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Termite damage to maize grown in agroforestry systems, traditional fallows and monoculture on nitrogen-limited soils in eastern Zambia

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Abstract

1 Termites cause significant damage to maize and other crops in southern Africa. Several studies were conducted with the objective of determining the difference in termite damage to maize in various land use systems between monoculture maize, maize grown using traditional fallows and improved fallows.

2 In an experiment conducted at four sites on noncoppicing fallows, maize planted after *Tephrosia candida* 02971 fallows had lower termite damage compared with fully fertilized monoculture maize. However, the termite suppression was not low enough to warrant rotation of noncoppicing fallows for termite management..

3 In four experiments comparing termite damage to maize grown in monoculture and in coppicing fallows, fully fertilized monoculture maize had a higher percentage of lodged plants compared with maize grown in pure *Leucaena leucocephala*, *Gliricidia sepium* and *Acacia anguistissima* fallows or in a mixture of *A. anguistissima* + *Sesbania sesban* or *Tephrosia vogelii* + *S. sesban*.

4 More than 50–75% of the variance in maize yield was explained by preseason inorganic nitrogen and termite damage. However, termite damage to maize was not influenced by inorganic nitrogen, which represents nitrogen readily available to maize. The decomposition rate of biomass (related to lignin + polyphenol to nitrogen ratio) and water retention under fallows also appeared to influence termite damage.

5 It is concluded that maize grown in *L. leucocephala*, *G. sepium*, *A. anguistissima* and *S. sesban* fallows suffers less termite damage and produces maize yields comparable with conventionally tilled and fully fertilized monoculture maize.

Keywords Improved fallows, organic matter quality, termites.

Introduction

Depletion of soil fertility, along with the concomitant problems of weeds, pests and diseases, is a major biophysical cause of low per capita food production in sub-Saharan Africa (Sanchez, 2002). More than 80% of the farm families in this region practice subsistence agriculture on poor soils with little external inputs and under erratic rainfall conditions (Beets, 1990). Agricultural inputs, such as fertilizers and pesticides, have become unaffordable to most smallholder farmers after the removal of government subsidies (Gladwin, 1991). In southern Africa, nitrogen deficiency and damage by pests such as termites are the major constraints to increasing the yield of maize (*Zea mays* L.), which is the staple food crop for millions of people in the region (Eicher, 1995; Smale, 1995; Barrios *et al.*, 1998). Researchers therefore continue to explore ways of incorporating N_2-fixing herbaceous and tree legumes into production systems to increase the availability of nitrogen to maize (Sanchez, 2002).

In Zambia, Malawi and Zimbabwe, improved fallows involving the rotation of N_2-fixing tree legumes with maize are considered to be a potential alternative to mineral fertilizers, the traditional bush and grass fallows and

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shifting cultivation (Barrios *et al.*, 1997, 1998; Mafongoya *et al.*, 1998; Kwesiga *et al.*, 1999). Two types of legume fallows are practiced (i.e. noncoppicing and coppicing fallows). Noncoppicing legume species are planted as short-duration rotational fallows and maize is grown after cutting the legumes at the end of 2–3 years. Noncoppicing legumes are those species that cannot re-sprout when cut. In eastern and southern Africa, *Sesbania sesban* (L.) Merrill, *Cajanus cajan* (L.) Millsp and *Tephrosia vogelii* Hook f., *Crotalaria grahamiana* Wight & Arn and *Crotalaria pawlonia* Schrank (Jama *et al.*, 1998; Kwesiga *et al.*, 1999) have been widely used. Tree species that re-sprout when cut at fallow termination are called coppicing species. These include *Gliricidia sepium* (Jacq.) Walp., *Leucaena leucocephala* (Lam.) de Wit, *Calliandra calothyrsus* Meisss., *Senna siamea* Lam and *Flemingia macrophylla* Roxb. The coppicing fallow species are grown alone for 2–3 years, and then maize is grown between the rows of tree stumps. In eastern Zambia, these fallows have increased soil fertility through maintenance of soil organic matter, biological nitrogen fixation, uptake of nutrients from below the reach of crop roots, increased water infiltration and storage, and improved soil physical properties (Barrios *et al.*, 1997; Phiri *et al.*, 2003). In addition to improving soil quality, certain fallows have also been shown to reduce weeds and some soil pests of maize (Kwesiga *et al.*, 1999; Sileshi & Mafongoya, 2003). However, the effect of the addition of organic inputs and the subsequent improvement of soil quality under legume fallows on termite damage to maize has not been systematically studied.

Fungus-growing termite, *Microtermes*, *Ancistrotermes*, *Macrotermes*, *Allodontermes*, *Odontotermes* and *Pseudacanthotermes* species, are the predominant pests of maize in southern Africa (Sands, 1977; Hillocks *et al.*, 1996; Munthali *et al.*, 1999; Uys, 2002). Termite attack is characterized by damage to the roots and above-ground parts, and results in lodging of mature plants (Wood *et al.*, 1980). Lodging is regarded as the most severe symptom of damage by termites (Van den Berg & Riekert, 2003), and this may result in further damage by rodents, fungi, and postharvest decay and aflatoxin contamination (Wood *et al.*, 1980; Hillocks *et al.*, 1996). In parts of Kenya, Tanzania, Zambia, Malawi, Zimbabwe and South Africa, 20–30% of preharvest loss in maize is due to termites (Wilson, 1972; Nkunika, 1994; Munthali *et al.*, 1999; Maniania *et al.*, 2002; Riekert & Van den Berg, 2003a,b; Van den Berg & Riekert, 2003). Termites are estimated to affect maize production in approximately 80 000 hectares in the arid north and north-western parts of South Africa (Riekert & Van den Berg, 1999). In these areas, up to 100% of the maize plants may be attacked, resulting in crop losses of between 3 and 30% (Riekert & Van den Berg, 1999; Van den Berg & Riekert, 2003).

Few, if any, effective control methods exist to control termite species with subterranean nest such as *Microtermes* and *Odontotermes* (Van den Berg & Riekert, 2003). Because termites play beneficial roles in soil processes in agroforestry by aiding in decomposition of organic matter, and by their influences on various soil properties (Mando *et al.*, 1999), their control needs to be based on a good understanding of their ecology. The present study is part of a larger project investigating the robustness of the improved fallow technology in improving soil fertility and reducing maize pests. Our hypothesis was that termite damage to maize grown in contrasting land use systems on nitrogen-limited soils with a long dry season is related to the quantity and quality of organic inputs added to the soil. The objectives of the study were to determine the difference in termite damage between monoculture maize grown with and without fertilizer, maize grown using traditional fallows and improved fallows.

Methods

Study area

The study was undertaken in separate field trials established at Msekera Research Station (13°39′S, 32°34′E, altitude 1025 m), Kalunga Farmers' Training Centre (13°15′S, 32°36′E, altitude 1015 m) and Kagoro village (14°15′S, 31°55′E, altitude 1003 m). The soils at Msekera were ferric luvisols (Food and Agriculture Organization of the United Nations classification) characterized by low organic carbon content and macronutrients. Those at Kalunga and Kagoro consisted of sandy-loam ferric luvisols and Acrisols, respectively, with less than 1% organic carbon content. The physical and chemical properties of the soil at the experimental sites are shown in Table 1. The climate of the study area is subtropical with three distinct seasons: the warm wet season (November to April), the cool winter (May to August) and the hot, dry season (September to October). The rainfall averages approximately 960 mm per year with approximately 85% of the rains falling during December to March. Annual rainfalls of 1342, 832 and 1402 mm were registered during 2001, 2002 and 2003, respectively, at Msekera. The maize growing season starts in November and lasts 135–155 days.

Noncoppicing fallows

The treatments included legume fallows, traditional fallows and continuous monoculture maize grown with and without fertilizer. The legume fallows included two provenances of *T. vogelii*, four provenances of *Tephrosia candida*, one provenance each of *S. sesban* and *C. pawlonia*. These were established at four sites (Kagoro, Kalichero, Kalunga and Mangwe) in December 2000. Planting was performed by direct seeding in pure stands at a spacing of 1 × 1 m, and the fallows were grown for 2 years. The traditional fallows involved leaving plots to vegetate naturally with native legume and grass species. At the end of the fallows (24 months), the leaves and twig litter in improved fallows and all biomass in traditional fallows were incorporated into the soil with hand hoes up to 15 cm depth. During the crop phase (2002-2003 cropping season), maize hybrid M604 was planted without fertilizer in all fallow plots. The monoculture maize crops with and without fertilizer were planted for three consecutive years.

Table 1 Physical and chemical properties of the top 20 cm of soil at the experimental sites

					Msekera	
Soil characteristics	Kagoro	Kalichero	Kalunga	Mangwe	Experiments 91-3 and 92-3	Experiment 99-3
Sand (%)	82	64	71	84	61	68
Clay (%)	12	22	17	7	28	16
Silt (%)	6	14	12	9	11	16
pH (1 : 2.5 soil/water suspension	4.51	5.08	4.51	4.96	5.3	4.35
Organic carbon (%)	0.42	0.44	0.74	0.56	10.2	0.97
Total inorganic nitrogen (mg/kg)	4.33	4.6	1.79	4.08	7.0	4.48
Calcium (cmol$_c$/kg)	3.17	3.2	0.73	2.33	3.0	2.4
Magnesium (cmol$_c$/kg)	1.03	0.77	0.8	0.77	1.73	0.4
Potassium (cmol$_c$/kg)	0.29	0.32	0.17	0.23	1.47	0.2

Tephrosia candida Leucaena leucocephala, Gliricidia sepium Acacia anguistissima A. anguistissima + *Sesbania sesban or Tephrosia vogelii*

Coppicing fallows

Experiment 91-3 and 92-3. Two identical experiments involving legume fallows of *G. sepium*, *L. leucocephala, S. siamea, Caliandra callothyrsus* and *F. macrophylla*, traditional fallows and continuous monoculture maize grown with and without fertilizer were established in December 1991 and 1992 at Msekera Research. Bare-rooted seedlings were planted in pure stands at a spacing of 1 × 1 m (10000 trees/ha) and the fallows were grown for 3 years. At the end of the fallow period (36 months), the trees were cut, and the leaf and twig biomass was incorporated into the soil with hand hoes. Barrios *et al*. (1997, 1998) described the management of these experiments in detail. Subsequently, the re-sprouts were cut back and the biomass was incorporated into the soil three times every year. The traditional fallow involved leaving plots to vegetate naturally with native legume and grass species, and incorporating all the biomass into the soil at the end of 3 years. Maize (hybrid M604) was planted on the ridges between the tree stumps for nine and eight consecutive years in Experiment 91-3 and Experiment 92-3, respectively. Continuous monoculture maize crops with and without fertilizer were planted for 12 and 11 consecutive years.

Experiment 97-3. This experiment involved legume fallows of *G. sepium*, *L. leucocephala, Senna spectabilis* and *Acacia anguistissima*, traditional fallows and continuous monoculture maize grown with and without fertilizer. The experiment was set up in 1997 at Msekera Research Station, and labelled Experiment 97-3. Bare-rooted seedlings of the legumes were planted in the field in pure stands at a spacing of 1 × 1 m and the fallows were grown for 3 years. At the end of the fallows (36 months), the trees were cut, and the leaves and twig were incorporated into the soil with hand hoes. Subsequently, the re-sprouts were cut and the biomass was incorporated into the soil three times every year. The traditional fallow involved leaving plots to vegetate naturally with native legume and grass species and, at the end of 3 years, all biomass was incorporated into the soil. Maize hybrid M604 was planted without fertilizer on the ridges between the tree stumps for three consecutive years. Monoculture maize crops with and without fertilizer were planted for six consecutive years.

Pure and mixed-species fallows (Experiment 99-3)

The experiment was planted at Msekera Research Station in December 1999. The treatments were pure *S. sesban*, *G. sepium*, and *T. vogelii*, *A. anguistissima*, *Leucaena diversifolia*, *S. sesban* + *G. sepium*, *S. sesban* + *T. vogelii*, *S. sesban* + *A. anguistissima*, *S. sesban* + *L. diversifolia*, grass fallow and sole maize with and without fertilizer. In the mixtures, two species were planted in alternate rows forming a 1 : 1 row arrangement. The spacing between rows and between plants was 1 × 1 m (10 000 trees/ha). The traditional fallow involved leaving plots to vegetate naturally with native legume and grass species, and incorporating all the biomass into the soil at the end of 3 years. Maize hybrid M604 was planted on the ridges without fertilizer application in all treatments except the fully fertilized maize.

In all experiments, the treatments were arranged in a randomized complete blocks design with four replicates. The fertilized maize received the recommended rate of 200 kg/ha compound fertilizer (nitrogen = 100 g/kg, phosphorus = 90 g/kg and potassium = 80 g/kg) at planting and 200 kg/ha urea at 4 weeks after planting. The spacing within and between rows was 0.30 and 0.75 m, respectively, giving a maize density of approximately 44 444 plants/ha. Weeding was carroed out manually, and all weeds were incorporated into the soil. Maize residues (cobs and stalks) were removed immediately after harvest from each plot because this was the normal farming practice.

Data collection and statistical analysis

Cumulative litter fall during the fallow phase was estimated using litter traps placed under each fallow species in non-coppicing fallows and in Experiment 99-3. To determine the nutrient content of the soil before planting maize, samples were taken in November from the top 20 cm of soil, which corresponds to the till layer. Plant litter was gently removed from the soil surface, and soil was collected from each plot, air-dried and nutrient analyses were performed as described by Barrios *et al.* (1997, 1998). Ammonium was determined by the salicilic-hypochlorite colourimetric method. Nitrate was determined by cadmium reduction with subsequent colourimetric determination of NO_2. Because the amount of NO_2 is small relative to NO_3, the values are reported as NO_3 for the sake of simplicity. Inorganic nitrogen refers to ammonium + nitrate. Gravimetric water was determined from soils collected for soil nitrogen analysis in Experiment 99-3. The lignin and polyphenol data used here are those reported by Barrios *et al.* (1998) and Mafongoya *et al.* (1998) for the species used at the experimental site and in Zimbabwe, respectively.

Maize seedlings are rarely attacked by termites (Wood *et al.*, 1980; Munthali *et al.*, 1999) and lodging commences at physiological maturity (Wood *et al.*, 1980; Van den Berg & Riekert, 2003). Therefore, damage was assessed at harvest in the noncoppicing fallows and twice (at 1 month before maize harvest and at harvest) in coppicing fallows. In all experiments, damage was assessed by recording the number of lodged plants per plot. Causes of lodging were ascertained by lifting the plant and examining the root and stem for typical termite damage. Results were expressed as the percentage of lodged plants out of the total number of maize plants per plot. Data were tested for normality using the UNIVARIATE procedure of SAS (SAS Institute, Inc., Cary, North Carolina). Because the percentages were not normally distributed, the data were transformed by the arcsine function before statistical analysis. At harvest, maize grain yield (moisture content 13%) was recorded. Analysis of variance was conducted for each experiment using the generalized linear model (GLM procedure) and, when the *F*-ratio showed significance at $P = 0.05$, means were separated using Tukey's Honestly Significant Difference (HSD) test. To compare termite damage in fertilized and nonfertilized continuously cropped monoculture maize, data were analysed by a *t*-test assuming unequal variance using the TTEST procedure of SAS. The relationship between percentage of lodged plants on one hand and total biomass and nutrient content (inorganic nitrogen, calcium, magnesium, phosphorus and potassium) on the other was examined using a bivariate correlation analysis. Because bivariate normal distribution was not satisfied by most of the datasets, a nonparametric method (Spearman's correlation) was used. When two or more variables were found to be correlated with termite damage, a stepwise multiple regression analysis was conducted.

Results

Termite damage to maize grown after noncoppicing fallows

At all the sites, the differences between treatments in the percentage of lodged maize plants were not significant (Table 2). Although the differences were not statistically significant ($P > 0.05$), maize planted after *T. candida* 02971 fallows had consistently lower termite damage compared with fully fertilized monoculture maize in three out of the four sites. The percentage of lodged maize plants was also not significantly correlated with any of the variables (plant litter, leaf + twig biomass, total inorganic nitrogen). Maize grain yield significantly differed between treatments at all the sites (Table 2). The highest maize yield was obtained from fully fertilized monoculture maize whereas the lowest was from monoculture maize grown without fertilizer. The correlation between the percentage of lodged plants and maize grain yield was not significant at all the sites, except at Mangwe ($r_s = -0.42$, $P = 0.0141$, $n = 33$).

Termite damage to maize in coppicing fallows

In Experiment 91-3, no difference in the percentage of lodged plants was noted between treatments during both cropping seasons (Table 3). However, monoculture maize grown with fertilizer and *L. leucocephala* had the highest percentage of lodged plants, respectively, during both seasons. Maize yield differed significantly between treatments in Experiment 92-3 during the two cropping seasons. During the 2001–2002 cropping season, the traditional fallow had a significantly higher percentage of lodged plants compared with the other fallows. During the 2002–2003 cropping season, fully fertilized monoculture maize had significantly more lodged plants compared with maize grown in the fallows (Table 3). Except for phosphorus input in Experiment 92-3, the percentage of lodged maize plants was not significantly correlated with any of the variables measured (coppice biomass, % carbon, gravimetric water, total inorganic nitrogen, and the nitrogen, phosphorus and potassium input from the coppice biomass) (Table 4). When data for the two experiments were combined and a stepwise regression was conducted, total inorganic nitrogen, soil water at planting and coppice biomass applied during the season accounted for 59% of the variance in the percentage of lodged maize plants (Table 4). In experiment 91-3, 65–71% of the variance in maize yield was explained by total inorganic nitrogen (Table 5).

Maize yield was significantly higher in fully fertilized monoculture maize, whereas unfertilized monoculture maize and maize planted after a traditional fallow had the lowest yields in both Experiments 91-3 and 92-3 during the two cropping seasons (Table 3). In Experiment 91-3, the correlations between the percentage of lodged plants and maize grain yield were not significant during the 2002 and 2003 cropping seasons. Stepwise multiple regression analysis showed that 65 and 71% of the variance in maize yield was explained by total inorganic nitrogen during the 2001–2002 and 2002–2003 crop seasons, respectively (Table 5). In Experiment 92-3, significantly negative correlations were noted between the percentage of lodged plants and maize yield during the 2001–2002 cropping season ($r_s = -0.68$, $P = 0.0001$, $n = 32$). More than 54 and 75% of the variance in maize yield was explained by termite damage during the 2001–2002 and 2002–2003 crop seasons (Table 5).

Table 2 Termite damage and grain yield of maize grown in contrasting land use systems on farmers' fields at four sites during the 2002-2003 cropping season in eastern Zambia

Variables	Treatments	Kagoro	Kalichero	Kalunga	Mangwe	Mean
Termite damage (% lodged plants)						
	Crotalaria pawlonia	8.8^{a}	26.2^{a}	8.8^{a}	8.3^{a}	13.0^{a}
	Maize with fertilizer	8.2^{a}	11.8^{a}	15.5^{a}	3.4^{a}	9.7^{a}
	Traditional fallow	4.5^{a}	7.7^{a}	13.1^{a}	12.6^{a}	9.5^{a}
	Sesbania sesban	2.1^{a}	11.5^{a}	6.0^{a}	18.5^{a}	9.5^{a}
	Tephrosia candida	5.3^{a}	10.8^{a}	13.4^{a}	1.4^{a}	7.7^{a}
	Tephrosia candida 02972	0.9^{a}	6.8^{a}	18.0^{a}	8.4^{a}	8.5^{a}
	Maize without fertilizer	3.3^{a}	12.9^{a}	4.1^{a}	11.7^{a}	8.0^{a}
	Tephrosia vogeli ex Misamfu	3.2^{a}	9.0^{a}	11.3^{a}	4.7^{a}	7.1^{a}
	Tephrosia vogeli ex Chambeshi	3.3^{a}	12.0^{a}	8.1^{a}	2.6^{a}	6.5^{a}
	Tephrosia candida 02970	1.2^{a}	8.3^{a}	9.3^{a}	4.8^{a}	5.9^{a}
	Tephrosia candida 02971	1.5^{a}	3.9^{a}	4.9^{a}	5.6^{a}	4.0^{a}
	$F_{10,20}$ value*	2.17	1.25	1.61	1.48	1.05
	P-value	0.066	0.321	0.174	0.218	0.408
Maize yield (t/ha)						
	Maize with fertilizer	3.2^{a}	4.1^{ab}	3.7^{ab}	3.3^{a}	3.6^{a}
	Sesbania sesban	0.5^{b}	4.7^{a}	4.4^{a}	2.3^{ab}	3.0
	Tephrosia vogeli ex Misamfu	1.7^{b}	3.5^{ab}	3.2^{abc}	0.8^{c}	2.3^{abc}
	Tephrosia candida 02970	0.6^{b}	3.6^{ab}	3.4^{abc}	1.1^{bc}	2.2^{abc}
	Tephrosia candida	0.9^{b}	3.2^{ab}	3.3^{abc}	1.5^{bc}	2.2^{abc}
	Tephrosia candida 02971	0.6^{b}	3.5^{ab}	2.9^{abc}	0.9^{c}	2.0^{abcc}
	Tephrosia vogeli ex Chambeshi	0.8^{b}	3.6^{ab}	2.3^{bc}	1.1^{bc}	1.9^{abc}
	Crotalaria pawlonia	0.7^{b}	2.8^{ab}	2.8^{abc}	1.2^{bc}	1.9^{abc}
	Tephrosia candida 02972	0.5^{b}	3.0^{ab}	2.8^{abc}	1.0^{c}	1.7^{bc}
	Maize without fertilizer	0.3^{b}	1.5^{b}	1.7^{cd}	0.7^{c}	1.1^{c}
	Traditional fallow	0.3^{b}	2.1^{ab}	0.8^{d}	0.7^{c}	1.0^{c}
	$F_{10,20}$ value	8.61	3.04	6.38	9.29	4.08
	P-value	0.0001	0.0178	0.0002	0.0001	0.0001

Means followed by the same superscript letters in a column do not significantly differ at 5% level according to HSD.

In Experiment 97-3, the percentage of lodged plants was significantly greater in monoculture maize grown continuously without fertilizer compared with monoculture maize grown continuously with fertilizer and maize planted in *A. anguistissima* fallows in the 2001–2002 cropping season (Table 6). In the 2002–2003 cropping season, the percentage of lodged plants was lower compared with the 2001–2002 cropping season, and no difference was noted among treatments. When termite damage in monoculture maize grown with and without fertilizer was compared using a *t*-test, a significant difference due to fertilizer application was found only during the 2002–2003 cropping season (Table 7). The percentage of lodged maize plants was significantly correlated ($r_s = -0.96$, $P = 0.0005$, $n = 32$) with preseason inorganic nitrogen. No other variable was associated with termite damage.

Maize grain yield was significantly greater in monoculture maize continuously grown with fertilizer compared with maize grown without fertilizer and maize grown after traditional fallows (Table 6). Maize grown using *G. sepium* fallows produced a higher maize gain yield than monoculture maize grown without fertilizer and maize grown after traditional fallows (Table 6). There was a significant negative correlation between the percentage of lodged plants and maize grain yield during the 2001–2002 cropping season ($r_s = -0.58$, $P = 0.0058$, $n = 21$), but not during the 2003 cropping season. More than 61% of the variance in maize yield was explained by termite damage during the 2001–2002 seasons (Table 5).

Termite damage to maize in pure and mixed-species fallows

Termite damage significantly differed among the various treatments (Table 8). The percentage of lodged plants was greatest in fully fertilized continuously cropped monoculture maize. Among the pure fallows, maize grown after *G. sepium* and *S. sesban* had less than 5% lodged plants. Termite damage in maize grown in pure fallows of *A. anguistissima* was comparable with that found in monoculture maize grown with or without fertilizer. Among the mixtures of fallow species, maize grown in *A. anguistissima* + *S. sesban* and *T. vogelii* + *S. sesban* fallows had lower percentages of lodged plants compared with that in monoculture maize. When termite damage in monoculture maize grown with and without fertilizer was compared using a *t*-test, no difference was found between the two treatments (Table 7). The percentage of lodged maize plants was negatively correlated with the amount of litter fall from trees incorporated into the soil ($r_s = -0.56$, $P = 0.0002$, $n = 39$) and soil water ($r_s = -0.43$, $P = 0.007$, $n = 39$) at maize planting. Among the variables entered in the stepwise regression, litter and soil water accounted for 38% of the variance in the percentage of

Table 3 Termite damage and grain yield of maize grown in contrasting land use systems during the 2001–2002 and 2002–2003 in Experiments 91-3 and 92-3 at Msekera Research Station

		Lodged plants(%)		Maize yield (t/ha)	
Experiment	Treatments	2001–2002	2002–2003	2001–2002	2002–2003
91-3	Maize with fertilizer	27.6^{a}	5.0^{a}	4.1^{a}	4.8^{a}
	Flemingia macrophylla	16.8^{a}	4.5^{a}	3.2^{ab}	4.4^{ab}
	Senna siamea	17.4^{a}	4.5^{a}	2.7^{abc}	3.2^{bc}
	Traditional fallow	11.5^{a}	2.6^{a}	1.8^{bcd}	2.0^{cd}
	Caliandra callothyrsus	16.7^{a}	3.3^{a}	1.4^{cd}	2.0^{cd}
	Gliricidia sepium	17.8^{a}	2.3^{a}	1.2^{cd}	1.8^{d}
	Maize without fertilizer	11.3^{a}	2.1^{a}	1.1^{cd}	1.6^{d}
	Leucaena leucocephala	14.8^{a}	1.0^{a}	0.9^{d}	1.6^{d}
	$F_{7,14}$ value*	0.66	1.81	10.4	22.3
	P-value	0.704	0.138	0.0001	0.0001
92-3	Maize with fertilizer	23.3^{cd}	39.2^{a}	4.2^{a}	3.5^{a}
	Leucaena leucocephala	35.6^{abc}	13.7^{b}	2.6^{bc}	1.7^{bc}
	Gliricidia sepium	16.5^{d}	27.4^{ab}	3.0^{ab}	1.8^{bc}
	Senna siamea	48.1^{a}	13.7^{b}	2.2^{bcd}	2.2^{b}
	Caliandra callothyrsus	29.0^{bcd}	12.0^{b}	1.0^{d}	0.5^{d}
	Flemingia macrophylla	13.7^{d}	25.3^{ab}	1.4^{cd}	0.9^{d}
	Traditional fallow	42.7^{ab}	16.0^{b}	0.9^{d}	0.6^{d}
	Maize without fertilizer	14.2^{d}	10.6^{b}	0.9^{d}	0.7^{d}
	$F_{7,14}$ value	15.9	4.02	17.1	17.5
	P-value	0.0001	0.06	0.0001	0.0001

Means followed by the same superscript letters in a column do not significantly differ at 5% level according to HSD.

lodged maize plants (Table 4). The inclusion of the other parameters in the multiple regression model did not increase the predictability of termite damage.

The highest and lowest maize grain yields were recorded in fully fertilized and nonfertilized monoculture maize, respectively. There was no difference between nonfertilized monoculture maize and maize grown after a traditional fallow. There was a significant negative correlation between the percentage of lodged plants and maize grain yield ($r_s = -0.32$, $P = 0.048$, $n = 39$).

Discussion

The present study shows that conventionally tilled monoculture maize and maize grown after traditional fallows suffer more termite damage compared with maize grown in rotation with noncoppicing legume fallows. However, the termite suppression offered by this rotation was not low enough to warrant the use of noncoppicing fallows for termite management. During the course of this study, termite damage in maize grown after *T. vogelii* and *T. candida* fallows did not significantly differ from monoculture maize. However, maize grown after the *T. candida* provenances (02971 and 02970) appeared to suffer lower termite damage at all four sites. The reduction in termite damage in maize grown after *T. candida* fallows could be due to the addition of more organic matter to the soil compared with *T. vogelii*, which produces only half of the biomass produced by *T. candida* (Mafongoya *et al.*, 2003).

Table 4 Parameter estimates of the multiple regression equation for relationship of percent lodged plants and significant explanatory variables in three experiments at Msekera Research Station

Experiment	Variable	Parameter	*F*	Probability > *F*	Model r^2
91-3	Intercept	0.83	8.43	0.034	
	Carbon (%)	−0.59	5.23	0.071	0.51
92-3	Intercept	0.38	92.87	0.0002	
	Phosphorus input	0.01	9.35	0.028	0.65
91-3 and 92-3 combined	Intercept	0.51	8.22	0.017	
	Soil water	−0.06	8.49	0.016	0.21
	Inorganic nitrogen	0.01	6.40	0.030	0.21
	Coppice biomass	0.05	3.99	0.074	0.17
99-3	Intercept	0.59	31.9	0.0001	
	Litter	−0.12	5.68	0.0226	0.28
	Soil water	−0.02	5.52	0.0244	0.10

Variables used were coppice biomass, litter biomass incorporated, preseason inorganic nitrogen, preseason and midseason soil water.

Table 5 Parameter estimates of the multiple regression equation for relationship of maize yield and significant explanatory variables in four experiments at Msekera Research Station

Experiment	Crop season	Variable	Parameter	F	Exact probability	Partial r^2
91-3	2001-2002	Intercept	−3.90	4.76	0.072	
		Inorganic nitrogen	0.39	11.31	0.015	0.65
	2002-2003	Intercept	−4.28	5.50	0.058	
		Inorganic nitrogen	0.45	14.81	0.009	0.71
92-3	2001-2002	Intercept	9.37	17.24	0.009	
		Termite	−8.14	14.83	0.012	0.54
		Soil water	−0.31	4.23	0.095	0.21
	2002-2003	Intercept	−3.99	12.18	0.018	
		Termite	−8.51	35.48	0.002	0.75
		Soil water	0.19	4.97	0.076	0.12
97-3	2001-2002	Intercept	5.85	14.36	0.013	
		Termite	−6.77	7.67	0.039	0.61
	2002-2003	No variable[a]	–	–	–	–
99-3	2002-2003	Intercept	1.68	8.75	0.013	
		Inorganic nitrogen	0.17	17.41	0.002	0.63
All experiments combined	2001-2002	Intercept	3.62	18.53	0.0001	
		Termite	−3.16	4.16	0.054	0.17
	2002-2003	Intercept	2.37	11.62	0.002	
		Termite	−2.80	3.10	0.088	0.23
		Soil water	0.13	9.96	0.003	0.07

Variables used were total preseason inorganic nitrogen, soil water, and termite damage.

[a] All variables entered did not meet the 0.10 significance level.

Among the coppicing fallows, termite damage was consistently lower in maize grown in *L. leucocephala* and *G. sepium* fallows compared with monoculture maize grown with or without fertilizer. Termite attack in crops is frequently associated with low soil fertility (Wardell, 1987) and water stress (Van den Berg & Riekert, 2003). However, our results show that termite damage in unfertilized maize was not significantly different from fully fertilized maize. The lack of a significant difference between fully fertilized and unfertilized maize, and the absence of a significant correlation between termite damage and preseason soil inorganic nitrogen, which represents nitrogen readily available to maize (Barrios *et al.*, 1998), and our earlier work (Sileshi & Mafongoya, 2003) shows that termite damage to maize is not influenced by soil nitrogen. The decrease in termite damage to maize grown in legume fallows compared with monoculture maize could be due to an improvement in soil organic matter and soil water retention. Fungus-growing termites feed on crop residues, mulches and soil organic matter. However, when this type of food is not available, they will eat live plants, including maize, and their damage is known to be greater in soils with low organic matter content (Uys, 2002). This is because such soils do not contain enough food to support termites, and they resort to feeding on living plant material. The addition of large quantities of litter and increased labile pools of soil organic matter under tree fallows (Rao *et al.*, 1998) could have reduced termite damage in maize grown in the fallows, whereas a lack of alternative food sources in the monoculture maize may have concentrated the termites on the crop itself. The difference among fallow species

Table 6 Termite damage and grain yield of maize grown in contrasting land use systems in Experiment 97-3 at Msekera Research Station during the 2001–2002 and 2002–2003 cropping seasons

	Lodged plants (%)		Maize yield (t/ha)	
Treatment	2001–2002	2002–2003	2001–2002	2002–2003
Maize without fertilizer	53.9^{a}	6.5^{a}	0.2^{cd}	0.1^{d}
Traditional fallow	48.2^{ab}	16.7^{a}	0.6^{cd}	0.5^{cd}
Leucaena leucocephala	36.0^{abc}	21.1^{a}	1.5^{c}	0.7^{bcd}
Senna spectabilis	30.2^{abc}	34.0^{a}	1.5^{c}	1.2^{bc}
Maize with fertilizer	23.4^{bc}	18.7^{a}	3.7^{a}	3.5^{a}
Gliricidia sepium	27.8^{abc}	15.3^{a}	2.5^{b}	1.6^{b}
Acacia anguistissima	19.8^{c}	25.0^{a}	1.6^{bc}	1.0^{bcd}
$F_{6,12}$ value	5.34	2.17	33.08	36.4
P-value	0.0067	0.1195	0.0001	0.0001

Means followed by the same superscript letters in a column do not significantly differ at 5% level according to HSD.

Table 7 Termites damage during 2001–2002 and 2002–2003 cropping seasons in maize grown in continuous monoculture with and without fertilizer in four different experiments at Msekera Research Station

			Lodged plants (%) in monoculture maize		Test statistic	
Cropping season	Experiment	Maize monoculture planted continuously (years)	With fertilizer	Without fertilizer	*t*-value	Significance
2001–2002	91-3	11	27.6 (14.1)	11.3 (2.7)	1.1	0.333
	92-3	10	23.3 (3.3)	42.7 (4.3)	3.6	0.013
	97-3	5	31.7 (2.4)	21.7 (7.3)	1.3	0.309
2002–2003	91-3	12	5.0 (1.2)	2.1 (0.5)	2.3	0.082
	92-3	11	39.2 (10.9)	16.0 (5.6)	1.9	0.125
	97-3	6	18.7 (3.2)	6.5 (2.1)	3.2	0.043
	99-3	4	21.9 (8.5)	6.5 (3.6)	1.7	0.170

Figures in parenthesis indicate standard errors of means.

could be explained in terms of the decomposition rate of the coppice biomass incorporated in to the soil. *Flemingia macrophylla*, *C. calothyrsus* and *S. siamea* prunings have high lignin and polyphenols, and low nitrogen, and therefore decompose more slowly and build organic matter compared with *L. leucocephala* and *G. sepium* (Barrios *et al.*, 1998; Mafongoya *et al.*, 1998). The slowly decomposing plant residues could attract more termites, thereby increasing damage to the maize crop.

Termite damage to maize was higher at all sites during 2001–2002, which was a relatively drier cropping season compared with 2002–2003. Most of the termite damage to maize in the study area occurred after the dry spells during March to April. This confirms earlier reports that water stress exacerbates termite damage to crops, particularly at the end of the crop season (Logan *et al.*, 1990; Wightman & Wightman, 1994; Van den Berg & Riekert, 2003). The lower termite damage in maize grown in *L. leucocephala* and *G. sepium* fallows compared with monoculture maize could be due to the lower water stress expected during dry spells in the fallows (Phiri *et al.*, 2003). Through their ability to improve organic matter (Rao *et al.*, 1998) and water retention, these fallows may have a moderating effect on termite damage to maize. On the other hand, the poor soil structure and water retention in continuous maize monoculture could have increased susceptibility to termite attack on maize. The intercropping effects of fallows contributing to an increase in populations of predators (Sekamatte *et al.*, 2003) may also have been important.

The study has shown that yields of maize will be higher when maize is grown in monoculture using the recommended rate of fertilizer. However, the increased termite damage may have a negative impact on yields. Although crop rotation has been recommended as a measure to manage termites, the results from the current study, together with those obtained in earlier work (Logan *et al.*, 1990; Sileshi & Mafongoya, 2003), suggest that some rotations could lead to greater levels of termite attack. We conclude that rotation of maize with improved fallow species such as *S. sesban*, *L. leucocephala* and *G. sepium*, which produce large amounts of high quality biomass (Mafongoya *et al.*, 1998), can improve soil fertility and reduce termite damage, and that these species are more robust than

Table 8 Termite damage and yield of maize grown in contrasting land use systems in Experiment 99–3 during the 2003 crop season at Msekera Research Station

Treatments	Gravimetric water (%)	Litter biomass (t/ha)	Re-sprout biomass (t/ha)	Inorganic nitrogen (mg/kg)	Termite lodged plants (%)	Maize grain yield (t/ha)
Maize with fertilizer	9.2^{b}	0.0^{b}	0.0^{a}	22.4^{a}	19.6^{a}	5.9^{a}
Pure *Acacia anguistissima*	15.6^{a}	0.5^{ab}	1.3^{a}	14.2^{a}	16.3^{a}	3.7^{abc}
Maize without fertilizer	10.3^{b}	0.0^{b}	0.0^{a}	4.4^{a}	14.7^{a}	1.7^{c}
Pure *Leucaena diversifolia*	15.1^{a}	0.8^{a}	1.6^{a}	8.8^{a}	8.9^{a}	3.6^{abc}
Traditional fallow	16.2^{a}	0.0^{b}	0.0^{a}	10.8^{a}	8.4^{a}	2.5^{bc}
Gliricidia sepium + *Tephrosia vogelii*	15.8^{a}	0.5^{ab}	0.5^{a}	11.7^{a}	8.2^{a}	3.3^{bc}
Leucaena diversifolia + *Sesbania sesban*	16.2^{a}	0.5^{ab}	1.3^{a}	10.5^{a}	7.7^{a}	4.3^{ab}
Gliricidia sepium + *Sesbania sesban*	15.5^{a}	0.5^{ab}	0.7^{a}	13.5^{a}	6.5^{a}	4.6^{ab}
Pure *Tephrosia vogelii*	16.0^{a}	0.4^{ab}	0.0^{a}	10.2^{a}	5.8^{a}	4.3^{ab}
Pure *Sesbania sesban*	15.3^{a}	0.3^{ab}	0.0^{a}	14.9^{a}	4.8^{a}	3.9^{abc}
Sesbania sesban + *Tephrosia vogelii*	15.8^{a}	0.6^{ab}	0.0^{a}	20.5^{a}	4.6^{a}	4.3^{ab}
Pure *Gliricidia sepium*	15.7^{a}	0.8^{a}	0.9^{a}	15.9^{a}	4.0^{a}	4.1^{ab}
Acacia anguistissima + *Sesbania sesban*	15.0^{a}	0.6^{ab}	1.1^{a}	17.1^{a}	2.7^{a}	4.6^{ab}
$F_{12,\ 24}$ value	8.64	3.20	3.78	1.02	2.22	5.34
P-value	0.0001	0.008	0.003	0.4570	0.044	0.0002

Means followed by the same superscript letters in a column do not significantly differ at 5% level according to HSD.

T. vogelii, *T. candida*, *C. pawlonia*, *F. congests*, *C. calothyrsus* and *S. siamea* in the maize production systems in eastern Zambia.

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