International Journal of Pest Management, April–June 2007; 53(2): 111 – 119

Taylor & Francis
Taylor & Francis Group

Farmers' knowledge, perceptions and management of the gall-forming wasp, *Leptocybe invasa* (Hymenoptera: Eulophidae), on *Eucalyptus* species in Uganda

PHILIP NYEKO[1], ESTON K. MUTITU[2], & ROGER K. DAY[3]

[1]*Department of Forest Biology and Ecosystems Management, Makerere University, Kampala, Uganda,* [2]*Kenya Forestry Research Institute (KEFRI), Nairobi, Kenya, and* [3]*CAB International Africa Regional Centre, Nairobi, Kenya*

Abstract
Farmers growing *Eucalyptus* species in Uganda were interviewed using a pre-tested questionnaire to investigate their knowledge, perceptions and management of the *Eucalyptus* gall-forming wasp, *Leptocybe invasa* Fisher & LaSalle, with the aim of developing integrated management programme for the pest. Farmers were aware of, and concerned about, the gall problem on *Eucalyptus*, but the vast majority of them did not know the cause. Most farmers did not attempt to control the infestation because they did not know of suitable control methods and/or the cause of the problem. Farmers' control decisions were not influenced by their experience in cultivating *Eucalyptus* or their education level. Only 20% of 59 farmers interviewed had received advice on *L. invasa*, suggesting poor flow of information on tree pests to farmers. Nearly all farmers interviewed still wanted to plant *Eucalyptus*, and they saw the trees as a source of several products and services. Problems relating to the increasing emergence of alien insect pests in tropical forests, and challenges and strategies for effective management of forest pests in developing countries are discussed.

Keywords: Eucalyptus*, indigenous knowledge,* Leptocybe invasa*, pest management, plantation forestry*

1. Introduction

Arthropod pests are one of the major constraints upon the productivity of plantation forestry in Africa (Wagner et al. 1991; Nicolas et al. 1999). However, there continues to be very little information on tree farmers' perceptions of such pests, their management practices and decision-making processes (but see Nyeko et al. 2002; Nyeko and Olubayo 2005). In contrast, traditional pest management practices in agriculture have been studied for a number of cropping systems and the results used as inputs for developing integrated pest management packages (Norton et al. 1999; Bentley and Baker 2002). Farmers have the advantage over scientists in that they often have a life-long experience of growing their crop; experience which has been built up through regular observations and exchange of information through formal and informal actor networks (Van Mele and Van Chien 2004). As plantation forestry is developed and promoted, there is a need to integrate indigenous knowledge about pest identification and management techniques into the development processes in order to improve tree farmers' pest management practices.

One of the tree species most widely promoted in the tropics to meet the high and increasing demands for tree products and services is *Eucalyptus*. The popularity of *Eucalyptus* species is attributable to them being generally adaptable, having fast growth and good potential for sawn wood and processed wood products, high calorific value fuelwood and a variety of environmental and ornamental uses (Poore and Fries 1989). In Uganda, many organisations and government institutions promote the planting of *Eucalyptus* by local farmers. Recently, the Forestry Resources Research Institute (FORRI) introduced a number of *Eucalyptus* clones from South Africa into the country to increase the *Eucalyptus* production. The Integrated Rural Development Initiative (IRDI), a non-profit making non-governmental organisation (NGO), has been establishing *Eucalyptus* woodlots in some refugee settlements in Uganda to protect the environment while ensuring sustainable supply of tree products in the settlements. Commercial companies such as British American Tobacco (BAT) also encourage the establishment of *Eucalyptus* woodlots as an alternative supply of timber and fuelwood. However, to be successful, such schemes require good management, and good management depends on knowledge of growth constraints, including pests and diseases.

An insect pest, *Leptocybe invasa* (Hymenoptera: Eulophidae), has recently been reported on *Eucalyptus*

Correspondence: Philip Nyeko, Department of Forest Biology and Ecosystems Management, Makerere University, P.O. Box 7062, Kampala, Uganda. Tel: 256 41 543647. Fax: 256 41 533574. E-mail: nyeko@forest.mak.ac.ug

ISSN 0967-0874 print/ISSN 1366-5863 online
DOI: 10.1080/09670870601185230

species in several countries including Algeria, Iran, Israel, Italy, Jordan, Kenya, Morocco, Spain, Syria, Turkey and Uganda (Mutitu 2003; Mendel et al. 2004; Nyeko 2004). The adult of *L. invasa* is a very small (1.0 – 1.4 mm long) black wasp (Mendel et al. 2004). The species has been described as a new taxon of Australian origin (Mendel et al. 2004). It lays eggs in the bark of shoots or the midribs of leaves. The eggs develop into minute, white, legless larvae within the host plant. The developing larvae induce coalescing galls to form on the host plant tissue (Mendel et al. 2004). The galls can cause the twigs to split, destroying the cambium. Small circular holes, indicating exit points of adults from pupae, are common on the galls. Severely infested trees show gnarled appearance, stunted growth, lodging dieback and eventually tree death (Mendel et al. 2004; Nyeko 2005).

In Uganda, several concerns have been raised about the *L. invasa* infestation on *Eucalyptus* (Nyeko 2005), but there has been no study on farmers' knowledge and perceptions of the pest problem, and their coping strategies. This paper documents farmers' knowledge, perceptions and management of *L. invasa* with the aim of developing integrated management of the pest. In addition, problems relating to emergence of such alien insect pests in tropical forests, and challenges and strategies for effective management of forest pests in developing countries are discussed.

2. Material and methods

The study was conducted in January and February 2006. In total, 59 respondents were interviewed using a pre-tested questionnaire in the districts of Arua, Isingiro, Kumi, Masindi, Mbale, Ntungamo, Sironko and Tororo in Uganda. The districts belong to five agroecological zones in the country: Eastern lowlands (Tororo and Kumi), Eastern highlands (Mbale and Sironko), Lake Albert crescent (Masindi), Southern drylands (Ntungamo and Isingiro) and West Nile (Arua) where severe *L. invasa* infestation on *Eucalyptus* species has been reported (Nyeko 2005). Farmers to be surveyed were selected from lists of farmers that were obtained from FORRI and BAT.

Most survey questions were open-ended in order to avoid limiting farmers' opinions. Data were collected on farmers' social and educational profiles as well as on their experiences of cultivation of *Eucalyptus*. Special emphasis was placed on exploring farmers' awareness of *L. invasa* and its infestation, advice they had recived on the pest, and their management practices against it. Specifically, farmers were asked to list and rank the following: (i) five causes of *Eucalyptus* mortality they had observed in the previous year, (ii) five main reasons for cultivating *Eucalyptus*, and (iii) five main problems they encountered in cultivating *Eucalyptus*. Farmers were also asked to rank the level of *L. invasa* infestation on different age categories (< 1 year, 1 – 3 years, 3 – 5 years and > 5 years old) of their *Eucalyptus* stands into the following classes: (i) none (no tree infested), (ii) low (< 20% of trees infested), (iii) moderate (20 – 50% of trees infested), and (iv) high (> 50% of trees infested). In order to elicit farmers' ability to manage *L. invasa*, farmers were asked to advise their neighbours or friends who might seek their advice on the pest. Finally, information was sought on farmers' future plans on cultivating *Eucalyptus*. In this we tried to understand the importance of *Eucalyptus* in farmers' livelihoods.

In each district, one research assistant who was conversant with the most commonly spoken local language was recruited and trained by the principal researcher to guide the researcher to the farmers and translate questions into the local language during the interviews. All interviews were conducted in farmers' *Eucalyptus* stands. This enabled researchers to crosscheck farmers' answers regarding the pest status with field observations.

The survey data were encoded, entered into a spreadsheet for collation and checking and then analysed with the SPSS statistical package (release 10 for windows) (Bryman and Cramer 2001). In addition to using descriptive statistics to summarise data, Pearson correlation was used to determine if farmers' educational level and their experience in cultivating *Eucalyptus* influenced their decision to control *L. invasa*. For this analysis, farmers' experiences (year since each farmer first planted *Eucalyptus* on his/her farm) were grouped into three categories; less than 5 years, 5 – 10 years and more than 10 years experience. Similarly, formal education level was categorised into none, primary, lower secondary, higher secondary and post secondary diploma or certificate.

3. Results

3.1. Profiles of respondents

The vast majority (92%) of respondents were from male-headed households. Most (93%) respondents were married and very few were either single (3%) or widowed (3%). Up to 73% of the respondents were *Eucalyptus* plantation/woodlot owners. Other respondents included relatives of plantation owners (15%), employees working in plantations (10%) and one was a wife to a plantation owner. The majority (70%) of the respondents were full time farmers, 25% were part-time and a further 5% were away from the districts where they established their *Eucalyptus* plantations. Most (97%) of the respondents had some formal education although the majority (41%) of them were only educated to primary level. Some (27%) of the respondents had attained diploma or post secondary certificates while 25 and 3% of them had left education in lower and higher secondary schools, respectively. The farmers acquired their land mainly through inheritance (56%) and purchase (36%). A few (7%) of them cultivated *Eucalyptus* on land owned by the Ugandan government (2%), schools (3%) and a church (2%). One respondent was the manager of a *Eucalyptus* stand in a forest reserve owned by the Uganda National Forestry Authority in Tororo district.

3.2. Cultivation of Eucalyptus *species*

Farmers' experience in cultivating *Eucalyptus* ranged from less than 1 year (first planting in 2005) to about 75 years (first planting in 1930). *Eucalyptus grandis* was the most commonly planted species (78% of total respondents). Other *Eucalyptus* species planted included *E. camaldulensis* planted by 29% of respondents, *E. saligna* (14%), *E. citriodora* (2%) and *E. robusta* (2%). The number of *Eucalyptus* trees the farmers had planted on their land varied markedly, with the majority (41%) having more than 2000 trees. Twenty four percent of the farmers had 100–500 trees, 20% had 1000–2000 trees while 15% had 500–1000 trees. Up to 73% of the respondents established their *Eucalyptus* stands using the taungya system only, 24% used grassland planting and only 3% of them had used both taungya and grassland planting. When asked to rate the mortality of their *Eucalyptus* in the previous year, 48% of the respondents ranked the mortality as low (less than 20% of trees dead), 25% moderate (20–50% trees dead), 20% high (more than 50% of trees dead) and 7% reported no dead trees. Farmers cited 11 causes of *Eucalyptus* mortality (Table I). Termites were the most commonly reported cause of tree death, accounting for 28% of 86 responses. Drought reported by 20% of respondents and unidentified diseases (16%) were also highly cited mortality causes. Three farmers showed the researchers trees that had typical symptoms of *Botryosphaeria* infection (cracks and oozing of brown sap from the stem), and they claimed that the disease had been the worst problem on their stands in the previous year. Similarly, four respondents presented samples of *Eucalyptus* infested by *L. invasa*, which they considered to be most damaging on their *Eucalyptus* stands.

Only 37% of the respondents had received advice on growing *Eucalyptus*. The farmers received such advice from various sources including, district forest department (38%), FORRI (14%), friends and/or neighbours (14%), secondary school teachers (10%), district department of agriculture (4.8%) and National Agricultural Advisory Services (NAADS) (4.8%).

Farmers mentioned several reasons for cultivating *Eucalyptus* (Table II). The commonly cited reasons for growing *Eucalyptus* were to supply construction materials (30% of 194 responses), fuelwood (29%) and income (28%). The majority of respondents (66% of total respondents) ranked income as their first reason for growing *Eucalyptus* compared with only 14% and 12% for fuelwood and construction materials, respectively. Very few farmers ranked boundary marking, environmental protection, beekeeping, draining swamp and ease of management as their first reasons for growing *Eucalyptus* (Table II).

Farmers mentioned a number of problems they faced when cultivating *Eucalyptus* (Table III). Insect pests and diseases were the most commonly and highly ranked problems, followed by lack of technical advice and lack of good quality planting material. One farmer claimed not to have any major problem in cultivating *Eucalyptus*, while 8% of farmers mentioned theft of their trees, suggesting inadequate supply of *Eucalyptus* products.

3.3. Knowledge and perceptions of Leptocybe invasa *and its infestation*

All of the respondents had observed the symptoms of *L. invasa* infestation on *Eucalyptus*.

Table I. Farmers' ranking of the causes of *Eucalyptus* mortality on their farm in the previous year.

	Rank (number of responses)				Total responses*	
Causes	1st	2nd	3rd	4th	No.	%
Termite	18	9	1	0	28	32.6
Drought	12	6	2	0	20	23.3
Disease	12	3	1	0	16	18.6
Late tending	4	1	0	0	5	5.8
Leptocybe invasa	4	0	0	0	4	4.7
Livestock	0	1	2	1	4	4.7
Unknown	3	0	0	0	3	3.5
Water logging	1	1	0	0	2	2.3
Vandals	0	1	1	0	2	2.3
Fire	1	0	0	0	1	1.2
Beetle	0	1	0	0	1	1.2

*Multiple responses were possible since most farmers cited more than one causes of tree mortality.

Table II. Farmers' main reasons for cultivating *Eucalyptus* species in Uganda.

	Rank (number of respondents)					Total responses*	
Reasons for growing *Eucalyptus*	1st	2nd	3rd	4th	5th	No.	%
Timber for construction	7	29	20	1	1	58	29.9
Fuelwood	8	22	23	3	0	56	28.9
Income	39	7	6	3	0	55	28.4
Boundary marking	1	0	3	4	1	9	4.6
Environmental protection	1	0	0	5	1	7	3.6
Windbreak	0	0	1	1	1	3	1.5
Beekeeping	1	0	0	1	0	2	1.0
Draining swamp	1	0	0	0	1	2	1.0
Easy management	1	0	0	0	0	1	0.5
Medicine	0	0	0	1	0	1	0.5

*Multiple responses were possible as most farmers planted *Eucalyptus* for more than one reason.

However, the majority of them (93%) pointed out that they did not know the cause of the problem. When asked to name the cause of the infestation, the few farmers who claimed to know cited ants (one farmer), an unidentified insect (one farmer), small white insects (one farmer) and an unidentified disease (one farmer). The majority (87%) of the farmers first observed *L. invasa* infestation on *Eucalyptus* between the years 2000 and 2005, with nearly half (49%) of them seeing the symptoms for the first time either in 2004 or 2005. Two farmers (one from Arua and the other from Ntungamo district) recalled seeing the problem for the first time in 1997 (the earliest time reported). Most farmers (60%) reported *L. invasa* infestation to be most common in the dry season although 25% perceived the damage to be common throughout the year. Some of the respondents (15%) were not sure of the seasonal variation in the incidence of *L. invasa* infestation.

The majority of farmers who had *Eucalyptus* seedlings or coppices less than 1-year-old ranked the incidence of *L. invasa* infestation on this growth stage as high (more than 50% of trees attacked) (Table IV). In contrast, most farmers who had *Eucalyptus* stands older than 1 year reported either no or low *L. invasa* infestations on these cohorts (Table IV). When asked to mention the effects of *L. invasa* infestation on *Eucalyptus*, the majority (46%) of farmers reported that the insect reduces the growth rate of *Eucalyptus*; 29% reported reduced growth and tree mortality; 12% mentioned reduced growth and tree deformation; 9% cited reduced growth, tree deformation and mortality; 2% had observed tree deformation only; 2% mention tree deformation and mortality; and 2% were not sure.

Up to 48% of the respondents claimed that they had observed *L. invasa* infestations on other tree species and/or crops. The farmers mentioned a total of 13 other plant species that they perceived was attacked by *L. invasa* (Table V). Of these, cassava was by far the most commonly mentioned species followed by oranges and mangoes (Table V). When farmers presented samples of the plants they perceived were infested by *L. invasa* to the researchers, no typical *L. invasa* gall damage on any of the samples were observed. Cassava samples showed symptoms of the cassava mosaic virus infection. Samples of oranges, mangoes, *Spathodea campanulata* and *Annona senegalensis* had leaf galls, which were not typical of *L. invasa* infestation. Banana and coffee samples were yellowish and wilting. The *Thevolia* species observed had curled leaves with yellowish strips, possibly caused by a virus. *Markhamia lutea* was infested by unidentified species of aphid and scale insects. No samples of maize, beans and groundnuts were observed during the study because these crops were out of season.

Table III. Farmers' ranking of their main problems in cultivating *Eucalyptus* in Uganda.

Problems in growing *Eucalyptus*	Rank (number of respondents)					Total responses*	
	1st	2nd	3rd	4th	5th	No.	%
Insect pests and diseases	28	14	9	0	1	52	32.7
Lack of technical advice	8	9	6	3	0	26	16.4
No quality planting material	4	10	5	1	0	20	12.6
Lack of ready market	3	4	4	1	0	12	7.5
Drought	2	5	4	1	0	12	7.5
Livestock damage	3	0	1	3	1	8	5.0
Thieves	1	3	1	0	0	5	3.1
Lack of labour	2	3	0	0	0	5	3.1
Lack of tools	1	1	1	0	0	3	1.9
Weeds	0	2	0	0	1	3	1.9
Lack of money	2	1	0	0	0	3	1.9
Fire	1	1	0	0	0	2	1.3
Limited land	1	0	0	0	1	2	1.3
Poor soils	1	0	0	1	0	2	1.3
Stinging bees	0	0	0	1	0	1	0.6
Water logging	0	0	1	0	0	1	0.6
Malicious damage	1	0	0	0	0	1	0.6

*Multiple responses were possible as each farmer could cite more than one problem encountered in cultivating *Eucalyptus*.

Table IV. Farmers' ranking of *Leptocybe invasa* damage on different growth stages of *Eucalyptus*.

Growth stage	Damage level (number of responses)*				Total responses	
	None	Low	Moderate	High	No.	%
< 1 year old	0	5	8	35	48	39.7
1–3 years old	16	17	9	9	51	42.1
3–5 years old	12	4	1	2	19	15.7
> 5 years old	2	1	0	0	3	2.5

*None refers to no tree infested by *L. invasa*; low, less than 25% of trees in stand infested by *L. invasa*; moderate, 25–50% of trees infested; high, more than 50% of trees infested.

Table V. Farmers' observations of *Leptocybe invasa* infestation on plants other than *Eucalyptus* species.

Tree/crop species	Total responses	
	No.	%
Manihot esculenta Grantz (cassava)	18	47.4
Citrius species (oranges)	5	13.2
Mangifera indica L. (mangoes)	3	7.9
Musa species (banana)	2	5.3
Spathodea campanulata Beauv.	2	5.3
Thevolia species	1	2.6
Persea americana Mill. (avocado)	1	2.6
Markhamia lutea (Benth.) K.Schum.	1	2.6
Phaseolus vulgaris L. (beans)	1	2.6
Coffea species (coffee)	1	2.6
Arachis hypogaea L. (groundnuts)	1	2.6
Zea mays L. (Maize)	1	2.6
Annona senegalensis Pers.	1	2.6
Total	38	100.0

3.4. *Control of* Leptocybe invasa

The vast majority (80%) of farmers had not attempted any control measure against *L. invasa*. The farmers cited a number of reasons for doing so. The majority of them mentioned lack of knowledge on suitable control methods (59%) followed by lack of knowledge on the cause of the problem (20%), lack of money (8%), and lack of interest (3%). One farmer claimed that he had not yet seriously thought about controlling the pest. Farmers' formal education level ($r = -0.189$; $P = 0.151$) and experience in cultivating *Eucalyptus* ($r = 0.022$; $P = 0.868$) showed no significant relationship with their decision to control *L. invasa*.

Of the 12 farmers who attempted to control *L. invasa*, 42% reported using chemicals only, 33% cultural methods only and 17% both chemicals and cultural methods. One farmer attempted foliar application of a liquid fertiliser, which he claimed was highly effective against *L. invasa*. The cultural control methods attempted by farmers included foilar application of ash dissolved in water (two farmers), uprooting infested seedlings by hand (two farmers), cutting off infested trees (one farmer), pruning infested trees (one farmer), and weeding (one farmer). The farmer who pruned affected trees claimed that the method was highly effective against *L. invasa*. In contrast, those who uprooted *L. invasa* infested seedlings reported this method was not effective. Application of ash was reported to be either ineffective (one farmer) or moderately effective (one farmer). Weeding and cutting of infested trees were reported to be moderately effective. The farmers who applied chemicals reported using foliar application of Sumithion (fenitrothion), Marathon (imidacloprid), malathion, Fenkil, diamethoate and Ambush (permethrin). Of these Sumithion, Malathion and Ambush were reported to be ineffective while Fenkil and diamethoate were reported as being highly effective against the insect.

3.5. *Advice on* Leptocybe invasa

The majority (81%) of farmers had not received any advice on *L. invasa*. The few who had received some advice did so from various sources (Table VI). The advice given to farmers ranged from preventive measures to cultural, mechanical and chemical control methods, which most of the farmers perceived as useful (Table VI). However, one farmer noted that the advice to cut and burn *L. invasa* infested trees was not useful in controlling the pest in his *Eucalyptus* stand. When suggesting advice on pest management to neighbours or friends who might be interested in planting *Eucalyptus*, farmers proposed several options (Table VII). Most farmers (22% of 67 responses) recommended planting resistant types of *Eucalyptus*, which they could not specify, and seeking advice from experts (19%). Some farmers (8%) pointed out that they would not offer any advice because of their inadequate knowledge of the insect.

3.6. *Future plans on cultivating* Eucalyptus *species*

The majority (95%) of farmers were still interested in planting *Eucalyptus* species despite the problems they had encountered in cultivating the species. They wanted to do so mostly for income generation (85% of total respondents), supply of construction materials (80%) and fuelwood (78%). Other reasons that some farmers considered important for future planting of *Eucalyptus* were environmental protection (15%), boundary marking (7%), beekeeping (3%), fast growth (2%), good coppicing ability (2%), less labour demanding (2%) and availability of land (2%). Of the few (5%) farmers who were not interested in planting *Eucalyptus* in the future, two had inadequate land and one was discouraged by *L. invasa* infestation.

Farmers commonly mentioned their own stands or nurseries (39% of total respondents) and open

Table VI. Advice received by farmers on *Leptocybe invasa* infestation in Uganda.

		Useful			Total responses	
Advice	Source*	Yes	No	NA*	No.	%
Wait, we are still researching	DFD, DDA, FORRI	2	1	0	3	18.8
Spray with chemicals	DDA, FORRI	2	1	0	3	18.8
Plant resistant types of *Eucalyptus*	NFA, NFC	1	1	0	2	12.5
Cut and burn affected trees	DAD, FORRI	1	0	1	2	12.5
No chemical can control the pest	DFD	0	1	0	1	6.3
Weed properly	NFA	1	0	0	1	6.3
Plant healthy seedlings from a good source	NFA	1	0	0	1	6.3
Ensure timely planting	NFA	1	0	0	1	6.3
Apply liquid fertilizer (rapid grow)	DFA	1	0	0	1	6.3
Beware of a disease on *Eucalyptus*	DFD	1	0	0	1	6.3
Total		11	4	1	16	100.0

*NA, advice not yet applied; DFD, District Forest Department; DAD, District Department of Agriculture; FORRI, Forestry Resources Research Institute; NFA, National Forestry Authority; NFC, Nyabyeya Forestry College; DFA, District Farmers' Association.

Table VII. Summary of the advice farmers would offer to friends/neighbours interested in planting *Eucalyptus* species.

Advice	Total responses No.	%
Plant resistant *Eucalyptus* species	15	22.4
Seek advice from experts	13	19.4
Cannot advise because of inadequate knowledge on the insect	5	7.5
Plant, some will survive	4	6.0
Plant, but beware of the problems	4	6.0
Plant, and spray with chemicals	4	6.0
Plant, control methods may be developed in future	3	4.5
Plant, and manage (weed) your plantation well	3	4.5
Prune-infested trees	3	4.5
Plant and wait for whatever comes out	2	3.0
Plant, the problem can be seasonal	2	3.0
Buy seedlings from a technical person	2	3.0
Plant different tree species from *Eucalyptus*	2	3.0
Plant, there are inadequate tree products in the area	1	1.5
Plant, it is a sure source of income	1	1.5
Mix manure with soil before planting	1	1.5
Plant, the problem is like any other tree and crop disease	1	1.5
Collect seeds from trees which are not attacked	1	1.5
Total	67	100.0

markets (37%) as sources of their planting materials (seeds and/or seedlings) for future planting. A few farmers planned to obtain their planting materials from FORRI (9%) and district forest departments or NFA (9%). The least mentioned sources of planting materials were neighbours (2%) and BAT (2%). One farmer pointed out that he needed to be informed about *Eucalyptus* species which are resistant to *L. invasa* before he could decide on the source of planting material.

4. Discussion

4.1. Emergence of alien insect pests in tropical forests

Results of this study further exemplify the problems caused by alien pests of trees in the tropics. Several insect pests of *Eucalyptus* from Australia have emerged in exotic plantations in tropical countries where they cause more serious damage than in Australia, apparently due to absence of their natural enemies. The empirical review of pest outbreaks in tropical forest plantations by Nair (2001) provides excellent examples of such pests, including curculionids, *Gonipterus scutellatus, G. gibberus* and *G. platensis*; the cerambycid, *Phoracantha semipunctata* and *P. recurva* recorded in south Africa, Zambia and South America; the chrysomelid, *Trachymela tincticollis* found in South Africa; the flower feeding beetle, *Drosophila flavohirta* observed in Madagascar and South Africa; and the scale insect, *Icerya purchasi* reported in Angola, Malawi and India. In the 1990s the cypress aphid, *Cinara cupressivora*, precipitated a crisis, especially on *Cupressus lusitanica* in eastern and central Africa (Murphy 1996). Similarly, the pantropical spread of Leucaena psyllid, *Heterosylla cubana*, from its centre of origin in the Caribbean to Hawaii in 1984, then to Asia and in Africa in 1990s inflicted major damage to *Leucaena leucocephala* (Napompeth 1994). Such pests will continue to appear in exotic plantations in the tropics (Nair 2001; Wingfield et al. 2001), posing a serious threat to the productivity of plantations and thus the livelihoods of people and industries that rely on them.

The increasing emergence of pests of trees in the tropics has been attributed to a number of factors. First, the trend in tropical plantation forestry has been to establish fast-growing exotic trees as pure stands. Exotic tree species run a high risk of attack by alien pests (Murphy 1998; Wingfield et al. 2001). Similarly, monocultures especially of genetically similar trees are associated with increased probability of pest outbreaks and can transform sporadic pests into permanent problems (Cock 2003). Second, there has been rapid increase in the area of tree plantation and on-farm trees in the last few decades and poor tree species-site matching, especially in sub-Saharan Africa (Murphy 1998). Third, the proliferation of international trade and travel, and the resultant overstretching of quarantine services, is a major factor influencing accidental introduction of alien pests (Bright 1999). Forest products such as packaging materials can be particularly important in facilitating the movement of pest species (Cock 2003). An example of this is the arrival of the devastating *Eucalyptus* snout beetle, *Gonipterus scutellatus*, in South Africa in 1916 in a consignment of apples from Tasmania (Annecke and Moran 1982). Fourth, several studies indicate that climate change can increase the range of many insects and thus their pest status (Watson 2001). However, empirical evidence on the effects of climate change on the invasion of alien insect pests in tropical forests is lacking.

4.2. Challenges to effective management of alien tree pests in developing countries

Forest pest management programmes in many developing countries have remained inadequate, although there are some examples of success, primarily through the use of classical biological control and host plant resistance (Wylie 2002; Day et al. 2003; Tribe 2003). In response to some countries' need for control of invasive alien pests, several forestry pest management programmes have been started in developing countries mostly with external support from international agencies (Cock 2003; Day et al. 2003). Although such programmes created opportunities to effect institutional development while addressing the immediate problem of forest pest management, there still exist a myriad of institutional and socio-economic barriers (Speight and Wylie 2001).

In most developing countries national plant protection organisations have been given extensive powers to control imports and exports, disposal, inspection and survey and treatment of plant and plant products, but they lack the means to implement the regulations. This situation is more alarming for forest pest management, which has low priority relative to the more pressing agricultural pest problems (Nair 1991). Often, the mechanism for monitoring and detecting forest pests, and rapid plans to allow for eradication of new invasions are lacking. Without sound monitoring and law enforcement teams, early detection and rapid response to new invasions are impossible and countries are left with expensive management options, often when the new invasive species has resulted in large-scale losses (Anon. 2005). Moreover the high cost of managing forest pest outbreaks generally prevents large-scale treatment, except in developed countries. National forestry programmes in low-income countries thus need to shift emphasis from such 'corrective' forest pest management to 'preventive' forest pest management. In developed countries, the trend in managing forest pests indicates increasing development of preventive methods such as pest risk analysis, quarantine laws and regulations, early detection methods, and public education programmes (Cock 2003).

Additional barriers to effective management of forest pests in developing countries are the small number of forest entomologists, their inadequate training in the concepts and techniques of IPM, and the lack of or inadequate support for research in forestry at institutional and national levels (Nair 1991). For example, analysis of forest pest management in 15 African countries by Akanbi and Ashiru (1991) showed that the plant protection services in all the countries involved very small teams, sometimes comprising a single person with little or no support facilities to practice effective plant protection. Some countries such as Malawi had excellent permanent forest pest monitoring teams in the past, but these teams have not been retrained in the last few years and many that have left have not been replaced (Anon. 2005).

The weak institutional, human and physical resources to address forest pest problems in developing countries are a handicap to the access, generation and transfer of vital information for making informed decisions on tree pests. Globally, there is an increasing body of relevant information that national forestry programmes need to access and contribute to, but the wherewithal to do this is lacking in many developing countries. There is inadequate sharing and exchange of tree pest information between different stakeholders, including the different arms of government, the private sector, civil society and the general public (Dix 1996). In the present study, for example, the vast majority of farmers were not only unaware that *L. invasa* is the cause of the gall damage on their *Eucalyptus*, but also reported not knowing the insect. Such limitations in farmers' knowledge clearly define the need for research and extension services.

4.3. Suggestions for improving management of forest pests in developing countries

4.3.1. Institutional strengthening. Most developing countries need major reforms in national forestry programmes for institutional strengthening, training and regional cooperation based on sustainable forest pest management strategies and implementing these in forest management plans. The main focus of such programmes must be on overall forest health, whether it be the case of forest monocultures, polycultures or natural forests (Murphy 1998). As pointed out by Dix (1996), assistance from international agencies in, for example, establishing research partnerships and information programmes, and providing financial and administrative support may be necessary for such programmes to succeed.

4.3.2. Political support. Successful implement of IPM often needs the right political structure and priorities, and change in attitude across a broad spectrum of stakeholders, at the national and international levels (Dix 1996; Neuenschwander et al. 2003). Governments need to develop the necessary infrastructure and institutional arrangements to effectively promote plant protection capacities and guarantee compliance with the related international agreements, conventions and treaties (Neuenschwander et al. 2003). This requires, among other things, appraisal and effective implementation of national policies that have direct and indirect effects on forestry, and in particular forest health.

4.3.3. Research. More research on forest pest management in developing countries needs to be directed into problem solving, involving multidisciplinary approaches with emphases on applied studies and transfer of appropriate technologies. Experience from IPM indicates that the complexity of ecologically based pest management may become a major limitation to its implementation (Wylie 2002). For example, farmers often lack the biological and ecological information necessary to implement IPM (Abate 2000). One way of empowering such farmers is through an educational system that combines aspects of western technical knowledge with local knowledge (Trutmann et al. 1996). The farmers' field school approach and community advisory concept (Van Huis and Meerman 1997; Norton et al. 1999; Price 2001) could be excellent ways for agencies promoting tree growing to both generate and spread information about integrated management of tree pests such as *L. invasa* among farmers.

Research is necessary to develop sustainable, low input technology, environmentally sound and cost-effective pest management strategies to particular local conditions. Important components that should be examined in an integrated approach include pest monitoring and detection, biological control methods, host resistance and silvicultural practices (Wylie 2002). Particular emphasis needs to be given to identification of IPM strategies such as use of resistant host tree species, correct tree germplasm-site matching and the conservation of natural enemies, which prevent or reduce the risk of pest problems occurring.

4.3.4. Information exchange. Synthesis, simplification and transfer of tree health information among researchers, extension agents, policy makers, tree growers, suppliers of forestry supplements, and private agencies are important in speeding up successful development and implementation of sustainable pest management. Forest extension agencies and scientists, in particular, need to become more active and interested participants for this to be successful. Cooperative activity among tree growers, suppliers of forestry supplements, and development agencies as well as the scientific community could facilitate information flow and rapid response to pest invasion and, thus, reduce pest management costs. For example, such cooperatives can link local communities to national and international research and development facilitators as partners in compiling, sharing and integrating their respective knowledge bases from which management options are derived for evaluation and adaptation in specific localities by local communities themselves. Internationally, tree pest information networks such as the Forest Invasive Species Network for Africa (FISNA) formed in 2005, could provide excellent channels for exchange of information on forest invasive species between countries and/or continents. Such networks could also be useful in alerting relevant agencies about new invasive species, and providing policy advice on trans-boundary movement and phytosanitary measures (Anon. 2005).

Acknowledgements

The African Forestry Research Network (AFORNET) funded this study. We gratefully acknowledge J. Ogwang, S. B. Ogwal, R. Twebaze, A. Ahimisibbwe, H. Mutabazi and F. Yiiki for their assistance in conducting the interviews.

References

Abate T, Van Huis A, Ampofo JK. 2000. Pest management strategies in traditional agriculture: an African perspective. Annual Review of Entomology 45:631–659.

Akanbi MO, Ashiru MO. 1991. Towards integrated management of forest defoliators: the Nigeria situation. Forest Ecology and Management 39:81–86.

Annecke DP, Moran VC. 1982. Insects and mite of cultivated plants in South Africa. Durban, South Africa: Butterworth.

Anon. 2005. FISNA: Forest Invasive Species network for Africa. Tree Protection Newsletter, 10. November 2005.

Bentley JW, Baker PS. 2002. Manual for collaborative research with smallholder coffer farmers. Egham, UK: CABI Commodities. p 130.

Bright C. 1999. Invasive species: pathogens of globalisation. Foreign Policy 116:50–64.

Bryman A, Cramer D. 2001. Quantitative data analysis with SPSS release 10 for windows. East Sussex, UK: Routledge. p 295.

Cock MJW. 2003. Biosecurity and Forests: An introduction with particular emphasis on forest pests. Forest Health and Biosecurity Working paper FBS/2E. FAO, Rome, Italy. p 61.

Day RK, Kairo MTK, Abraham YJ, Kfir R, Murphy ST, Mutitu KE, Chilima C. 2003. Biological control of Homopteran pests of conifers in Africa. In: Neuenschwander P, Borgemeister C, Langewald J, editors. Biological control in IPM systems in Africa. Wallingford, UK: CAB International. pp 101–112.

Dix ME. 1996. Pest management in agroforestry systems. Worldwide challenges in the 21st century. Journal of Forestry 94:8–12.

Mendel Z, Protasov A, Fisher N, Lasalle J. 2004. Taxonomy and biology of *L. invasa* General and sp. n (Hymenoptera: Eulopidae), an invasive gall inducer on *Eucalyptus*. Australian Journal of Entomology 43:51–63.

Murphy ST. 1996. Status and impact of invasive conifer aphid in Africa. In: Nair KSS, Sharma JK, Varma RV, editors. Impact of diseases and insect pests in topical forests. Proceedings of the IUFRO symposium, 23–26 November 1993, Peechi, India. Peechi, India: Kerela Forest Research Institute. pp 289–297.

Murphy ST. 1998. Protecting Africa's trees. Unasylva 49: 57–61.

Mutitu KE. 2003. A pest threat to *Eucalyptus* species in Kenya. KEFRI Technical Report. p 12.

Nair KSS. 1991. Social, economic and policy aspects of integrated pest management of forest defoliators in India. Forest Ecology and Management 39:283–288.

Nair KSS. 2001. Pest outbreaks in tropical forest plantations: is there a greater risk for exotic tree species? Bogor, Indonesia, Centre for International Forestry Research. p 74.

Napompeth B. 1994. Leucaena psyllid in the Asia-Pacific Region: Implications for its management in Africa. FAO RAPA Publication, 13.

Neuenschwander P, Langewald J, Borgemeister C, James B. 2003. Biological control for increased agricultural productivity and environmental protection in Africa. In: Neuenschwander P, Borgemeister C, Langewald J, editors. Biological control in IPM systems in Africa. Wallingford, UK: CAB International. pp 377–405.

Nicholas JD, Ofori DA, Wagner MR, Bosu Pl, Cobbinah JR. 1999. Survival, growth and gall formation by *Phytolyma lata* on *Milicia excelsa* established in mixed-species tropical plantations in Ghana. Agricultural and Forest Entomology 1: 137–141.

Norton GW, Rajotte EG, Gapud V. 1999. Participatory research in integrated pest management: Lessons from the IPM CRSP. Agricultural and Human Values 16:431–439.

Nyeko P. 2004. The occurrence and severity of a new and threatening gall damage on *Eucalyptus* species in Uganda. In: Cobbinah JR, Ofori DA, Bosu PP, editors. Pest management in tropical plantations. Kumasi, Ghana: University Printing Press (UPK), KNUST. pp 100–107.

Nyeko P. 2005. The cause, incidence and severity of a new gall damage on *Eucalyptus* species at Oruchinga refugee settlement in Mbarara district, Uganda. Uganda Journal of Agricultural Sciences 11:47–50.

Nyeko P, Olubayo FM. 2005. Participatory assessment of farmers' experiences on termite problems in agroforestry in Tororo district, Uganda. Agricultural Research and Extension (AgREN) Paper No. 143.

Nyeko P, Edwards-Jones G, Day RK, Thomas R. 2002. Farmers' knowledge and perceptions of pests in agroforestry with specific reference to *Alnus* species in Kabale District, Uganda. Crop protection 21:929–941.

Poore MED, Fries C. 1989. The ecological effects of *Eucalyptus*. FAO, Rome, Italy.

Price LL. 2001. Demystifying farmers' entomological and pest management knowledge: A methodology for assessing the impacts on knowledge from IPM-FFS and NES interventions. Agriculture and Human Values 18:153–176.

Speight MR, Wylie FR. 2001. Insect pests in tropical forestry. Wallingford, UK: CAB International. p 307.

Tribe GD. 2003. Biological control of defoliating, and phloem- or wood-feeding insects in commercial forestry in southern Africa. In: Neuenschwander P, Borgemeister C, Langewald J, editors. Biological control in IPM systems in Africa. Wallingford, UK: CAB International. pp 113–129.

Trutmann P, Voss J, Fairhead J. 1996. Local knowledge and farmer perceptions in bean diseases in the central African highlands. Agriculture and Human Values 13:64–70.

Van Huis A, Meerman F. 1997. Can we make IPM work for resource-poor farmers in sub-Sahara Africa? International Journal of Pest Management 43:313–320.

Van Mele P, Van Chien H. 2004. Farmers, biodiversity and plant protection: developing a learning environment for sustainable tree cropping systems. International Journal of Agricultural Sustainability 2:67–75.

Wagner MR, Atuahene SKN, Cobbinah JR. 1991. Forest Entomology in West Tropical Africa: Forest Insects of Ghana. Dordrecht: Kluwer Academic Publishers. p 270.

Watson RT. 2001. Climate change 2001. Paper presented at the sixth conference of parties to the United nations Framework Convention on climate change, July 19, 2001. Available from: http://www.ipcc.ch/present/COP65/COP-6-bis.htm. Accessed on 15 August 2006.

Wingfield MJ, Slippers B, Roux J, Wingfield BD. 2001. Worldwide movement of exotic forest fungi, especially in the tropics and the southern hemisphere. Bioscience 51:134–140.

Wylie R. 2002. Integrated pest management in tropical forestry. In: Proceedings of the International Conference on timber plantation development held from 7–9 November 2000, Manila, Philippines. Available from: http://www.fao.org/DOCREP/005/AC781E/AC781E07.htm