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Honeybee, *Apis mellifera* (Hymenoptera: Apidae), leaf damage on *Alnus* species in Uganda: a blessing or curse in agroforestry?

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Abstract

It is a dictum that *Apis mellifera* Linnaeus is innocuous in agricultural ecosystems. This study provides the first record of *A. mellifera* as a significant defoliator of *Alnus* species. Careful field observations coupled with microscopic examination provided convincing evidence implicating *A. mellifera* as the cause of leaf perforation on *Alnus* species in Uganda. *Apis mellifera* was observed foraging selectively on young *Alnus* leaves and buds in search of a sticky substance, apparently propolis. In so doing, the bee created wounds that enlarged and caused tattering of *Alnus* leaves as they matured. Biological surveys indicated that the damage was prevalent and occurred widely, particularly on *Alnus acuminata* Kunth in Uganda. Incidence of the *Apis mellifera* damage on *Alnus acuminata* peaked in the dry season, with up to 90% of leaves emerging per shoot per month damaged, and was lowest in the wet months during peak leaf emergence. *Apis mellifera* leaf damage was consistently higher on *Alnus acuminata* than *A. nepalensis* D. Don., on saplings than mature trees, and on sun exposed than shaded leaves. The activity of honeybees may be detrimental to the productivity of *Alnus*, yet the substance for which the insect forages on *Alnus* is a resource with potential economic importance.

Introduction

The importance of pest problems in agroforestry is gaining recognition as serious pests continue to emerge on promising agroforestry woody species. Recent debates on this subject have discredited the widespread belief that there are no substantial pest infestations in agroforestry as based on desultory and subjective assessments (Day & Murphy, 1998; Boa, 1998; Boa & Bentley, 1998; Schroth *et al.*, 2000; Rao *et al.*, 2000). Rao *et al.* (2000) pointed out that researchers and extension staff often fail to correctly identify the pest problems in agroforestry because many tree pests have not been identified. This study provides the first record of damage caused by *Apis mellifera* Linnaeus (Hymenoptera: Apidae) on *Alnus* species in Uganda.

Alnus species, particularly *A. acuminata* Kunth and *A. nepalensis* D. Don. (Betulaceae), have in recent years received considerable attention for highland agroforestry in tropical countries (van Houten, 1997; Neil, 1997; Dhyani, 1998). These *Alnus* species are capable of providing a wide range of important products such as firewood, poles, stakes, fodder, timber, shelter and herbal medicine. They have the ability to fix atmospheric nitrogen and are well suited for improving soil fertility and for reforestation purposes. On unstable slopes their extensive lateral root system contributes to watershed protection and erosion control (Russo, 1995; Neil, 1997).

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The genus *Alnus* is exotic to Uganda, with *A. acuminata* and *A. nepalensis* introduced in 1988 (Okorio *et al.*, 1994). Owing to the rapid growth and provision of a diversity of products that are crucial to the predominantly subsistence farmers in the country, the demand for *Alnus* species, especially *A. acuminata*, has escalated particularly in the Kigezi highlands. However, the appearance of pest infestations on these species is raising concerns of pest risks as cultivation of *Alnus* species intensifies in the country. One relatively major damage type, whose primary cause has been unknown, is so called 'leaf perforations' (Maiteki & Owera, 1996; Roux, 1999). Maiteki & Owera (1996) have described the damage as 'gunshot holes' on *Alnus* leaves. The objectives of this study were to: (i) identify the main cause and frequency of occurrence of leaf perforation on *Alnus* species in Uganda; and (ii) assess the spatial and temporal variations in the incidence and levels (leaf area damaged) of the *Alnus* leaf perforation over time.

Materials and methods

Identification of Apis mellifera *as the cause of leaf perforation on* Alnus

Careful inspections of canopies of *Alnus* trees revealed *Apis mellifera* foraging selectively on young (not fully opened) *Alnus* leaves and buds. A total of ten bees landing on young *Alnus* leaves were each monitored for their activity on the leaves for 2–5 min after which they were caught and examined under a dissecting microscope for evidence of material collected. Each leaf upon which a bee was monitored was collected and examined for fresh injury. In addition, samples of *Alnus acuminata* leaves perforated by *Apis mellifera* were cultured for diagnosis of associated pathogens.

Biological surveys

Biological surveys of the occurrence of *A. mellifera* leaf damage on *Alnus acuminata* and *A. nepalensis* were conducted between March 1999 and August 2000 in Kabale district (0°16'S, 29°57'E) where the species have proven suitable for agroforestry in Uganda. Additional observations in Mbale district (0°52'N, 34°14'E) were limited to *A. acuminata*. The surveys in Mbale district were conducted on farmers' fields in Bulago and Busano sub-counties, and at the Forestry Resources Research Institute's (FORRI) peri-urban seed orchard and experimental trials. The sites were each visited in March and June 1999, and January, April and July 2000, covering three dry and two wet periods in the district. A total of 15 farm sites were surveyed in the district. More extensive surveys were conducted in Kabale district with a total of 72 farmers' fields and experimental trials, and three nurseries visited in the district.

Monthly incidence of shoot damage

The incidence of *Apis mellifera* damage on young *Alnus acuminata* leaves was assessed monthly at Buhara, Kachwekano 1 and Kachwekano 3 in Kabale district between June 1999 and August 2000 (table 1). *Apis mellifera* damage incidence rather than the number of bees was assessed because the bees can sting aggressively, making sampling not only difficult, but also risky. On every sampling occasion, the last three leaves at the tip of actively growing shoots were scored for the presence or absence of *A. mellifera* leaf damage. This is because a preliminary leaf phenology study indicated that an actively growing shoot of *Alnus acuminata* can produce at least three leaves each month (Nyeko, 2001).

Different shoots were randomly selected at every sampling date. A total of ten shoots per tree was sampled on

Table 1. Characteristics of sites used for assessing the incidence and level of *Apis mellifera* leaf damage on *Alnus* species in Kabale district, Uganda.

Site	Description
Buhara[ab]	Young (saplings) *Alnus acuminata* AFRENA seed orchard compartment (a single species stand) established in 1997 at mid-slope. A total of 90 trees spaced 2 m × 2 m were present during the study. Tree canopies were open at the onset of the study but later closed starting December 1999. Slashing and spot weeding were done to suppress weeds in the compartment.
Kachwekano 1[ab]	Old AFRENA multi-purpose tree species trial established in 1989 at low- to mid-slope. Both *A. acuminata* and *A. nepalensis* were available for study. Other multipurpose tree species included *Cupressus lusitanica* Miller (*Cupressaceae*), *Calliandra calothyrsus* Meisn. (Fabaceae), *Grevillea robusta* A. Cunn. (Proteaceae), *Markhamia lutea* Benth. (Bignoniaceae), *Casuarina cunninghamiana* Miq. (Casuarinaceae), *Casuarina equisetifolia* L. Forst, *Leucaena* spp., *Erythrina* spp. and *Vernonia* spp. A number of herbaceous and woody weeds were also present. There were 15 trees of each *Alnus* species in 3 rows of 5 trees. Within-row tree canopies were closed throughout the period of study. No weeding was done during the study.
Kachwekano 2[b]	Old *A. acuminata* AFRENA seed orchard compartment (a single species stand) established in 1990 near hilltop. Tree canopies were closed throughout the study period with virtually no undergrowth. There were 40 trees at a spacing of 4 m × 4 m at the onset of the study. No weeding was done during the study.
Kachwekano 3[a]	AFRENA trial with *A. acuminata* and *C. calothyrsus* coppices at mid-slope. *A. acuminata* coppices were two years old at the onset of the study. Maize, beans and wheat were planted at different seasons during the study. Because the woody species were closely spaced (about 0.5 m) within rows, they were periodically pruned and thinned to allow for crop growth.
Kijuguta[b]	Farmer's homegarden established in 1996/7 at valley bottom. Comprised of a random mixture of *A. acuminata*, *Eucalyptus* spp., *Sesbania* spp., *G. robusta*, *C. lusitanica* and vegetables. A total of 16 *A. acuminata* trees were available at the onset of the study. Weeds were removed by hoeing.

[a] Only damage incidence assessed; [b] only damage level assessed; [ab] both damage incidence and level assessed. AFRENA denotes the Agroforestry Research Networks for Africa.

20 trees in each of Buhara and Kachwekano 3 while 20 shoots per tree were sampled from six trees in Kachwekano 1 where relatively fewer trees were available. Thus, at every sampling occasion a total of 600 leaves were scored in each of Buhara and Kachwekano 3 while 360 leaves were scored in Kachwekano 1. However, two sample trees were burnt by wildfire at Kachwekano 1 in July 2000. Hence only 240 leaves could be scored at the site in each of the last two months of this study (July and August 2000).

Monthly assessment of leaf damage

Long-term monitoring (Lowman, 1985) was used to measure the leaf surface area damaged by *Apis mellifera* and leaf phenology at four sites (tables 1 and 2) between March 1999 and August 2000. Branches within 0.5–3 m above ground, and consisting of 5–11 leaves, were marked with respect to aspect and light. Leaves on the marked branches were counted and labelled sequentially from the base to the tip using black waterproof pens in order to conduct quantitative assessments on their growth dynamics and damage. Subsequent leaves on the marked branches were numbered as they emerged, and lateral new leaves were indicated by a hyphenated number. Leaves on the marked branches were scored for *A. mellifera* damage monthly using a visual injury index consisting of the following percent damage categories: 0, 2, 5, 10, 15, 20, 30, 50, 60, 70 and 80 (Nyeko, 2001).

The length and width (at the widest point) of 100 preliminary leaf samples were measured, and the relationship between the leaf length × width and measured leaf surface area was determined using regression. The coefficient of determination (r^2) values were very high (0.990 for *Alnus acuminata* and 0.992 for *A. nepalensis*), allowing precise estimation of leaf surface area of both species from their leaf length and width. Therefore the length and width of every marked leaf was measured during each damage assessment until full expansion. Because it is difficult to differentiate leaf abortion due to *Apis mellifera* damage from that induced by other factors, aborted leaves were not included in this study.

Data analysis

For each site, the incidence of *A. mellifera* damage was expressed as percentage of damaged leaves per shoot and the mean monthly damage incidence determined using descriptive statistics. Leaf emergence and leaf fall at each site were expressed as percentage of emerged and fallen leaves per month, over 17 months, respectively. *Apis mellifera* leaf damage at each site was expressed as the total proportion of leaf surface area damaged per branch (Williams & Abbott, 1991). The monthly leaf damage data were not combined for further analyses because the objective of the study was to determine the monthly patterns in *A. mellifera* damage over sites. Pearson's correlation in Minitab statistical package was used to determine the relationship between the mean monthly rainfall pattern and incidence of *A. mellifera* leaf perforation on *Alnus* at each site. Sites were compared pairwise in the overall patterns of *A. mellifera* damage using two-sample Kolmogorov-Smirnov test in SPSS statistical package.

Results

Evidence implicating A. mellifera *as a defoliator of* Alnus

Apis mellifera was observed selectively foraging on young *Alnus* leaves (fig. 1a) and sometimes buds in search of a sticky substance, apparently propolis (R.G. Danka, personal communication). This suggests that the substance for which *Apis mellifera* forages on *Alnus* is confined to young leaves and buds. All ten bees caught foraging on *Alnus* had collected propolis in their corbiculae (fig. 1b), and all the ten leaves upon which the bees were monitored and examined microscopically showed strips of fresh interveinal wounds (fig. 1c). Such wounds often expanded, causing *Alnus* leaves to tatter as they matured (fig. 1d). The wounds appeared to provide favourable avenues for the entrance of opportunistic pathogens. A *Pestalotiopsis* species, *Botrytis* species and a *Cladosporium* species were isolated from cultured specimens of *Alnus* leaves perforated by *Apis mellifera*. The bees foraged on *Alnus* leaves particularly between 11.00 and 15.00 h on warm days. The restriction of *Apis mellifera* foraging to warm periods appeared to be an adaptation to gathering less viscous propolis from *Alnus* leaves. Though sticky, the propolis on *Alnus* leaves was observed to be less viscous at higher temperatures thus becoming easier for the bees to gather.

Biological surveys

Generally, *Apis mellifera* leaf perforation was prevalent on *Alnus* trees in both Kabale and Mbale districts (table 3) although trees in Mbale district were less severely attacked than in Kabale district. In addition to these districts, *Apis mellifera* damage was observed on *Alnus acuminata* during visits to Makerere University Agricultural Research Institute, Kabanyolo (Wakiso district) and Agroforestry Research Networks for Africa's (AFRENA) experimental trials at Kifu, Mukono district during this study. This indicated that *Apis mellifera* leaf perforation on *Alnus* was widespread in Uganda. Moreover, the leaf perforations were evident on

Table 2. Sampling units used for monitoring *Apis mellifera* damage on *Alnus acuminata* and *A. nepalensis* at four sites in Kabale district, Uganda.

Site	Trees sampled	Branches per tree	Total branches
Buhara	10	4	40
Kijuguta	10	4	40
Kachwekano 1: *A. acuminata**	5	8: 4 sun, 4 shade	40 (24)
Kachwekano 1: *A. nepalensis**	5	8: 4 sun, 4 shade	40 (24)
Kachwekano 2	5	8: 4 sun, 4 shade	40

* Denotes two sample trees burnt by wildfire at the site in early July 2000; numbers in brackets are total number of branches sampled per month after the occurrence of wildfire.



Fig. 1. *Apis mellifera* activity and damage on *Alnus acuminata* foliage: (a) *A. mellifera* collecting propolis from young *A. acuminata* leaf: note resulting damage on mature leaves; (b) portion of *A. mellifera* showing propolis in the corbicula gathered from young *A. acuminata* leaves; (c) fresh *A. mellifera* damage on young *A. acuminata* leaf: note the creamy propolis on the leaf surface; (d) typical *A. mellifera* damage on *Alnus* leaves.

Alnus throughout the survey period. The bee damage was more prevalent on *A. acuminata* than on *A. nepalensis* (table 3). Whereas *Apis mellifera* leaf perforation was prevalent on saplings and mature trees of *Alnus acuminata* (up to 100% of trees attacked in most stands), nursery seedlings of this species sustained negligible attack (less than 10% prevalence) by the insect (table 3).

Monthly incidence of shoot damage

The incidence of *Apis mellifera* damage on *Alnus acuminata* peaked in the dry season, particularly from June to August (fig. 2). The mean monthly incidence of *Apis mellifera* damage ranged from 22 to 90% at Buhara, 21–60% at Kachwekano 1 and 16–88% at Kachwekano 3. The lowest

Table 3. The frequency of occurrence of *Apis mellifera* leaf damage on *Alnus* species in Kabale and Mbale districts, Uganda.

Tree category	Kabale district		Mbale district
	A. acuminata	*A. nepalensis*	*A. acuminata*
Nursery seedlings	+	+	not available
Outplanted seedlings (< 1 year)	+ + +	+	+ +
Saplings (1–7 years)	+ + + +	+ +	+ + + +
Mature trees (> 7 years)	+ + + +	+ +	+ + + +

+, Low (less than 10% of *Alnus* trees attacked); + +, moderate (10–40% of *Alnus* trees attacked); + + +, high (40–70% of *Alnus* trees attacked); + + + +, very high (> 70% of *Alnus* trees attacked).

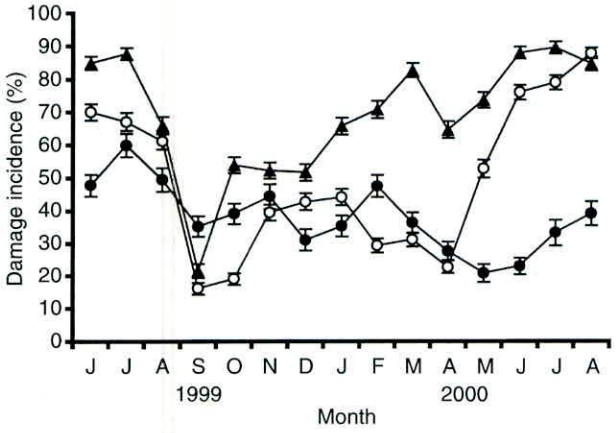

Fig. 2. Mean monthly percentage of three new *Alnus acuminata* leaves per shoot damaged by *Apis mellifera* at Buhara (▲), Kachwekano 1 (●), and Kachwekano 3 (○). Error bars are ± standard errors of means.

incidence of *A. mellifera* damage occurred during September and April (fig. 2), coinciding with periods of peak leaf emergence and lowest leaf fall (fig. 3). The incidence of *A. mellifera* damage showed a weak negative correlation with rainfall at Buhara ($r = -0.388$, $P = 0.153$) and Kachwekano 3 ($r = -0.501$, $P = 0.057$), but not at Kachwekano 1 ($r = 0.057$, $P = 0.840$) where damage incidence was generally low (fig. 2). Overall, the pattern of *A. mellifera* damage differed significantly between Buhara and Kachwekano 1 (Kolmogorov-Simornov $Z = 2.373$, $P < 0.001$) but was statistically similar between Buhara and Kachwekano 3 (Kolmogorov-Simornov $Z = 1.278$, $P = 0.076$), and Kachwekano 1 and Kachwekano 3 (Kolmogorov-Simornov $Z = 1.095$, $P = 0.181$).

Variation in Alnus *leaf surface area damaged by* Apis mellifera

Overall, 1307, 1111, 1015, 946 and 804 leaves were assessed in Buhara, Kijuguta, Kachwekano 1 (*Alnus acuminata*), Kachwekano 1 (*A. nepalensis*) and Kachwekano 2, respectively. The mean monthly percent leaf surface area damaged by *Apis mellifera* varied markedly over time at all sites, ranging from 3 to 11% at Buhara, 2–10% at Kijuguta, 1–3% at Kachwekano 1 (*Alnus acuminata*), 0–0.2% at

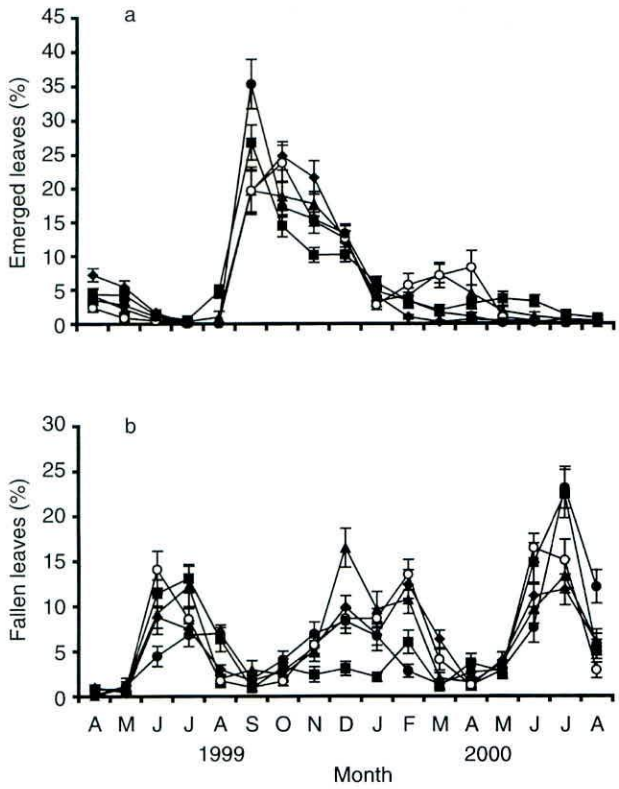

Fig. 3. Mean monthly percentage of (a) leaf emergence and (b) leaf fall for *Alnus acuminata* and *A. nepalensis* at four sites in Kabale district. ◆, Buhara; ■, Kijuguta; ▲, Kachwekano 1 (*A. acuminata*); ○, Kachwekano 1 (*A. nepalensis*); ●, Kachwekano 2. Total leaf emergence at Buhara = 982, Kijuguta = 871, Kachwekano 1 (*A. acuminata*) = 744, Kachwekano 1 (*A. nepalensis*) = 691, and Kachwekano 2 = 562. Total leaf fall at Buhara = 1254, Kijuguta = 858, Kachwekano 1 (*A. acuminata*) = 660, Kachwekano 1 (*A. nepalensis*) = 765, and Kachwekano 2 = 602. Error bars are ± standard errors of means.

Kachwekano 1 (*A. nepalensis*), and 1–5% at Kachwekano 2 (fig. 4). This signifies the need for lengthy monitoring of pest damage in order to reliably identify critical periods. There were greater levels of *Apis mellifera* damage on stands of *Alnus* saplings (Buhara and Kijuguta) than on mature stands (Kachwekano 1 and Kachwekano 2) through both wet and

dry seasons (fig. 4, table 4). The damage was significantly ($P < 0.05$) lower on *A. nepalensis* than on *A. acuminata* at any site. Similarly, the mean monthly damage caused by *Apis mellifera* was consistently lower on shaded leaves than those exposed to the sun throughout the study period (fig. 5).

Discussion

Occurrence and importance of Apis mellifera *damage*

Very little is known about *A. mellifera* causing damage to plants. The findings of this study concur with Palmberg (1977) who reported damage by an unspecified honeybee species on leaves and buds of poplars (*Populus* species) in Australia. Odebiyi *et al.* (2000) reported *Apis mellifera adansonii* Latreille as damaging *Vitellaria paradoxa* C.F. Gaertner (Sapotaceae) and *Parkia biglobosa* (Jacq.) Benth. (Fabaceae) in Nigeria, but these authors did not specify the damage inflicted by the bees on the tree species. No *A. mellifera* damage has hitherto been reported on *Alnus* although some species in the genus are known propolis sources (Ghisalberti, 1979; Mochida *et al.*, 1985).

The fact that there is the first record of *Apis mellifera* damaging species of *Alnus* in this study is rather surprising since the species of honeybee occurs in many countries where *Alnus* species are cultivated. In a follow-up provenance trial in Kabale district, Nyeko (2001) observed *Apis mellifera* leaf perforation on *Alnus* provenances from various countries including Costa Rica, Guatemala, Rwanda,

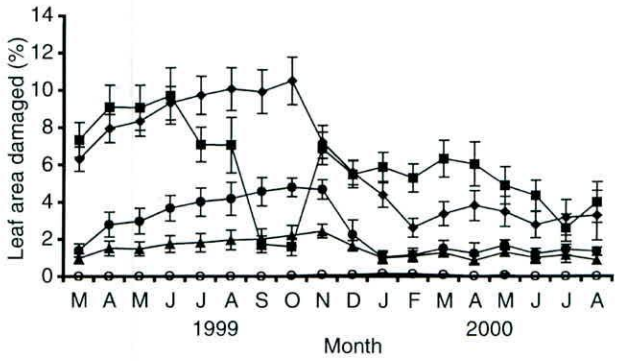

Fig. 4. Mean monthly *Apis mellifera* damage on *Alnus* leaves at four sites in Kabale district. ◆, Buhara; ■, Kijuguta; ▲, Kachwekano 1 (*A. acuminata*); , Kachwekano 1 (*A. nepalensis*); ●, Kachwekano 2. Error bars are ± standard errors of means. Buhara and Kijuguta comprised of *A. acuminata* saplings while Kachwekano 1 (*A. acuminata*), Kachwekano 1 (*A. nepalensis*) and Kachwekano 2 had mature *A. acuminata* stands (table 1).

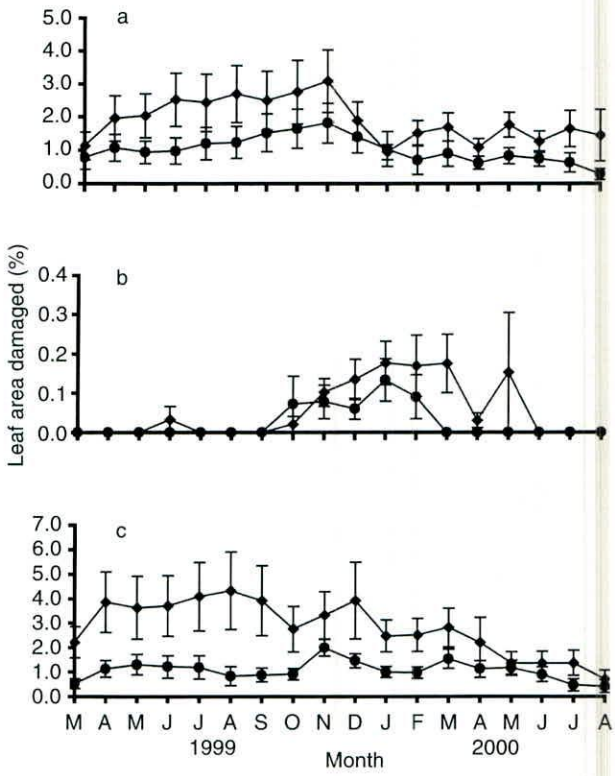

Fig. 5. Monthly patterns of mean *Apis mellifera* damage on sun exposed (◆) and shaded (●) *Alnus acuminata* and *A. nepalensis* leaves at two sites in Kabale: (a) *A. acuminata* at Kachwekano 1; (b) *A. nepalensis* at Kachwekano 1; (c) *A. acuminata* at Kachwekano 2. Error bars are ± standard errors of means. Note the differences in scales on y-axis.

Table 4. Pairwise relationships between sites in the patterns of percentage *Alnus* leaf surface area damaged by *Apis mellifera* in Kabale district, Uganda.

Relationship	Kolmogorov-Smirnov statistics	
	Z	P
Buhara vs. Kijuguta	0.660	0.766
Buhara vs. Kachwekano 1[a]	3.000	0.000
Buhara vs. Kachwekano 1[b]	3.000	0.000
Buhara vs. Kachwekano 2	1.667	0.008
Kijuguta vs. Kachwekano 1[a]	2.667	0.000
Kijuguta vs. Kachwekano 1[b]	3.000	0.000
Kijuguta vs. Kachwekano 2	2.167	0.000
Kachwekano 1[a] vs. Kachwekano 1 [b]	3.000	0.000
Kachwekano 1[a] vs. Kachwekano 2	1.333	0.057
Kachwekano 2 vs. Kachwekano 1[b]	3.000	0.000

[a]*Alnus acuminata*; [b]*A. nepalensis*.

and Uganda. This suggests that the bee damage on *Alnus* might be widely distributed. However, the race of *Apis mellifera* found damaging *Alnus* species was not established in this study. Some races of honeybees are known to collect propolis more actively than others (Malkov & Sadovnikov, 1985). The *Apis mellifera* races present in Uganda are *Apis mellifera scutellata* Lepeletier, *Apis mellifera adansonii* and *Apis mellifera monticola* Smith (Commonwealth Secretariat, 2001). It seems more probable that *A. mellifera* leaf perforation on *Alnus* species has been overlooked and/or misdiagnosed as very few studies have intensively investigated pest problems on *Alnus* species in the tropics. Lack of knowledge and misdiagnosis of *Apis mellifera* leaf perforation on *Alnus* were evident among farmers growing alders in Kabale district (Nyeko, 2001).

Damage caused to the young leaves or buds, as observed on *Alnus* in this study, has been noted to have the largest negative effect on lifetime leaf profitability since the tissue is damaged before 'returning' the energy expended for its production (Lowman, 1985; Jurik & Chabot, 1986). Palmberg (1977) reported severe deformation and loss of height increment in *Populus* species as a result of honeybee damage to buds. However, no tree mortality resulting directly from *Apis mellifera* leaf damage was observed during this study although severe defoliation has been shown to significantly reduce the growth rate of *Alnus acuminata* (Nyeko, 2001). Moreover, the wounds caused by *Apis mellifera* on *Alnus* leaves may provide favourable avenues for the entrance of opportunistic pathogens which may aggravate the bee damage.

The attention shown by *Apis mellifera* on *Alnus* may not be entirely detrimental to agroforestry because the substance the bees forage for on *Alnus* could be a resource of great importance. Propolis is used by bees as a general purpose sealer, draught excluder and antibiotic in their hives (Taber & Barker, 1974; Ghisalberti, 1979). It is the main source for the majority of phenolic compounds present in honey (Tomas-Baberan *et al.*, 1993). Moreover propolis is prized for varnishes, and is most sought after for its alleged medicinal properties (Simons, 1987). Therefore susceptible *Alnus* provenances could be cultivated with the main aim of promoting beekeeping, which is an important activity in many regions of Uganda. For example, the current national annual honey production in the country is estimated at 3000 tonnes, worth US$2.7 million (Commonwealth Secretariat, 2001).

Spatiotemporal variations in Apis mellifera *damage on* Alnus

Apis mellifera damage on *Alnus* varied markedly over the wet and dry seasons. This may be attributed to variations in the quantity and quality of the propolis produced on *Alnus* leaves, and/or the seasonality of bee abundance, foraging behaviour and propolis requirements. In northern Italy, Marletto & Olivero (1981) pointed out weather, colony requirements, resin availability on buds, and honey flows as the main factors affecting foraging behaviour of *Apis mellifera* for propolis on *Populus*. These authors noted that the bees foraged for propolis only during the warmest periods in spring and autumn, an observation that is supportive of our findings. The decline in leaf damage in the rainy season may also be attributed to increased leaf availability which may satiate the bees (Angulo-Sandoval & Aide, 2000).

Significant differences occurred in leaf damage among sites, indicating the patchy distribution of *A. mellifera* damage. The small-scale cultivation of *Alnus* species in scattered fields means that pockets of *Alnus* stands are geographically isolated, and hence some may escape attack by pests (Selman & Lowman, 1983). For example, it is conceivable that *Alnus* stands located far away from beehives should be less attacked by *Apis mellifera* than a similar stand located closer to beehives. The higher *A. mellifera* damage in stands of *Alnus acuminata* saplings than in stands of mature trees appears to be associated with preference for light-exposed leaves as *Apis mellifera* caused higher damage on leaves exposed to light than on shaded leaves. Possibly, *Alnus* leaves exposed to the sun produce higher quantities of, or less viscous propolis than shaded leaves. Alternatively, the bees may prefer to forage on exposed leaves in fear of natural enemies or for ease of manoeuvrability at the periphery of tree canopies. Gadgil & Bain (1999) pointed out that *Pissodes strobi* Peck (Coleoptera: Curculionidae) in North America and *Hypsipyla* species (Lepidoptera: Pyralidae) in the tropics favour open-grown trees, and that common strategies to minimize their damage include planting at closer spacing and ensuring that stand reaches canopy closure as soon as possible. Such control strategies may well be applied against *Apis mellifera*, especially when cultivating susceptible *Alnus* species in rotational fallows.

Apis mellifera damage was significantly higher on *Alnus acuminata* than on *A. nepalensis*, indicating interspecific variation in propolis production and/or defensive mechanisms between the *Alnus* species. There is an obvious need to take advantage of this variation between the *Alnus* species. Damage assessments should be developed to identify further natural resistance. Such programmes should be aimed at several genetic levels including *Alnus* species, provenances, clonal lines and individual trees. This can be accelerated by utilizing both traditional breeding strategies and modern clonal techniques (Stone *et al.*, 1998).

In conclusion, *Apis mellifera* activity resulting in leaf perforation on *Alnus* species appears to be potentially both detrimental and beneficial in agroforestry. Therefore some economic analysis of the *Apis mellifera* activity is necessary. Accurate identification of the composition of the propolis for which the insect apparently forages on *Alnus*, and evaluation of propolis production over seasons, sites, and species, provenances and growth stages of *Alnus* are urgently required. Such studies would yield necessary information for determining management strategies against *Apis mellifera* and would provide sound data for the economic potential of the propolis.

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References

Angulo-Sandoval, P. & Aide, T.M. (2000) Leaf phenology and leaf damage of saplings in the Luquillo experimental forest, Puerto Rico. *Biotropica* **32**, 415–422.

Boa, E. (1998) Diseases of agroforestry trees: do they really matter? *Agroforestry Forum*, **9**, 19–22.

Boa, E.R. & Bentley, J. (1998) Tree health: the Bolivia experience. *Tropical Forest Update* **8**, 16–17.

Commonwealth Secretariat (2001) *Report on the strategy for development of apiculture sector in Uganda*. 47 pp. Ministry of Agriculture Animal Industry and Fisheries, Entebbe.

Day, R.K. & Murphy, S.T. (1998) Pest management in tropical agroforestry: prevention rather than cure. *Agroforestry Forum*, **9**, 11–14.

Dhyani, S.K. (1998) Tribal alders: an agroforestry system in the north eastern hills of India. *Agroforestry Today* **10**, 14–15.

Gadgil, P. & Bain, J. (1999) Vulnerability of planted forests to biotic and abiotic disturbances. *New Forests* **17**, 227–238.

Ghisalberti, E.L. (1979) Propolis: a review. *Bee World* **60**, 59–84.

Jurik, T.W. & Chabot, B.F. (1986) Leaf dynamics and profitability in wild strawberries. *Oecologia* **69**, 296–304.

Lowman, M.D. (1985) Temporal and spatial variability in insect grazing of the canopies of five Australian rainforest tree species. *Australian Journal of Ecology* **10**, 7–24.

Maiteki, G. & Owera, S. (1996) *Report on the health problems of agroforestry tree species at Kifu and Kabale, 1996*. 18 pp. Consultancy report submitted to AFRENA Project, Uganda.

Malkov, V.V. & Sadovnikov, A.A. (1985) Propolis collecting can be increased. *Pchelovodstvo* No. 6, 10–11.

Marletto, F. & Olivero, G. (1981) Collection and use of propolis by honeybees. *Apicoltore Moderno* **72**, 131–140.

Mochida, S., Haga, M. & Takino, Y. (1985) Chemical constituents and antimicrobial activity of Japanese propolis. pp. 455–456 in *Proceedings of 30th Apiculture Congress*.

Neil, P.E. (1997) *Alnus* Miller. pp. 68–71 *in* Faridah Hanum, I. & van der Maesen, L.J.G. (*Eds*) *Plant resources of South-East Asia* No. 11. *Auxiliary Plants*. Leiden, The Netherlands, Backhuys Publishers.

Nyeko, P. (2001) *The diversity and impact of herbivorous insects and pathogens on* Alnus *species in Uganda: a challenge in agroforestry*. 287 pp. PhD thesis, University of Wales, Bangor, UK.

Odebiyi, J.A., Oni, P.I., Tijani-Eniola, H., Adebayo, A., Omoloye, A. & Awodoyin, R.O. (2000) Parasites and pests of *Vitellaria* and *Parkia* and methods of control. pp. 139–149 in *Improved management of agroforestry parkland systems in Sub-Saharan Africa. Second Annual Report, 1 October – 30 September 2000*. University of Wales, Bangor, UK.

Okorio, J., Byenkya, S., Wajja, N. & Peden, G. (1994) Comparative performance of seventeen upperstorey tree species associated with crops in the highlands of Uganda. *Agroforestry Systems* **26**, 185–203.

Palmberg, C. (1977) Introduction and improvement of poplars in Australia. *Australian Forestry* **40**, 20–27.

Rao, M.R., Singh, M.P. & Day, R. (2000) Insect problems in tropical agroforestry systems: contributory factors and strategies for management. *Agroforestry Systems* **50**, 243–277.

Roux, J. (1999) *Pathology survey of plantation forest trees in southern Uganda*. 30 pp. Report prepared for Ugandan forestry department and South African forestry department. Tree pathology cooperate programme, University of Pretoria, South Africa.

Russo, R.O. (1995) *Alnus acuminata* ssp. *arguta*, a valuable resource for neotropical highlands. pp. 156–163 *in* Evans, D.O. & Szott, L.T. (*Eds*) *Nitrogen fixing trees for acid soils. Proceedings of a workshop held on 3–8 October, 1994, Turrialba, Costa Rica*. Nitrogen fixing tree research reports, special issue.

Schroth, G., Krauss, U., Grasparott, L., Aguilar, D.J.A. & Vohland, K. (2000) Pests and diseases in agroforestry systems of humid tropics. *Agroforestry Systems* **50**, 199–241.

Selman, B. & Lowman, M.D. (1983) The biology and herbivory rates of *Novocastria nothofagi* Selman (Coleoptera: Chrysomelidae), a new genus and species on *Nothofagus moorei* in Australian temperate rain forests. *Australian Journal of Zoology* **31**, 179–191.

Simons, P. (1987) Hives of industry. *New Scientist* **116**, 56–58.

Stone, C., Simpson, J.A. & Eldridge, R.H. (1998) Insect and fungal damage to young eucalypt trial plantings in northern New South Wales. *Australian Forester* **61**, 7–20.

Taber, S. III & Baker, R.J. (1974) Honeybees collect caulking material as propolis. *American Bee Journal* **114**, 90.

Tomas-Barberan, F.A., Garcia-Viguera, C., Vit-Olivier, P., Ferreres, F. & Tomas-Lorente, F. (1993) Phytochemical evidence for the botanical origin of tropical propolis from Venezuela. *Phytochemistry* **43**, 191–196.

van Houten, H. (1997) *International Centre for Research in Agroforestry (ICRAF), annual report 1996*. 340 pp. ICRAF, Nairobi, Kenya.

Williams, M.R. & Abbott, I. (1991) Quantifying average defoliation using leaf-level measurements. *Ecology* **72**, 1510–1511.

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