations in Katsina, with neem soil amendments on 1000 grain-weights of sieved grain yields collected on 2.36mm sieve at harvests, during the 2002 and 2003 trials.

Neem Treatment Dose kg/m^2	Mean 1000- grain weights (g)			
	2002		2003	
	Site 1	Site 2	Site 1	Site 2
0	11.71	11.99	10.58	9.13
4	12.59	13.57	11.11	11.48
6	11.35	13.96	11.31	11.53
8	13.23	13.74	12.18	11.36
r	0.50	0.90	0.94	0.86

28). Although 1000-grain weights of seed aggregates from plots amended with neem soil amendments at 6.0 and 8.0 kg/m^2 were consistently higher than those of all other treatments including control treatments on each sieve, the observed differences, however, were not statistically significant at P= 0.05. This was the case with all seed aggregates on all sieves, at all sites and in all years.

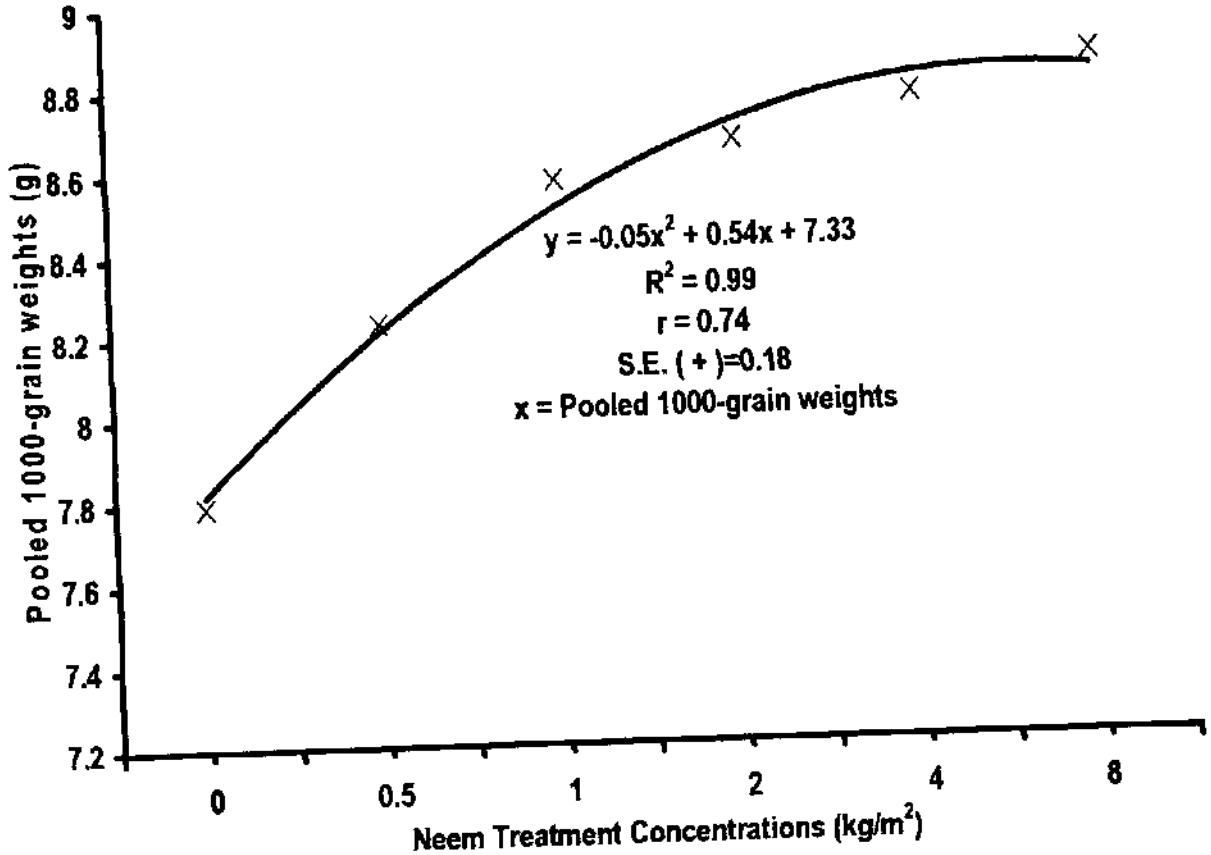
Amending *Striga*-infested soil with neem soil amendments at 0.5-8.0 kg/m^2 did not significantly affected 1000-grain weights of seed aggregates from sieved grain yield collected on the individual test sieves. In the year 2001, neem treatments at 0.5-8.0 kg/m^2 increased the 1000-grain weights of seed aggregates collected on 1.18, 1.70, 2.00, and 2.36 mm sieves by -0.27 to 14.89%, 0.0-13.62%, 0.0-12.86%, and 0.0-18.89%, respectively, compared with the control treatment. At the four other sites in the years 2002 and 2003, the neem treatments at 4.0 - 8.0 kg/m^2 increased the 1000-grain weights of seed aggregates collected on 1.18, 1.70, 2.00, and 2.36 mm sieves by -10.08 to 33.15%, -8.33 to 15.72%, -16.82 to 12.93%, and -3.07 to 26.29%, respectively.

Though there was no statistical significance in the observed differences among the treatment means, the tested concentrations of neem soil amendments were related in most instances to 1000-grain weights by statistically significant coefficients of linear correlations. In the year 2001, for instance, the coefficient of linear correlations for sieved grain yields collected on 1.18, 1.70, 2.00 and 2.36 mm sieves

were 0.93, 0.6, 0.97 and 0.43 respectively. For sieved grain yields collected on 1.18 mm sieve at site 1 and 2, in the year 2002 were 0.89 and 0.96 respectively, though the corresponding values for sites 1 and 2 in the year 2003 were -0.28 and -0.37, respectively, as shown in Tables 25-28.

Amending *Striga*-infested soils with neem soil amendments significantly increased pooled or mean 1000-grain weights of all seed aggregates collected on 1.18, 1.70, 2.00 and 2.36 mm sieves (Figure 22, Table 29). The neem treatment at 0.5-8.0 kg/m^2 significantly (P=0.01) affected pooled 1000-grain weights of seed aggregates collected on all sieves. In the year 2001, the neem treatments at 0.5-8.0 kg/m^2 increased pooled 1000-grain weights by 0.0-13.51%, compared with the control treatment. At the four other sites in the years 2002 and 2003, the neem treatments at 4.0 - 8.0 kg/m^2 increased the pooled 1000-grain weights by -0.37 to 18.45%. Neem treatments at 6.0 and 8.0 kg/m^2 produced significantly better than all other treatments, including control treatment, in increasing the pooled 1000-grain weights. The observed differences in the treatment means at site 1 and 2 in the year 2003 were not statistically significant.

The tested concentrations of neem soil amendments were related, in these experiments, to pooled 1000-grain weights by statistically significant coefficients of multiple determinations, R^2, that ranged between 0.97 at site 1 in the year 2002 and 0.99 in the year 2001, and site 2 in the year 2002. The two variables were also related by coefficients of linear correlations, r, that ranged between 0.76 at site 1 in



LSD (P=0.01) = 0.71

Figure 22: Effect of amending *Striga*-infested plots with neem soil amendments on pooled 1000 grain-weights of sieved grain yield collected on 1.18, 1.70, 2.00 and 2.36mm sieves at Katsina, during the 2001 trial.

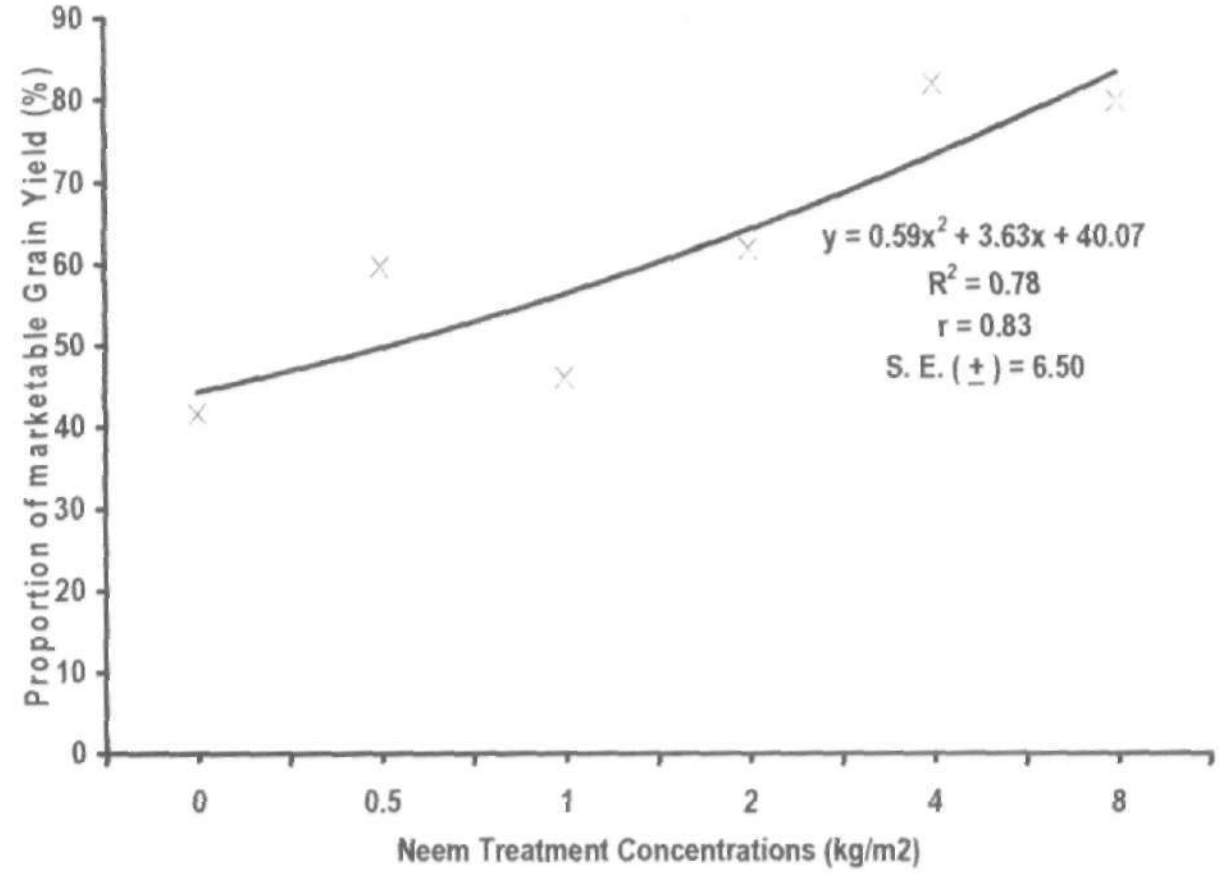
Table 29: Effect of amending *Striga*-infested plots, at four locations in Katsina, with neem soil amendments on pooled 1000 grain-weights of sieved grain yields collected on 1.18, 1.70, 2.00 and 2.36mm sieves at Katsina, during the 2002 and 2003 trials.

Neem Treatment Dose kg/m^2	Mean Pooled 1000-grain weights			
	2002		2003	
	Site 1	Site 2	Site 1	Site 2
0	7.40	7.75	8.08	7.33
4	7.90	8.42	8.05	7.59
6	8.05	9.03	8.36	8.19
8	8.59	9.18	8.82	8.16
S.E (+/-)	0.19	0.16	ns	ns
LSD (P=0.01)	0.76	0.72	ns	ns
r	0.76	0.99	-	-
R^2	0.97	0.99	-	-

the year 2002 to 0.99 at site 2 in the year 2002. In Figure 22 the two variables were related and closely fitted by a polynomial quadratic equation, $y = -x^2 + x + 15$.

Proportion of marketable grain yield: Amending *Striga*-infested soil with neem soil amendments at 0.5-8.0 kg/m^2 significantly (P=0.01) affected proportion of marketable grain yield collected on 2.00 and 2.36mm sieves (Figure 23, Table 30). In the year 2001, the neem treatments at 0.5-8.0 kg/m^2 increased proportion of marketable grain yield collected 2.00 and 2.36 mm sieves by 0.0-91.86%, compared with the control treatment. At the four other sites in the years 2002 and 2003, the neem treatments at 4.0 - 8.0 kg/m^2 increased proportion of marketable grain yield by 38.04-177.57%. The neem soil amendments at 4.00-8.0 kg/m^2 significantly (P=0.01) increased the proportion of marketable grain yields collected on 2.00 and 2.36 mm sieves compared with the control treatments (Figure 23, Table 30). These seeds were considered to be marketable on account of their relatively big sizes.

The tested concentrations of neem soil amendments were related, in these experiments, to the proportion of marketable grain yields by statistically significant coefficients of multiple determinations, R^2, which ranged between 0.78 in the year 2001 to 1.00 at site 1 in the year 2002. The two variables were also related by coefficients of linear correlations, r, that ranged between 0.83 in the year 2001 to 0.99 at site 1 in the year 2003. In Figure 23 the two variables were related and closely fitted by a polynomial quadratic equation, $y = x^2 + 6x + 68$.



LSD (P=0.01) = 26.15

Figure 23: **Effect of amending *Striga*-infested plots with neem soil amendments on proportion of marketable grain yield sieved and collected on 2.00 and 2.36mm sieves at Katsina, during the 2001 trial**

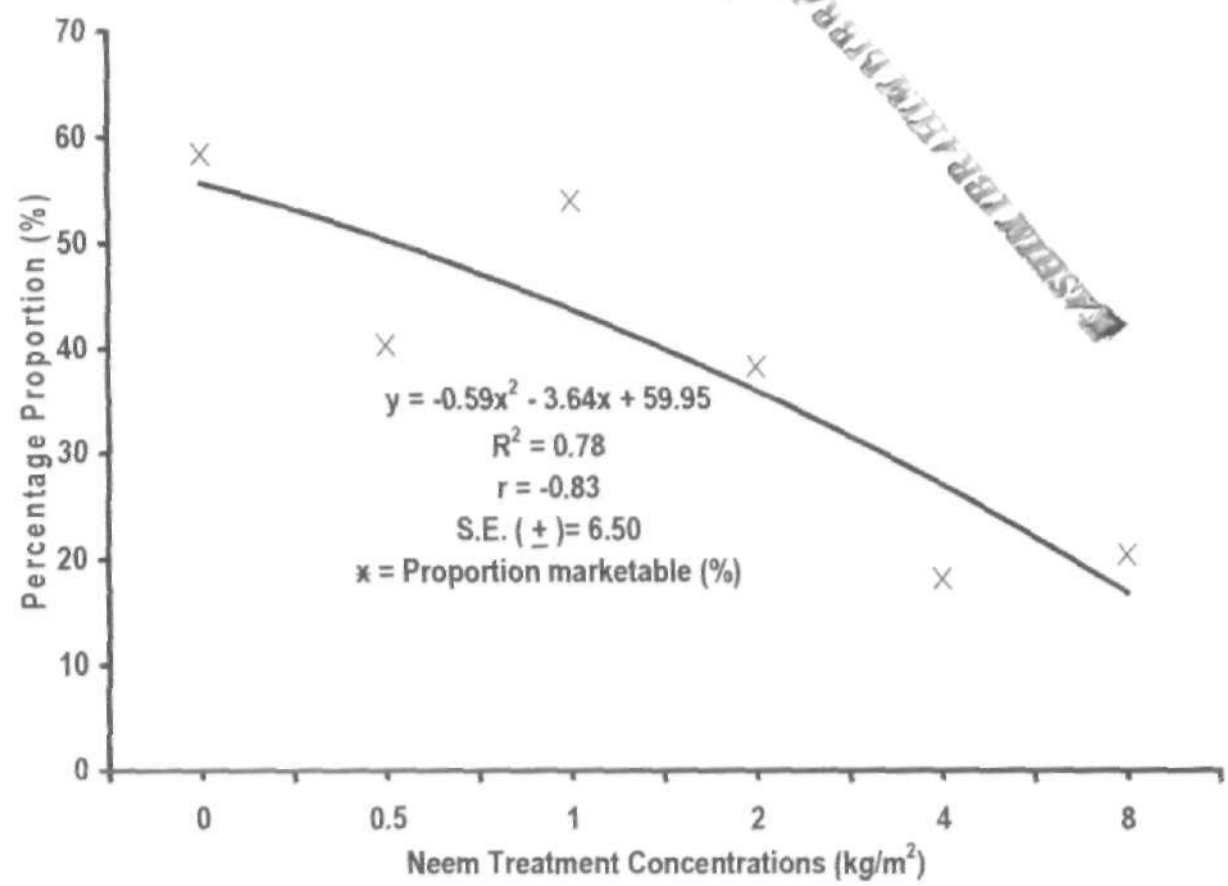
Table 30: Effect of amending *Striga*-infested plots, at four locations in Katsina, with neem soil amendments on % proportion of marketable Grain yields sieved and collected on 2.00 and 2.36mm sieves at Katsina, during the 2002 and 2003 trials.

Neem Treatment Dose kg/m^2	Mean percentage (%)			
	2002		2003	
	Site 1	Site 2	Site 1	Site 2
0	27.55	33.86	37.07	33.07
4	48.87	46.98	51.17	47.63
6	54.55	64.77	63.19	63.1
8	76.47	74.47	68.38	68.01
S.E (+/-)	2.59	2.62	2.21	2.17
LSD (P=0.01)	11.89	12.04	10.15	9.97
r	0.98	0.98	0.99	0.91
R^2	0.96	0.99	1.00	0.99

Conversely, amending *Striga*-infested soils with neem soil amendments at 4.0-8.0 kg/m^2 significantly (*P*=0.01) decreased the proportion of unmarketable grain yields collected on 1.80 and 1.70 mm sieves compared with the control treatments (Figure 24, Table 31). Control treatment produced significantly higher proportion of grain yield retained on 1.18 and 1.70 mm sieves. Amending *Striga*-infested soil with neem soil amendments at 0.5-8.0 kg/m^2 significantly (P=0.01) affected proportion of unmarketable grain yield (Figure 24, Table 31). In the year 2001, the neem treatments at 0.5-8.0 kg/m^2 decreased proportion of unmarketable grain yield collected 1.18 and 1.70 mm sieves by 0.00 to -65.23%, compared with the control treatment. At the four other sites in the years 2002 and 2003, the neem treatments at 4.0 - 8.0 kg/m^2 decreased proportion of unmarketable grain yield by 17.84 to 67.52%. These seeds were considered to be unmarketable on account of their relatively small sizes. Most of them were malformed and readily float in water.

4.1.3 Short term effect of neem soil amendments on soil physico-chemical properties

Amending *Striga*-infested soil with neem soil amendments was not found to have any short term effect (within three months) on any of the tested physico-chemical properties of the neem-amended soils, except that of the soil pH (in potassium chloride) and organic carbon content of the host soil was significantly (P=0.01) affected (Table 32). Only neem treatments at 1.0 and 2.0 kg/m^2, significantly raised the soil pH only by 0.2 point. Neem soil amendments at 2.0 kg/m^2 and above were significantly better than control treatment in increasing organic matter content of the



LSD (P=0.01) = 26.15

Figure 24: Effect of amending *Striga*-infested plots with powered fruits of neem tree on the proportion of unmarketable grain yield sieved and collected on 1.18 and 1.70mm sieves at Katsina, during the 2001 trial.

Table 31: **Effect of amending *Striga*-infested plots, at four locations in Katsina, with neem soil amendments on the % proportion of unmarketable grain yields sieved and collected on 1.18 and 1.70mm sieves at harvests, during the 2002 and 2003 trials.**

Neem Treatment Dose $^{kg/m2}$	Mean percentage (%)			
	2002		2003	
	Site 1	Site 2	Site 1	Site 2
0	72.45	66.14	62.93	66.93
4	51.13	53.02	48.84	52.37
6	45.45	35.22	36.81	36.90
8	23.53	25.53	31.63	32.00
S.E (+/-)	2.59	2.62	2.21	2.17
LSD(P=0.01)	11.89	12.04	10.15	14.33
r	-098	-0.98	-0.99	-0.99
R^2	0.96	1.00	0.99	0.99

Table 32: Effect of amending *Striga*-infested plots in Katsina, with neem soil amendments on soil Physico-chemical properties in the year 2001

Soil Physico-chemical properties	Soil physico-chemical Property Readings						Calculated f	Linear correlation r
	Neem soil amendment concentrations (kg/m^2)							
	0.0	0.5	1.0	2.0	4.0	8.0		
Total Nitrogen (%	0.04	0.06	0.06	0.06	0.06	0.09	2.96ns	0.89
Phosphorous [x]	32.93	27.55	26.07	25.73	22.04	43.46	1.4ns	0.59
Calcium [xx]	1.6	1.2	1.27	1.80	1.53	1.53	1.61ns	0.24
Magnesium [xx]	0.47	0.53	0.6	0.87	0.53	0.53	2.21ns	-0.06
Potassium [xx]	0.28	0.55	0.5	0.28	0.34	0.58	0.45ns	0.37
Sodium [xx]	0.29	0.16	0.16	0.10	0.05	0.08	2.25ns	-0.71
CEC	2.73	3	2.8	3.33	2.93	2.93	1.5ns	0.11
pH in water (1:2:5)	6.47	6.57	6.47	6.40	6.2	6.27	1.53ns	-7.9
pH in KCl (1:2:5)	5.77b	5.83b	5.97a	5.97a	5.73b	5.8b	3.53	-0.29
Conductivity	0.07	0.07	0.07	0.08	0.07	0.07	1.82ns	0.22
$H + Al^{3+}$	0.10	0.10	0.10	0.10	0.10	0.10	0ns	0.00
Sand (%)	91	91	91	91	91	91	0ns	0.00
Silt (%)	4.67	3.33	2.67	4.00	3.33	3.33	1.39ns	-0.27
Clay (%)	5	5.67	6.33	5.00	5.67	5.67	0.49ns	0.14
Organic matter %	0.02b	0.31b	0.28b	0.38c	0.4c	0.5a	15.34**	0.95

Xx=Exchangeable base (Meq/100g)
x = Available phosphorous (ppm)
CEC=Cation Exchange capacity (Meq/100g)
Conductivity =Electrical Conductivity
** = statistically significant at P=0.05
ns= not statistically significant

neem treated soils, and 8.0 kg/m^2 was the best treatment in this regard. Even though the increases or decreases in the tested soil parameters with increasing concentration of neem soil amendments, particularly increases in total nitrogen, and decreases in soil pH (in water) were not statistically significant at 5% level of significance, there however existed a statistically significant correlation between the parameters and the concentration of neem treatments.

Though effect on total nitrogen was not statistically significant, the parameter was increased by 50-125% by the neem treatments compared with the control treatment and the coefficient of linear correlation, r, was 0.89 was statistically significant. Available phosphorous was decreased by the neem treatment by 16 to 33%, except for neem treatment at 8.0 kg/m^2 that increased the parameter by 32%, and correlation coefficient was 0.59. The neem treatments reduced exchangeable calcium by 4 to 25%, and exchangeable magnesium was increased by 12.8-85%. While exchangeable potassium was increased by 0.0-107% by the neem treatments, exchangeable sodium was reduced by 45 to 83% and correlation coefficient , (r = -0.71) was negative and statistically significant. Cation Exchange Capacity (CEC) and clay content were only increased by 3-22% and 0.0-27%

4.2 Long Term Effects of Neem Residues on Growth and Grain Yield of Millet, Sorghum, Groundnut and Cowpea and on Soil Physico-Chemical Properties

The long term effects of continuous deposition of neem residues in *Striga*-free plots were found to have positive effects on the growth and grain yield of some of the tested crops:

4.2.1 Long term effects of neem residues on germination of crop seeds

Twenty years of continuous deposition of neem residues into neem shelterbelt soils had no significant long term effect on the germination of millet, sorghum, cowpea and groundnut seeds at the test sites, except that for sorghum at site 1, where seed germination was significantly (P=0.01) suppressed by 34.17% compared with the *control plots (Table 33). Percentage change in germination of millet, sorghum,* cowpea and groundnut seeds at site 1 and 2 in the year 2004 ranged between -5.78 to 3.07%, -10.51 to -37.17%, 1.9 to 11.22% and 5.91 to 8.92%, respectively. Though not statistically significant, the general pattern was that of improvement in *cowpea and groundnut seeds, and suppression in millet and sorghum.*

4.2.2 Effects of neem residues on growth vigor of treated crops

Twenty years of continuous deposition of neem residues into neem shelterbelt soils had significant (P=0.01-0.5) effect on the growth vigor of all the tested crops at all sites (Table 34). *Both crops exhibited luxuriant shoot growth, and deep green* leaves for all the plants grown on the neem shelterbelt plots. There was extensive

Table 33: Effect of neem residues on the germination of some cereal and leguminous crops at Katsina, during the 2004 trial.

Treatments	Mean germination count (%)							
	Site 1				Site 2			
	Millet	Sorghum	cowpea	G/nut	Millet	Sorghum	cowpea	G/nut
Neem [a]	40.3	39.3	86.0	91.6	44	49.4	91.2	73.5
Control [b]	39.1	59.7	84.4	84.1	46.7	55.2	82.0	69.4
% change [c]	3.07	-34.17	1.9	8.92	-5.78	-10.51	11.22	5.91
t value	0.2ns	3.4**	0.2ns	1.4ns	0.5ns	1.5ns	2.0ns	0.7ns

Neem = 20-year old neem shelterbelt, pollarded for crop production

Control = Control plot located outside the neem shelterbelt

** =Statistically significant effect at P=0.05

ns = Not statistically significant

Percentage change, c= 100(a-b)/b

Table 34: *Effect of neem residues on visually rated growth assessment scores* of some cereal and leguminous crops at Katsina, during the 2004 trial.

Treatments	Mean visual growth assessment rating scores							
	Site 1				Site 1I			
	Millet	*Sorghum*	*cowpea*	*G/nut*	*Millet*	*Sorghum*	*Cowpea*	*G/nut*
Neem [a]	3.5	3.5	4.7	4.1	m	m	4.7	4.7
Control [b]	2.4	2.2	3.1	3.3	m	m	3.1	3.8
% change [c]	45.83	59.09	51.61	24.24	-	-	51.61	23.68
t value	2.91**	3.88**	6.79**	2.53	-	-	6.13**	2.54*

Neem = 20-year old neem shelterbelt, pollarded for crop production

Control = Control plot located outside the neem shelterbelt

*= Statistically significant effect at P=0.05

** =Statistically significant effect at P=0.05

m = missed data, but growth trends by the two crops was similar to that at site 1.

Percentage change, c= 100(a-b)/b

vegetative growth and ground cover by cowpea and groundnut. However, at the on set of the rainy season, long dry spells (of about 3-4 weeks) adversely affected growth vigor in millet and sorghum alone, with symptoms including wilting and yellowing of leaves, particularly at the tips and margins, and death of plants in severe cases. However, plants soon recover and assume normal growth with the resumption of rains. Cowpea and groundnut, however, were not affected. The observed suppression of growth in millet and sorghum, however, soon reverses into rapid growth with the resumption and stabilization of rains. However the plants grown on the control plots showed visibly clear different reaction. The growth of plants in the control plot exhibited all symptoms of nutrient deficiency, particularly yellowing of leaves by sorghum and millet. Growth of cowpea and groundnut in the control plots was not as luxuriant as that in neem shelterbelt plot; however the growth was apparently normal compared with that of nutrient deficiency shown by sorghum and millet in the control plots. The observed growth of these legumes under the neem shelterbelt appeared similar to luxuriant growth of cowpea if over fertilized with nitrogenous fertilizer. The observed growth of the crops in the control plot appeared to suggest better grain yield than the luxuriant growth under the neem shelterbelt that may apparently be associated with good grain yield.

4.2.3 Long term effects of neem residues on shoot biomass

Twenty years of continuous deposition of neem residues into neem shelterbelt soils had significant (P=0.01-0.5) effect on plant shoot biomass (Table 35). Shoot biomass appeared significantly correlated with the growth vigor, both of which were

Table 35: Effect of Neem Residues on plant biomass of some cereal and leguminous crops at Katsina, during the 2004 trial.

Treatments	Mean plant biomass (g)/ $2m^2$ plots							
	Site 1				Site 2			
	Millet	Sorghum	Cowpea	G/nut	Millet	Sorghum	Cowpea	G/nut
Neem [a]	734.33	721.0	656.2	555.5	401.2	504.3	400.7	282.4
Control [b]	243.89	101.0	338.2	267.3	260.4	251	275.9	190.4
% change [c]	201.09	613.86	94.03	107.8	54.07	100.92	45.23	48.32
t value	3.18**	4.16**	4.02*	7.9**	2.11*	3.58**	4.18**	3.54*

Neem = 20-year old neem shelterbelt, pollarded for crop production

Control = Control plot located outside the neem shelterbelt

t = Calculated t value

*= Statistically significant effect at P=0.05

** =Statistically significant effect at P=0.05

Percentage change, c= 100(a-b)/b

significantly highest under neem shelterbelt than under control plots. When compared with control plot, biomass production under neem shelterbelt was significantly increased by 54.07-201.09% in millet, 100.92-613.86% in sorghum, 45.23-94.03% in cowpea, and 48.32-107.8% in groundnut. The observed differences in the treatment means were highly significant (P=0.01).

4.2.4 Long term effects of neem residues on crop yield and yield components

4.2.4.1 Long term effects of neem residues on pod and panicle biomass

Twenty years of continuous deposition of neem residues into neem shelterbelt soils had significant (P=0.01-0.5) effect on dry weights of sorghum and millet panicles and on that of cowpea and groundnut pods (Table 36). The observed percentage increases in panicle biomass for millet (146-175.1%) and sorghum (98.3-158.4) were statistically significant (P=0.01-0.05) compared with panicle biomass in control plots for the two cereals. Growing cowpea and groundnut in neem shelterbelt soil significantly (P=0.01-.0.05) reduced pod biomass by 58.9-98.3% at sites 1 and 2 for cowpea, and by 31.2% for groundnut at site 1. However, at site 2 the 127.9% increase in pod biomass in neem shelterbelt soil was not statistically significant even at 5% level of significance.

Table 36: Effect of Neem Residues on panicle and pod biomass of some cereal and leguminous crops at Katsina, during the 2004 trial.

Treatments	Weight of pods/panicles (g) / 2m² plots at							
	Site 1				Site 2			
	Millet x	Sorghum x	Cowpea xx	G/nut xx	Millet x	Sorghum x	Cowpea xx	G/nut xx
Neem [a]	73.67	160.11	29.75	10.8	36.9	107.67	0.17	9.8
Control [b]	26.78	9.5	72.4	15.7	15.0	54.3	10.12	4.3
% change [c]	175.1	1584.4	-58.9	-31.2	146	98.3	-98.3	127.9
t value	2.37*	3.44**	3.1**	1.1ns	2.17*	2.26*	3.86*	2.0ns

Neem = 20-year old neem shelterbelt, pollarded for crop production

Control = Control plot located outside the neem shelterbelt

*= Statistically significant effect at P=0.01

** =Statistically significant effect at P=0.05

ns = No statistically significant effect

Percentage change, c= 100(a-b)/b

x = panicle

xx =pod

4.2.4.2 Long term effects of neem residues on crop grain yield

Growing the cereal and leguminous crops in the 20 years old neem shelterbelts was found to have significant effect on grain yield (P=0.01-0.5) (Table 37). The respective 355.4-539.5% and 236.6-3448.8% increase in millet and sorghum grain yields in neem-treated plots were statistically significant (P=0.05) compared with that in the control plots. The 66.9 to 99.6% reductions in cowpea grain yield in neem plot at sites 1 and 2 were statistically significant, compared with yield of millet in control plots. However, the 25% reduction and 191.7% increase in groundnut grain yield at sites 1 and 2, respectively, were not statistically significant.

4.2.5 Long term effects of neem residues on soil physico-chemical properties

The long term effects of neem residues, particularly neem fruits, leaves, flowers and root exudates within a period of 20 years on the physico-chemical properties of host soil in the two neem shelterbelts are presented in Table 38. During this period the soil texture was found to be significantly affected. The proportion of sand aggregates was significantly (P=0.05) reduced at both sites, while clay and silt were significantly (P=0.01) increased only in either of the two sites. Both total nitrogen and organic matter contents of the shelterbelt soils were significantly (P=0.05) increased at both locations by neem soil residues within the 20 year period. However, exchangeable calcium (at P=0.01), magnesium (at P=0.01), sodium (at P=0.05) and concentration of $H^{+}Al^{3+}$ ions (at P=0.01) were significantly increased only in either of the two test sites. But available phosphorous, exchangeable

Table 37: Effect of Neem Residues on the shelled/threshed grain yields of some cereal and leguminous crops at Katsina, during the 2004 trial.

Treatments	Mean grain yield/plot (kg)/ha							
	Site 1				Site 2			
	Millet	Sorghum	Cowpea	G/nut	Millet	Sorghum	Cowpea	G/nut
Neem [a]	132.5	283.9	95.25	15.5	62.25	114.45	0.55	17.5
Control [b]	20.75	8.00	288.00	22.00	14.00	34.00	39.25	6.00
% change [c]	539.5	3448.8	-66.93	-25.0	355.4	236.6	-98.6	191.7
t value	2.14*	2.2*	3.64**	0.6ns	2.13*	2.12*	6.1**	2.0ns

Neem = 20-year old neem shelterbelt, pollarded for crop production

Control = Control plot located outside the neem shelterbelt

*= Statistically significant effect at P=0.05

** =Statistically significant effect at P=0.05

ns = No statistically significant effect

Percentage change, c= 100(a-b)/b

Table 38: Effect of neem residues on the physico-chemical properties of host soil at two locations in Katsina, during the 2004 trial.

Soil physico-chemical properties	Soil physico-chemical property Readings					
	Site 1			Site 2		
	Neem plot	Control Plot	% Change	Neem plot	Control plot	% Change
Total Nitrogen (%)	0.105	0.035	200.00*	0.07	0.035	100.0**
Phosphorous [x]	8.42	4.96	69.76ns	5.76	3.9	47.7ns
Calcium [xx]	3	1.47	104.08**	1.53	1.67	-8.38 ns
Magnesium [xx]	1.1	0.6	83.33**	0.6	0.6	0.00 ns
Potassium [xx]	0.27	0.2	35.00ns	0.2	0.22	-9.09 ns
Sodium [xx]	0.2	0.13	53.85ns	0.18	0.06	200.0*
CEC	4.47	3.53	26.63ns	3.27	3.93	-16.8ns
pH in water (1:2:5)	6.17	5.8	6.38ns	5.4	5.8	-6.90**
pH in KCl (1:2:5)	5.63	4.77	18.03**	4.57	5	-8.6***
Electrical Conductivity	0.077	0.07	10.00ns	0.07	0.09	-22.2ns
H^+Al^{3+}	0.10	0.13	-23.08**	0.40	0.10	300.0ns
Sand (%)	87	92.33	-5.77*	86.33	91.67	-5.83*
Silt (%)	7.33	2.0	266.50**	4.67	3.33	40.24ns
Clay (%)	6.33	5.67	11.64ns	8.33	5	66.60**
Organic matter (%)	0.25	0.11	127.27*	0.67	0.31	116.1**

xx=Exchangeable base (Meq/100g)
x= Available phosphorous (ppm)
CEC=Cation Exchange capacity (Meq/100g)
* and ** = statistical significance at P=0.01 and 0.05 respectively.

potassium, cation exchange capacity (CEC) and electrical conductivity of the shelterbelt soils were not significantly affected by the neem soil residues compared with the control plots at the two test sites. Neem soil residues were also found to have some effects on the soil acidity. Soil pH in water and in potassium chloride were also significantly affected (P=0.01-0.05) at site 2. At site 1, pH in water was not significantly affected by neem residues, while pH in potassium chloride was significantly increased (P=0.01).

The long term effects of neem residues, particularly neem fruits, leaves, flowers and root exudates within a period of 20 years on the physico-chemical properties of host soil in the two neem shelterbelts are presented in Table 38. During this period the soil texture was found to be significantly affected. The proportion of sand aggregates was significantly (P=0.05) reduced at both sites, while clay and silt were significantly (P=0.01) increased only in either of the two sites. During this period the soil texture was found to be significantly affected. The proportion of sand aggregates was significantly (P=0.05) reduced at both sites, while clay and silt were significantly (P=0.01) increased only in either of the two sites. Both total nitrogen and organic matter contents of the shelterbelt soils were significantly (P=0.05) increased at both locations by neem soil residues within the 20 year period. However, exchangeable calcium (at P=0.01), magnesium (at P=0.01), sodium (at P=0.05) and concentration of $H^{+}Al^{3+}$ ions (at P=0.01) were

significantly increased only in either of the two test sites. But available phosphorous, exchangeable potassium, cation exchange capacity (CEC) and electrical conductivity of the shelterbelt soils were not significantly affected by the neem soil residues compared with the control plots at the two test sites. Neem soil residues were also found to have some effects on the soil acidity. Soil pH in water and in potassium chloride were also significantly affected (P=0.01-0.05) at site 2. At site 1, pH in water was not significantly affected by neem residues, while pH in potassium chloride was significantly increased (P=0.01).

CHAPTER FIVE

5.0 DISCUSSIONS

This research has shown that neem tree has the potential to be useful in sustainable *Striga* management in subsistence agriculture in Africa, where the parasitic weeds are causing a great havoc to crop production. The research has further confirmed the idea of bits and pieces of proven evidences that seem to suggest such potentials of neem tree in managing *Striga*. The research appears to be the first of its kind, since the literature has not, apparently reported any instance of managing *Striga* with neem soil amendments under field conditions.

Neem is a pesticidal tree crop, widely used in Asia and increasingly so in the West for the management of a wide range of pests of agricultural importance (National Research Council, 1992). Neem extracts have been reported to exhibit microbicidal activity, particularly against viruses, nematodes, fungi, and bacteria (Schmutterer and Ascher, 1987). It is anticipated that the same microbicidal potency of neem extracts may not spare the parasite, since at some crucial early stages of its life cycle *Striga* is microscopic, and its germ tubes and seeds physically resemble fungal hyphae, and seeds respectively.

A *Striga* seed is very tiny, measuring 200 x 300µ in size (Berner *et al.*, 1997), and is several times smaller than most cereal seeds (Plate I). Tiny *Striga* seeds would germinate to produce tinier and more delicate germ tubes or radicles (Plate II).

Striga germ tubes physically resemble fungal hyphae (Plate III); both are microscopic, filamentous, delicate and very susceptible, and responsive, to chemical changes within their immediate environments. Since neem extracts were previously reported to inhibit the vegetative growth of fungal hyphae (Obagwu *et al.*, 1997, Yar'adua, 1987 and Yar'adua, 2002), it is reasonable to anticipate that neem extracts could inhibit the growth of *Striga* germ tubes, in neem amended soils, thereby blocking vital stages in *Striga* life cycle.

Striga life cycle is governed by, and entirely dependant on, various chemical substances from the root exudates of its (Figure 1). These exudates, according to Ejeta *et al.* (1992) regulate key stages in the life cycle of the parasite. Anything that could affect soil chemistry is likely to affect the role of host root exudates in *Striga* parasitism, particularly chemotropic movement of *Striga* germ-tubes, between soil particles, towards host roots. Limonoids (Appendix 1), a group of bioactively potent chemical substances found only in neem tree, are such chemicals that may likely affect chemotropism in *Striga*. According to Addae-Menseh (1998) limonoids are tetranortriterpenoids, that include azadiron, azadiradion, epoxyazadiradion, gedunin, nimbin, salannin, 1,3-diacetyl vilasinin, 1-tiglyl-3-acetyl vilasinin, 3-deacetyl salannin, salannol, salannol acetate, nimbandiol, 6-acetyl nimbandiol, nimbinen, 6-deacetyl nimbinen, meliantriol, nimbidin (1-1) and azadirachtin. Preponderance of these bioactive chemical substances, from neem soil amendments at root zone of the host plant, may serve to physically block, chemically modify, bind and/or dilute the host root exudates, in such away as to evoke no response from surrounding

Striga seeds. In this way, conditioned viable *Striga* seeds may fail to germinate, and germ-tubes may fail to respond by chemotropism towards the host root, or may fail to attach to the host root. Limonoids may inhibit successful completion of *Striga* life cycle, in much the same way they abort metamorphosis, by blocking the activity of metamorphosis-regulating hormone, ecdysone, in insects (National Research Council, 1992). If *Striga* germ tubes do not successfully get attached to host roots within 5 days of germination they soon perish (Ejeta *et al.*, 1992), thereby suppressing *Striga* emergence.

Circumstantial evidence that seems to indicate the possibility of neem preventing *Striga* emergence arises from the fact that in nature, neem tree is allelophathic. An established neem, particularly that tree whose dropped leaves and fruits are aloud to accumulate and decompose around the tree, does not allow most weeds to germinate and grow around itself. In this way, neem competitively suppresses the growth of most weeds (Appendix 3). This is true even of neem trees whose canopies have been pruned or neem residues that were washed and deposited elsewhere by rainwater runoff (Appendix 4). Under such circumstances, neem only selectively allows the growth and germination of its own seeds and seedlings (Appendix 5). If by allelophathy, neem trees can suppress the emergence and growth of most weeds, it is reasonable to anticipate the same suppressive effects on *Striga* emergence; even in nutrient deficient soils that favor *Striga* infestation most. In nutrient deficient soils, neem may suppress *Striga* emergence either by allelophathy, or by way of improving soil fertility. *Striga* is essentially a problem of

nutrient deficient soils (Mabasa, 1994), for which it serves as an indicator plant (Kranz, 1999; Kranz *et al.,* 1998). Various sources of nitrogen, both organic and inorganic, have been variously reported to control *Striga* at relatively higher doses (Mabasa, 1994 and Ogborn, 1972; Lagoke *et al.*, 1994b). Neem residues, particularly neem cakes, obtained after pressing out oil, are widely used in Asia as fertilizer for amending nutrient deficient soils (Addae-Menseh, 1998). Neem fruits have been reported to be rich in crude protein (13-35%), carbohydrates (26-50%), crude fiber (8-26), fat (2-13%) and acid-soluble and -insoluble ashes (6-35%), which on decomposition are returned to the soil as nutrients (National Research Council, 1992). As a good source of organic nitrogen neem fruits may, therefore, be potentially useful in suppressing *Striga* emergence. The constituent neem oil may, in addition, be detrimental to *Striga* emergence, besides being pesticidal in nature (National Research Council, 1992).

Oil constitutes about 2-13% of neem fruits. When whole fruits were crushed and used for amending the soil, the oil component with its high specific heat capacity, may increase the soil's capacity to absorb more solar heat to solarize the soil and kill vulnerable *Striga* germ-tubes. *Striga* management through solarization techniques that allows trapping of solar energy with polythene sheets to heat up the soil have been reported by Sauerborn *et al.* (1991).

5.1 Effects of Neem Soil Amendments on *Striga hermonthica*, Pearl Millet and Soil Physico-Chemical Properties Under Field Conditions

5.1.1 Effects of neem soil amendments on *Striga hermonthica*

At 0.5-4.0 kg/m^2, the neem treatments were found to be significantly (P=0.01) better the control treatments in supporting more *Striga* emergence and biomass at harvest. This was contrary to this writer's expectations, at the commencement of the research. At these concentrations, the neem treatments were not found to be negatively allelophathic to both *Striga* and the host millet. Rather, the growth of *Striga*, in terms of emergence and biomass accumulation, and the vegetative growth of the host millet were observed to be significantly improved.

However, this implies that neem soil amendments could thus be used, in practical terms by peasant farmers, as undecomposed organic manure at rates ranging between 0.5-2.0 kg/m^2 or 5-20 tons/ha to manage *Striga* in infested soils. This accelerates *Striga* emergence and if coupled with hoe weeding and hand pulling before flowering over a period of, perhaps, 3-5 years may significantly deplete the soil free of resilient *Striga* seeds, while at the same time the resultant accelerated host growth compensates the damage done by the parasite. To be effective, this simple technique must, however, be integrated with late hoe weeding and/or hand pulling and destruction of the emerged parasites before they start to bear flowers, otherwise accelerating shoot emergence will be associated accelerated seed production. To set the infested fields free of *Striga* seeds, in this way, may take a

couple of years of repeated operation, at least once every year at the commencement of the rainy season for 3-5 years, so that the parasitic seeds are conditioned and germinated in medium containing the undecomposed neem soil amendments. During this period the neem-treated millet will record boosted vegetative growth, despite the neem-enhanced *Striga* emergence. This is an important development since the neem treatments can now be used, at the stated rate, to induce tolerance in millet against *Striga*, reduce severity of *Striga* syndrome in infested millet, and hence reduce yield losses in treated crops. However, boosting *Striga* emergence with the neem treatment may prove catastrophic if a farmer fails to rogue and destroy the parasites in good time, as is presently the common practice. A farmer normally harvests his crops, leaving behind an army of blooming *Striga* to complete their life cycle on root stumps of harvested millet stalks, to mature, dry and shade their seeds into the soil. In such contaminated soils, seeds could survive and retain their viability for up to 20 years (M'Boob, 1994). There is also the need to conduct further research to verify if all other cereal hosts of *S. hermonthica* and leguminous hosts of *S. gesnerioides* can develop tolerance to *Striga* in neem treated soils, similar to that of millet.

Even though this writer's initial expectations were proved wrong with neem soil amendments at 0.5-4 kg/m^2, however, at concentrations beyond that they were proved right; allelophathic effects of neem soil amendments began to manifest itself, with total inhibition of *Striga* emergence at 8 kg/m^2, and germination of millet seeds was totally inhibited. At 6-8.0 kg/m^2 "minimum lethal dose" appeared to have been

attained and so little or no *Striga* emergence was observed in the neem treated plots. The observed differences between the neem and the control treatment means were highly significant at P=0.01 level of significance.

Striga management with neem soil amendments at 4-8 kg/m^2 or at 40-80 tons/ha does not appear feasible through biomass transfer. However, this may be achieved through neem based agroforestry systems. Growing enough number of trees within the same field could produce the required quantity of neem residues to fertilize the land. Growing 50-100 neem tress/ha in boarder planting can produce neem residues at rates of about 50-100 tons/annum (Neem Foundation, 1997b), out of which 2/3 are fruits and leaves, the sit of the pesticidal components in neem. Continuous deposition and gradual accumulation of the neem residues over a period of 3-5 years may perhaps improve soil fertility to such a level that discourages *Striga* emergence. The fact that neem, at 6-8 kg/m^2, significantly suppressed emergence and biomass of *Striga* in treated plots implies that neem tree may be a good source of organic biopesticides, active ingredients, for the profitable management of *Striga hermonthica*, and perhaps many other parasitic weeds, by peasant farmers in their low input subsistence agriculture. Reduced *Striga* parasitism achieved through amending *Striga*-infested soil with neem soil amendments would mean reduced *Striga* syndrome and consequently more vegetative host growth and yield. This would also imply that neem tree holds a high potential, if judiciously utilized, for greatly curtailing the volume of *Striga* seeds produced each year. Concerted and coordinated use of neem residues for suppressing *Striga* emergence and for

fertilizing the soil continuously for a couple of years may have great impact in reducing existing *Striga* seed bank in soils already infested with *Striga* seeds and would also go along way in curtailing *Striga* endemics in all areas where neem trees are grown abundantly. In this way neem holds a high potential for reclaiming the 2/3rd of the 73 million hectares of cereal farmlands in Africa that had already been infested with *Striga*, and in saving the US$ 7.0 billion lost every to *Striga* in Africa (M'Boob, 1994). In India and many other Asian countries neem residues are used as principal components for organic farming to suppress the growth of soil borne pests and diseases and simultaneously increase crop yield when used as organic fertilizer (National Research Council, 1992). However, neem residues in Nigeria have not been used for any such purposes in agriculture by peasant farmers. Thus neem trees in the country may represent a hitherto untapped natural resource that can possibly and beneficially be used for managing *Striga* by peasant farmers, and of course fertilizing their farms.

This piece of research has added to the neem's tally-score on its broad spectrum pesticidal effects. It has commonly been reported that neem residues are pesticidal against some viruses, nematodes, fungi, bacteria, snails and over 300 insect species (National Research Council, 1992), and now *Striga hermonthica* is added to the long list of neem's susceptible pests of agricultural importance. The fact that neem residues are pesticidal to a number of agricultural pests and diseases (National Research Council, 1992) imply that amending *Striga*-infested soils with neem residues will not only kill *Striga* but will also simultaneously control many

other non-target soil borne pests and diseases, thereby further increasing fodder and grain yield. In Katsina state, sourcing neem residues for *Striga* control cannot be much of a problem, since neem is found in abundance in gigantic neem plantations, in private woodlots, in side farms (Appendix 6) and as individual stands along urban and rural feeder roads, and in almost all towns and villages (Appendix 7) all over the state, where it is important for the provision of shade.

This is apparently the first reported case of the *in-vivo* suppressive effects of amending *Striga*-infested plots with neem soil amendments on emergence and biomass of *Striga hermonthica* under field conditions. These findings are indirectly corroborated by the reported *in-vitro* suppressive effect of neem-cake on *Striga* emergence on potted sorghum, under screenhouse conditions (Kranz, 1999, Kranz *et al.,* 1998). *Striga* emergence was, reportedly, suppressed by 10g of neem-oil-cake/kg of soil, but not at 2.5 or 5.0 g neem-cake/kg of soil. This indirectly corroborates these findings that powdered (whole) neem soil amendments could suppress *Striga* emergence only at higher neem concentrations (6-8.0 kg/m^2 under field conditions), but not at lower concentrations (0.5-2.0 kg/m^2).

5.1.2 Effects of neem soil amendments on pearl millet grown on *Striga*-infested soil

5.1.2.1 Effect on neem soil amendments on germination of millet seeds

Concentrations of neem soil amendments, used in these experiments, were observed to be inversely related to germination of millet seeds. Based on the

observed F values, coefficients of linear correlation (r), and coefficients of multiple determinations (R^2) the observed differences between treatment means were considered to be highly significant, (P= 0.01). In this research, neem treatments, at 8 kg/m^2, more or less completely suppressed germination of millet seeds and *Striga* emergence in *Striga*-sick plots. This may be accounted by the presence of allelochemicals, probably the limonoids (Appendix 1), in neem fruits. if the neem treatments can completely inhibit germination of millet seeds, such treatments could, impliedly and possibly, exert more suppressive effects on the germination of much smaller *Striga* seeds, which according to Berner *et al.* (1997), measure only 300 x 200 microns. Inhibition of millet seed germination may be caused by neem oil present in the neem soil amendment. One implication of this research finding is that precautions must have to be taken in any organic farming practice that may involve amending farms with neem soil amendments. In India residual neem cake, a byproduct of neem oil extraction, is actively used in organic farming for fertilizing nutrient deficient soils, and in controlling soil borne insect pests and nematodes (National Research Council, 1992). It was, however, observed during the course of this research that if millet seeds were sown either two weeks after amending the soil or two weeks before amending it the problem of inhibiting germination and growth of millet seeds were avoided or at least minimized to acceptable levels, since 70-80% of the seedlings of manually sown millet seeds are normally thinned out about two weeks after emergence. Whatever may be thinned out during the first weeding and thinning operation could have been suppressed by the neem treatments, and whatever may survive neem treatment may have been what may be left out after

thinning the seedlings. About 100 assorted limonoids (Appendix 1) found abundantly in neem fruits confer neem with its variously reported bioactive potency against insects, fungi, bacteria and nematodes (National Research Council, 1992; Addae-Menseh, 1998). These compounds may perhaps be responsible for the observed *suppressive effects of neem soil amendments on the germination of the millet seeds*, and *Striga* emergence. Azadirachtin is the most potent and the most abundant limonoids found in neem fruits and to lesser extent in neem leaves and bark (National Research Council, 1992).

This is apparently the first reported case of the suppression of the germination of millet seeds by neem soil amendments. Thus, neem residues are not only pesticidal against insects, nematodes, fungi, and bacteria of agricultural importance (National Research Council, 1992), but are now shown by this research to be also pesticidal against germination of millet and *Striga* seeds. Perhaps, such allelophathic suppressive effects may possibly affect the germination of many other seeds too, particularly the small seeds of parasitic weeds, (such as *Striga gesnerioides, Striga asiatica, Alectra vogelli*), common weeds and the seeds of other crop plants. Hence there is the need for further research to verify such effects with a view of managing such small seeded weeds through the use of neem soil amendments.

5.1.2.2 Effects of neem soil amendments on severity of *Striga* syndrome

Severity of *Striga* syndrome was found inversely related to neem treatment concentration (r= -0.96) and directly related to *Striga* count (r = 0.70) in the year

2001, and the same result pattern was manifested at all other experimental sites in the years 2002 and 2003. The reason for the observed suppression of *Striga* syndrome on infested millet treated with neem soil amendments could be attributed to the discovered ability of some of the neem treatments to suppress *Striga* emergence in treated plots. Consequently this eliminated some of the major problems associated with *Striga* parasitism, particularly siphoning of manufactured foods, water and mineral nutrients from the host roots (Gurney *et al.*, 2000). Consequently, food materials that may have been siphoned away by the parasite were then judiciously utilized for the betterment of the host in enhancing vegetative growth. This helps in reducing severity of *Striga* syndrome normally observed in *Striga*-infested fields. Besides that, parasitism in *Striga* has been reported to be complicated by the ability of the parasite to secrete toxins that seriously retard growth and development of the host crop, leading to stunted growth, chlorosis, tattering of leaves, and production of very short or no harvestable panicles, short and thin millet stalks and severe *Striga* syndrome (Lagoke *et al.*, 1991 and 1994a). *Striga* syndrome associated with tested neem treatment at 2.00 kg/m^2 was significantly not as severe as that in the control plot, despite the fact that neem treatments at 2.00 kg/m^2 supported significantly higher *Striga* count and biomass than that in the control treatment. At that concentration the treated host plants appeared to have become more tolerant of the parasites, and the host was compensating for all the losses due to *Striga*. The growth of the host was luxuriant growth did not tally with the *Striga* shoots they were supporting. This may, perhaps, be due the soil fertilizing effects of the neem treatments (National Research

Council, 1992; Neem Foundation, 1997a). This observation has been indirectly corroborated by reports that nitrogenous fertilizers increase growth and biomass accumulation in both the parasite and the host, and the latter gave good yield despite being parasitized (Ogborn, 1972). Even though this may significantly reduce yield losses suffered by the millet plants in such plots amended with neem at 2.0 kg/m^2 the problem of supporting more *Striga* plants, however, is a matter of concern, as far as *Striga* seed production is concerned. This problem, however, can be avoided if *Striga* management, at 2.0 kg/m^2 (20 tons/ha) is integrated with hand pulling of emerged *Striga* or hoe weeding to kill the emerged *Striga* plants before flowering. In this way, it is anticipated that in a couple of years of repeated application of neem soil amendments at the rate of 20 tons/ha may have the *Striga* seed bank in infested soil soon depleted. This would mean the modus operandi of using this technique is make the host plants more tolerant of the parasites, such that the farmer suffers little or no yield losses, while he deliberately uses the susceptible host to induce more *Striga* seeds to germinate and subsequently emerge, and be rouged before flowering. If the host suffers no yield losses, integrating this technique with weeding may be a new kind of trap-cropping in which the trap crop is never eliminated with the parasite after inducing germination of the parasitic seeds.

5.1.2.3 Effects of neem soil amendments on plant growth parameters

In the year 2001, the height of neem treated millet plants grown on *Striga*-infested soil and their stalk biomass were found significantly (P=0.01) and directly related to neem treatment concentration (0.0-8.00 kg/m^2) (r = 0.95-0.98), and inversely related to *Striga* syndrome (r = -0.97) and *Striga* count (r = -0.80). Height of neem treated millet plants was also directly related to millet stalk biomass (r = 0.94). The same result pattern was observed at all other sites in the year 2002 and 2003. Neem treatments at 6.0-8.0 kg/m^2 were found to be statistically the best treatments in supporting the most luxuriant vegetative growth of millet in *Striga*-infested plots. The treatments were associated with significantly more harvestable and longer panicles, and with longer and heavier millet stalks.

The observed trends may perhaps be accounted by the fact that, at 6.0 and 8.0 kg/m^2, *Striga* emergence, in all the treated plots, was more or less totally suppressed, consequently leading to the observed luxuriant vegetative growth of the host millet plants. It is therefore anticipated that anything that would prevent *Striga* parasitism, would significantly improve all the tested parameters, as observed at all test sites and in all years. *Striga* emergence was, perhaps, suppressed by the neem tree's constituent limonoids (Appendix 1), particularly azadirachtin that may act by inhibiting *Striga* seed conditioning, germination and/or attachment to the host in neem treated soils. Anything that could prevent *Striga* seed germination or attachment to the host root would certainly improve host plant growth parameters.

Some other reasons that may be advanced to account for the observed increases in length and biomass of millet stalks with increasing concentration of neem soil amendments could be could accounted, perhaps by the ability of neem the neem treatments to, not only sterilize the soil free of *Striga* seeds, but also to sterilize it free of many other soil borne pathogenic fungi, bacteria, insects and nematodes (Schmutterer and Ascher, 1987). It was variously reported that preponderance of bioactively potent limonoids in neem tree has been responsible for the broad spectrum pesticidal effects of neem tree on those pests of agricultural importance (Addae-Menseh, 1998; National Research Council, 1992). Such suppressive effects of the neem's constituent limonoids on these non-target pests may contribute greatly in increasing the number and length of harvestable panicles, length and weight of millet stalks. Besides that, neem is important in soil fertility management. Neem fruits are rich in crude protein, potassium and phosphorous containing compounds (National Research Council, 1992), which on decomposition in neem amended soils, may release a lot of useful nutrients to fertilize the soil, and hence encourage more vegetative growth, increase number and length of harvestable panicles, increase plant height length and weight of millet stalks. In India, neem play prominent role in organic farming practices, on account of its ability to decompose and release vital nutrients for fertilizing soils and controlling a number of soil borne pests and diseases (National Research Council, 1992).

5.1.2.4 Effects of neem soil amendments on grain yield and yield components of millet

Data from this research have shown that concentration of neem soil amendments, used for amending *Striga*-infested plots, were consistently and significantly associated with increased grain yield/ha, increased quality of grain yield sieved and collected on 2.00 and 2.36mm sieves, increased 1000-grain weights (pooled) and increased proportion of grain yields that were of marketable grain sizes. The concentration of neem treatments was also found to be inversely related both to the proportion of sieved grain yields that were collected on 1.18 and 1.70mm sieves and the proportion of grain yields that were of unmarketable grain sizes. Yield and yield components of pearl millet, grown on *Striga*-infested soil, were significantly (P= 0.01-0.05) affected by the tested neem treatments at all sites in the years 2001-2003. For instance, In the year 2001, grain yield/ha, panicle length, marketable grain yield and pooled 1000 grain weights were significantly and directly related (r = 0.74-1.0) to neem treatment concentrations. Conversely, the relations between grain yield/ha and *Striga* counts, *Striga* biomass and *Striga* syndrome on millet were inverse and statistically significant (r = -0.47 to -0.97). The significant effects of the neem treatments on panicle length, proportion of marketable grain yield and pooled 1000 grain weights (r = 0.74-0.88), in turn had statistically significant effects on total grain yield/ha (r = 0.71-0.86). At all sites and in all the years neem soil amendments at 6-8.0 kg/m^2 were the best treatments for increasing all the tested yield parameters. The observed general increases in yield and yield components of pearl millet in neem treated plots at 6-8.0 kg/m^2 can be accounted by the dual ability of neem treatments to significantly suppress *Striga* counts, control non-target soil borne pests

and diseases, and their simultaneous soil fertilizing effects on soil physico-chemical properties. Consequently vegetative growth of millet was enhanced, as shown by suppressed *Striga* syndrome in neem treated plots, particularly at 2.0-8.00 kg/m^2. This is apparently the first reported case of increasing grain yield of millet as a result of effectively managing *Striga* through the use of neem soil amendments under field conditions.

Despite the fact that neem treatment at 2.0 kg/m^2, significantly supported more *Striga* counts than the control treatment, the neem treatment gave significantly higher grain yields, higher proportion of sieved grain yield collected on 2.00 and 2.36mm sieve, higher 1000-grain weights (pooled) and lower proportion of sieved grain yields collected on 1.18 and 1.70mm sieves than the control treatments. Millet plants treated with soil amendment at 2.0 kg/m^2 appeared to have developed tolerance against increased *Striga* emergence, by significantly out yielding control treatments. This seems to suggest that *Striga* problem only gets compounded in nutrient deficient soils in control plots. It also suggested that under field conditions *Striga* seeds can survive neem soil amendment at 2.0 kg/m^2 and as the neem residues decompose to fertilize the soil the treated millet plants draw enough nutrients from the decomposed neem residues to compensate for whatever was siphoned away by the parasite, and so suffered little or no yield decrease when compared with control treatment. Both the parasite and the host recorded accelerated vegetative growth.

Amending *Striga*-infested plots with neem soil amendments did not significantly affect 1000-grain weights of individual seed aggregates collected on each of the 1.18, 1.70, 2.00, and 2.36 mm sieves used for sieving the grain yield from each plot. When pooled together, however, pooled 1000-grain weights from seeds produced in neem treated plots at 6-8.0 kg/m^2 gave significantly higher grain weights than the control treatments. This may not be unconnected with the observed ability of the treatments to significantly suppress *Striga* emergence, in the absence of which treated plants may enjoy the benefit of the neem treatment's soil fertilizing and sterilizing effects and so therefore exhibited excellent vegetative growth, and good grain filling.

A measure of pooled 1000-grain weights, rather than the ordinary 1000-grain weights, may be better for determining degree of grain filling. The pooled 1000-grain weights took into consideration that in *Striga*-infested plots some grains may be poorly filled and so appeared shriveled. During random sampling, of counting out 100 grains from each grain yield from a plot, these shriveled seeds do not have the same chances of being picked up as the seeds that were relatively bigger. In order to give these shriveled seeds equal chances of being picked up, the grain yield in each plot were thus sieved into its constituent aggregates collected on 1.18, 1.70, 2.00, and 2.36 mm sieves. Observed differences on the 1000-grain weights of seed aggregates collected on each sieve were not statistically significant probably because the size of the sieve on which each seed aggregate was collected was the

same, thereby allowing seeds to pass through them only if they are more or less of uniform grain sizes and perhaps of the same weights too.

5.1.3 Short of neem soil amendments on soil physico-chemical properties

The observed dramatic effects of amending *Striga*-infested plots with neem soil amendments on both growth and grain yield of millet and on syndrome, biomass and emergence of *Striga* in neem treated plots was not found to be commensurate with the observed short term effects of the same treatments on soil physico-chemical properties, most of which remained practically unchanged. This seems to suggest that the effect of neem soil amendments on *Striga* suppression and on improved growth and grain yield of millet at 6-8 kg/m^2 cannot be explained purely on the basis of increased soil fertility alone. This is most so since the neem soil amendments could not have been decomposed into absorbable nitrogen compounds within the first few weeks of the rainy season, during which period a *Striga* seed must have to be suppressed or else it escapes being suppressed by the neem soil amendments. However the suppressive effects of high dosage of nitrogenous fertilizers and manures on *Striga* emergence were variously reported (Gworgwor and Weber, 1991; Mabasa, 1994), but it is not likely that it was the high nitrogen content (National Research Council, 1992) in neem fruits, that was responsible for the observed suppressive effects of neem on *Striga* emergence. Thus something else in neem fruits was responsible for the observed suppressive effects on *Striga* emergence, and consequently on improved growth and yield of

treated millet. The absence of statistical significance of the effect the neem treatments on most of the tested physico-chemical soil properties and the existence of statistically significant coefficient of linear correlations between the neem treatments and the physico-chemical soil properties, are suggestive of a complex chemical interactions in neem treated soils, that cannot easily be altered in the short run, but are likely to be significantly altered in the long run, with regards to soil fertility and texture status.

KASHIM IBRAHIM LIBRARY

5.2 Long Term Effects of Neem Residues on Growth and Grain Yield of Millet, Sorghum, Groundnut and Cowpea and on Soil Physico-Chemical Properties

5.2.1 Long term effects of neem residues on germination of crop seeds

These results have provided ample evidence to prove that long term deposition of neem soil amendments into cropland, in the course of *Striga* management, would not likely have any serious suppressive effects, by allelophathy, on the germination of arable crops seeds commonly found grown in *Striga*-infested farms in Katsina. The implication of these findings is that neem tree can be used for sustainable *Striga* and soil fertility management without entertaining fear that prolonged deposition of allelophathic neem residues may in the long run suppress germination of cop seeds. Based on allelophathy in neem, pessimism was earlier expressed on the use of neem trees in agroforestry (Radwanski, 1969; National Research Council, 1992). Same fears are also being expressed by local farmers in Katsina

that neem literally "kills" farm by making it unproductive since the tree does not usually allow grasses to grow around it and under certain conditions it does not allow crop seedlings to establish well. These results have shown that suppression of seed germination appeared to be may be inversely related with the size of seeds in question. Perhaps germination in small seeded grasses, particularly *Striga,* may be adversely affected by neem residues, but not that of big seeded crops, particularly groundnut, cowpea and maize. More research needs to be conducted to further verify the effect size of seeds on their germination in neem amended soils, particularly as it may affect small seeded crops and weeds.

5.2.2 Long term effects of neem residues on growth parameters

Prolonged deposition of neem residues in the neem shelterbelt soil was not found to bring about undesirable side effects on the growth and growth vigor of millet and sorghum, by allelophathy, except of course during periods of long dry spells at the early part of the rainy season, when seedlings were more prone to wilting. Growth of cowpea and groundnut were scarcely affected by dry spells at the early part of the rainy season, as was observed in millet and sorghum plots. Neem residues were not proved aggressive against growth of the tested crops, rather they encouraged plant growth. However, cowpea at all the sites was found to suffer from luxuriant-growth syndrome, in which accelerated vegetative growth was at the expense of reproductive growth phase of the plant. The growth vigor of groundnut in neem plots was significantly enhanced. Observed accelerated growth in groundnut was not as spontaneous as that in cowpea. Long term deposition of neem residues

was not found to retard biomass accumulation in millet, sorghum, cowpea and groundnut plants, rather they were significantly enhanced at all test sites.

These results further proved that prolonged deposition of allelophathic neem residues, during the course of *Striga* and soil fertility management, would not be associated with any undesirable side effects on the growth and growth vigor of the tested crops, except in the case of cowpea, where it may associated with accelerated vegetative growth of cowpea at the expense of reproductive growth. This suggests that regular soil testing may be required to determine levels of soil total nitrogen, in order not to over fertilize the soil in areas sown to cowpea, where neem residues are used for *Striga* management.

5.2.3 Long term effects of neem residues on yield components

Panicle and pod biomass and total grain yield/ha were significantly effected by prolonged deposition of neem residues into the soil at the test sites. However, the neem residues were observed to seriously suppress grain yield in cowpea, while grain yield of groundnut was neither suppressed nor enhanced.

These results have served to dispelled fears being expressed by some farmers that neem "kills the farm". Rather, neem encourages vegetative growth in tested cereal and leguminous crops, and this resembles the effect of nitrogenous fertilizers on these crops. The ability of neem to increase biomass accumulation in neem treated crops, particularly millet and sorghum, is likely to encourage farmers to use neem

residues for soil fertility management, and thereby intentionally or unintentionally managing *Striga*. It was suggested that an ideal technique for sustainable *Striga* management would be a multipurpose technique that may be used by farmers for one reason or another (Berner *et al.*, 1997). The ability of neem to control *Striga*, and simultaneously control several other soil borne pests and diseases (National Research Council, 1992), and increase fertility and texture of treated soils have undoubtedly identified use of neem soil amendments as the ideal multipurpose technique for sustainable *Striga* management. The multipurpose attributes of neem tree for pest management in organic farming and in soil fertility management has been variously reported (Young, 1997; Lampkin, 1998; National Research Council, 1992). Trees play important roles in organic farming and agroforestry for sustainable crop production (Altieri, 1995). Where cowpea and groundnut are grown as fodder crops, neem is thus capable of assisting to boost fodder production.

However, the suppressive effects of prolonged deposition of neem residues on the grain yield of cowpea suggests that precaution aught to be taken since prolonged use of neem residues for *Striga* management may be inimical to grain yield of cowpea in *Striga*-infested farms where cowpea is mixed with cereal crops. Under field conditions, neem was not reported to adversely affect the yield of irrigated wheat in India (Puri and Bangarwa, 1992). The grain yield of chickpea was reported significantly improved under neem-based agroforestry system in India (Gili, 2006).

5.2.4 Long term effects of neem residues on soil physico-chemical properties

Data from these experiments have provided ample evidence to believe that long term deposition of neem soil amendments would not have any serious detrimental effects that may be inimical to soil fertility. In 20 years, continuous deposition of neem residues was found to significantly improve soil texture, by reducing the proportion of its sand contents, while simultaneously increasing clay and silt soil aggregates is suggestive of its potential for improving plant growth, enhancing water and nutrient holding capacity of the soil, and increasing its cation exchange capacity. Neem can be an important component for sustainable ecological management for checking land degradation and wasteland reclamation. Soil fertility, according to Olaitan *et al.* (1984) is accounted by soil's total nitrogen and organic matter content, and neem's long term ability to increase these soil chemical properties makes neem tree important in soil fertility management. High organic matter content in the soil is always associated with high humus and litter contents that enhance biological activities including that of earthworms and soil microbes in the top soil. This increases biodiversity of soil fauna and flora, including more earthworms and soil microbes in the soil. Soil organic matter, according to Olaitan *et al.* (1984) is important in several respects. It is the storehouse for supplying food to soil borne organisms, including earthworms which aerate the soil, and microbes are important in recycling processes in the soil. Organic humus is the source of exchangeable and available cations, including potassium, calcium, and magnesium. Organic matter improves soil texture, aeration, water percolation rate, and improves

soil tilth. It is the source of essential micro and macro soil nutrients. It acts as buffer for rapid chemical changes within the soil. All these are important in soil fertility management and hence assist in *Striga* management in nutrient deficient soils. Particularly important in *Striga* management through soil fertility is the soil nitrogen content. Organic nitrogen, according to Rowell (1996) is the main source of soil mineral-nitrogen, particularly ammonium (NH^{4+}), nitrite (NO^{2-}), nitrate (NO^{3+}), which are directly used by plants. Soil nitrogen is one of the most important soil fertility ingredients, while calcium (Ca^{2+}), according to Rowell (1996) and Olaitan *et al.* (1984), is important in enhancing root development, an activity that is suppressed in *Striga*-infested cereals. Ability of neem to improve calcium content of soil is thus important in enhancing plant growth by way of increasing root development. Neem's ability to increase magnesium content in treated soils is thus important for neem's potential to enhance chlorophyll formation in plants, which is one of the principal functions of magnesium ions (Mg^{2+}) (Olaitan *et al.*, 1984). Despite neem's ability to significantly increase soil organic matter content at both sites it is not immediately clear why it fails to significantly improve the soil's cation exchange capacity in 20 years within the neem shelterbelt area. Neem's ability to decrease soil acidity is thus important in enhancing availability of nutrients to neem treated crop plants. The potential of neem tree in sustainable *Striga* management is particularly important if neem is incorporated in agroforestry production systems. Young (1997) listed neem tree as one of the important trees for agroforestry soil improvement programmes, along with such other trees as *Acacia spp, Albazia saman, Cajanus cajan, Dalbergia sissoo, Faidherbia albida, and Zizyphus spina-christi etc.* Early reports

highlighting the soil improving potentials of neem trees include that of Radwanski (1969). Agroforestry potentials of neem tree do not only lie with its ability to improve soil fertility, but also in its ability to act as windbreaks and retard removal of top soil through wind erosion. In Republic of Niger, neem windbreaks in 5- and 10-year-old neem shelterbelts measuring 7 and 10 m high, respectively, were reported to increase yield of millet by 20-50% up to 80 m downwind (Kort, 1988; Byington, 1990; Vandenbeldt, 1990). Reports corroborating these results on neem's substantial improvement on soil properties, including calcium and increased pH of topsoil on acrisols in Togo include that of Drechsel et al. (1991).

25 FEB 20
UNIVERSITY

CHAPTER SIX

6.0 SUMMARY, CONCLUSION AND RECOMMENDATION

6.1 Summary

Striga is economically one of the most important biotic factors militating against cereal cultivation in the whole of Africa; where the parasites have infested over 2/3 of an estimated 73 million ha of cereal farmlands, inflicts crop yield losses worth over US$7.0 billion/annum and affects the livelihood of some 300 million people in over 42 countries. *Striga* problem in Africa has been aggravated by the inability of resource-poor farmers to sustainably adopt, virtually, most of the common *Striga* management techniques. This group of farmers is dearly in need of new *Striga* management resources and techniques that are sustainable in mitigating *Striga* endemics that is ravaging the African continent. This research was, therefore, untaken to evaluate the performances of a new *Striga* management resource (pesticidal and allelophathic neem tree) and a new technique (amending *Striga*-infested soil with neem soil amendments) in sustainable *Striga* management.

This pioneer neem research that tested the effects of neem soil amendments at 0, 0.5, 1.0, 2.0, 4.0, 6.0 and 8.0 kg/m^2 on emergence and biomass accumulation in *Striga*, on growth and grain yield of pearl millet and on soil physico-chemical properties was conducted, using randomized block design with 4-5 replications, in a total of five locations during the 2001, 2002 and 2003 rainy seasons, at Katsina,

Nigeria. Secondly, short and long term detrimental effects of allelophathic neem residues on soil physicochemical properties and on the growth and grain yield of sorghum, millet, groundnut and cowpea (common mixed cropping components in Nigeria) were also investigated, using student t-test with 10 replications, at two 20-year old neem shelterbelts at Katsina during the 2004 rainy season.

The result showed, perhaps, for the first time that:

Neem soil amendments significantly suppressed *Striga* emergence and biomass accumulation, and improved growth and grain yield of millet in *Striga*-infested and neem-amended plots at 6.0 and 8.0 kg/m^2 (60-80 tons/ha). The neem treatments were also found to significantly confer some sort of tolerance to *Striga*-infested millet, and significantly encouraged more *Striga* emergence in *Striga*-infested millet plots at 1.0-2.0 kg/m^2 (10-20 tons/ha). At these concentrations neem-treated millet showed significantly less *Striga* syndrome and more grain yield/quality than the untreated control millet. The treatments also showed adverse short term effects on the germination of millet seeds, only when the seeds were sown immediately after amending the plots with the neem treatments at 8.0 kg/m^2, but not strikingly so at lower concentrations or two weeks after amending the plots with the treatments.

Long term deposition of neem residues was not found to have adverse effects on the germination of sorghum, millet, cowpea and groundnut seeds. However, under such conditions growth vigor of emerged young millet seedlings, and to lesser

extent sorghum seedlings, appeared to have been temporarily suppressed at both sites during the first few weeks of the rainy season before stabilization of the rains. Prolonged drought was also noted to kill the seedlings after emergence in the neem treated plots. The residues were not found to have long-term detrimental effects on the growth and grain yield of the tested cereals, which recorded significant improvement on growth and grain yield. Though growth vigor was significantly improved in the tested legumes, particularly cowpea, grain yield in cowpea was significantly suppressed, while in groundnut it was not significantly affected.

Though neem soil amendments were not found to have significant short term effects on most of the soil's physicochemical properties, however, prolonged deposition of neem residues into neem shelterbelt soil was found to have significant long-term effects on soil physicochemical properties. Proportion of clay, silt, total nitrogen and organic carbon were significantly increased, while soil acidity was significantly reduced.

6.2 Conclusion

The hitherto untapped neem resources in Nigeria, estimated at 100-150 million stands, mostly located in *Striga*-infested northern states in Nigeria, could possibility be used for sustainable and durable *Striga* management under field conditions, either through biomass transfer or through carefully designed and managed agroforestry systems.

6.3 Recommendation

Based on the present research work it may be premature to make tentative recommendations, because much needs to be investigated further. However ad hoc recommendation can be made in favor of prolonged *Striga* management with neem soil amendments at the rate of 10-20 tons/ha integrated with hoe weeding. This improves growth and grain yield of treated millet while simultaneously stimulating more *Striga* emergence, which must then be weeded before flowering in order to deplete *Striga* seed reserve in the soil. Prolonging treatment for at least 5 years may not only serve to deplete *Striga* seed reserve in infested soil, but will also significantly improve soil's physicochemical properties, including soil fertility that retards *Striga* emergence.

Further research, however, needs to be carried out to determine the precise mode of action of neem residues against *Striga*. It is worth knowing whether neem suppresses *Striga* emergence by way of increasing soil fertility, or through pesticidal action that kills the tiny microscopic *Striga* seeds during conditioning, germination or attachment to host root, or perhaps possibly by way of blocking chemotrophism during *Striga* parasitism so that the host escapes detection. We also need to investigate the conditions under which neem suppresses *Striga* emergence. Effects of neem soil amendments on other root parasites, particularly *S. gesnerioides*, and *Alectra vogelli* needs to be investigated.

REFERENCES

Addae-Menseh, I. (1998). The use of the Neem (Azadirachta indica).in Ghana and their relationships to the chemical constituents and biological activities. In: Forster, D. (1998). *The potentials of the neem tree in Ghana*. Proceedings of a seminar held in Dodawa, October, 1988.11- 12pp.

Agbawi, K. A. and Younis, A. E. (1965). Effects of nitrogen application on growth and nitrogen content of *Striga* hermonthica Benth. and Sorghum vulgare Lur. grown for forage. *Plant and Soil* 23:295-304.

Aggrawal, V. D. (1986). An approach to cowpea *Striga* control through plant Breeding. In: F. A. O. (Food and Agriculture Organization of the United Nations).(1986). *Striga-Improved management in Africa*. Proceedings of the F. A. O./O. A. U. All-African Government Consultation on *Striga* Control, October 20-24 1986, Maroua, Cameroon (Edited by Robson, T.O. and Broad, H.R.). F. A. O. Rome.

Aggrawal, G. K. S., Bolfery, G., Arias, F. R. and Sallah, P. Y. K (1994). *Striga* control research in 1990 and future perspectives in northern Ghana. In: Lagoke, S. T. O., Hoevers, R., M'Boob, S. S., and Traboulsi, R.(eds).(1994). *Breeding for Striga resistance in cereals*, 2nd General Workshop of the Pan African *Striga* Control Network (PASCON), 23-29 June 1991. Nairobi, Kenya. Accra (Ghana). F. A. O. 131-134pp.

Altieri, M. A. (1995). *Agroecology, The Science of Sustainable Agriculture*. 2nd Edition, IT Publications, London, UK 433pp.

Anonymous (2005a). General information about parasitic weeds. *http://www.uni-hohenheim.de/~www380/parasite* (Accessed 24/1/2005).

Anonymous (2005b). Strategies to stop *Striga* *http://www.new-agri.co.uk/04-1/focuson/focuson5.html#Striga* (Accessed January 2004).

Anonymous (2005c). Plant Ecology: *http://www.bio.vu.nl/vakgroepen/plantecologie/weeds/stridis.html* (Accessed 11/5/2005).

Anonymous (2005d). Parasitic Plants, *http://www.science.siu.edu/parasitic-plants/tables/Table-otherpars.html* (Accessed 17/5/2005).

Anonymous (2005e). *Striga*: *http://www.itis.usda.gov/servlet/SingleRpt/RefRpt?search_type=source&search_id=source_id&search_id_value=168* (Accessed 11/5/2005).

Anonymous (2005f). Genus *Striga* *http://www.invasive.org/browse/genus.cfm?id=Striga* (Accessed 11/5/2005).

Anonymous (2005g). Parasitic weeds, Namibian crop pests, # 63, 64, 65 and 73 *http://hjem.get2net.dk/arne_larsen1/08weeds.html#Weeds* (Accessed 11/5/2005).

Anonymous (2005h). Parasitic weeds: *http://www.cals.vt.edu/ail/ipmcw/doc19.htm* (Accessed 21/7/2005).

Anonymous (2005i). *Striga*: *http://pi.cdfa.ca.gov/weedinfo/STRIGA2.html#anchor220678* (Accessed 17/2/2005).

Anonymous (2005j). Project: Biocontrol, a component of an integrated *Striga* hermonthica (Del.).Benth Control in Mali *http://www.niwi.knaw.nl/en/toon* (Accessed 11/5/2005).

Anonymous (2005k). IPM Systems *http://pest.cabweb.org/Journals/BNI/Bni24_1/IPM .HTM* (March 2003, Volume 24 No. 1 (Accessed 21/6/2005).

Anonymous (2005m). Weeds: *http://www.dpw.wageningen-ur.nl/cwe/weed_research/ nature-problem.html* (Accessed 17/2/2005).

Anonymous (2006). General information about parasitic weeds http://www.uni-hohenheim.de/www380/380b/science/supraregional/CourseHH.htm (Accessed 7/1/2006).

Ayensu, E. S., Doggett, H., Keynes, R. D., Marton-LeFevre, J., Musselman, L. J., Parker, C., and Pickering, A. (eds).(1994). *Striga biology and control. International*; Council of Scientific Unions, Paris, 216pp.

Bala, B. K. (1997). *Drying and storage of cereal grains.* Science Publishers, Inc, USA, 302pp.

Berner, D. K., Winslow, M. D., Awad, A. E., Cardwell, K. F., Mohan Raj, D. R., and Kim, S. K. (1997). *Striga Research Methods. A manual.* 2nd Edition. International Institute of Tropical Agriculture. 80pp.

Blade, S. (2006). *Reducing poverty through improved Striga control.* 3-6pp In: Chikoye, D., Ellis-Jones, T., Tarawali, G., and Lum, A.F. (2006).(eds). Reducing poverty through improved *Striga* control. Proceedings of the second *Striga* Management Stakeholders' conference. 8-9 September, 2004, Zaria, Kaduna State, Nigeria.

Butler, L. G. (1989). *Striga scourge of African cereals.* INTSORMIL Publication #89-1, University of Nebraska, Lincoln, NE.

Byington, E. K. (1990). Agroforestry and the temperate zone. In: MacDicken, K. G., and Vergara, N. T. (eds).(1990).*Agroforestry: Classification and Management.* Wiley, Chischester, UK. 228-289pp.

Carson, A. G. (1986). Research and development strategies for the control of *Striga* hermonthica in The Gambia. In: *F. A. O. (Food and Agriculture Organization of the United Nations).*(1986). *Striga-Improved management in Africa.* Proceedings of the F. A. O./O. A. U. All-African Government Consultation on *Striga* Control, October 20-24 1986, Maroua, Cameroon (Edited by Robson, T.O. and Broad, H.R.). F. A. O.Rome.100-117pp

Ciotola, M., Watson, A. K., Hallett, S. G. (1995). Discovery of an isolate of Fusarium oxysporum with potential to control *Striga* hermonthica in Africa. *Weed Research 35* (4).303-309.

Chikoye, D., Ellis-Jones, T., Tarawali, G., and Lum, A.F. (2006).(eds). *Reducing poverty through improved Striga control.* Proceedings of the second *Striga* Management Stakeholders' conference. 8-9 September, 2004, Zaria, Kaduna State, Nigeria.

Dawoud D. and Sauerborn J. (1994). Impact of drought stress and temperature on *Striga hermonthica* and *Alectra vogelii* at early growth stages. Experimental Agriculture 30, 249-257.

Dreschsel, P., Glaser, B., and Zech, W. (1991). Effects of four multipurpose tree species on soil amelioration during tree fallow in Central Togo. *Agroforestry Systems 16*,193-202.

Ejeta, G., Butler, L. G., Hess, D. E., and Vogler, R. K. (1991). *Genetic breeding strategies for Striga resistance in sorghum.* Paper presented at the fifth International Symposium on parasitic Weeds. Nairobi, Kenya.

Ejeta, G., Butler. L. and Babiker, A. G. T. (1992). New approach to the control of *Striga* In: Ejeta, G., Butler, L., and Babiker, A. G. T. (1992). *Host plant resistance to Striga.* Paper presented at First International Crop Science, Ames, Iowa, 14-22 July, 1991. 26pp.

Emechebe, A. M. (1994). Pan-African *Striga* Control Network (PASCON)- Feasibility and relevance- A consultancy report. In: Lagoke, S. T. O., Hoevers, R.S., M'Boob, S., and Traboulsi, R. (eds)(1994). *Breeding for Striga resistance in cereals, 2nd General Workshop of the Pan African Striga Control Network* (PASCON), 23-29 June 1991. Nairobi, Kenya. Accra (Ghana). F. A. O. 187-119pp.

Eplee, R. E., Westbrooks, R. G., and Norris, R. S. (1991). Chemical Control of *Striga*. In: Kim, S. K. (1991). *Combating Striga in Africa* (eds). Proceedings of the International Workshop organized by International Institute of Tropical Agriculture (IITA), International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)., and International Development Research Centre (IDRC).22-24 August 1988, Ibadan Nigeria. 61-65pp.

Ezeaku, I. E., and Gupta, S. C. (2004). Development of sorghum populations for resistance to *Striga* hermonthica in the- Nigerian Sudan Savannah. African *Journal of Biotechnology* Vol. 3 (6), 324-329pp. http://www.academicjournals.org/AJB ISSN 1684–5315.

Friend, J.A. (1995). Usefulness of neem extract in tropical pest control. *The Australian New Crops Newsletter* 4, 1995.

Franke, A.C., Ellis-Jones, J., Hussaini, M.A., Kureh, I., Tarawalli, G., Chikoye, D., and Schulz, S. (2006). Dissemination of integrated *Striga* hermonthica control technologies through on farm trials in the savanna zone of northern Nigeria. 30-45pp In: Chikoye, D., Ellis-Jones, T., Tarawali, G., and Lum, A.F. (2006).(eds). *Reducing poverty through improved Striga control.* Proceedings of the second *Striga* Management Stakeholders' conference. 8-9 September, 2004, Zaria, Kaduna State, Nigeria.

Gili, A.S. (2006). Neem in agroforestry. *Global Neem Update* VI (I).12.

Gurney, A. L., Adcock, Scholes, M. J. D., and Press, M. C. (2000). Physiological processes during *Striga* infestation in maize and sorghum. In: Haussmann, B. I. G., Hess, D. E., Koyama, M. L., Grivet, I., Rattunde, H. F. W., and Geiger, H. H. (eds).(1999). *Breeding for Striga resistance in cereals.* Proceedings of a workshop held at IITA, Ibadan, Nigeria, from 18-20 August 1999. Margraf Verlag. 3-17pp.

Gworgwor, N.A. (2000). Effect of intercropping sorghum with groundnut on *Striga hermonthica* on sorghum in the semi-arid zone of Borno State, Nigeria. *Nigerian Journal of Weed Science* 13: 63-67.

Gworgwor, N.A. (2006). The potentials of *Faidherbia albida* (Del.).A. Chev. trees in controlling *Striga hermonthica* (Del.).Benth. in pearl millet in the semi-arid zone of Nigeria. *Agronomie* (in the press).

Gworgwor, N.A. and Weber, H.C (1991). Effect of N-application on sorghum growth, *Striga* infest and osmotic pressure of the parasite in relation to the host. *Journal of Plant Physiology*, 139:194-198.

Gworgwor, N.A., Ndahi, W.B., Weber H.C. (2001). Parasitic weeds of north-eastern Nigeria: a new potential threat to crop production. *BCPC (eds).Proceedings of the British Crop Protection Council, (BCPC).– Weeds 2001 Conference*, Brighton, UK. BCPC, 12-15 November, 2001. Brighton, pp 181-186.

Gworgwor, N.A., Hudu, A.I., and Joshua, S.D. (2002). Seed treatment of sorghum varieties with brine (NaCl).solution for control of *Striga hermonthica* in sorghum. *Crop Protection*, 21: 1015-1021.

Gworgwor, N.A. and Weber, H.C (2003). Arbuscular mycorrhizal fungi-parasite interaction for the control of *Striga hermonthica* (Del.).Benth. In sorghum [*Sorghum bicolor* (L.).Moench]. *Mycorrhiza* 13:277-281.

Hudu, A.I. and Gworgwor, N.A. (1999). Effect of intercropping trap crop (bambara groundnut, *Vigna subterranae* (L.).Verdcourt).with resistant sorghum varieties on the control of *Striga hermonthica* (Del.).Benth. In sorghum in the semi-arid zone of Nigeria. *Journal of Arid Agriculture*, 9: 9-15

Haussmann, B. I. G., Hess, D. E., Koyama, M. L., Grivet, I., Rattunde, H. F. W., and Geiger, H. H. (eds).(1999). *Breeding for Striga resistance in cereals.* Proceedings of a workshop held at IITA, Ibadan, Nigeria, from 18-20 August 1999. Margraf Verlag. 376pp.

Hess, D. E., Ejeta, G., and Butler, L. G. (1992). Selecting sorghum genotypes expressing a quantitative biosynthetic trait that confers resistance to *Striga*. *Phytochemistry* 31: 493-497.

Hess, D. E. (1994). *Striga* research activities at ICRISAT Sahelian Center. In: Lagoke, S. T. O., Hoevers, R., M'Boob, S. S., and Traboulsi, R. (eds).(1994). *Breeding for Striga resistance in cereals*, 2nd General Workshop of the Pan African *Striga* Control Network (PASCON), 23-29 June 1991. Nairobi, Kenya. Accra (Ghana). F. A. O. 166-167pp.

Johnson, D. E., Riches, C. R., Jones, M. P., and Kent, R. (2000). The potential for host resistance to *Striga* on rice in West Africa. In: Haussmann, B. I. G., Hess, D. E., Koyama, M. L., Grivet, I., Rattunde, H. F. W., and Geiger, H. H. (eds).(1999). *Breeding for Striga resistance in cereals.* Proceedings of a workshop held at IITA, Ibadan, Nigeria, from 18-20 August 1999. Margraf Verlag: 139-145pp.

Kim, S.K. (1991). *Combating Striga in Africa.* Proceedings of the International Workshop organized by International Institute of Tropical Agriculture (IITA), International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)., and International Development Research Centre (IDRC).22-24 August 1988, Ibadan Nigeria. 145pp.

Kirlro, F. H. (1991). The *Striga* problem in Kenya. In: Kim, S. K. 1991. *Combating Striga in Africa.* Proceedings of the International Workshop organized by International Institute of Tropical Agriculture (IITA), International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)., and International Development Research Centre (IDRC).22-24 August 1988, Ibadan Nigeria 15-17pp.

Kort, J. (1988). Benefits of windbreaks to field and forage crops. In: Brandle, J. R. and Hintz, D. L. (1988).*Windbreak technology, Agriculture, Ecosystems and Environments Special Issue* 22/23. 165-190pp.

Kranz, B. (1999). Bedeutung von organischer Dungung fur die keimung und das Auftreten der parasitichen Blutenpflanze *Striga* hermonthica (Del.).Benth. *Agroecology* 2: 110-115pp.

Kranz, B., Fugger, W. D., Kroschel, J., and Sauerborn, J. (1998). The influence of organic manure on *Striga* hermonthica (Del.).Benth., Infestation in Northern Ghana. In: *Towards sustainable land use. Furthering cooperation between people and institutions. Volume 1*, Proceedings of the International Soil Conservation Organization, Bonn, 1996. *Advances in Geoecology No. 31:* 615-619.

Lagoke, S. T. O. (1986). *Striga* in Nigeria. *In:* F. A. O. (Food and Agriculture Organization of the United Nations).(1986). *Striga*-Improved management in Africa. *Proceedings of the F. A. O./O. A. U. All-African Government Consultation on Striga Control,* October 20-24 1986, Maroua, Cameroon (Edited by Robson, T.O. and Broad, H.R.). F. A. O. Rome. 10-20pp.

Lagoke, S. T. O. (1998). *Proceedings of the Integrated Pest Management Communications Workshop: Eastern/Southern Africa* March 1-6,1998, Nairobi, Kenya International Centre for Insect Physiology and Ecology (ICIPE). Pan African *Striga* management Network
http://www.cals.vt.edu/ail/ipmcw/doc19.htm.

Lagoke, S. T. O., Manzo, S. K., Emechebe, A. M., and Ajayi, O. (1986). *Status of parasitic weed research in Nigeria savannah. Paper presented at the 15th Annual conference of the Weed Science of Nigeria*, Nsukka, December 1-3, 1986.

Lagoke, S. T. O., Parkinson, V., and Agunbiade, R. M. (1991). Parasitic weeds and control methods in Africa. *In:* Kim, S. K. (1991).(eds). *Combating Striga in Africa.* Proceedings of the International Workshop organized by International Institute of Tropical Agriculture (IITA), International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)., and International Development Research Centre (IDRC).22-24 August 1988, Ibadan Nigeria. 3-14pp.

Lagoke, S. T. O., Shebayan, J. Y., Weber, G., Olufajo, O., Elemo, K., Adu, J. K., Emechebe, A. M., Singh, B. B., Zaria, A. A., Awad, A., Ngawa, L., Olaniyan, G. O., Olafare, S. O., Adeoti, A., and Odion, C. (1994a). Survey of *Striga* problem and evaluation of *Striga* control methods and packages in crops in the Nigerian Savannah. *In*: Lagoke, S. T. O., Hoevers, R., M'Boob, S. S., and Traboulsi, R. (eds).(1994a). *Breeding for Striga resistance in cereals*, 2nd General Workshop of the Pan African *Striga* Control Network (PASCON), 23-29 June 1991. Nairobi, Kenya. Accra (Ghana). F. A. O. 91-120pp.

Lagoke, S. T. O., Hoevers, R., M'Boob, S. S., and Traboulsi, R. (eds)(1994b). *Breeding for Striga resistance in cereals,* 2nd General Workshop of the Pan African *Striga* Control Network (PASCON), 23-29 June 1991. Nairobi, Kenya. Accra (Ghana). F. A. O. 131-134pp.

Lagoke, S. T. O., Kureh, I., Aba, D. A., and Gupta, S. C. (1999). Host plant resistance for *Striga* control in sorghum activity at IAR, Samaru, Nigeria. *Poster presentation at Workshop on Breeding for Striga resistance in cereals,* 18-20 Aug. 1999, IITA, Ibadan, Nigeria.

Lampkin, N. (1998). *Organic Farming.* Farming Press. Miller Freeman, UK. 246-247pp.

Little, T. M. and Hill, F.J. (1978). *Agricultural Experimental Design and Analysis.* John Wiley and sons, New York, 302pp.

M'Boob, S. S. (1986). A Regional Program for West and Central Africa. *In:* F. A. O. (Food and Agriculture Organization of the United Nations).(1986). *Striga*-Improved Management in Africa. Proceedings of the F. A. O./O. A. U. All-African Government Consultation on *Striga* Control, October 20-24 1986, Maroua, Cameroon (Edited by Robson, T.O. and Broad, H.R.). F. A. O. Rome.

M'Boob, S. S. (1994). *Striga* in Africa. *In*: Lagoke, S. T. O., Hoevers, R., M'Boob, S. S. and Traboulsi, R. (eds)(1994). *Breeding for Striga resistance in cereals,* 2nd General Workshop of the Pan African *Striga* Control Network (PASCON), 23-29 June 1991. Nairobi, Kenya. Accra (Ghana). F. A. O. 25-29pp.

Mabasa, S. (1994). *Striga* activity in Zimbabwe. *In*: Lagoke, S. T. O., Hoevers, R., M'Boob, S. S., and Traboulsi, R. (eds).(1994).*Breeding for Striga resistance in cereals,* 2nd General Workshop of the Pan African *Striga* Control Network (PASCON), 23-29 June 1991. Nairobi, Kenya. Accra (Ghana). F. A. O. 143-156pp.

Maiti, R. K., Ramaiah, K. V., Bisen, S. S., and Chidley, V. I. (1984). A comparative study of the haustoria development of *Striga* asiatica (L.).Kuntze on sorghum cultivars. Annals of Botany 54: 447-457.

Mansfield, R.A. (1982). *Striga research at the Institute for Agricultural Research* 1979-1982. Agronomy Department, ABU, Zaria, Nigeria. 38pp.

Marley, P.S. Aba, D. A. Shebayan, J. A. Y. Musa, R. and Sanni, A. (2004). Integrated management of *Striga hermonthica* in sorghum using a mycoherbicide and host plant resistance in the Nigerian Sudano-Sahelian savannah. *Weed Research, 44 (3).* 157-162. June 2004, http://www.ingenta.com/isis/browsing/AllIssues/ingenta;jsessionid=7853g0haaiui.circus?journal=pubinfobike://bsc/weed.

Mohamed, K. I., Musselman, L. J., and Riches, C.R. (2001). The Genus *Striga* (Scrophulariaceae).in Africa. *Annals of the Missouri Botanical Garden 88*:60-103.

Murty, D. S., Bello, S. A., and Aladele, S. E. (1995). Screening of sorghum for resistance to *Striga* under artificial field inoculation. *International Sorghum and Millet Newsletter*. 36: 84-86.

Musselman, L. J. (1987). Taxonomy of witchweeds. *In*: Musselman, L.J. (1987). *Parasitic weeds in Agriculture Vol 1 Striga* CRC Press, 4-12pp.

Musselman, L. J., and Dickson, W. C. (1975). The structure and development of the haustorium in parasitic Scrophulariaceae. Botanical Journal of the Linnean Society *70*:183-212.

Musselman, L. J., and Parker, C. (1983). *Biosystematic research in the genus Striga (Scrophulariaceae). In*: ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), 1983. *Proceedings of the second International Workshop on Striga*, 5-6 Oct. 1981, IDRC/ICRISAT, Ouagadougou, Upper Volta, Pantacheru, A.P., India, ICRISAT.

Musselman, L. J., Bhrathalaksmi, S. B., Safa, S. B., Knepper, D. A., Mohamed K. I., and White, C. L. (1991). Recent research on the biology of *Striga asiatica, S. gesnerioides* and S. *hermonthica. In*: Kim S. K. (1991).(eds). *Combating Striga in Africa*. Proceedings of the International Workshop organized by International Institute of Tropical Agriculture (IITA), International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)., and International Development Research Centre (IDRC).22-24 August 1988, Ibadan Nigeria. 31-41pp.

National Research Council, (1992). *Neem: A tree for solving global problems.* National Academy Press, Washington CC. 141pp.

NARICT, 2004(National Research Institute for Chemical Technology). (2004). Neem: Its economic importance. Being a seminar paper presented by and at NARICT, Zaria on 27 October, 2004.

Neem Foundation, (1997a).Neem for Fertilizer Management. *http://www.neemfoundation.org/fert.htm#sa*

Neem Foundation, (1997b).Biomass Production and Utilization. *www.organicneem.com*

Neem Foundation, (2005). Organic Farming and Neem *http://www.neemfoundation.org/farming.htm#chem* (Accessed 2/9/2004

Neem Foundation, (2006). Greening India with neem. *Global Neem Update*, VI; 1-2

Nickrent, D. L. and L. J. Musselman (2004). Introduction to Parasitic Flowering Plants. http://www.apsnet.org/education/IntroPlantPath/PathogenGroups/Parasiticplants.

Nyarko, A. (1986). *Striga* in Ghana. In: *F. A. O. (Food and Agriculture Organization of the United Nations).(1986). Striga-Improved management in Africa.* Proceedings of the F. A. O./O. A. U. All-African Government Consultation on *Striga* Control, October 20-24 1986, Maroua, Cameroon (Edited by Robson, T.O. and Broad, H.R.). F. A. O. Rome. 51-53pp.

Obagwu, J., Emechebe, A. M., and Adeoti, A. A. (1997). Effects of extracts of garlic (*Allium sativum* L.).bulb and Neem (*Azadirachta indica* Juss).seed on the mycelial growth and sporulation of *Collectotrichum capsi* (Syd).Butler and

Bisby. *Journal of Agricultural Technology 5(1).* 51-55, NBTE, Kaduna, Nigeria.

Obilana, A. T. (1980). Yield loss and reaction of sorghum F1 crosses to *Striga hermonthica* Benth. *Paper presented at the Annual Conference of the Weed Science Society of Nigeria, NIFOR, Benin City,* 2-5 December.

Obilana, A. T. (1983). *Striga* studies and control in Nigeria. *In: ICRISAT (1983). Proceedings of the second International Workshop on Striga, sponsored by International Development Research Centre (IDRC).and the International Institute for the Semi-arid Tropics (ICRISAT).*on 5-8 October1981, Ouagadougou, Upper Volta (eds: Ramaiah, K. V., Rao, V and Kumble, V), 87-98pp.

Obilana, A. T. (2003). Constraints to food production and quality in Sub-Saharan Africa: Potential biotechnological solutions. *Being the text of the paper presented at the Unido Global Biotechnology Forum – Regional consultative meeting,* Nairobi, Kenya. 20-23 March 2003.

Ogborn, J. E. A. (1972). The control of *Striga hermonthica* in peasant farming. *Paper presented at the Conference of the 11th British Weed control conference.*

Ogborn, J. E. A. (1987). *Striga* control under peasant farming conditions. *In:* Musselman, L. (1987). *Parasitic weeds in Agriculture, vol. 1. Striga.* CRC Press, Boca Raton, USA. 145-171pp.

Ogunremi L.T. and Olaniyan, G.O. (1994). Effects of soil and seed treatments on the performance of maize (*Zea mays).*on *Striga* infested fields. *In:* Traboulsi R., Lagoke, S. T. O., Hoevers, R., and M'Boob, S.S. (eds).(1994). *Towards an integrated control of Striga in Africa.* Proceedings of 1st General Workshop of the Pan-African *Striga* Control Network (PASCON), 11-14 March, 1990, Ibadan, Nigeria (43-49pp).

Okonkwo, S. N. O. (1994). The elusive witchweeds (*Striga* spp).problem: Strategies for effective management in African peasant agriculture. *In:* Traboulsi, R., Lagoke, S. T. O., Hoevers, R., and M'Boob, S. S. (eds).(1994). *Towards an integrated control of Striga in Africa.* Proceedings of 1st General Workshop of the Pan-African *Striga* Control Network (PASCON), 11-14 March, 1990, Ibadan, Nigeria. 35-45pp.

Olaitan, S. O., Lombin, G. Onizi O. C. (1984).*Introduction to Tropical Soil Science.* Macmillan Intermediate Agriculture Series. Macmillan Press London 126pp.

Orodopho, A. B., and Kirlro, F. H. (1994). Recherche sur le *Striga* au Mali-Synthese des resultats de la campgne 1990-1991 *In:* Lagoke, S. T. O., Hoevers, R., M'Boob, S. S. and Traboulsi, R. (eds).(1994).Breeding for *Striga resistance in cereals*, 2nd General Workshop of the Pan African *Striga* Control Network (PASCON), 23-29 June 1991. Nairobi, Kenya. Accra (Ghana). F. A. O. 88-90pp

OISAT, (2006). *Striga* Weed. http://www.oisat.org/pestsmap.htm

Oswald, A., Frost H., Ransom J.K., Kroschel J., Shepherd K. & Sauerborn J. (1996).Pot and root chamber experiments evaluated several perennial species for their ability to stimulate germination of *Striga* seeds. The results indicate that *Sesbania sesban*, *Markhamia lutea* and *Leucaena diversifolia* have potential to reduce *Striga* seed banks in the soil

Ouedrago, A. and Bain, D. (1994). Influence de divers herbicides sur l'emergence de *Striga hermonthica* au Burkina Faso. *In*: Lagoke, S. T. O., Hoevers, R., M'Boob, S. S. and Traboulsi, R. (eds).(1994). *Breeding for Striga resistance in cereals*, 2nd General Workshop of the Pan African *Striga* Control Network (PASCON), 23-29 June 1991. Nairobi, Kenya. Accra (Ghana). F. A. O. 51-58pp.

Parker, C. (1983). *Striga* - Analysis of past research and summary of the problem. *In:* ICRISAT (International Crop Research Institute for the Semi- Arid Tropics).1983. *Proceedings of the second International Workshop on Striga* 5-8 Oct 1981, IDRC/ICRISAT, Ouagadougou, Upper Volta, Pantacheru, A.P., India: ICRISAT. 9-16pp

Parker, C. (1984). The influence of *Striga* sp on sorghum under varying nitrogen fertilization, *In:* Parker, C., Musselman, L. J., Polhill, R. M. and Wilson, A. K. (1984). *Proceedings of the Third International Symposium on Parasitic Weeds, Aleppo, Syria*. 90-98, pp.

Parker, C. and Riches, C.R. (1993). Parasitic weeds of the world: biology and control. CAB International, wallington, uk, 332pp.

Parker, C. (2003). Parasitic Scrophs – No Such Thing? *Haustorium Parasitic Plants Newsletter* (Dec 2003). #44.

Parkinson, V. (1985). *Striga*, a serous threat to maize production in Africa and research being conducted at IITA. In: *Proceedings of O. A. U./F. A. O. Workshop on Striga*. Rome. F. A. O. Yaoundé (Cameroon). 23-27 September 1985. 47-55pp.

Parmar, B. S. (1986). An overview of neem research and use in India during the years 1983-1986. *In:* Schmutterer, H, K.R.S. Ascher, (1987). *Natural pesticides from the neem tree (Azadirachta indica).and other tropical plants.* Proceedings of the third International Neem Conference, Nairobi, Kenya, 10-15 July, 1986.55-80pp.

Pesch, C. J., and Pieterse, A. H. (1985). Inhibition of germination in *Striga* by means of urea. *Experimentia 38*:559-560

Pieterse, A. H. 1985. Control of *Striga* at the level of the small-scale farmer. *In:* Proceedings of the O. A. U./F. A. O. Workshop on *Striga* , 23-27 September 1985, Yaounde, Cameroon. 23-27pp.

Press, M. C., Touhy, J. M., and Stewart, G. R. (1987). Leaf conductance, transpiration and relative content of *Striga hermonthica* (Del).Benth and S. asiatica (L).Kuntze (Scrophulariaceae).and their host *sorghum bicolar* (L).Moench (Gramineae). In: Weber, H. Chi., and Forstreuter, W. (eds). *Parasitic flowering plants.* Proceedings of the fourth International Symposium on parasitic flowering plants. Phillipps Universit at Marbury (Germany, Fr). 631-636pp.

Puri, S., and Banganwa, K. S. (1992). Effects of trees on the yield of irrigated wheat crop in semi-arid regions. *Agroforestry Systems 20*, 229-241.

Radwanski, S. A. (1969). Improvement of red acid sands by the neem tree (Azadirachta indica).in Sokoto, North-Western State of Nigeria. *Journal of Applied Ecology 6*, 505-511.

Ramaiah, K.V. (1986). Status of ICRISAT's *Striga* resistance breeding in sorghum and millet in Africa. *In:* F. A. O. (Food and Agriculture Organization of the United Nations).(1986). *Striga-Improved management in Africa. Proceedings of the F. A. O./O. A. U. All-African Government Consultation on Striga Control,* October 20-24 1986, Maroua, Cameroon (Edited by Robson, T.O. and Broad, H.R.). F. A. O. Rome. 154-161pp.

Ramaiah, K.V. (1991). Breeding for *Striga* resistance in sorghum and millet. *In: Kim S.K.* (1991).*Combating Striga in Africa.* Proceedings of the International Workshop organized by International Institute of Tropical Agriculture (IITA), International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).and International Development Research Centre (IDRC). 22-24 August 1988, Ibadan, Nigeria. 75-80pp.

Ramaiah, K. V., Parker, C., Vasudeva Rao, M. J., and Musselman, I. J. (1983). *Striga* identification and control handbook. *Information Bulletin No 15.* Pantacheru A.P. (International Crop Research Institute for the Semi-Arid Tropics, India).

Raynal-Roques, A. (1987). The genus *Striga*, Scrophulariaceae, in Western and Central Africa. A survey In: Weber, H and Forstreuter, W. (eds). *Parasitic Flowering Plants*. Proceedings of the 4th International Symposium on parasitic flowering plants,1987, Phillipps-Universitat, Marburg (Germany).

Raynal-Roques, A. (1996). A hypothetic history of *Striga* - a preliminary draft. *In* Moreno, M.T., Cubero, J.I., Berner, D., Joel, D.M., Musselman, L.J. & Parker, C. eds. Advances in Parasitic Plant Research. *Proceedings of the 6th Parasitic Weed Symposium*. Cordoba, Spain. 105-111.

Rembold, H., Forster, H., and Ch. Czoppelt (1987). Structure and biological activity of azadirachtin A and B. *In:* Schmutterer, H, K.R.S. Ascher, (1987). *Natural pesticides from the neem tree (Azadirachta indica).and other tropical plants.* Proceedings of the third International Neem Conference, Nairobi, Kenya, 10-15 July, 1986. 149-160pp.

Rowell, D.L. (1996): *Soil Scince. Methods and Applications*, 350pp, Longman Group, Edinburgh, UK

Sand, P.F. (1987). The American witch quarantine and eradication program. In: Musselman L.J. (1987). *Parasitic Weeds in Agriculture. Volume 1. Striga*. CRC Press. 207-223pp.

Sauerborn, J. Mussa, H. and Linke, K. H. (1991). Physical control of *Striga*. *In:* Kim S.K. (1991), *Combating Striga in Africa*. Proceedings of the International Workshop organized International Institute of Tropical Agriculture (IITA), International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), and International Development Research Centre (IDRC). 22-24 August, 1988, IITA, Ibadan, Nigeria. 61-65pp.

Schlauer, J. (1996).What is a Parasitic Plant?: *http://www.bio.vu.nl/vakgroepen/plantecologie/index.html*.

Schmutterer, H, and K.R.S. Ascher, (1987). *Natural pesticides from the neem tree (Azadirachta indica).and other tropical plants.* Proceedings of the third International Neem Conference, Nairobi, Kenya, 10-15 July, 1986.750pp.

Tchemi, 1986, W. (1986). Serious pest in Togo. *Striga* situation in Togo. *In:* F. A. O. (Food and Agriculture Organization of the United Nations).(1986). *Striga-Improved management in Africa. Proceedings of the F. A. O./O. A. U. All-African Government Consultation on Striga Control*, October 20-24 1986, Maroua, Cameroon (Edited by Robson, T.O. and Broad, H.R.). F. A. O. Rome. 92-97pp.

Tilander, Y., Oudraogo, G., and Youggma, F. (1995). Impact of tree coppicing on tree-crop competition in parkland and alley farming system in Burkina Faso. *Agroforestry Systems:* 3:363-378.

Traboulsi, R., Lagoke, S. T. O., Hoevers, R., and M'Boob, S.S. (eds).(1994). *Towards an integrated control of Striga in Africa.* Proceedings of 1st General Workshop of the Pan-African *Striga* Control Network (PASCON), 11-14 March, 1990, Ibadan, Nigeria.

Vaidya, P.K., Raghavender, B., and Mukuru, S.Z. (1991). Progress in breeding resistance to *Striga* asiatica in sorghum at the ICRISAT Center. *In*: Kim S.K. (1991), *Combating Striga in Africa*. Proceedings of the International Workshop organized International Institute of Tropical Agriculture (IITA), International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), and International Development Research Centre (IDRC). 22-24 August, 1988, IITA, Ibadan, Nigeria. 81-86pp.

Vandenbeldt, R.J. (1990). Agroforestry in semi arid tropics. *In:* MacDicken, K. G. and Vergara, N.T. (eds).(1990).*Agroforestry: Classification and Management*. Wiley, Chischester, UK.

Verkleij, J.A.C. and Kuiper, E. (2000). Various Approaches to Controlling Root Parasitic Weeds. *Biotechnology and Development Monitor*, No. 41, p. 16-19.

Walker. R. (2004). Plant Ecology:
http://www.bio.vu.nl/vakgroepen/plantecologie/weeds/weed.html
(Accessed 17/2/2004).

WARDA, (1998). Allies in the war on weeds. *WARDA Annual Report, 1998.*

Watson, A. K., Ciotola, M., and Peden, D. (1993). Controlling the Noxious Weed *Striga*. *http://web.idrc.ca/en/ev-8534-201-1-DO_TOPIC.html.*

Wilson, J.P., Hess, D.E., and Hanna, W.W. (2000). Resistance to *Striga hermonthica* in the primary gene pool of Pennisetum glaucum. *In:* Haussmann, B.I.G., Hess, D.E., Koyama, M.L., Grivet, I., Rattunde, H. F. W., and Geiger, H.H. (eds).(1999). *Breeding for Striga resistance in cereals*. Proceedings of a workshop held at IITA, Ibadan, Nigeria, from 18-20 August 1999. Margraf Verlag. 147-156pp.

Yar'adua, A. A. (1987). *Studies on Alternaria porri(Ell), Cif., the causal organism of purple blotch disease of onion (Allium cepa L).in the Zaria environs*. MSc. Thesis. Ahmad Bello University, Zaria

Yar'adua, A. A. (2000). Laboratory studies on mycelial growth & sporulation of *Alternaria porri*, the causal agent of onion purple blotch in Nigeria. *Dan-Masani*, 1:132-140, 2000.

Yar'adua, *A. A.* (2002). In-vitro effect of aqueous extracts of neem tree (*Azadirachta indica).*on the mycelial growth of *Alternaria porri* (Ell).Cif. *Journal of Agricultural Technology 10* (2).16-21, 2002.

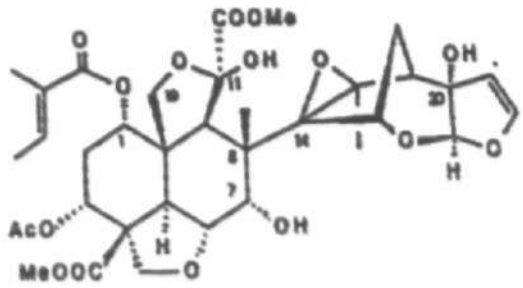
Young, A. (1997). *Agroforestry for Soil Management*. 2nd Edition. CAB International in Association with International Centre for Research in Agroforestry, Oxon, UK. 320pp.

Appendices

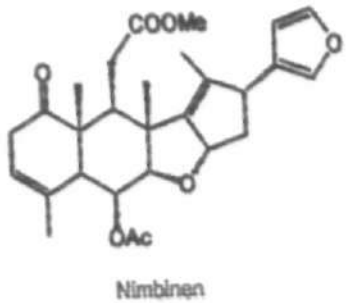
Appendix 1: **The chemical structures of bioactively potent chemical compounds found only in neem tree (Source: Addae-Menseh, 1998)**



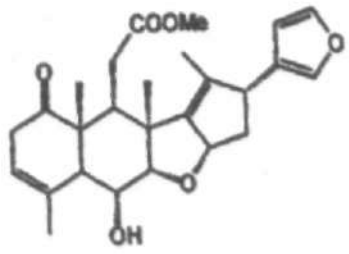
Meliacan



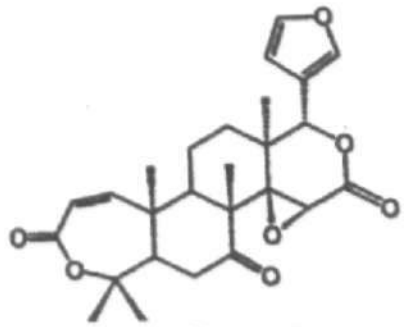
Azadirachtin



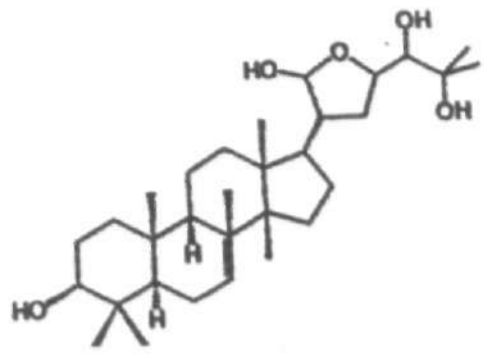
Nimbinen



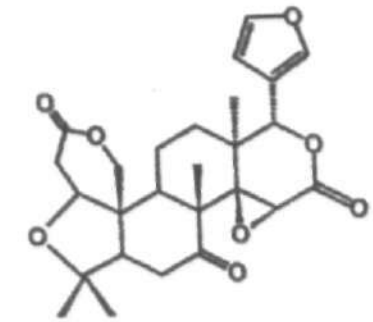
6-Deacetylnimbinen



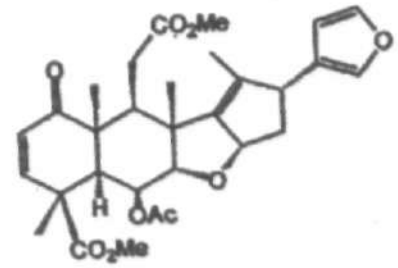
Obacunone



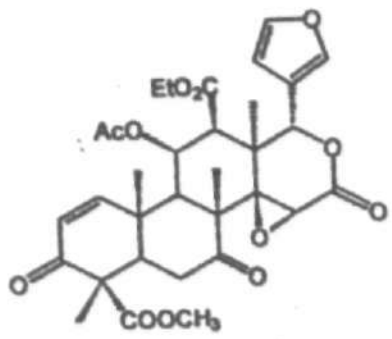
Meliantriol



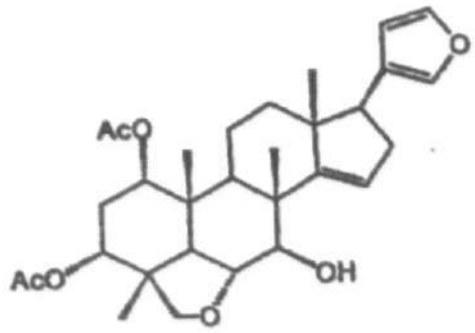
Limonin



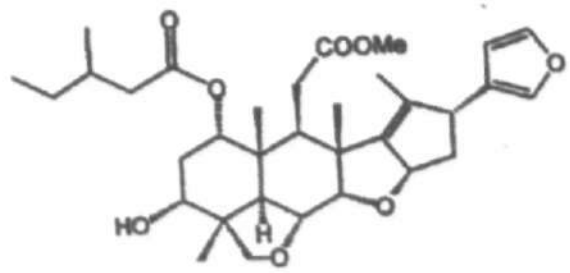
Nimbin



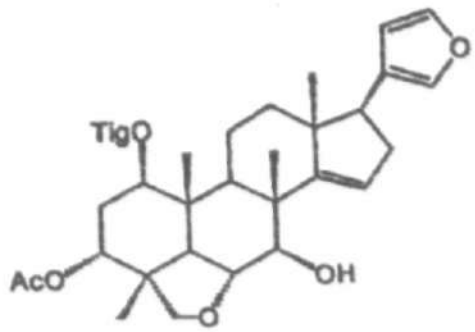
Hirtin



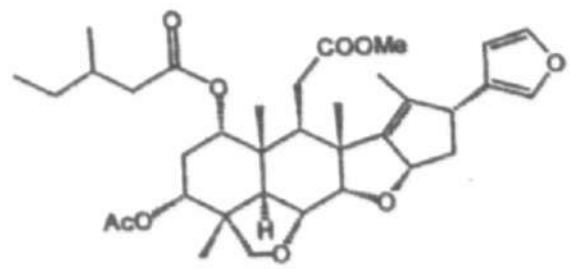
1,3-Diacetyl-vitasinin



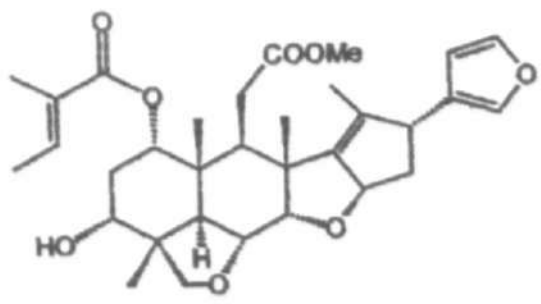
Salannol



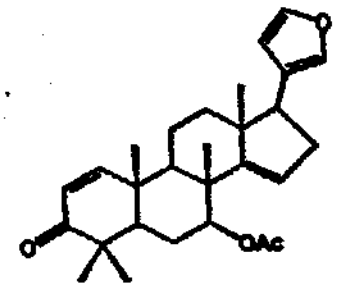
1-Tigloyl-3-acetyl-vilasinin



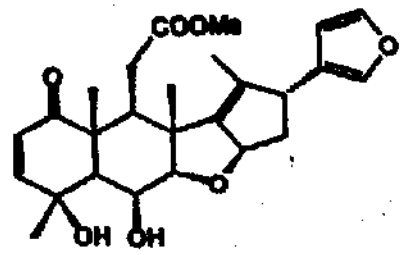
Salannol acetate



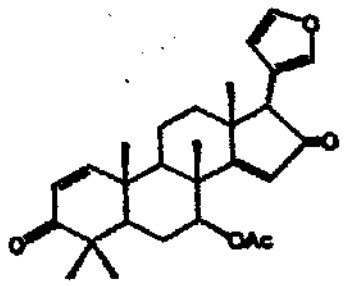
3-Deacetyl-salannin



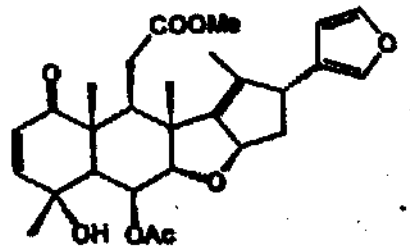
Azadiron



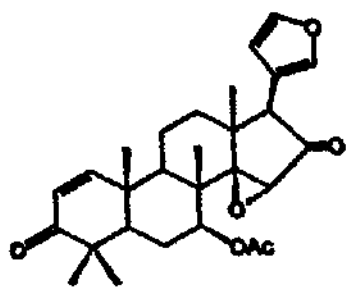
Nimbandiol



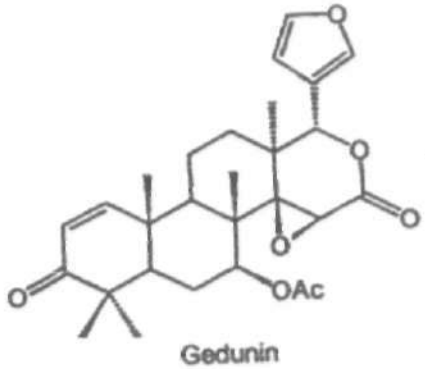
Azadiradion



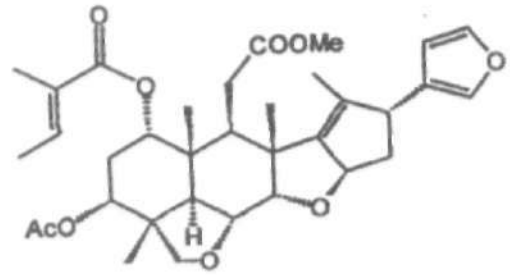
6-acetylnimbandiol



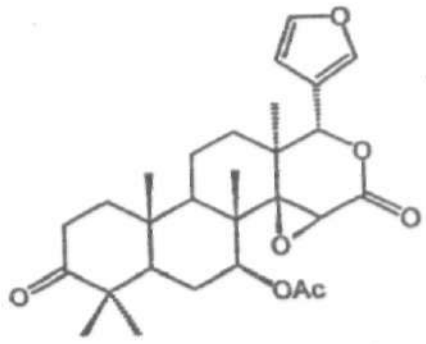
Epoxyazadiradion



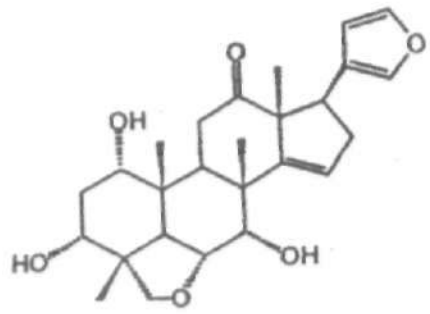
Gedunin



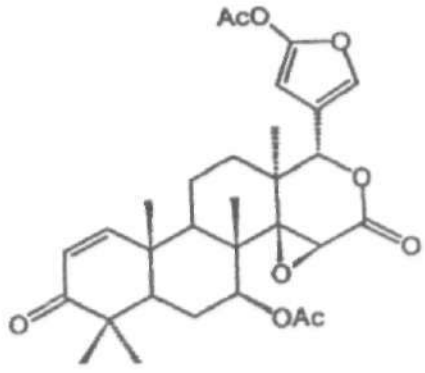
Salannin



1,2-Dihydrogedunin



Nimbidin



23-Acetylgedunin

Appendix 2: Analyses of variances on the effect of neem soil amendments on *Striga* and millet at Katsina, during the 2001 field trials

ANOVA 1:Effect of neem soil amendments on the germination of millet seeds, sown immediately after amending the soil at Katsina, during the 2001 trial

Sources	DF	SS	MS	F
Treatments	5	45360.00	9072.00	67.03**
Blocks	4	853.33	213.33	1.58ns
Error	20	2706.67	135.33	

LSD (P=O.01) = t0.01.√{(2Error MS)/r} =20.93
Coefficient of linear correlation, r = 0.89

ANOVA 2. Effect of neem soil amendments on the germination of millet seeds, sown 14 days after amending the soil at Katsina, during the 2001 trial

Sources of variation	DF	SS	MS	F
Treatments	5	15146.67	3029.33	23.12**
Blocks	4	1580.00	395.00	3.02ns
Error	20	2620.00	131.00	

LSD (P=O.01) = t0.01.√{(2Error MS)/r} = 20.59
Coefficient of linear correlation, r = 0.92

ANOVA 3. Effect of neem soil amendments on *Striga*-syndrome on *Striga*-infested millet at Katsina, during the 2001 trial

Sources	DF	SS	MS	F
Treatments	5	274.27	54.85	30.42**
Blocks	4	9.53	2.38	1.32ns
Error	20	36.07	1.80	

LSD (P=O.01) =t0.01.√{(2Error MS)/r} = 2.42
Coefficient of linear correlation, r = 0.96

ANOVA 4. Effect of neem soil amendments on mean height of millet plants at harvest, at Katsina, during the 2001 trial

Sources of variation	DF	SS	MS	F
Treatments	5	52165.37	10433.07	34.24**
Blocks	4	1819.73	454.93	1.49ns
Error	20	6093.90	304.69	

LSD (P=O.01) = t0.01.√{(2Error MS)/r} = 31.41
Coefficient of linear correlation, r = 0.95

ANOVA 5. Effect of neem soil amendments on length of millet panicles at Katsina, during the 2001 trial

Sources	DF	SS	MS	F
Treatments	5	551.01	110.20	8.38**
Blocks	4	51.28	12.82	0.97ns
Error	20	262.98	13.15	

LSD (P=O.01) = t0.01.√{(2Error MS)/r} = 6.52
Coefficient of linear correlation, r = 0.88

ANOVA 6. Effect of amending *Striga*-infested plots with neem soil amendments on the Grain yields of millet at Katsina, during the 2001 trial

Sources	DF	SS	MS	F
Treatments	5	15821974	3164395	31.84**
Blocks	4	511374	127844	1.29ns
Error	20	1987761	99388	

LSD (P=O.01) = t0.01.√{(2Error MS)/r} = 567.26
Coefficient of linear correlation, r = 1.00

ANOVA 7. Effect of amending *Striga*-infested plots with neem soil amendments on the % proportion of sieved grain yields collected on 1.18mm sieve at Katsina, during the 2001 trial

Sources	DF	SS	MS	F
Treatments	5	691.70	138.34	4.62**
Blocks	4	64.90	16.22	0.54ns
Error	20	598.87	29.94	

LSD (P=O.01) = t0.01.√{(2Error MS)/r} = 9.85
Coefficient of linear correlation, r = 0.78

ANOVA 8. Effect of amending *Striga*-infested plots with neem soil amendments on the % proportion of sieved grain yields collected on 1.70mm sieve at Katsina, during the 2001 trial

Sources	DF	SS	MS	F
Treatments	5	3289.55	657.91	5.75**
Blocks	4	212.23	53.06	0.46ns
Error	20	2289.45	114.47	

LSD (P=O.01) = t0.01.√{(2Error MS)/r} = 19.25
Coefficient of linear correlation, r = 0.84

ANOVA 9. Effect of amending *Striga*-infested plots with neem soil amendments on the % proportion of sieved grain yields collected on 2.00mm sieve at Katsina, during the 2001 trial

Sources	DF	SS	MS	F
Treatments	5	2447.82	489.56	2.58ns
Blocks	4	510.71	127.68	0.67ns
Error	20	3799.76	189.99	

ANOVA 10. Effect of amending *Striga*-infested plots with neem soil amendments on the % proportion of sieved grain yields collected on 2.36mm sieve at Katsina, during the 2001 trial

Sources	DF	SS	MS	F
Treatments	5	1910.51	382.10	20.86**
Blocks	4	311.27	77.82	4.25ns
Error	20	366.39	18.32	

LSD (P=O.01) = t0.01.√{(2Error MS)/r} = 7.70
Coefficient of linear correlation, *r* =0.95

ANOVA 11. Effect of amending *Striga*-infested plots with neem soil amendments on 1000-grain weights of sieved grain yields collected on 1.18mm sieve at Katsina, 2001

Sources	DF	SS	MS	F
Treatments	5	1.14	0.23	2.01
Blocks	4	0.89	0.22	1.98
Error	20	2.26	0.11	

ANOVA 12. Effect of amending *Striga*-infested plots with neem soil amendments on 1000-grain weights of sieved grain yield collected on 1.70mm sieve at Katsina, 2001

Sources	DF	SS	MS	F
Treatments	5	2.44	0.49	2.52ns
Blocks	4	1.55	0.39	2.00ns
Error	20	3.86	0.19	

ANOVA 13. Effect of amending *Striga*-infested plots with neem soil amendments on 1000-grain weights of sieved grain yields collected on 2.00mm sieve at Katsina, 2001

Sources	DF	SS	MS	F
Treatments	5	4.97	0.99	2.29ns
Blocks	4	0.59	0.15	0.34ns
Error	20	8.70	0.43	

ANOVA 14. Effect of amending *Striga*-infested plots with neem soil amendments on 1000-grain weights of sieved grain yields collected on 2.36mm sieve at Katsina, 2001

Sources	DF	SS	MS	F
Treatments	5	18.11	3.62	2.69ns
Blocks	4	2.24	0.56	0.42ns
Error	20	26.91	1.35	

ANOVA 15. Effect of amending *Striga*-infested plots with neem soil amendments on the % proportion of marketable Grain yields sieved and collected on 2.00 and 2.36mm sieve at Katsina, 2001

Sources	DF	SS	MS	F
Treatments	5	6923.18	1384.64	6.56**
Blocks	4	414.26	103.57	0.49ns
Error	20	4223.07	211.15	

LSD (P=O.01) =t0.01√{(2Error MS)/r } = 26.15
Coefficient of linear correlation, r = 0.83

ANOVA 16. Effect of amending *Striga*-infested plots with neem soil amendments on the % proportion of unmarketable Grain Yields collected 1.18 and 1.70mm sieve at Katsina, 2001

Sources	DF	SS	MS	F
Treatments	5	6923	1385	6.56**
Blocks	4	414	104	0.49ns
Error	20	4223	211	

LSD (P=O.01) = t0.01.√{(2Error MS)/r} = 26.15
Coefficient of linear correlation, r = 0.83

ANOVA 17. Effect of amending *Striga*-infested plots with neem soil amendments on pooled 1000-grain weights of the Grain yields of millet at Katsina, during the 2001 trial

Sources	DF	SS	MS	F
Treatments	5	4.03	0.81	5.17**
Blocks	4	0.41	0.10	0.65ns
Error	20	3.12	0.16	

LSD (P=O.01)= t0.01.√{(2Error MS)/r} = 0.71
Coefficient of linear correlation, r =0.74

ANOVA 18. Effect of amending *Striga*-infested plots with neem soil amendments on final *Striga* counts at harvest in Katsina, during the 2001 trial

Sources	DF	SS	MS	F
Treatments	5	54028.67	10805.73	53.59**
Blocks	4	2149.80	537.45	2.67ns
Error	20	4033	201.65	

LSD (P=O.01) = $t_{0.01}\sqrt{}$(2Error MS)/r = 25.55

Coefficient of linear correlation, r = -0.83

ANOVA 19. Effect of amending *Striga*-infested plots with neem soil amendments on the dry biomass of emerged *Striga* in Katsina, during the 2001 trial

Sources	DF	SS	MS	F
Treatments	5	339650.36	67930.07	7.42**
Blocks	4	35005.07	8751.27	0.96ns
Error	20	183113.38	9155.67	

LSD (P=O.01)= $t_{0.01}\sqrt{\{(2\text{Error MS})/r\}}$ = 172.17

Coefficient of linear correlation, r = -0.47

Appendix 3: Allelophathy in neem, suppressing the growth of most weed.



Appendix 4: Allelophathy in neem residue deposits (a) and pruned neem trees (*b*) *suppressing* weeds.



(a)

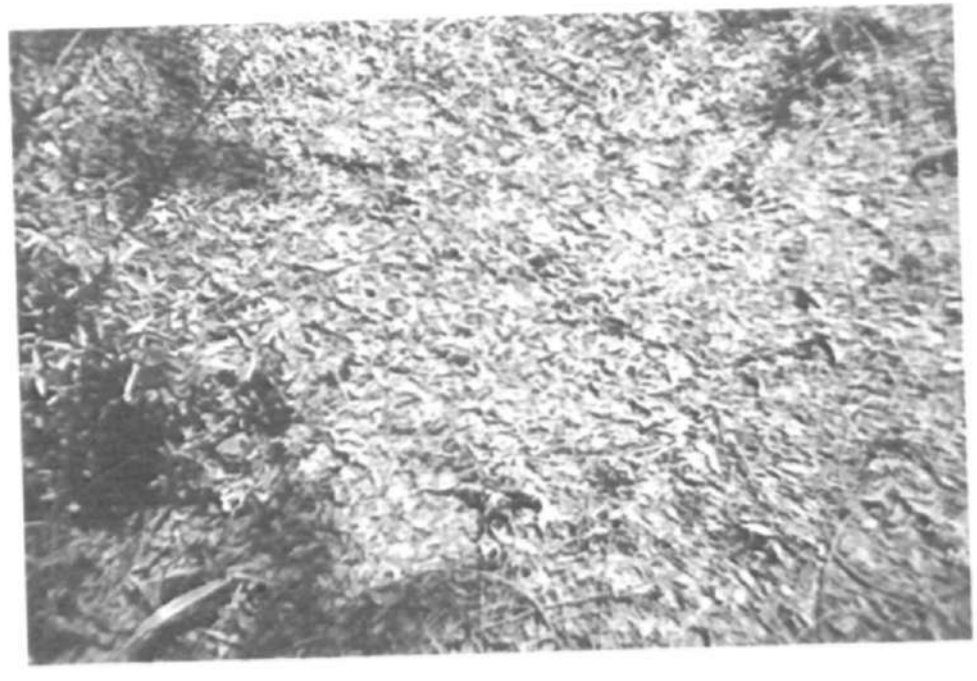


(b)

Appendix 5: Allelophathic neem trees (a) and deposits of neem residues (b) selectively allow the germination and growth of their seeds and seedlings only.



(a)



(b)

Appendix 6: Neem trees on croplands at Katsina.









Appendix 7: Neem trees planted along highways, rural feeder roads, village paths, city streets and public buildings in Katsina.









SHORT BIOGRAPHY

Name: Yar'adua, Abdullahi Ahmad

Date of birth: 1st October, 1957

Business Address: College of Agriculture
Hassan Usman Katsina Polytechnic,
PMB 2056, Katsina

Home Address: #137 Yahaya Madaki Way Katsina, Nigeria.

Previous Qualifications:

Institutions Attended	From	To	Certificate
Gobarau Primary Sch, Katsina	1963	1970	Primary certificate
G.S.S Malunfashi	1971	1975	WASC
KCAST Zaria	1975	1977	IJMB
ABU Zaria	1977	1980	B.Sc. Microbiology
ABU Zaria	1983	1986	M.Sc Crop Protection

Posts Held Since the Award of first degree

Organization	From	To	Position
N.Y.S.C, Sokoto State	1980	1981	Teacher
HUK Polytechnic	1981	Date	Chief lecturer

Year of Admission for Postgraduate Studies: 1999/2000 Academic Session

Admission Number: Ph.D/Agric/22520/99-2000