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EVALUATING THE IMPACT OF *GLIRICIDIA SEPIUM* ON SOIL ORGANIC MATTER IN MAIZE-BASED CROPPING SYSTEMS IN SOUTHERN MALAWI

presented by

Tracy L. Beedy

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of the requirements for the

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EVALUATING THE IMPACT OF *GLIRICIDIA SEPIUM* ON SOIL ORGANIC MATTER IN MAIZE-BASED CROPPING SYSTEMS IN SOUTHERN MALAWI

By

Tracy L. Beedy

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ABSTRACT

EVALUATING THE IMPACT OF *GLIRICIDIA SEPIUM* ON SOIL ORGANIC MATTER IN MAIZE-BASED CROPPING SYSTEMS IN SOUTHERN MALAWI

By

Tracy L. Beedy

There is considerable interest in soil organic matter technologies and fertility sources in intensified maize-based cropping systems in Southern Africa. This study investigated the effect of the *Gliricidia sepium* (Jacq.) Walp and maize intercrop on soil organic matter (SOM) fractions and soil fertility indices in southern Malawi. Part 1 investigated the response of SOM fractions to the intercrop, inorganic nitrogen (N), and phosphorus (P) on a long-term trial established in 1991 on a Ferric Lixisol in southern Malawi. Soil was sampled to a 20 cm depth in July of 2006. SOM, available P, exchangeable K^+, and CEC were determined on whole soil samples. Particulate organic matter (POM) was separated from the soil by size and density fractionation and analyzed for C and N. The intercrop had a positive effect on all SOM fractions. With the intercrop, POM was increased by 37%, carbon in POM by 60% and nitrogen in POM by 78% compared to sole maize. C/N ratio of POM decreased from 17.9 with sole maize to 15.5 with the intercrop. After 14 years, predictors of soil fertility and SOM fractions were significantly greater under the intercrop than under sole maize. In part 2, an on-farm study in the same district described characteristics of intercrop users and their placement of the intercrop on different soils. Thirty-seven households using the intercrop and 28 households not using the intercrop were interviewed in June and July of 2006.

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Questionnaires were completed with each household concerning demographic statistics and the soil types found and cropping systems used in their fields. In female-headed households use of the intercrop was 66% compared to 49% in households headed by males. Intercrop use was 50% among households in the lower half of the socioeconomic scale and 63 % in the upper half. Households using the intercrop had an average of 0.4 hectares of land, while those not using the intercrop had an average of 0.83 hectares. Placement of the *gliricidia*/maize intercrop on sandy M'chenga soils was less common than on Katondo and Makande soils. In part 3, the SOM and soil nutrient effects of the intercrop were compared to prevailing soil management practices in smallholder's fields. Soil samples were taken from the 2005/6 planting rows from the fields with and without the gliricidia intercrop. Soil samples were analyzed for SOM, sand content, available P, exchangeable K^+ and CEC. Soil organic matter values associated with the intercrop were not significantly different from those for other cropping systems. When the gliricidia/maize intercrop fields were analyzed separately, soil type, elevation, and their interaction affected trends in soil organic matter. A positive relationship between soil organic matter and elevation was evident in the two finer-textured soil types, Makande and Katondo. The addition of pigeonpea, *Cajanus cajan* (L.), to the maize cropping system at elevations below 877 meters was associated with an increasing trend in SOM compared to the sole maize cropping system. The emergence of increasing trends in SOM correlated with increasing elevation and fineness of soil texture in fields with the *gliricidia*/maize intercrop may indicate that a SOM benefit will develop over time in fields at relatively higher elevations with finer soil textures.

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I would like to thank the sixty-four cooperator households in Zomba District, Malawi, for their generosity in sharing with us their farming practices, and to Mr. Ladson Chirwa and Miss Martha Chiwaya for soil sampling and information gathering. Laboratory analyses by Miss Andrea Posigian are gratefully acknowledged.

PREFACE

Chapter 1 in this dissertation was written in the style required for publication in *Agriculture, Ecosystems, and Environment.* Chapters 2 and 3 were written in the style required by *Agroforestry Systems.*

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KEY TO SYMBOLS OR ABREVIATIONS

C/N	Carbon/nitrogen ratio, ratio of carbon to nitrogen
CEC	Cation exchange capacity
ICRAF	International Centre for Research in Agroforestry (see WAC)
POM	Particulate organic matter
POM-C	Carbon in particulate organic matter
POM-N	Nitrogen in particulate organic matter
POM-C/N	Carbon/nitrogen ratio in particulate organic matter
SOM	Soil organic matter
WAC	World Agroforestry Centre

CHAPTER ONE

LONG-TERM IMPACT OF *GLIRICIDIA SEPIUM* INTERCROPPING AND INORGANIC FERTILIZER ON SOIL CARBON AND NITROGEN IN A MAIZE-BASED CROPPING SYSTEM IN SOUTHERN MALAWI

ABSTRACT

There is considerable interest in the role of soil organic matter technologies and fertility sources in intensified maize-based cropping systems in Southern Africa. Yield gains and seasonal N dynamics for the *Gliricidia sepium*-maize intercropping system have been studied, but the long-term effects of the intercrop on soil organic matter fractions and N pools have not been documented. Soil organic matter (SOM), particulate organic matter (POM) and soil nutrient responses were quantified in response to a gliricidia intercrop at three rates of added inorganic nitrogen (N) and phosphorus (P), compared to sole maize. This trial was established in 1991 on a Ferric Lixisol in southern Malawi. Gliricidia was established at a 150 cm x 90 cm spacing. Calcium ammonium nitrate was applied at 0, 46, and 92 kg N ha^{-1}, and triple superphosphate at 0, 20 and 40 kg P ha^{-1} annually. Soil was sampled to a 20 cm depth in July of 2006. SOM, POM, carbon and nitrogen in POM (POM-C, POM-N) inorganic N, Nitrogen mineralization potential, available P, exchangeable K, CEC and base saturation were determined. The gliricidia/maize intercrop had a significant and positive effect on SOM fractions: SOM was increased by 12.5% and POM was increased by 37% under the intercrop versus sole maize. Fertilizer additions of N and P did not result in significant changes in SOM in

both production systems, although N fertilizer increased POM by 16% in the intercrop and 24% in sole maize. The gliricidia/maize intercrop was associated with marked increases in POM-C (60%) and POM-N (78%). A decrease was observed in C/N ratio of POM from 17.9 with sole maize to 15.5 with the intercrop indicating N enrichment although depletion of N due at the end of the cropping season might have been expected. The gliricidia/maize intercrop and increasing soil clay content were associated with significantly increased soil CEC. After 14 years, predictors of soil fertility and supporting SOM fractions were significantly greater under the gliricidia/maize cropping system than under sole maize.

1. INTRODUCTION

Soil organic matter is often the single largest source of nutrients for smallholder farming systems in Southern Africa according to Mtambanengwe et al. . Because maize is the staple crop in Malawi (Chirwa et al., 2003), as in the rest of southern Africa, food security in the region depends heavily on enhancing the performance of this crop. How to build up and maintain soil fertility is a central issue in increasing agricultural productivity in Africa (Mafongoya et al., 2006a).

The use of nitrogen fertilizers to improve maize production in the landlocked African countries is constrained by the high fertilizer costs, shipping costs and difficult logistics in terms of transport and timeliness. Price ratios of nitrogen to maize in Malawi may be almost double those in Mozambique, which borders Malawi on the east, and is able to bring fertilizer cheaply by sea to the northern maize production region (Mafongoya et al., 2006a). Compounding this fertilizer availability problem is the low level of fertility and depleted soil organic matter on smallholder farms due to continuous cultivation without adequate soil replenishment. Thus, examining soil organic matter dynamics is crucial to understanding soil fertility issues in southern Africa.

Annual and perennial intercrops and rotations have been developed in this region to enhance soil fertility (Snapp et al., 2002a). A wide range of physical, chemical, and biological interactions occur in both agroforestry systems which affect plant nutrient cycling (Schroth, 1998). Several leguminous trees and shrubs such as *Sesbania sesban* (L.) Merr., *Tephrosia vogelii* Hook, f., *Gliricidia sepium* (Jacq.) Walp. And *Leucaena leucocephala* (Lam.) have been developed and introduced in southern Africa as renewable soil nitrogen (N) and soil organic matter (SOM) sources in maize-based cropping systems (Kwesiga et al., 2003). Sesbania, tephrosia, and gliricidia have been investigated in southern Malawi for soil fertility replenishment (Harawa et al., 2006). Sesbania and tephrosia are used as improved fallows and relay intercrops, while gliricidia is managed as a long-term intercrop.

Gliricidia is one of a group of species which tolerates periodic coppicing and removal of leaves for use as green manure or mulch of crops. The quality of leaves from these species varies widely. Gliricidia produces a very high quality green manure (Makumba, 2003). When managed as an intercrop, Makumba et al. (2003) found that the primary rooting zone of gliricidia was below that of maize, and Harawa et al. (2006) found that gliricidia reduced leaching of N below the maize rooting zone compared to sole maize.

A long-term trial established on a Ferric Lixisol at the Makoka research station in southern Malawi gliricidia has been shown to increase maize yield (Akinnifesi et al., 2007). In a meta-analysis of the performance of woody and herbaceous legumes, Sileshi at al. (2008) found coppicing legumes to be associated with greater yield increases in maize than non-coppicing legumes.

This trial allows investigation of fertilizer interactions with organic matter technologies, at three rates of application for both N and P. This interaction of inorganic and organic nutrient sources is important in developing feasible production systems in Africa (Sanchez et al., 2007). Long-term research station trials, such as the one in this study, play an important role in providing detailed information on biological variables over multiple cropping seasons (Richter et al., 2007).

Oorts et al. (2000) evaluated the effect of several agroforestry species on soil organic matter fractions and the effect of these fractions on the cation-exchange capacity of the soil. They found that the organic inputs from the agroforestry species were associated with an increase in silt-sized particles with the highest charge density of the organic fractions, and noted the promise of these systems for increasing the CEC of weathered soils.

Release of nutrients such as nitrogen from soil organic matter depends on mineralization of its biologically active (or labile) fractions (Barrios et al., 1996). Labile soil organic matter (SOM) can be assessed effectively by characterizing the particulate organic matter (POM) fraction. The POM fraction of SOM is typically low-density (usually 1.4-2.2 g cm^{-3}) and/or coarse (53-250μm), and commonly derived from biomass additions from the previous year (Wander, 2004). Szott et al. (1999) found this fraction to be larger after short-duration fallows with species having high-quality foliage such as sesbania and gliricidia.

Waddington et al. (2004) found N mineralization potential to be dependent on annual organic inputs from in crop residues or manure, where residues were recycled through animals. Because N is the most common limiting nutrient to maize growth, and N is mineralized from POM it is important to study the interaction between POM and the mineralization of nitrogen. In an earlier study of N dynamics in the gliricidia/maize intercrop trial in southern Malawi, Makumba et al. (2003) found that the yield increase associated with N additions from gliricidia and added inorganic N was significant, but this yield increase was not associated with increased total soil organic matter. Akinnifesi et al. (2007) also found maize yield to be related to first and second order N in the monoculture and to the first and second order of N and rainfall in the intercrop. Soil texture is also an important variable in soil nutrient cycling (Giller et al., 1997; Hao et al., 2006) however the relationships between soil carbon, soil texture and microstructure are complex (Plante et al., 2006). Because soil texture is heterogenous, spatial variability of soil can also be an important factor in SOM characterization. Kravchenko et al. (2006) found that assessment of soil carbon based on both treatment effects and spatially sampled data such as topography and texture improved the accuracy of analysis in a trial comparing tillage regimes.

The current study investigates SOM and POM response to the gliricidia intercrop and three rates of added inorganic nitrogen (N) and phosphorus (P), compared to sole maize. The first objective was to determine whether the gliricidia intercrop significantly increased SOM, POM, and labile N pools, and whether the effect of gliricidia interacted with the effect of inorganic N and P fertilizer. The second objective was to determine whether the gliricidia intercrop increased soil's ability to supply plant nutrients beyond those added as inorganic N and P.

2. MATERIALS AND METHODS

2.1. Site description and management

This trial was established in 1991 as a randomized complete plot design with three replications to test the factorial combination of two cropping systems, three N fertilizer rates (0, 46, and 92 kg N ha^{-1}) and 3 P fertilizer rates (0, 20 and 40 kg P ha^{-1}) with three replications (Akinnifesi et al., 2007). The soil at the trial site is classified as a Ferric Lixisol (Ikerra et al., 1999), with an initial SOM level of 15.2 g kg^{-1}, based at the Makoka Research Station (latitude 15° 30′ S, longitude 35° 15′ E). The rainfall pattern at the station is unimodal with most rain falling between November and March. The mean annual rainfall between 1997 and 2006 was 964 mm. Monthly rainfall during the growing seasons of 2003-2006 ranged from 11.5 mm to 363.9 mm (Figure 1.1) and varied widely between cropping seasons. Nitrogen was applied annually, four weeks after planting. Phosphorus was applied annually as triple super phosphate except for 1993-2002, because no P yield effects were demonstrated in the initial years of the trial. Phosphorus applications were resumed in 2002 at the rates listed above (Akinnifesi et al., 2007), which corresponded to 0, 50%, and 100% of the recommended rates (Malawi Government Ministry of Agriculture, 1996).

2.2. Establishment and management of gliricidia

The 6.7 x 6.0 m plots were separated by iron sheets inserted to a 1m depth to minimize root encroachment. The three replicate blocks were separated by a 1 m path. Planting ridges were established at 75 cm spacing. Gliricidia was planted in alternate ridges (150 cm spacing) and with a 90 cm spacing within the ridge, which results in a gliricidia population of 7,400 trees ha^{-1}. The trees were pruned to a height of 30 cm in October, December, and February of each year, and the leaves and tender twigs incorporated into the maize ridges, which were rebuilt in October of each year. Biomass was recycled within each treatment plot each year. After the onset of rains, usually in November or December, both sole maize and gliricidia/maize plots were planted with maize hybrid NSCM 41. The maize was seeded at 30 cm intervals in all of the ridges, resulting in a plant population of 44,400 plants ha^{-1}. The maize grain was harvested after drying down in the field, usually in May. Sub-samples were taken for moisture determination, and yield and biomass data were expressed as kilograms per hectare on a dry weight basis. A more detailed description of site management may be found in Makumba et al. (2006b) and Akinnifesi et al.(2007).

2.3. Soil sampling and analysis

Soil samples (0-20cm) were taken in July, 2006, composited from six samples per plot using a straight-walled soil probe with 2cm diameter. The samples were mixed, air-dried, passed through a 2 mm sieve, and stored. A sub-sample of the soil was dried overnight at 40°C, crushed with an Agvise flail-type grinder and analyzed for organic matter, pH, available phosphorus (P), exchangeable potassium (K), magnesium (Mg), and calcium (Ca) (A & L Great Lakes Laboratories, Fort Wayne, IN). Organic matter was determined by loss on ignition at 360 °C and the data correlated with and reported as Walkley-Black titration. Soil pH was determined in a 1:1 soil to water slurry. Available phosphorus and exchangeable cations were extracted according to Mehlich III (Mehlich, 1984), and analyzed by inductively-coupled plasma spectrometry (ICP). The P data was correlated to and reported as Bray P-1 (Bray and Kurtz., 1945). The data for exchangeable cations correlated to and reported as a 1 N ammonium acetate extraction (McIntosh, 1969). Percent base saturation and CEC were calculated from the results for exchangeable cations.

Particle size distribution, nitrogen mineralization potential and particulate organic matter were determined on subsamples of soil that had not been ground. Particle size distribution of the samples was determined by gravimetric sedimentation after removal of the organic fraction with 30% H_2O_2 (Gee and Bauder, 1986).

Nitrogen mineralization was determined using an aerobic 30-day incubation of rewetted soils after Haney, et al. (2004). One 10 g sample was dried at 105° C overnight for moisture determination. Four sub-samples (40 g each) were weighed into half-pint glass jars. Water was added to 50% of field capacity (Saxton and Rawls, 2006), and the containers were covered with parafilm in which four 1 cm holes had been made for atmospheric exchange. The quadruplicate samples were incubated at 25° C in an incubator with extra jars of water to maintain high humidity levels. Soil moisture was returned to 50% of field capacity, measured gravimetrically, on a weekly basis. After 30 days of incubation, each sample was extracted with 200 ml of 2 N KCl.

Initial inorganic N was determined from duplicate 10 g samples of non-incubated soil extracted with 2N KCl. The extracts from the non-incubated and incubated soils were analyzed with a Westco Smartchem analyzer for nitrogen from NH_4^+, NO_2^-, and NO_3^-. Nitrate and nitrite were determined by hydrazine reduction and ammonium was determined with the Berthelot reaction (WestcoScientific, 2007).

POM was separated from the soil samples by size and density fractionation (Cambardella and Elliott, 1993; Wander et al., 1994) and the values presented as a fraction of total soil weight. Quadruplicate 25 g samples of soil were dispersed in 125 mL 0.5 g L^{-1} sodium hexametaphosphate for 17 hours on a reciprocating shaker at 180 rpm. The dispersed fraction was passed through a 53 μm sieve. The fraction remaining on the screen, containing both sand and POM, was well washed with deionized water, and dried 48 hours at 60° C. The dry sample was carefully transferred into 50 ml plastic conical centrifuge tubes, and 35 mL of sodium polytungstate of density 1.85 Mg/m^3 added. The tubes were capped, and inverted slowly several times to ensure that the suspended material was completely wetted and mixed with the sodium polytungstate. The tubes were then placed in a vertical position and centrifuged at 1000 rpm for 30 minutes. The POM plus sodium polytungstate was decanted onto a 20 μm mesh nylon filter connected to a vacuum filtration system. The POM remaining on the mesh was rinsed thoroughly with deionized water to remove traces of sodium polytungstate, and dried overnight at 60° C. Sodium polytugnstate was recycled according to Six et al. (1999). The weight of POM was recorded for each sample and the quadruplicate samples were combined and ground for 2 minutes each in a Shatterbox 8515 mill (SPEX SamplePrep, Metuchen, NJ). Carbon and nitrogen were determined on the ground samples by dry combustion in a CHNS analyzer (Costech ECS 4010, Costech Analytical Technologies, Valencia, CA).

2.4. Data analysis

Analysis of variance was conducted to determine the effect of the gliricidia intercrop and inorganic N and P rates, as well as the continuous variables of sand and clay content on response variables related to the organic fraction: SOM, POM, POM carbon and POM nitrogen. Response variables relating soil fertility to the treatment factors were available

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inorganic N, N mineralization potential, Bray P1 phosphorus, exchangeable K^+, CEC, and percent base saturation,.

Ancovas were conducted using the PROC MIXED procedure in SAS (Littell et al., 2006) to determine if soil textural variables influenced the relationship between the treatment factors and the response variables. Where soil texture had no significant influence, the models were three-way Anovas using SAS Type 3 analysis, which uses expected mean squares to estimate variance components. In the PROC MIXED analysis, standard errors are calculated considering both the fixed effects and random effect components of the model. Planned contrasts were included in the Anovas for treatments which had similar N additions from inorganic and organic sources. Because variances of exchangeable K^+ were unequal among gliricidia and sole maize, this analysis was conducted using the restricted maximum likelihood method, and different variances specified for the two groups.

Nitrogen mineralization was calculated by subtracting inorganic nitrogen (NH_4^+ plus NO_2^- plus NO_3) values in non-incubated samples from the corresponding values in the incubated samples, and expressed as mg N per kg dry soil. POM values were expressed as g per kg of dry soil mass. Carbon and nitrogen in POM were expressed as mg per kg dry soil, and as a C/N ratio. Because SOM is often spatially correlated (Kravchenko et al., 2006), Soil organic carbon values, and soil sand and clay content were analyzed for spatial correlation using the PROC MIXED procedure in SAS (Littell et al., 2006). Spatial modeling did not improve the fit of the soil organic carbon model, and was dropped from the modeling strategy.

3. RESULTS

Southern Malawi lies in the southernmost portion of the eastern Rift Valley. Elevations range from less than 100m above sea level (asl) in the southern Shire valley to more than 2000m atop Mount Mulange. Zomba district lies mostly between 300m and 1200m (Benson et al., 2002). Rainfall is unimodal (Figure1. 1), with the majority of rains falling between December and April. Population density for Malawi averages 105 persons km^{-2}. In southern Malawi, population densities range from 50 to 400 persons km^{-2} outside of urban centers. The population density of Zomba district ranges from 100 to 200 persons km^{-2} (Benson et al., 2002). Rainfall in southern Malawi ranges from 600mm to 1600mm annually. Most of Zomba district receives 800mm to 1200mm of rainfall annually (Reynolds, 2000).

3.1. Soil organic matter

Soil organic matter ranged from 18 to 33 g kg^{-1} of total soil mass across all gliricidia, N and P treatments. The presence of gliricidia increased SOM 3.4 g kg^{-1} beyond the SOM maintained in the sole maize cropping system (Figure 1.2) averaged across N and P treatments. At the median clay content, the gliricidia /maize system contained 26.2 g kg^{-1} SOM compared to 22.8 g kg^{-1} in the sole maize system. The increase of SOM was constant across the range of clay content (Figure 1.3). The clay content of the soil ranged from 18.4 to 44.6 percent, the average base saturation was 67% and the average pH was 5.6 (Table 1.1). The presence of clay increased SOM 0.19 g kg^{-1} for each 1% increase in clay content.

3.2. Particulate organic matter

Both the presence of gliricidia and fertilizer N positively influenced POM values (Table 1. 2). The presence of gliricidia increased POM by 4.7 g kg^{-1} (37%) at each rate of N addition (Figure1.2). With 48 kg ha fertilizer N added to the system, POM increased from 12.6 g kg^{-1} in the sole maize plots to 17.3 g kg^{-1} in the intercrop. Fertilizer N addition increased POM by 2.4 g kg^{-1} over no N additions, which amounts to 18% with the intercrop and 33% in the sole maize plots.

Both gliricidia and fertilizer N had positive effects (Table 1.2) on carbon in the POM fraction (POM-C) and nitrogen in the POM fraction (POM-N). The presence of gliricidia was associated with increased POM-C by 0.76 g kg^{-1} or 60% (Figure 1.4), and POM-N by 0.06 g kg^{-1} or 78% (Figure 1.4). With 48 kg ha N fertilizer addition, POM-C was increased from 1.27 g kg^{-1} with sole maize to 2.03 g kg^{-1} with the intercrop. At the same rate of fertilizer N addition, POM-N was increased from 0.071 g kg^{-1} with sole maize to 0.126 g kg^{-1} with the intercrop (Figure 1.4). The first increment of N fertilizer was associated with increases in POM-C and POM-N, 0.32 g kg^{-1} and 0.015 g kg^{-1} respectively.

POM-C and POM-N values with similar levels of inorganic N + organic N were also contrasted. The treatment combination gliricidia + 0 added N is associated with a POM-C value of 1.71 g kg^{-1}, contrasted to sole maize + 48 kg ha^{-1} added N, with to 1.27 g kg^{-1} of POM-C ($p = 0.0025$). The same contrast is associated with POM-N values of 0.111 and 0.071 g kg^{-1} respectively, ($p=<.0001$).

The ratio of C to N in POM varied from 14.7 to 18.6 (Figure 1.5). The gliricidia, N and P treatments resulted in statistically significant decreases in the C/N ratio of POM

(Table 1.2). The presence of gliricidia was associated with a C/N ratio of 15.6 compared to 17.9 for sole maize, averaged across N and P treatments (Figure 1.5). The first and second increments of N fertilizer were associated with C/N ratios of 17.2 and 16.3 compared to 16.8 for no N fertilizer, averaged across cropping and P treatments. The first and second increments of P fertilizer were associated with C/N ratios of 16.4 and 16.9, compared to 16.9 with no P fertilizer, averaged across cropping and N treatments.

3.3. Available nitrogen

The effect of gliricidia and fertilizer N on inorganic N values (ammonium+nitrate+nitrite) prior to incubation (Table 1.4) was positive (Table 1.3). Eighty-seven percent of inorganic N was in ammonium form. This ratio was relatively uniform among the three N treatments. Gliricidia increased inorganic N from 7.93 g kg^{-1} in sole maize to 12.8 in the intercrop. The effect of increasing P addition was negative.

Nitrogen values after incubation were negative, and were 22% to 32% of pre-incubation values, indicating immobilization (Figure 1.6). Initial inorganic N values were greater in the gliricidia treatment and immobilization values were correspondingly greater. The effects of gliricidia and fertilizer N treatments on N mineralization potential were significant.

3.4. Soil fertility indices

The gliricidia intercrop, fertilizer N, and increasing clay content were associated with decreasing soil phosphorus values (Table 1.4) while soil phosphorus values were increased by increasing P additions (Table 1.3). Decreasing soil potassium values were associated increasing fertilizer N and P additions in the sole maize system (Table 1.3,

Table 1.4), while the opposite trend was observed in the intercrop. Increasing soil potassium was also associated with increasing clay content in the gliricidia cropping system, but not in sole maize (Table 1.3). Gliricidia, the first increment of N fertilizer, clay content and the interaction of gliricidia and clay content significantly increased cation exchange capacity (CEC) (Table 1.3 and Table 1.4). Base saturation was significantly increased only by N addition.

3.5. Soil Texture and Soil Fertility

Sand content modified the effect of gliricidia on inorganic available N, which was increased by 0.074 g kg^{-1} for each 1% increase in sand content in the sole maize cropping system, and decreased by 0.29 g kg^{-1} for each 1% increase in sand content in the intercrop (Figure 1.6). The interaction between gliricidia and sand content was also evident in N mineralization values, and similar in proportion (Figure 1.6). Soils in the gliricidia cropping system also maintained CEC between 8.5 and 9 cmol kg^{-1} of soil across the range of clay content (Figure 1.7), while CEC varied significantly with clay content in the sole maize treatments.

4. DISCUSSION

4.1. Site soil characteristics and production history

Though the base saturation of Lixisols is comparatively high, the CEC and absolute level of plant nutrients is low, which makes recurrent inputs of plant nutrients a pre-condition for continuous cultivation (FAO, 1999a). Given the limited natural fertility of these soils, the gliricidia/maize intercrop could play an important role in replenishing labile organic matter pools, an important plant nutrient source for smallholders continuously cropping Lixisols. Organic matter technology effects on soil properties is often not discernable in studies with a two to three-year time frame (Lehmann et al., 2001). This trial is an opportunity to study treatment effects on soil organic matter levels that have been built over a period of fifteen years.

Makumba et al. (2006b) gives maize yield ranges in this trial from 1.5 to 4 Mg ha^{-1} for the sole maize treatments and from 4 to 6 Mg ha^{-1} between 1993 and 2003. One of their conclusions is that the maize yield in gliricidia treatments averaged 1.9 times that in the sole maize treatments over the decade. The average N content in the leaves is given as 29mg N per g of leaf, and the average annual gliricidia biomass addition as 4.8 Mg ha^{-1} yr^{-1}. From these figures, N added through gliricidia biomass averaged approximately 139 kg ha^{-1} yr^{-1} between 1993 and 2003.

4.2. Soil organic matter

The gliricidia cropping system had a positive effect on all SOM fractions. Soil organic matter ranges across all treatments were consistent with soil organic carbon values of 11.4 to 29.1 g kg^{-1} reported by Akinnifesi (2007) in a previous study in the same trial. The effect of gliricidia on both SOM and POM (Table 1. 2) in soils may be due to both the direct effect of decomposition of gliricidia biomass and an indirect effect as plant nutrients released in gliricidia decomposition increase maize biomass production, which is then recycled within each treatment plot. Between 1998 and 2002, biomass additions averaged near 1.1 Mg ha^{-1} in the sole maize treatments and near 4.5 Mg ha^{-1} in the gliricidia treatments (Makumba, 2003). Sherrod et al. (2005) found that differences in stover production accounted for 80% of the variability in SOC associated with increased cropping intensity. Akinnefesi et al. (2007) reported a significant first-order interaction between N rate and gliricidia with production of stover biomass between 2002 and 2006 in this trial. However, this interaction was not carried forward into the SOM reported in this study. After 14 years of biomass additions, SOM values were 15% higher in the gliricidia/maize intercrop than in the sole maize cropping system, however fertilizer N and P treatments did not have a significant effect on SOM.

4.3. Particulate organic matter

In addition to the significant effect associated with gliricidia in maintaining SOM and POM (Table 1.2), increases in fertilizer N were associated with significant increases in POM values (Figure 1.2). Moran et al. (2005) found that addition of mineral N increased the rate of soil C respiration and SOM decomposition. Our study followed a similar pattern, in which the 48 kg ha^{-1} rate of fertilizer N was related to an increase ($Pr>F=0.0169$) in POM values from 10.2 to 12.6 g kg^{-1} (Figure 1.2).

Use of the gliricidia intercrop and addition of fertilizer N to the cropping system resulted in increased POM-C and POM-N compared to sole maize and no addition of fertilizer N. Vanlauwe et al. (2000) found that N in the POM fraction was significantly related to N uptake by maize in coarse savannah soils. Moran (2005) found enrichment of POM-N with N fertilizer to be greater than with other organic matter fractions in a greenhouse study of rice residue decomposition. Figure 1.4 demonstrates that POM-C and POM-N values with the gliricidia intercrop but no N fertilizer were greater than POM-C and POM-N in the sole maize cropping system. The increase in POM-C and POM-N amounted to 35% and 56% respectively. A planned contrast showed these differences to be statistically significant (Table 1.3). Marriot et al. (2006) reported similar results in a comparison of organic and conventionally fertilized trials in the U.S.

Makumba et al. (2006a) demonstrated annual N additions from gliricidia that averaged near 100 kg ha^{-1}, but produced grain yield increases commensurate with 50 kg N ha^{-1} applied as calcium ammonium nitrate. This indicates that gliricidia is associated with a lower yield efficiency than fertilizer N. The enrichment of POM-C and POM-N, however, demonstrates the potential of gliricidia-derived N to become available to maize in subsequent years. The lessening of N efficiency in a given year may be less important than the hedge against the risk of a shortfall in availability of fertilizer N in the future, where POM-N provides that buffer.

POM C/N ratios were decreased by the gliricidia cropping system, and N and P additions (Table 1.2 and Figure 1.5). This may have important impacts on early-season maize nutrition and yield. Maroko et al. (1998) found a similar effect with a sesbania fallow on both an alfisol and an oxisol. The effect of the gliricidia was far greater than the effect of the N and P additions. Since the C/N ratios were reduced from 17.9 to 15.5, decomposition of POM should release N upon decomposition, rather than immobilizing

N. This result is contradicted by the data in Figure 1.6, which shows greater immobilization with the gliricidia intercrop. This effect, however, may be associated with the dry season, when soil was sampled. This immobilized N may be remobilized with the onset of seasonal rains and addition of gliricidia green manure and added mineral N. Makumba et al. (2006a) found that gliricidia green manure added in October increased yields of maize planted in December more than green manure added later in the cropping season, so that re-mobilization would be expected to occur after the 30 days of interval used in the incubation.

4.4. Soil texture and soil organic matter

Giller et al. (1997) state that temperature and moisture availability control the initial rate of decomposition of SOM, while texture controls the extent to which decomposition eventually proceeds. The tendency of finer-textures soils to maintain higher SOM levels has been widely reported. The tendency of clay colloids to slow decomposition of organic matter may result both from adherence between colloid and organic molecules (Giller et al., 1997), and increased aggregation with increasing clay content (Vanlauwe et al., 1998). In our study, SOM increased with clay contents increasing from 18.7% to 44.6% equally in gliricidia and sole maize treatments (Figure 1.3), and the additive effect of the gliricidia and clay raised SOM to 29.4 g kg^{-1} in the gliricidia treatments with the finest texture, compared to 21.1 g kg^{-1} SOM in the sole maize treatments with the coarsest soil texture.

4.5. Available nitrogen

Inorganic N and N mineralization potential (NMP) under these treatments was characterized to elucidate more clearly the N-supplying power of POM in the maize system when intensified by addition of the gliricidia intercrop and/or by fertilizer N. Giller (1997) listed the three principal sources of N for crop production in Africa as biologically fixed N, organic biomass recycled in the field and mineral N fertilizers. Each of these sources was included in this study, as all maize biomass was recycled in each treatment in both cropping systems and the biological and inorganic sources of N were systematically varied in the research design.

The increase in inorganic N observed in the gliricidia cropping system was presumably derived from both biological and fertilizer N (except in N=0 plots). In a field study of seasonal inorganic N in smallholder maize production on sandy soils in Zimbabwe, Chikowo et al. (2004) found that mucuna (*Mucuna pruriens),* and soybean *(Glycine max)* rotations were associated with 50% increases in soil inorganic nitrogen over the season compared to unfertilized maize, which was similar to the increases found in our study.

The high proportion of ammonium-N in the pre-incubated N analysis was typical of soils in climates with a pronounced dry season. Because mineralization proceeds under slightly drier soil conditions than nitrification, ammonium-N tends to accumulate during the dry season (Giller et al., 1997). The materials incorporated in this trial, gliricidia prunings and maize stover, have been described as high and low quality materials with C:N ratios of 16 and 86, respectively, by Makumba (2003). Though the maize stover had not been incorporated at the time of sampling, maize root fragments sm

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smaller than the 2mm sieve size were observed in the soil samples, and might have contributed to immobilization of N. Vanlauwe et al. (2005) observed complete immobilization of N of in soil with added maize stover in a 28 day incubation, as compared to incubation of soil with gliricidia leaves added, which mineralized 30% of the N present in the leaves. Makumba (2003) also noted initial N immobilization with the gliricidia/maize residue combination and related increased immobilization to years with lower rainfall totals and increased remineralization of N to higher rainfall totals in some study years. In a temperate field study, Gentry et al. (1998) also linked N immobilization to crop root residues and low rainfall cropping seasons.

The effect of increasing soil sand content on available N under the gliricidia cropping system (Figure 1.6) may derive from protection of organic matter from decomposition with increasing clay content. This is supported by the significant effect of clay on total soil organic matter (Figure 1.3). However, leaching of N can also limit the efficiency of N derived from annual legumes in coarse soils under heavy rainfall in southern Malawi (Mwato et al., 1999). This leaching of N from coarse surface horizons would occur equally in agroforestry species, but may also be limited by tree uptake of N (Harawa et al., 2006).

4.6. Soil fertility

Overall, gliricidia had positive effects on available N and P in the soil, and on CEC, although not on exchangeable K. Nitrogen fertilizer treatments were positively associated with all soil fertility indices in the intercrop, while the shorter term application of fertilizer P had a substantial effect only on soil available P. Vanlauwe et al. (2000) found Olsen P levels under unfertilized alley cropping and sole maize in West African savannah soils did not differ, indicating that the woody species were not associated with increased availability of P to the cropping system. The decrease in Bray-1 P values in our study under gliricidia may have been the result of an export of soil P in increased grain and biomass yields (Table 1.4). Akinnifesi et al. (2007) found that gliricidia and the first increment of N and P additions had a synergistic effect on grain yields. Mweta et al. (2007) has described maize uptake of P in excess of the soil's ability to supply P in this trial.

Both designations of the soil, a Ferric Lixisol (FAO), or Oxic Haplusalf (USDA) (Ikerra et al., 1999), highlight the presence of Fe and Al oxides in the clay fraction which typically fix P, and lessen the ability of the soil to supply sufficient P under high production conditions. Mweta et al. (2007) reported that the Fe-P fraction was the dominant form of inorganic P in soils in this trial. The fixation capacity of the soil in our study may be altered by the extent to which SOM binds with Fe and Al oxides, lessening their fixation capacity, however, not sufficiently to maintain soil P in maize cropping systems. Gliricidia significantly increased available P in all soils, but available P more than doubled as clay content declined from 36% to 24%.

Decrease in soil potassium (K^+) values associated with increasing N additions in the sole maize system (Table 1.3, Table 1.4) may have been an export effect of higher yields similar to that observed with soil P. Soil K^+ is rarely deficient in Malawi agricultural soils (Snapp, 1998), and the Ministry of Agriculture has not recommended K^+ additions (Malawi Government Ministry of Agriculture, 1996).

The significant effect of gliricidia and N addition and their interactions on CEC (Table 1.4) could be related to the significant increase of SOM from these treatments.

Though the increase was only 0.2 cmol kg^{-1}, it is operationally important because CEC serves as a conduit for the supply of nutrients for maize in a given year, and lessens the leaching of monovalent cations such as K^+ and NH_4^+ in coarse-textured alfisols.
The significant effect of clay and its interactions on CEC should be due to clay's character as a source for much of the CEC at neutral or near neutral pH in most soils. The highly significant interaction of clay with gliricidia in CEC (Figure 1.7) demonstrates the ability of gliricidia to maintain soil CEC through SOM additions in soils with low clay contents. The ability of SOM to maintain CEC and soil fertility in sandy soils is an important factor in maize-based cropping systems in alfisols.

5. CONCLUSIONS

The results from this study are consistent with the maize/gliricidia intercrop increasing SOM levels compared to sole maize. As production systems are intensified, tree intercrops may play an important role in preventing or slowing soil degradation and maintaining the supply of plant nutrients to maize in intensified cropping systems in the coarse soils typical in the region.

Particulate organic matter pools, which act as a reservoir of crop nutrients, were enhanced by the gliricidia intercrop, which was also associated with a significant decrease in POM C/N ratio from 17.9 to 15.5, potentially increasing N availability to crops. However, because of immobilization during the dry season timing of application of gliricidia very early in the cropping season is important so that immobilization may be reversed (Makumba et al., 2006a). That immobilization is eventually reversed is supported by findings that maize yields in the gliricidia cropping system averaged four times those in the sole maize system (Akinnifesi et al., 2007).

TABLES

Table 1.1 Mean, maximum, minimum, and standard deviation for response variables.

	Mean	Max.	Min.	St. Dev.
SOM (g kg^{-1})	24.6	33.0	18.0	3.41
POM (g kg^{-1})	14.0	23.0	6.6	3.80
POM-C (g kg^{-1})	1.58	2.49	0.63	0.504
POM-N (g kg^{-1})	0.09	0.16	0.03	0.035
POM C/N	17.1	19.6	14.6	1.39
Avail. N (mg kg^{-1})	10.8	28.4	4.49	4.64
NMP (mg kg^{-1})	-7.72	-1.10	-22.2	4.00
Bray P (mg kg^{-1})	61.0	123	17.0	24.4
Exch. K^+ (mg kg^{-1})	176	373	44.0	75.6
CEC (cmol kg^{-1})	8.49	10.5	5.00	1.11
Clay content (%)	28.1	44.6	18.4	6.32
Sand content (%)	56.0	66.2	41.7	5.76
Base saturation (%)	67.2	86.3	50.9	8.55
pH	5.62	6.20	5.00	0.25

Table 1.2 Means and significance of cropping system, N rate, P rate, and clay and sand content on soil organic matter, particulate organic matter, and carbon in particulate organic matter of whole soil. Standard errors are in parentheses following the means.

	SOM	POM	POM-C	POM-N	POMC/N
		Statistical significance (Pr>F)			
Cropping System (CS)	<.0001	<.0001	<.0001	<.0001	<.0001
N fertilizer (N)	NS	0.0169	0.0058	0.0026	0.0013
P fertilizer (P)	NS	NS	NS	NS	0.0399
Clay	0.0161	NS	NS	NS	NS
Sand	NS	NS	NS	NS	NS
N*P	NS	0.0471	NS	NS	NS
CS. x N	NS	NS	NS	NS	NS
Planned contrast:(intercrop + N fertilizer=0) versus (sole maize + N fertilizer=48 kg ha^{-1})			0.0025	<.0001	
		Means			
Sole Maize	(g kg^{-1}) (g kg^{-1})	(g kg^{-1})	(g kg^{-1})	(g kg^{-1})	
N =0	20.7(0.37)	10.2(2.6)	0.95(0.31)	0.056(0.018)	17.9(0.85)
N=48	21.9(0.38)	12.6(2.6)	1.27(0.29)	0.071(0.018)	18.3(0.82)
N=96	22.2(0.20)	12.3(1.7)	1.31(0.20)	0.080(0.012)	17.5(0.68)
Maize/Gliricidia					
N =0	23.3(0.29)	14.9(1.8)	1.71(0.23)	0.111(0.013)	15.6(0.66)
N=48	24.6(0.30)	17.3(2.6)	2.03(0.21)	0.126(0.013)	16.0(0.62)
N=96	24.8(0.12)	17.0(1.7)	2.07(0.11)	0.135(0.006)	15.1(0.49)
Sole Maize	21.6(0.32)	11.7(2.3)	1.18(0.27)	0.069(0.016)	17.9(0.78)
Maize/Gliricidia	24.3(0.24)	16.4(2.0)	1.94(0.18)	0.124(0.011)	15.5(0.59)
N=0	22.0(0.33)	12.6(2.2)	1.33(0.27)	0.084(0.016)	16.8(0.76)
N=48	23.3(0.34)	15.0(2.6)	1.65(0.10)	0.098(0.016)	17.2(0.72)
N=96	23.5(0.16)	16.0(1.7)	1.69(0.16)	0.108(0.009)	16.3(0.59)

Interactions not listed were non-significant at 0.05 for all response variables.

*NS: non-significant (Pr > F) >0.05

Table 1.3 Significance of cropping system, N rate, P rate, and clay and sand content on available N, Bray P, cation exchange capacity, and potassium (K^+) values of soil.

	Inorg. N	Bray P	K+	CEC
Statistical significance (Pr>F)				
Cropping System	0.0054	0.0014	NS	0.0002
N	<.0001	0.0495	<.0001	0.0115
P	0.0334	<.0001	0.0147	NS
Clay	NS	<.0001	NS	0.0005
Sand	NS	NS	NS	NS
Cropping System x N	NS	NS	NS	0.0304
Cropping System x clay	NS	NS	0.0010	0.0009
N x clay	NS	NS	NS	0.0104
P x clay	NS	NS	NS	0.0291
Cropping System x sand	0.0232	NS	NS	NS
P x sand	0.0416	NS	NS	NS

Interactions not listed were non-significant at 0.05 for all response variables.
NS: non-significant (Pr > F) >0.05

Table 1.4 The effect of cropping system and added N or added P on concentration of plant nutrients in study soils, with standard errors of treatment means in parentheses following concentrations.

	Inorg. N ($mg\ kg^{-1}$)	NMP ($mg\ kg^{-1}$)	Exch. K+ ($mg\ kg^{-1}$)	CEC ($cmol\ kg^{-1}$)	pH		Bray P ($mg\ kg^{-1}$)
Sole Maize						Sole Maize	
N = 0	6.2 (3.1)	3.4(1.7)	166(39.8)	7.75(0.99)	5.8(0.09)	P = 0	40.4(12.5)
N = 48	6.6 (3.1)	3.0(1.8)	132(40.1)	8.82(0.99)	5.6(0.08)	P = 20	68.6(12.5)
N = 96	11.0(2.1)	5.6(0.8)	81.0(24.9)	8.22(0.65)	5.3(0.16)	P = 40	87.3 (8.2)
Gliricidia/Maize						Gliricidia/Maize	
N = 0	11.1(2.3)	-8.0(1.7)	96.4(27.5)	8.01(0.71)	5.9(0.09)	P = 0	31.7 (9.1)
N = 48	11.5(2.3)	-7.6(1.8)	130(27.8)	9.08(0.71)	5.7(0.16)	P = 20	61.6 (9.0)
N = 96	15.8(1.2)	-10.2(0.8)	181(12.6)	8.48(0.36)	5.5(0.26)	P = 40	78.8 (4.7)

FIGURES

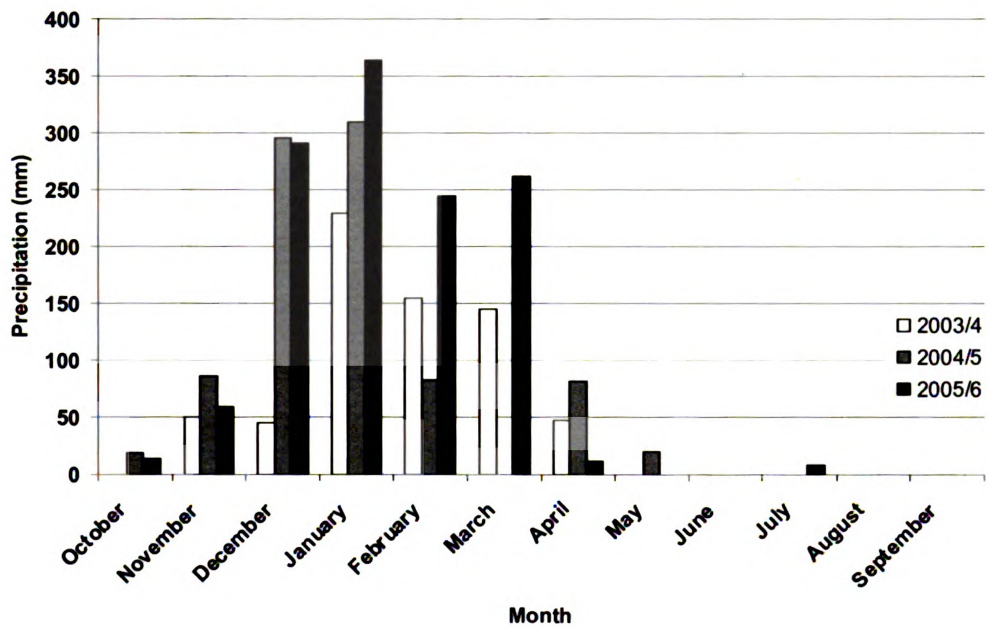

Fig. 1.1 Monthly precipitation, Makoka Research Station, 2003-2006.

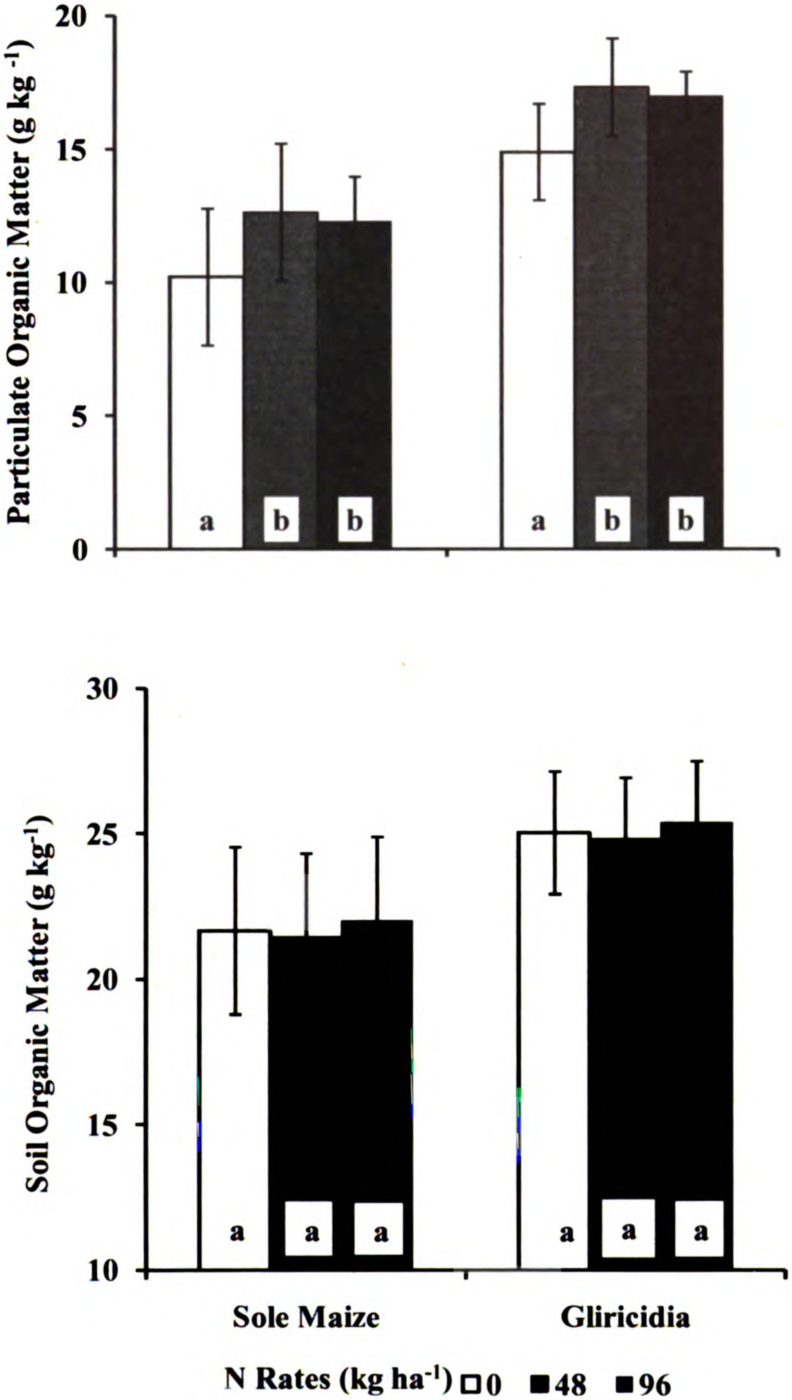

Fig. 1.2 The effect of fertilizer N rate and gliricidia on soil organic matter and particulate organic matter. Error bars represent standard error of treatment means. Bars with the same letter within each cropping system are not significantly different.

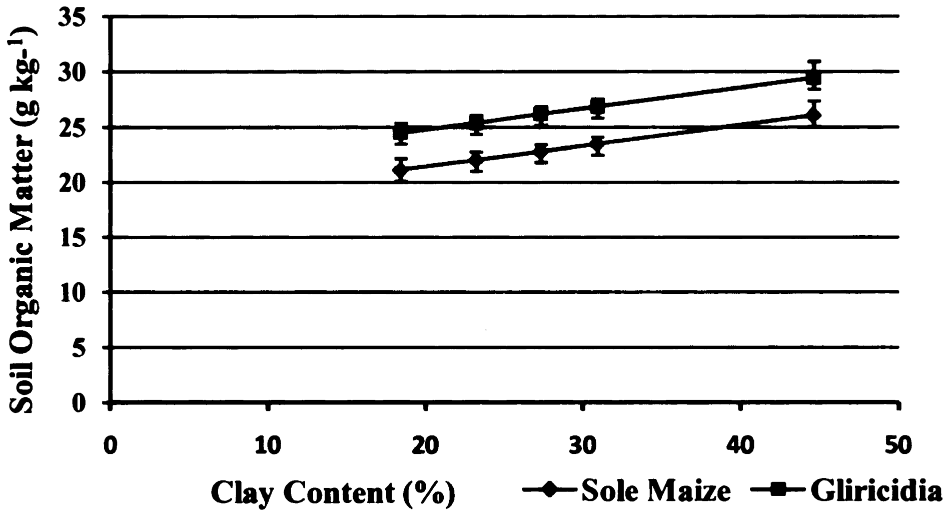

Fig. 1.3 The effect of clay content and gliricidia on soil organic matter, estimated at endpoints and quartiles of clay content. Error bars represent standard error of treatment means.

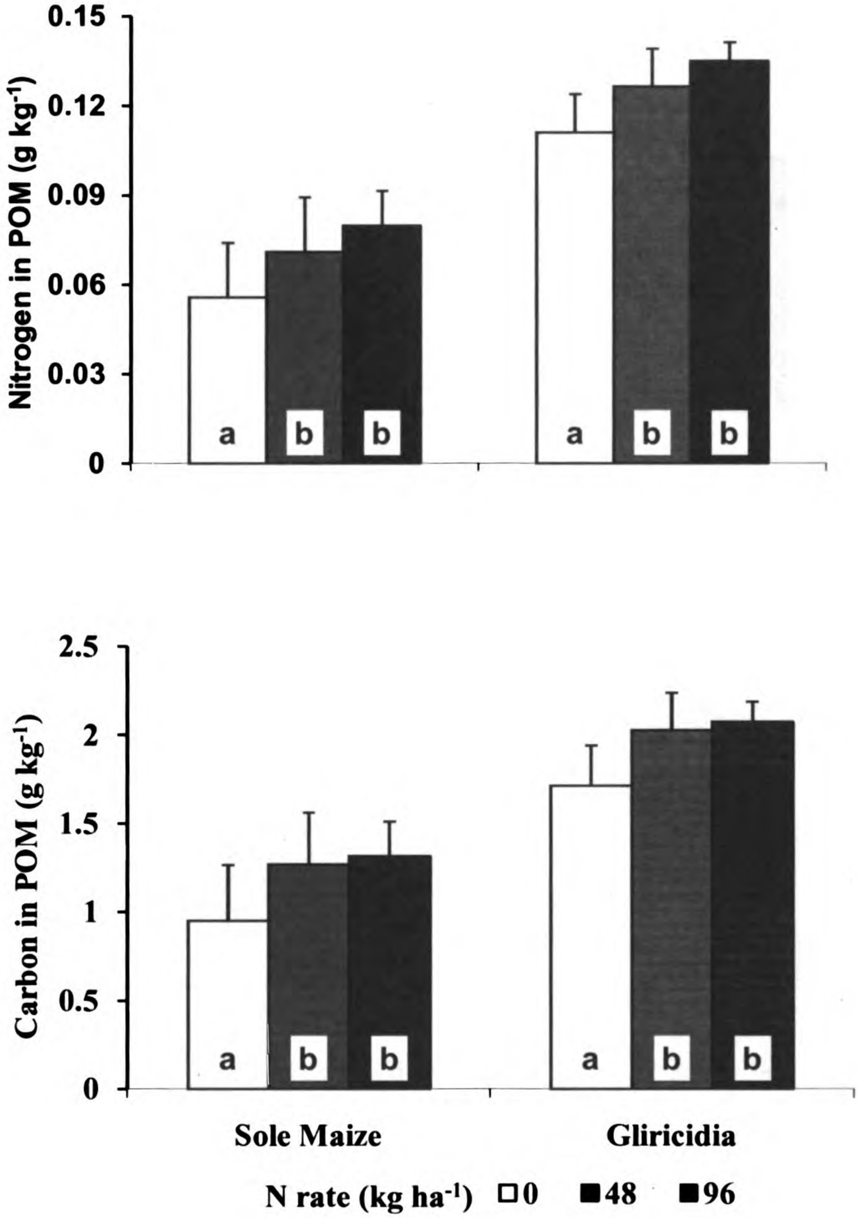

Fig.1.4 The effect of gliricidia and fertilizer N on carbon and nitrogen in particulate organic matter. Error bars represent standard error of treatment means. Bars with the same letter within each cropping system are not significantly different.

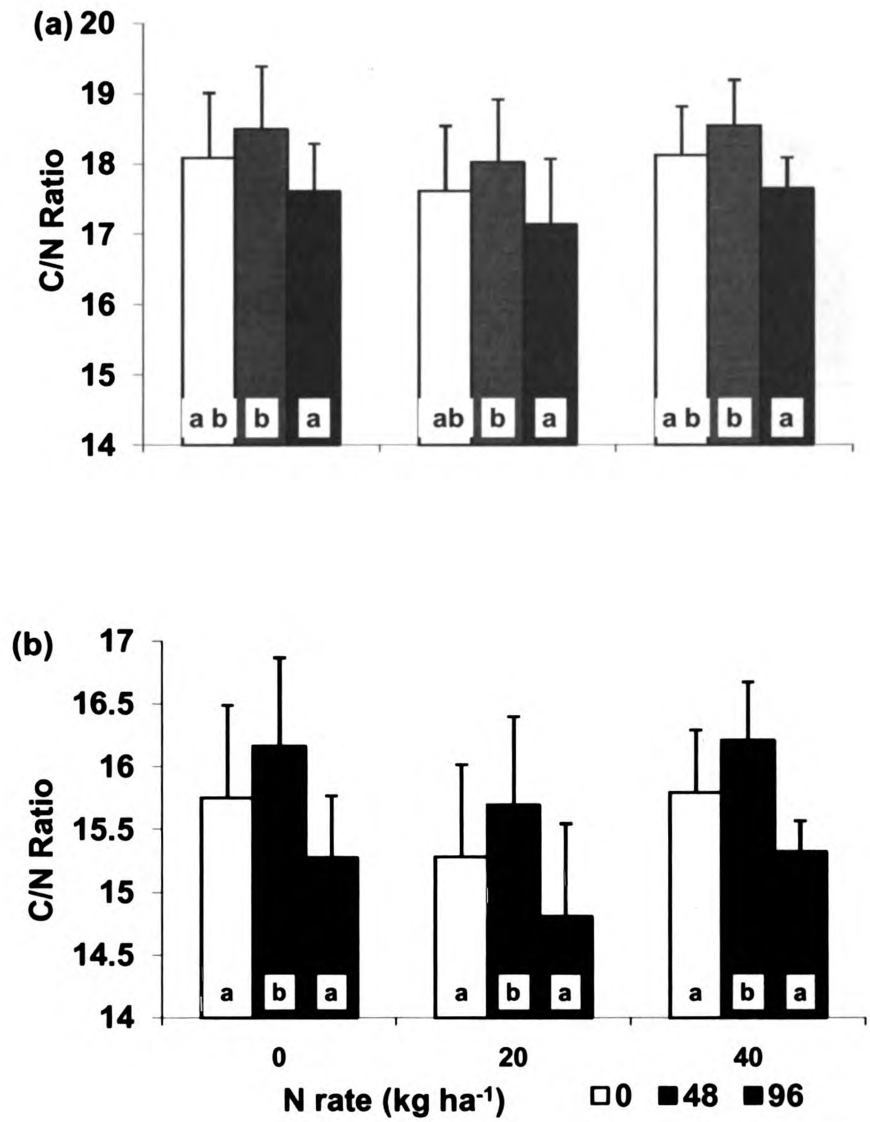

Fig. 1.5 The effect of gliricidia, fertilizer N and fertilizer P on C/N ratios of particulate organic matter. (a) Sole maize (b) Gliricidia/maize intercrop Error bars represent standard error of treatment means. Bars with the same letter within each P rate are not significantly different.

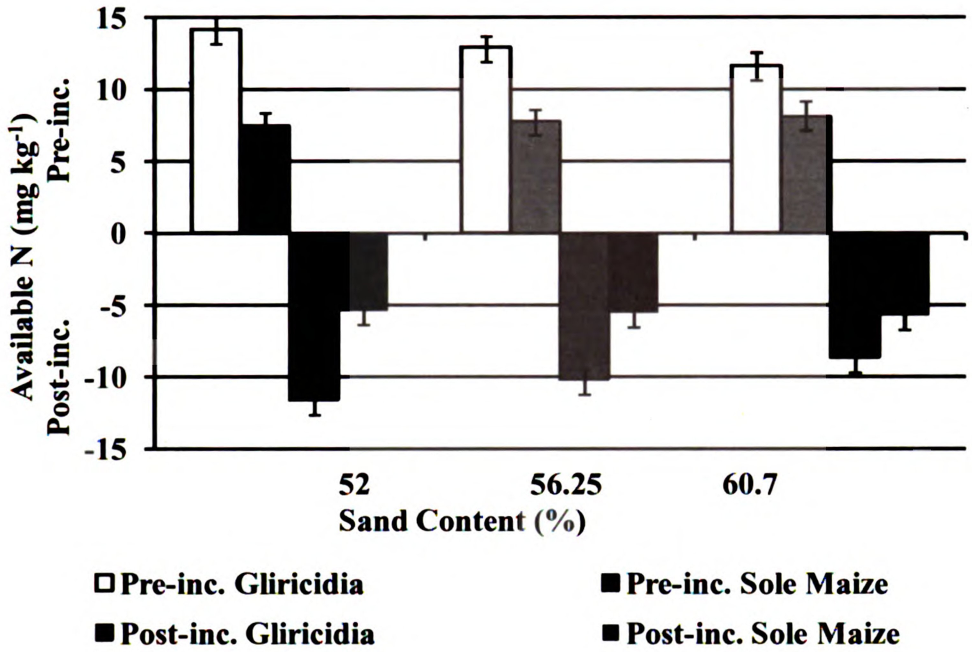

Fig. 1.6 The effect of gliricidia and sand content on available N pre-incubation and post-incubation, estimated at the quartile boundaries of sand content. Error bars represent standard error of treatment means.

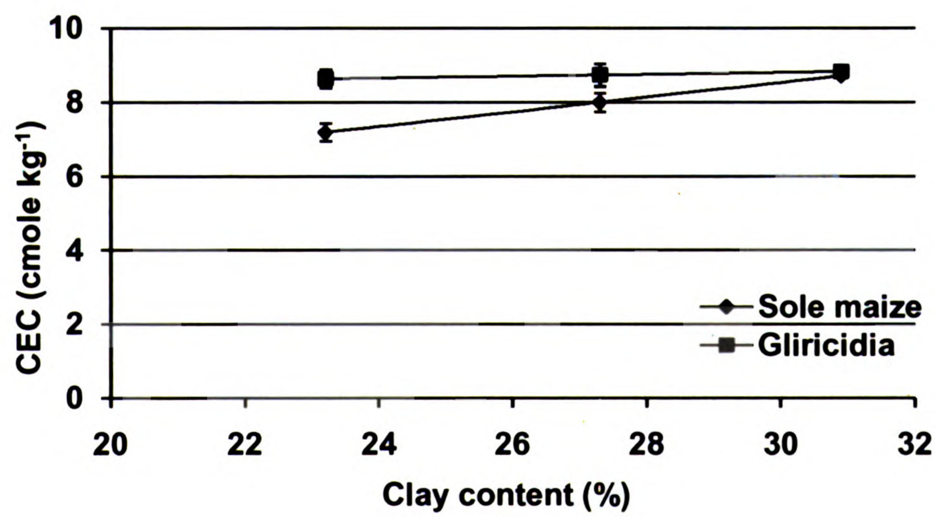

Fig. 1.7 The effect of gliricidia and clay content on cation exchange capacity, estimated at the quartile boundaries of clay content. Error bars represent standard error of treatment means.

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CHAPTER TWO

CHARACTERISTICS OF SMALLHOLDERS AND THEIR PLACEMENT OF *GLIRICIDIA SEPIUM* ON VARIOUS SOIL TYPES IN SOUTHERN MALAWI

ABSTRACT

Gliricidia sepium (Jacq.) Walp has been promoted as an intercrop in maize-based cropping systems in southern Malawi to increase yields and improve soil quality. However, smallholders use and placement of the cropping system by soil types has not been investigated. Thirty-seven households using the *gliricida*/maize intercrop were interviewed in June and July of 2006. Two questionnaires were completed with each household concerning specific cropping practices, and demographic statistics in the household. Socioeconomic status, the number and gender of the people in the household, total land area available to each household, soil types found and cropping systems used on the land were documented so that household characteristics could also be related to use of the gliricidia/maize intercrop. The total area of land used by each household ranged from 0.75 hectares to 2.8 hectares with an average of 0.58 hectares per household. Households using the intercrop had an average of 0.4 hectares of land, while those not using the intercrop had an average of 0.83 hectares. A chi-square test of this relationship indicated dependence of use of the intercrop and landholding size. Female-headed households were more heavily represented in use of the intercrop than households headed by males with 66% using *gliricidia*, versus 49% intercrop use among households headed

by males. Intercrop use was 50% among households in the lower half of the socioeconomic scale and 63 % in the upper half. Use of the intercrop was found not to be dependent on the number of adults between 15 and 49 years of age in the household. Placement of the gliricidia/maize intercrop on sandy M'chenga soils was less common than on finer-textured Katondo and Makande soils. Nevertheless, a chi-square test showed placement of the intercrop to be independent of soil type. Among the households surveyed, gender, income, and the number of adults per houshold appeared to present little barrier to use of the intercrop. Households with lower than average landholdings were more likely to use the intercrop. The intercrop was placed on all soil types, though there was a trend toward placement on finer-textured soils (Figure 2.5).

INTRODUCTION

Declining yields in sub-Saharan Africa have been attributed to soils degraded from continuous cropping with few inputs. Whiteside and Carr (1997) have described 60% of Malawian smallholders as net buyers of maize. They must work in other's fields to buy or earn food. Their own fields are often cultivated and weeded poorly or late, reducing yields and forcing households further down the poverty spiral with each cropping season. Maize is the staple crop among most of Malawi's population. Malawi's maize production fell short of the food requirement in 4 of 10 years from 1997 to 2007 (FEWSNET, 2007).

Maize production depends heavily on rainfall, soil fertility, and availability of nitrogen (N) inputs (Giller et al., 1997). The use of nitrogen fertilizers to improve maize production in the landlocked countries of southern Africa is constrained by the high fertilizer prices and difficult logistics in terms of transport and timeliness. Smallholders in southern Malawi have listed high prices as the major limitation to expansion of fertilizer N use (Chinangua, 2006). Both annual and perennial legumes have been rotated and intercropped with maize to increase soil N in circumstances where addition of nitrogen fertilizer is limited (Phiri et al., 1999; Snapp et al., 2002b). Several agroforestry species such as *Sesbania sesban* (L.) Merr., *Tephrosia vogelii* Hook, f., *Gliricidia sepium* (Jacq.) Walp. And *Leucaena leucocephala* (Lam.) have been developed and introduced in southern Africa as renewable soil nitrogen (N) and soil organic matter (SOM) sources in maize-based cropping systems (Kwesiga et al., 2003)

Gliricidia was introduced into southern Malawi to increase biological N fixation in areas where high demographic pressures required the use of intercropping strategies rather than rotations (Akinnifesi et al., 2007). Gliricidia may be intercropped with maize without reducing maize populations if it is regularly coppiced (Makumba, 2003).

Tripp (Tripp, 2008) lists labor requirement as a fundamental determinant of the acceptability of a technology to farmers. Labor availability has been found to be negatively related to adoption of the gliricidia/maize intercrop in southern Malawi (Chinangua, 2006). Because gliricidia must be regularly coppiced, preferably in October and again in December or January (Makumba, 2003), it adds a labor requirement to the cropping cycle. For some smallholders, the timing of the second pruning conflicts with labor needed for tobacco production (Harawa et al., 2006).

Snapp (2008) has described crop species as adapted to particular features of the landscape. Barrios et al. (2003) have described smallholders classification of soil types in Honduras as heavily dependent on slope position and plant species descriptors. However, in the same study, soils in Columbia were categorized by color and soils in Venezuela were categorized by vegetation and texture. Ettema (1994) has compiled a list of 20 published soil ethnographies in which indigenous peoples describe soil color and texture to categorize soil types. In Nigeria, Raji et al. (2006) found smallholders using landscape position and soil fertility to describe primary soil categories, then adding more detail by using color and texture. Kamanga has studied smallholder's categories for soils in central and southern Malawi, facilitating smallholder's descriptions of the use of different intercrops on specific soil types in our study.

In moving technologies that show biological promise for increasing soil fertility from research stations to farms, it is important to study the technology under the variety of growing conditions imposed by variation in soil types, elevation and temperature, rainfall and other biophysical factors. It is also important to verify that technologies such as the gliricidia intercrop may be integrated into local farming systems not only by well-to-do innovators, but also by households such as those described by Whiteside and Carr, which are more subject to the cycle of poverty and land degradation.

The current study investigates whether the gliricidia/maize intercrop has been successfully used by households which are relatively impoverished, female-headed, or have restricted access to land or labor. It also describes smallholder use of the gliricidia/maize intercrop as one of a number of intercrops typical of the region, and investigates whether their placement on various soil types is independent.

MATERIALS AND METHODS

The households and fields in this study were located between 15° 12′ and 15° 37′ S latitude and 35° 12′ E and 35° 23′ E longitude, in Zomba district, in southern Malawi. Zomba district was chosen as the location for this study because of the high concentration of fields with the gliricidia/maize intercrop within the district and within individual villages. Three other districts were considered, but had lower incidence of use of the gliricidia/maize intercrop.

Survey methods

Thirty-seven of the households interviewed were chosen purposively chosen based on ICRAF records for their use of the gliricidia/maize intercrop. In addition, twenty-eight fields were chosen from those near and similar in soil type to the gliricidia/maize fields, from households that did not adopt the maize/gliricidia intercrop (Table 2.1). The non-adopter households chosen represented nineteen villages scattered across 35% of the area of the district. Because the sampling was purposive rather than random it is possible that the sample membership and the properties of interest are not entirely independent. For example, those with higher income often have more education, and thus more access to information on innovations such as agroforestry practices. Because they have more information the probability that they will adopt agroforestry practices may be higher than the probability for a low income household. To the extent that the probabilities diverge, the two groups are not directly comparable. The information presented in the results section assumes that any divergent probabilities have less influence than the variables listed, for example that the necessity of intensifying a smaller than average size landholding influences the decision to adopt the gliricidia intercrop more than the difference in information access.

The two questionnaires (Appendix 1) used in the survey were developed by the author at Michigan State University, and pre-tested and refined with the assistance of the study enumerator and three users of the gliricidia/maize intercrop near Lilongwe. In the study, carried out in the eastern half of Zomba district, two questionnaires were completed with each household, one concerning specific cropping practices used in the fields that were sampled, and another concerning demographic statistics of the household. Socioeconomic status, the number and gender of the people in the household, total land area available to each household, soil types found and the cropping systems used on the land were taken so that household characteristics could also be related to use of the gliricidia/maize intercrop. The total land area available to each household, the soil types found and the cropping systems used on the land were noted so that use of the gliricidia/maize intercrop could analyzed in context of typical cropping systems.

A rough gauge of comparative prosperity the household was taken by noting improvements in the quality of the dwelling. A score of zero represented a house without a metal roof, glassed windows, or fired bricks, while a score of three indicated addition of all of these elements.

Placement of the intercrop

Brief information was taken on the aggregate land available to the household, including the size of each field, the soil type predominant there and the cropping system typically used in the field. The area of the gliricidia intercrop and comparison fields was measured with a Garmin Etrex Legend GPS. This GPS unit has an accuracy of ± 15m, which was adequate while measuring fields greater than one-tenth hectare. Other fields areas were described by the farmer in relation to the size of the gliricidia intercrop field.

Four soil types were included in the questionnaire: Katondo, Makande, M'chenga, and Mtsilo. These classifications were among seven listed by Kamanga (2002), as used by smallholders to describe soil types in central and southern Malawi. The cropping systems identified by the farmers included sole maize, maize/pigeonpea intercrop, maize/gliricidia/pigeonpea intercrop, maize/gliricidia intercrop, tobacco, and vegetables.

Data analysis

Means and standard deviation are presented for continuous variables such as landholdings and number of people per household (Table 2.2). Frequencies are presented for categorical variables such as farmer-defined soil types. A Pearson's Chi-square test was used to test independence of four relationships: gender and prosperity, landholding size and gliricidia use, number of adults and gliricidia use, and cropping system and soil type.

Pearson's Chi-square test is a simple method for examining statistical independence of categorical data (Schabenberger and Pierce, 2002, p. 385). A two-way table was constructed for each relationship with the observed frequency each possible outcome. Expected frequencies were calculated for each cell in the table using the frequencies of occurrence of each of the categories (Table 2.3). Pearson's Chi-square test was used to test whether the occurrence of the possible outcomes indicated independence or dependence of the two categories. Four fields typically used for tobacco production and one field with the mtsilo soil type were excluded from the intercrop placement analysis, and the male household was left out of the gender and prosperity analysis as the presence of categories with very few entries makes the Pearson's chi-square test less reliable (Cochran, 1954). Two households were excluded from the analyses of gender and prosperity because of missing data.

RESULTS

Demographic data

Households using the gliricidia/maize intercrop were found in all the prosperity groups studied (Table 22, Figure 2.2). Increased use of the intercrop was seen in the more prosperous groups, with gliricidia use at 60% in the poorest group, 43% and 60% of the second and third groups, and 67% of those households who were the most well off (e.g., who could afford three improvements to their dwelling). The group was structured with 37 households using the intercrop out of 65 households, or 57%, so that the two poorer groups of households were reduced below the average in use of the intercrop, and the two more prosperous households were increased above the average in use of the intercrop.

Household size ranged from one to fifteen people, with an average of 5.5 people per household. The average number of people between the ages of 15 and 49 across all households is 2.3, and the standard deviation is 1.4. A chi-square test of independence indicated that use of the gliricidia intercrop was independent of the number of prime-age adults resident in the household (Table 2.3). The gliricidia/maize intercrop was used by households headed by male and female individuals (Table 2.1, Figure 2.3). Female-headed households were more heavily represented in use of the intercrop than households headed by couples with 66% using gliricidia, versus 49% gliricidia intercrop use among households headed by couples. Because gender and socioeconomic status may be linked, i.e. households without an adult male may have less access to resources, this relationship was tested. Among the households in this study, gender status was found to be independent of socioeconomic status (Table 2.3).

Land available to the household ranged from 0.75 hectares to 2.8 hectares with an average of 0.58 hectares per household (Table 2.2). Households using the intercrop had an average of 0.4 hectares of land available for their use, while those not using the intercrop had an average of 0.83 hectares of land available (Figure 2.4). The chi-square test indicated that landholding size and use of gliricidia were not independent (Table 2.3). Although land is sometimes allotted based on size of households, the number of people in the household and land available were not strongly correlated (Figure 2.4).

Placement of the intercrop

The households described three major categories of soil types available to them: Katondo, Makande, and M'chenga. These soil types occurred in similar proportions among respondents fields, with 59 fields in which the Katondo soil type predominated, 59 in Makande, and 58 in M'chenga (Table1.2). Of the four cropping systems considered, maize/pigeonpea was the most common with 107 fields. There were 37 Maize/gliricidia/pigeonpea and 22 sole maize fields. The gliricidia/maize intercrop was the least common with 10 fields. The most common combination of cropping system and soil was the maize/pigeonpea intercrop on M'chenga soils (Figure 2.5). The two intercrops which contained gliricidia were more commonly placed on Katondo and Makande soils, and less common on M'chenga soils.

The chi-square test of independence indicated that cropping system placement was statistically independent of soil type, as the test statistic of 5.7 did not exceed the critical value of 12.6 (Table 2.3). Thus, the trends seen in the present data set toward placing gliricidia intercrops on finer-textured soils may or may indicate widespread farmer preferences. When the chi-square test was done with the two gliricidia cropping categories combined, the test statistic of 4.6 also did not exceed the critical value of 9.5.

DISCUSSION

Demographic setting

Southern Malawi is a densely populated landscape (Peters, 1996). Maize harvest provides rural households in southern Malawi with the bulk of their food supply, though the majority of households are net purchasers of maize (Peters, 1996). Most landholdings in southern Malawi are less than 0.5ha per household (Chirwa et al., 2003), on which maize, pigeonpea (*Cajanus cajan* L.), beans (*Phaseolus vulgaris* L.), pumpkin (*Cucurbita pepo* L.), and cowpea (*Vigna unguiculata* L.) are commonly cropped. Maize and pigeonpea are the most common intercrop (Chirwa et al., 2003). Ellis et al. (2003) also found that 40% of household landholdings in Malawi were less than 0.5ha. Benson et al. (2002) gave a population density of near 200 persons per km^2 for Zomba district, versus 105 persons km^2 for Malawi.

Benson et al.(2002) in the Malawi, An Atlas of Social Statistics, classify households according to the use of traditional versus permanent housing, where traditional corresponds to our prosperity rating of 0, and permanent housing corresponds with our rating of 3. Benson et al.(2002) give 66% of Malawian houses as traditional versus 15% permanent, with similar proportions for Zomba district. They also designate 31% of households in Malawi as female-headed in 2002 (Benson et al., 2002), while more than 45% were female headed in Zomba district. In our sample, 41% of households were female-headed, which is near the district average.

Therefore the sample of households in our study were comparable in landholdings to others in southern Malawi, with 0.58ha of land. In our sample, 41% of households were female-headed, which is near the district average of 45%. The households in our sample, however, used less often in traditional housing, which could indicate higher prosperity and ability to invest in agricultural improvements. The households in our sample were similar in the number of female-headed households to the district average, which was well above the national average.

Demographic data

Pattanayak et al. (2003) have found measures of income and assets to be positively correlated with agroforestry adoption, except when these assets were from non-farm sources. The finding from the survey were generally consistent with Pattanyak. Households in the upper half of the prosperity scale in our study used gliricidia 10% more often than the average for the whole group, while households in the lower half had 7% less gliricidia use than the average.

Whiteside and Carr (1997) find that 60% of the smallholders in Malawi are net buyers of maize, and in many cases labor in neighbor's fields to buy or earn maize. As a result, many have insufficient time to apply soil improvement practices on their own land. Households in the lower half of the socioeconomic scale in our study used the gliricidia/maize intercrop less than the average of all households. This reduction in intercrop use may stem from the circumstances described above; however even in these most impoverished groups, adoption of the technology did occur.

Pattanayak et al. (2003) have found that households with higher proportions of males were more likely to adopt agroforestry practices. Among the smallholders in our study, the opposite case was true. Sixty-six percent of female-headed households used the gliricidia/maize intercrop, while 49% of households headed by a couple used the intercrop. The somewhat greater use of the gliricidia/maize intercrop by female-headed households in Zomba district implies that the intercrop is manageable and useful under the conditions faced by female-headed smallholder households. Given that gender-based measurements often reflect both economic and cultural realities, it may be that this group of female-headed households are no more constrained from adopting the intercrop by these economic realities than households headed by couples. The lack of dependence between gender and socioeconomic scale in this sample supports this hypothesis.

Ajayi et al.(2003) found farm size to be positively correlated with adoption of improved fallows in five of seven studies reviewed. The difference in these findings and ours may be in the cropping systems referenced. The improved fallows studied by Ajayi require land to be taken out of maize production, while the gliricidia/maize does not, making it more acceptable to those with smaller plots of land. Nkamleu et al. (2005) found different factors to affect adoption of different agroforestry practices in Cameroon, and warned against generalization.

Placement of the intercrop

Kamanga (2002) lists seven soil types by indigenous descriptors as common agricultural soils in Malawi. Of these, he describes M'chenga and Katondo as the two most common agricultural soils in Malawi. These two were listed by smallholders in our study, as well as Makande soils. Kamanga (2002) equates Katondo soils with ferric rhodustalfs, Makande soils with vertisols, and M'chenga soils with sandy ferralitic soils. Though the three soil types were found in almost equal measure among the smallholders (Table 2.2), the gliricidia/maize intercrop was used less on sandy M'chenga soils than on the finer-textured Katondo and Makande soils. However, the placement of cropping systems was found to be statistically independent of soil type. The trend toward establishing gliricidia on finer-textured soils did not reach statistical significance, but it should not be ignored. Focus group discussions conducted in April of 2006 in Kasungu district indicated that gliricidia was less drought resistant in sandy soils than in fine-textured soils. The issue of the drought resistance of gliricidia in different soil types deserves further attention.

CONCLUSIONS

Household with limited resources were associated with a moderate reduction in the use of the gliricidia/maize intercrop. However, many of these resource-poor households were able to use of the technology. The fact that gliricidia intercrop users had half the average landholdings as non-users may indicate that it is especially useful in high population density regions such as southern Malawi. Since female-headed households were more heavily represented in the use of the intercrop than households headed by a couple, the constraints faced by female-headed households do not seem to limit the use of the intercrop, an important issue, given the loss of working-age adults to HIV/AIDS in the current generation.

Since cropping system placement was found to be independent of soil type, it might be assumed that the gliricidia/maize cropping system could be promoted for all soil types. However, the issue of drought resistance of gliricidia in differing soil types should be more carefully investigated to avoid burdening impoverished households with unnecessary production risk.

TABLES

Table 2.1 Sampling frame for the on-farm study.

EPA	Cropping System	No. villages	No. households	No. fields
Thondwe	gliricidia	2	4	4
	paired maize			4
	non-gliricidia		3	3
Total			*7*	*11*
Dzaone	gliricidia	7	14	14
	paired maize			14
	non-gliricidia		11	11
Total			*25*	*39*
Mpokwa	gliricidia	4	8	8
	paired maize			8
	non-gliricidia		7	7
Total			*15*	*23*
Malosa	gliricidia	6	11	11
	paired maize			11
	non-gliricidia		7	7
Total			*18*	*29*
Grand total		19	65	102

Table 2.2 Mean and standard deviation for continuous variables and frequencies for categorical variables among the 65 households surveyed.

	Mean	Minimum	Maximum	St. Dev.
Land available (ha)	0.58	0.075	2.75	0.55
Number of people/household	5.5	1	15	2.8
Number of people aged 15-49	2.3	1	5	1.4
Dependency ratio	1.9	0	5	1.4

Frequencies of categorical variables:

Improvements to dwelling:		Gender of household heads:	
None	11	Male	38
One	14	Female	27
Two	18		
Three	18		

Frequencies of cropping systems:		Frequencies of soil types:	
Sole Maize	22	Katondo	59
Gliricidia/maize	10	Makande	59
Gliricidia/maize/pigeonpea	37	M'chenga	58
Maize/pigeonpea	107		

Table 2.3 Chi-Square test of independence for resource availability and gender and for the use of the gliricidia/maize intercrop and available land and labor.

Variables	alpha	d.f.	table value	test statistic**
Use of intercrop x available labor	0.05	1	3.84	0.148
	0.10	1	2.71	0.148
Prosperity x gender	0.05	3	7.81	2.26
	0.10	3	6.25	2.26
Use of intercrop x landholdings	0.05	1	3.84	4.86
	0.10	1	2.71	4.86
Cropping system x soil type	0.05	6	12.6	5.7
	0.10	6	10.6	5.7

** The chi-square test statistic is generated by Σ ((obs. value – exp. value)^2)/exp. value

Table 2.4 Two-way table of frequencies for Chi-square test of cropping system placement on farmer-defined soil types.

	No. Fields	Sole maize	Gliricidia/ maize	Gliricidia/maize/ pigeonpea	Maize/ pigeonpea
Observed values:					
Katondo	59	*7(12)**	5 (8)	14 (24)	33(56)
Makande	59	10(17)	2 (3)	14 (24)	33(56)
M'chenga	58	5 (9)	3 (5)	9 (16)	41(71)

*frequency of occurrence

**Percent occurrence across all cropping system and soil categories

FIGURES

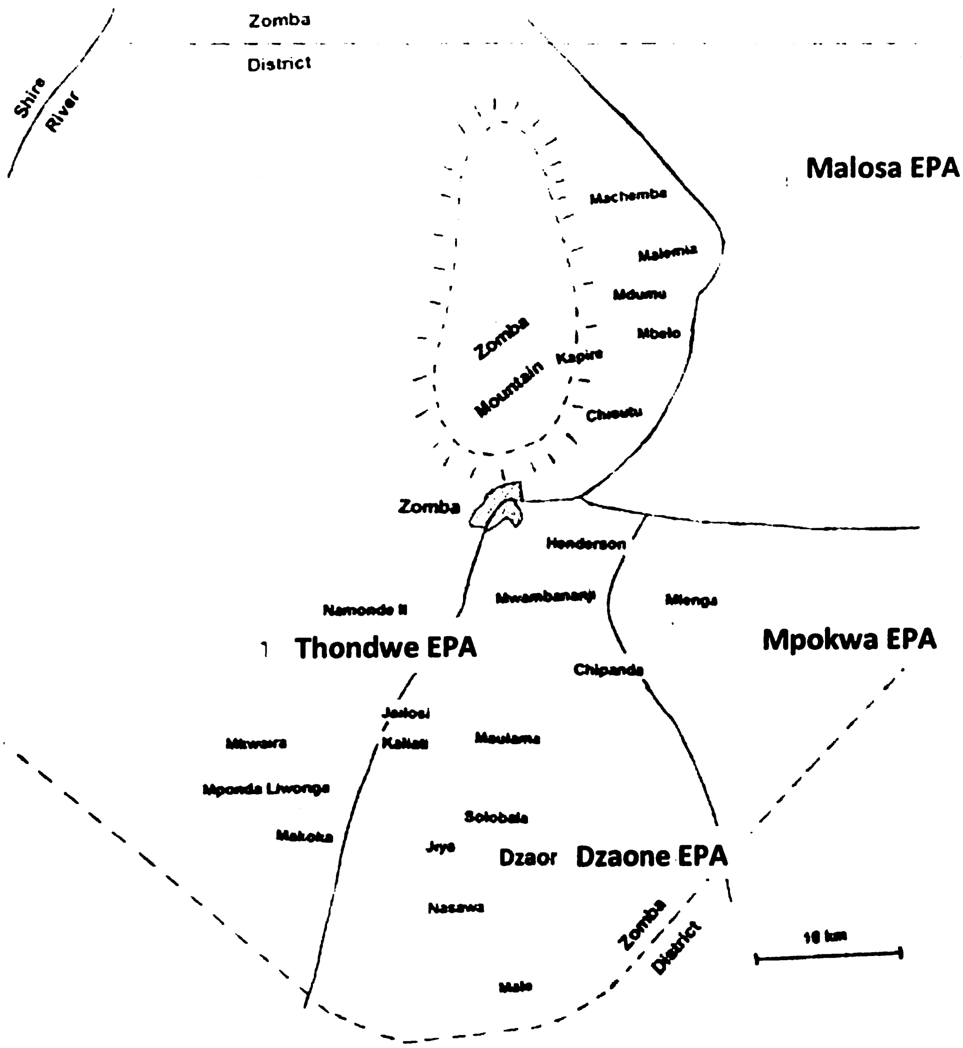

Figure 2.1 Map of Zomba district, with the study fields and villages.

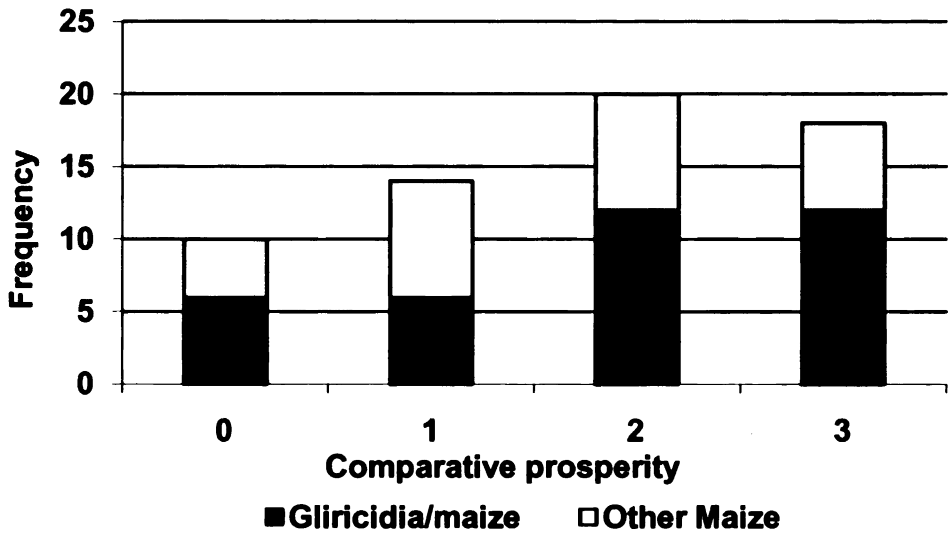

Figure 2.2 Comparative prosperity of households and use of the gliricidia/maize, as estimated by the number of improvements made to the family dwelling among tin roof, glassed windows, and fired bricks.

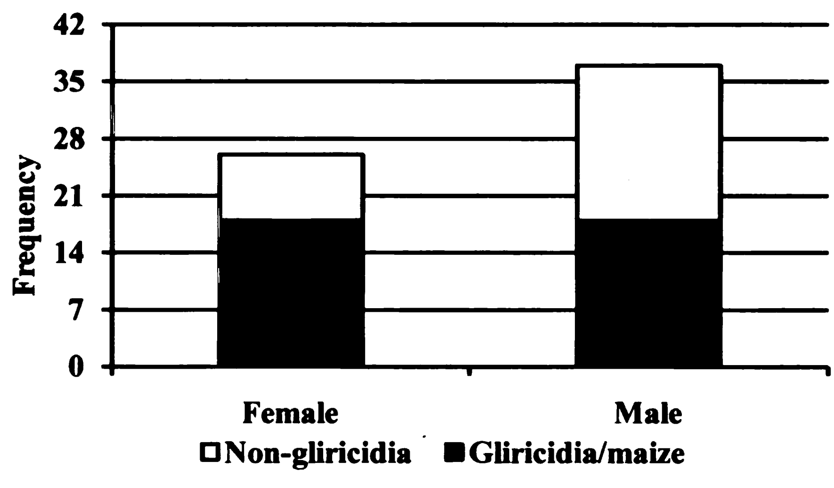

Figure 2.3 Gender of household head/s and use of the gliricidia/maize intercrop.

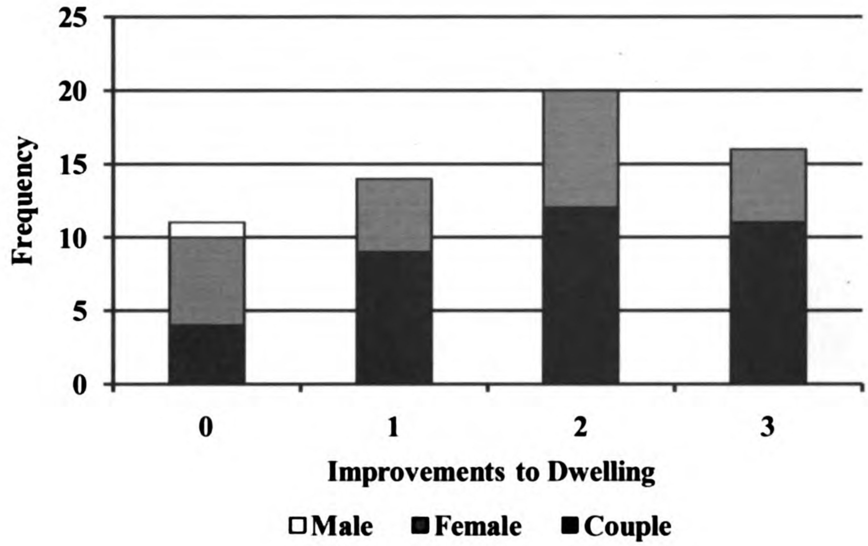

Figure 2.4 Relationship of available resources and gender.

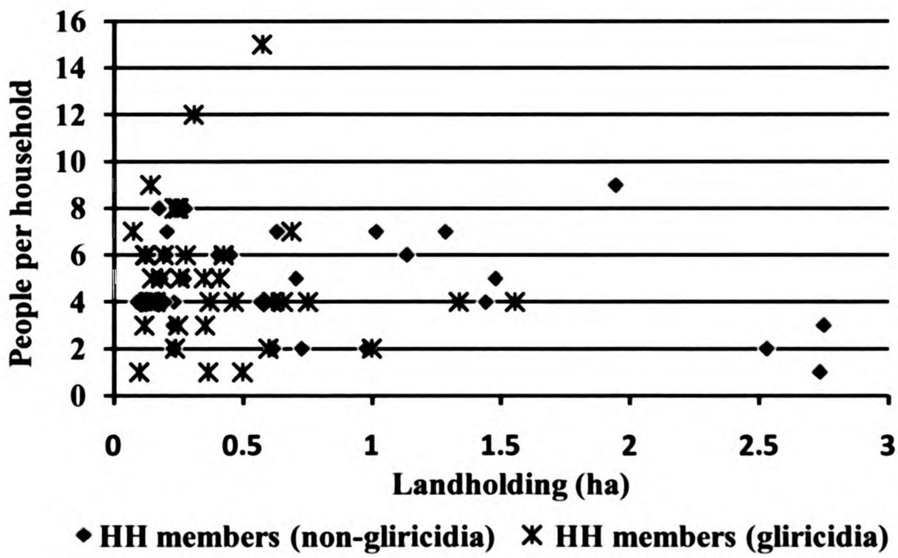

Figure 2.5 Landholding size and number of people per household.

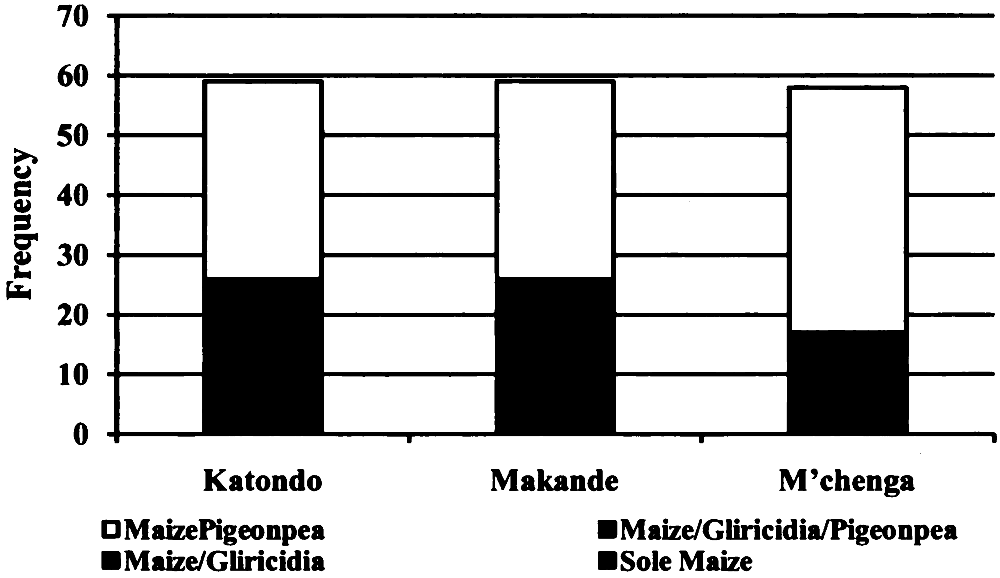

Figure 2.6 Frequency of cropping systems on soil types.

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CHAPTER THREE

EVALUATING THE IMPACT OF *GLIRICIDIA SEPIUM* ON SOIL ORGANIC MATTER IN SMALLHOLDER CROPPING SYSTEMS IN SOUTHERN MALAWI

ABSTRACT

Intercropping maize with *Gliricidia sepium* (Jacq.) Walp has been promoted in southern Malawi to increase maize yields and improve soil quality. This study investigated whether the *gliricidia*/maize intercropping increases soil organic matter and soil nutrient values compared to prevailing maize cropping practices in smallholders fields on various soil types at a range of elevations in southern Malawi. Other management factors included in the analysis were sand content of the soil, age and population density of *gliricidia*, use of nitrogen fertilizer, rainfall, and presence and population of pigeonpea/maize intercrop. Thirty-seven households using the gliricidia/maize intercrop were interviewed as well as twenty-eight that did not adopt the maize/gliricidia intercrop. One questionnaire investigated specific cropping practices used in intercrop fields and comparison fields. Another questionnaire recorded demographic information about the household. Soil samples were taken to a 20 cm depth in the center of the 2005/6 planting rows from the fields categorized in the questionnaires. Analyses were performed on the soil samples for soil organic matter

(SOM), sand content, available P, exchangeable K and CEC. Soil organic matter values associated with the intercrop were not significantly different from other cropping systems. Sand content was negatively related to SOM and was the only factor tested that had a significant impact on SOM. When the gliricidia/maize intercrop fields were analyzed separately, soil type, elevation, and their interaction affected trends in soil organic matter. Trendlines with positive slopes indicate a positive relationship between soil organic matter and elevation in the two finer soil types, Makande and Katondo, while the relationship was negative in the coarser M'chenga soils. For each 100m increase above sea level (asl) from the mean elevation, Katondo and Makande soils increased in soil organic matter 10 and 4 g kg^{-1} or 1.1% and 0.46% respectively. Elevations among the fields in the study ranged from 760m to 1064m. Fertilizer N was associated with a slight positive trend in soil organic matter. The addition of pigeonpea, *Cajanus cajan* (L.), to the maize cropping system at elevations below 877m asl was associated with an increase of 1.8 g kg^{-1} or 11% in soil organic matter values compared to the sole maize cropping system. The emergence of increasing trends in SOM correlated with increasing elevation and fineness of soil texture in fields with the *gliricidia*/maize intercrop may indicate that a SOM benefit will develop over time in fields at relatively higher elevations and finer soil textures. The trend toward increase in SOM with addition of pigeonpea may indicate a SOM benefit to this intercrop at relatively lower elevations.

INTRODUCTION

Because maize is the staple crop in Malawi and in most of southern Africa (Chirwa et al., 2003), enhancing production in this crop is a major factor in food security in the region. In Malawi, more than 50% of land farmed by smallholders is annually planted in maize with yields averaging only 1375 kg ha^{-1}(Benson et al., 2002). The price of fertilizer is the major reason smallholders in southern Malawi give for not using N fertilizers to improve their maize yields (Chinangua, 2006).

Annual legumes such as pigeonpea *Cajanus cajan* (L.) Millsp. (van der Maesen), and agroforestry species such as *Tephrosia* volgelli produce leaf litter that has been shown to contribute as much as 50 kg ha^{-1} of nitrogen (N) to soil nutrient flows in on-farm studies (Snapp, 1998). Several leguminous trees and shrubs such as *Sesbania sesban* (L.) Merr., *Tephrosia vogelii* Hook, f., *Gliricidia sepium* (Jacq.) Walp. and *Leucaena leucocephala* (Lam.) have been adapted and developed in southern Africa to increase soil nitrogen (N) and soil organic matter (SOM) in maize-based cropping systems (Kwesiga et al., 2003). Agroforestry practices have a long history in Malawian agriculture, beginning with the indigenous *Faidherbia albida*. Dewees (1995) listed Faidherbia and mango (*Mangifera indica*) as the two trees in occupying the most space in farmer's fields near Lilongwe in the mid-1990's. In the same study, the plant population of the introduced species *Gliricidia sepium* (Jacq.) Walp., was higher than the plant population of Faidherbia, but occupied much less space. Intercropping of gliricidia with maize has been shown to increase maize yield in trials at the Makoka agricultural research station in Zomba district in southern Malawi (Akinnifesi et al., 2007).

The gliricidia/maize intercrop is promoted as being especially suited to southern Malawi, because the high population densities do not permit rotation of land out of food crops (Thangata and Alavalapati, 2003). Population densities in Zomba district range from 100-200 persons km^2 in the north to 200-400 persons km^2 in the south. Increasing population densities and lack of sufficient land to maintain fallow periods have often been identified as important drivers of soil degradation in sub-Saharan Africa. Benson et al. (2002) found that maize productivity in southern Malawi was lower than in the central and northern regions because high population pressures were required continual cropping, which depleted soil fertility. Tittonell et al. (2008) noted widespread negative nutrient balances on smallholder farms and large gaps between potential and actual maize yields as markers of unproductive soils in western Kenya. Mtambanengwe et al. (2005) have found that soil organic matter is often the single largest source of nutrients for growing crops. As such, characterization of SOM in smallholder fields is crucial in understanding soil nutrient status and potential productivity.

Giller et al. (1997) noted the importance of temperature and moisture availability in controlling the rate of decomposition of SOM, and the importance of soil texture in controlling the extent to which decomposition eventually proceeds. In this study, elevation is used as a proxy for temperature. Lovett (Lovett, 1999), while studying tree plot diversity in Tanzania, found elevation and temperature to be strongly correlated. Thus, decreasing temperatures with increasing elevations slow the decomposition of SOM, as does decreasing available moisture, measured as annual rainfall.

While the capital city, Lilongwe, is on the Central African Plateau, the southern region is dominated by the final section of the East African rift valley system (Msiska et al., 1987). Elevations are much more variable, even away from uplifts such as Zomba and Mulange mountains, and range from less than 100m above sea level (asl) to 1200m asl (Benson et al., 2002). Kamanga (2002) described seven soil types typically cited by smallholders in central and southern Malawi in describing land, and ranging from high to low sand and clay content. The two most common soils were Katondo and M'chenga soils, which varied in texture from sandy clay loam sandy loam. Variations in these biophysical drivers of SOM cycling will be demonstrably important in modifying the effects of the gliricidia/maize intercrop on SOM values in smallholder's fields.

It is important that the promising technologies for enhancing maize production such as agroforestry intercrops and improved fallows are also tested on smallholder farms after they are identified at research stations. Franzel et al. (2001) note that replicated on-farm biophysical trials of agroforestry technologies are vital in evaluating the performance of a given technology across the typical range of biophysical conditions encountered by smallholders, but are expensive to maintain. Mutsaers has recommended an alternative method that treats a trial as a randomized complete block with a single replicate in each farmer's field (Mutsaers et al., 1997). This permits each farmer to evaluate soil fertility management options under her/his own conditions and criteria, while allowing the trial to represent performance under a realistic range of conditions and practices. Hildebrand et al. (1996) has noted that with farmer-managed single replicate trials, Anova analysis tests only the main effect, rather than the main effect plus any main effect by environment interaction. They advocate using two replicates per field so as to capture the environmental effect, while acknowledging the difficulties inherent in implementation of multiple replicates in farmer-managed trials. However, the use of mixed analysis allows both categorical variables, such as treatment effects, and continuous covariates, such as elevation to be tested within the same model (Littell et al., 2006). For each on-farm trial, the benefits of farmer management, including farmer preference for single replicate tests must be balanced against the researcher's desire to test treatment by environment interactions.

Because on-farm trials typically contain more variability in conditions than researcher-managed fields, it is also necessary to set an appropriate measure of statistical significance, or apha value for the trial. In researcher-managed plots on research stations, this is usually $Pr > F \geq 0.050$. Snedecor et al. (1967) argue that this value should be seen as a convention to be discussed, rather than an automatic rule. Manderscheid (1965) suggests that the researcher should consider the costs associated with Type One and Type Two errors, the prior probabilities of the hypothesis and alternative, and the size of the Type Two error associated with each significance level. Perry et al. (2003) designate an alpha of 0.1000 for a field-scale study in Great Britain, while Anderson (no date) argues that many real differences in treatment effects have been ignored in on-farm research and accepts alpha values up to 0.3000. In the current study, the bulk of the cost of a rejecting the null hypothesis is the extra labor associated with implementing the gliricidia/maize intercrop versus typical practices. The cost of accepting the null hypothesis when it is false is in lost yields when the intercrop is not implemented. Given the fragility of food security in southern Malawi, an increase in the alpha value beyond 0.050 is warranted.

The on-farm research approach used in this study will provide an opportunity to study the effects of the gliricidia/maize technology within the smallholders biophysical and management constraints. It will also allow differences in SOM dynamics with changes in elevation and soil type to become apparent. However, the effect on SOM of variability in soil types, available water, and management among the fields may mask SOM effects of the intercrop, especially in those fields which contain young gliricidia plantings. Because farmers often manage higher potential fields more intensively (Scoones and Toulmin, 1998) than low potential fields and many tend to use both organic and inorganic treatments in the same field (Omamo et al., 2002) it is often challenging to separate the effects of different interventions.

The current study investigates (1) whether the gliricidia/maize intercrop increases SOM and soil fertility values compared to prevailing maize cropping practices in smallholders fields on various soil types at a range of elevations, (2) whether increasing age or population density of gliricidia is related to increased SOM values, and (3) whether population density of pigeonpea is related to increased SOM values. Other management factors included in the analysis were addition of fertilizer nitrogen (N), rainfall, and the presence of pigeonpea.

MATERIALS AND METHODS

Agroecology

The rainfall pattern in Zomba district where this study was conducted, is unimodal with most rain falling between November and March (Figure 3.1). Three-year annual rainfall averages ranged from 836mm to 1648mm for the areas studied. Soil types included in the study ranged from sandy M'chenga soils, to sandy clay loam and sandy clay Katondo soils, and Makande soils with vertic properties.

Maize cultivation among smallholders in Southern Malawi is typically done manually with hoes. Planting rows are built in October, before the onset of heavy rains and are usually perpendicular to any slope. After the onset of rains, usually in November or December, maize is planted at populations near 44,400 plants ha^{-1}. The traditional planting pattern spaced rows at 90cm and planting stations within the rows at 90cm. Three seeds are typically planted per planting station which resulted in a maize population of 37,000 per hectare. This pattern has been partially displaced by a pattern with rows spaced at 75cm and single seeds planted at 30cm intervals which results in a maize population of 44,400 per hectare.

Maize is typically weeded twice, once in January and again in February. The maize grain is harvested after drying down in the field, usually in May. Maize biomass is usually recycled within the fields. In southern Malawi, maize is commonly intercropped with legumes, the most common of which is pigeonpea. Pigeonpea is planted soon after maize emergence, and is harvested in September and October.

Gliricidia intercrop practices

Recommendations for gliricidia/maize intercrops in southern Malawi call for gliricidia to be planted in alternating maize rows at 90 cm spacing within the row (Makumba, 2003), which results in a gliricidia population of 6,150 trees ha^{-1} with the 90cm row spacing and 7,400 trees $ha^{-1}$with the 75cm row spacing (Figure 3.2). The trees are usually pruned twice per year, during land preparation and again during the first weeding and leaves and tender twigs incorporated into the maize rows. A pruning during August is sometimes done to produce tender foliage for incorporation during land preparation.

Survey methods

Zomba district was chosen as the study location because of the high concentration of fields within the district and within individual villages, permitting possible village-level effects to be included in the analysis (Figure 3.1). Three other districts were considered, but had lower incidence of use of the gliricidia/maize intercrop. Thirty-seven of the households interviewed were chosen purposively because they were the households in the district currently using the gliricidia/maize intercrop. Twenty-eight fields were chosen from among those near and similar in soil type to the gliricidia/maize fields, as a comparison among those households in each village which did not adopt the maize/gliricidia intercrop (Table 3.1). The non-adopter households chosen represented nineteen villages scattered across 35% of the area of the district.

The proportions of fields in the three cropping system treatments were planned rather than random. Each gliricidia field was paired with a maize field that was managed by the same household, usually adjacent, and as similar as possible in soil type. Another field similar in soil type from a non-adopter household was also included as a comparison (Table 3.1). Comparisons of cropping systems in this chapter refer to three categories: (1) maize/gliricidia intercrop fields, (2) maize/pigeonpea or sole maize fields managed by the same household, and (3) two fields per village of maize/pigeonpea or sole maize managed by households not using gliricidia.

The two questionnaires used in the survey were developed by the author at Michigan State University, and pre-tested and refined with the assistance of the study enumerator in Malawi. One questionnaire investigated specific cropping practices used in the fields that were sampled, and another recorded simple demographic statistics in the household. One of the demographic statistics concerned improvements in the quality of housing, with a score of zero representing a house without a metal roof, glassed windows, or fired bricks. A score of three indicated addition of all of these elements. This score gave a rough estimate of the comparative prosperity of the household. Soil types were characterized in the questionnaire by local descriptors (Kamanga, 2002).

Soil Sampling and analysis

Soil samples were taken to a 20 cm depth in the center of the 2005/6 planting rows from the fields categorized above using a straight-walled soil probe with 2cm diameter. Eight samples were taken for each 1/10 hectare of field area. Areas near houses were avoided when sampling to minimize variability from additions of household ash. The samples from each field were combined, air-dried, passed through a 2 mm sieve, and stored. Analyses for soil organic matter, available P, exchangeable K and CEC were performed by A & L Great Lakes Laboratories. A sub-sample of the soil was dried overnight at 40°C and crushed with an Agvise flail-type grinder. Organic matter was determined by loss on ignition at 360 °C and the data correlated with and reported as a Walkley-Black titration.

Available phosphorus and exchangeable potassium (K^+) were extracted according to Mehlich III (Mehlich, 1984), and analyzed by inductively-coupled plasma spectrometry (ICP). The P data was correlated to and reported as Bray P-1 (Bray and Kurtz., 1945). The data for exchangeable K^+ correlated to and reported as a 1 N ammonium acetate extraction (McIntosh, 1969). CEC was calculated from the results for exchangeable cations.

Sand content was determined after Gee and Bauder (1986). Ten grams of soil was dispersed by reciprocal shaking for 8 hours with 5 g L^{-1} sodium hexametaphosphate. The dispersed samples were washed through a 53 micron sieve with deionized water. The material remaining on the screen was dried overnight at 105 °C and weighed.

Field measurements and calculations

Elevation was measured at the approximate center of each field with a Garmin Etrex Legend GPS. This GPS unit has an accuracy of ± 15m, which was adequate to record field locations on a map. This instrument proved inadequate when measuring the area of fields of less than one-tenth hectare and this data is not reported. Because of the height of gliricidia and pigeonpea, random population measurement of gliricidia and pigeonpea with quadrats was not practical. A 4m by 4m section of each field was chosen to be representative of the average population of gliricidia and pigeonpea in the field, and the populations of the target plants counted within the area.

None of smallholders surveyed applied nitrogen (N) fertilizer prior to planting. The amount of N applied as a side-dress was calculated for each field using the concentration of N in urea or calcium ammonium nitrate applied, and the volume and spacing of the applications given by the smallholders. Monthly rainfall data for 2003-2006 was provided by the four agricultural extension planning offices containing fields in the study. Rainfall for each field was estimated by summing the seasonal rainfall after the planting date given by the smallholder for 2005/6 cropping season.

Statistical analysis methods

Because the sampling was purposive rather than random it is possible that the sample membership and the properties of interest are not entirely independent. For example, those with higher income often have more education, and thus more access to information on innovations such as agroforestry practices. Because they have more information the probability that they will adopt agroforestry practices may be higher than the probability for a low income household. To the extent that the probabilities diverge, the two groups are not directly comparable. The information presented in the results section assumes that any divergent probabilities have less influence than the variables listed, for example that the necessity of intensifying a smaller than average size landholding influences the decision to adopt the gliricidia intercrop more than the difference in information access.

Ancovas were conducted using the PROC MIXED procedure in SAS (Littell et al., 2006) to determine if continuous variables such as soil sand content and categorical variables such as cropping system and soil type had significant influence on soil organic matter and soil nutrients. The Ancovas were structured with cropping system as a fixed effect. Village and household were designated as random effects. Other independent variables were designated as covariates. Soil type designations commonly used by smallholders in central and southern Malawi were included in the questionnaire (Kamanga, 2002), as well as sand content by weight. Sand content and soil type were always analyzed in separate models because smallholder's soil type descriptors depended heavily on sand content.

Ancova analyses in PROC MIXED combine categorical variables such as cropping system with continuous variables such as sand content in a fixed effects model. In the PROC MIXED analysis, standard errors are calculated considering both the fixed effects and random effect components of the model (Littell et al., 2006). Where covariates had no significant influence, the models reduced to Anovas using SAS Type 3 analysis, which uses expected mean squares to estimate variance components (Littell et al., 2006). The Ancovas were built parsimoniously to avoid over-fitting. No more than three explanatory variables were included in any model.

The probability of a type one error, or alpha value, designated as acceptable is often greater in on-farm and farm-scale studies than in researcher-managed plots. An alpha value of 0.1500 is used in this study, which is intermediate between those given by Perry et al. (2003) and Anderson (no date).

RESULTS

Environmental variables

The households and fields in this study were located between 15° 12′ and 15° 37′ S latitude and 35° 12′ E and 35° 23′ E longitude, in Zomba district, in southern Malawi. Sand content of soil ranged from 45% to 86% across all fields, which corresponds to soil textural classes ranging from sandy clay to loamy sand, assuming low silt content. Average sand content varied little across the four extension planning areas (EPA) (Table 3.2). Elevation of the fields in the study varied from 760 to 1064 meters above sea level, in the upper half of the 100m to 1200m range given for Southern Malawi. Average elevations decreased 200m from Thondwe EPA to Malosa EPA. Rainfall in the 2005-2006 cropping season varied from 496mm to 1370mm across all households, and from 565mm in Thondwe EPA to 1350mm in Malosa EPA, probably due to the influence of Zomba mountain, which rises to 2087 meters.

Across all fields available to all households, soil types were divided evenly (Table 3.2, Chapter 3). Among the fields sampled for the cropping system comparison however, 36 were Katondo, 37 were Makande, and 28 were M'chenga. Katondo soils predominated in the Thondwe and Malosa EPA's, M'chenga soils in Dzaone EPA, and Makande soils in Mpokwa EPA (Table 3.2).

Management variables

Fertilizer N was added to eighty-seven percent of the maize fields sampled during the 2005/6 cropping season. Less than 7 kg ha^{-1} N was added to seventy percent of the fertilized fields in the study. Fertilizer use was highest in Thondwe EPA and lowest in Mpokwa EPA. Populations of gliricidia plants per hectare in the gliricidia/maize intercrop fields varied from 420 to 7500 plants per hectare, averaging of 2300 plants per hectare across all fields. Only gliricidia populations in Thondwe EPA surpassed this average, while gliricidia populations in the other three EPA's were lower. Gliricidia plantings ranged in age from 4 to 12 years in age, averaging 8.1 years. Gliricidia plantings in Thondwe and Dzaone EPAs fell below this average, while those in Mpokwa and Malosa surpassed it. Pigeon pea populations ranged from 0 to 6250 plants per hectare, with an average of 1360 plants per hectare. Pigeonpea populations were highest in Mpokwa EPA and lowest in Thondwe EPA.

Response variables

Soil organic matter values averaged 20.4 g kg^{-1} and ranged from 10 to 49 g kg^{-1} across all fields. SOM values across EPA's were similar, except for Malosa EPA. Malosa EPA had an average SOM of 17.7 g kg^{-1} which was 4.9 g kg^{-1} lower than Thondwe with of 22.6 g kg^{-1} . Malosa EPA included fewer M'chenga soils than the other EPA's, and was at a lower elevation than the other EPA's. The difference in average SOM values between Malosa and Thondwe EPA's was 4.9 g kg^{-1} . Differences in SOM within the farms ranged from 0 to 6 g kg^{-1} across all fields. Eight pairs of fields or 22% had differences in SOM values that exceeded the difference between EPA mean SOM values. The difference between SOM means for Thondwe and Mpokwa was 1.3 g

kg^{-1} Twenty-seven pairs of fields, or 73% had greater difference in SOM values than the difference in the mean SOM in Thondwe and Mpokwa.

Bray P values ranged from 4 to 135 mg kg^{-1}, with a mean of 33.6 mg kg^{-1} and a standard deviation of 25.2 mg kg^{-1}. Bray P values in Thondwe and Dzaone EPA's were lower than in Mpokwa and Malosa EPA's. Exchangeable K^+ values ranged from 46 to 424 mg kg^{-1} with a mean of 169 mg kg^{-1} and a standard deviation of 80 mg kg^{-1}. Exchangeable K^+ values for Mpokwa EPA were markedly higher than those for the other EPA's. CEC's ranged from 3.2 to 17.6 cmol kg^{-1}, with an average and standard deviation of 7.1 and 2.6 cmol kg^{-1}. Average CEC's for Dzaone and Mpokwa EPA's were higher than the overall average, while CEC's for Thondwe and Malosa were lower.

Multiple soil fertility enhancing practices

The two most common soil-fertility-enhancing practices, aside from the gliricidia/maize intercrop were incorporation of crop residues and the addition of N in fertilizer. The gliricidia/maize intercrop was usually used in addition to incorporation of crop residues and addition of fertilizer N. Crop residues were incorporated in 36 of the 37 or 97% of the maize/gliricidia fields, and in 36 of the 37 paired maize fields. Crop residues were incorporated in all of the 28 non-adopter maize fields. Fertilizer N was applied in 76% of the maize/gliricidia fields, and 89% of the paired and non-adopter fields, indicating that N from gliricidia may have been considered a substitute for fertilizer N in some fields. In six of the thirty-seven, or 16% of the households using the maize/gliricidia intercrop, an average of 5.3 kg ha^{-1} of fertilizer N was applied to the maize field without the gliricidia intercrop, while no N was applied to the field with the intercrop. On 27 of the 37, or 73 % of households using the maize/gliricidia intercrop, an average of 5.8 kg ha^{-1} of fertilizer N was applied at equal rates to the gliricidia intercrop and comparison fields.

Livestock manure, compost, and legume rotation were used in 13%, 9%, and 1% of fields, respectively, and in similar proportions across the three cropping systems. Pigeonpea intercrops were not listed by smallholders as legume rotations, even though 56 of the 102 fields in the study, or 55%, contained pigeonpea. Thirty-eight percent of the gliricidia/maize intercrop fields contained pigeonpea, while 78% of the paired maize fields and 43% of the non-adopter maize fields contained pigeonpea.

Soil Organic Matter

Cropping system, sand content, soil type, elevation, fertilizer N, rainfall, population and age of gliricidia and presence and population of pigeonpea were tested in a SAS mixed model for effect on soil organic matter, Bray P, exchangeable K+, and CEC. Though SAS mixed analysis showed trends several in relation to Bray P, exchangeable K+ and CEC, the relationships were biologically counterintuitive, and the results are not reported.

Variability of soil organic matter among villages

Soil organic matter data is presented grouped by elevation and soil type in Table 3.3, because SOM trends were associated with these explanatory variables. The significance of covariance parameters for the random variables of village, household nested within village, and residual variance are presented in Table 3.3. SOM variability among villages is similar but about 2/3 of the scale of that in individual fields (Table 3.2). When soils were characterized by sand content, the significance of variations in SOM attributable to village effect were highest in the model that included elevation (Table 3.4). However, the residual SOM variability was greater than the village effect in each case. Variability attributable to village effect was less when soils were characterized by soil type than when characterized by sand content (Table 3.4), and residual SOM variation was greater. This indicates that variability in SOM associated with the village effect is much less significant (Pr>F = 0.0140) than the residual variability (Pr>F = 0.0003) between fields after variability from the listed explanatory variables is taken into account. For this reason, the village effect is not explored further.

The multiple soil fertility enhancing practices used on fields in this study are discussed in the following section. Subsequent sections discuss SOM effects of the explanatory variables when the full set of fields studied is included, followed by a discussion of the effects of the explanatory variables in the fields containing gliricidia, and finally in the fields containing no gliricidia.

Soil organic matter and explanatory variables

Soil organic matter values, associated with the three cropping systems were not significantly different (Pr>F = 0.8245 to 0.2591) across all fields (Table 3.3) in the study whether soils were characterized by sand content or by soil type. Increasing sand content was strongly and negatively related to SOM (Table 3.3, Figure 3.3). For each 10% increase in sand content, SOM decreased approximately 10 g kg^{-1}, or 14% at the mean sand content. The non-gliricidia cropping systems were concentrated on M'chenga soils with higher sand content while the gliricidia cropping system was more common on soils with lower sand content (Figure 3.3). This is consistent with the trend seen in Chapter 3 that gliricidia placement was less common on the sandier M'chenga soil. When the sand content of the three soil types was compared (Figure 3.4), soils labeled by the smallholders as Mchenga were concentrated at the higher sand contents while the Katondo soils were distributed at lower sand contents. A wide range of sand contents were found in Makande soils.

When soil was characterized by sand content (Table 3.4), the soil organic matter trend increased with increasing annual rainfall through 830mm annually, and declined with increasing rainfall above 830mm. When soils were characterized by soil type (Table 3.4), soil organic matter showed an increasing trend with increasing elevation. At the mean elevation of 882m, an increase of 100m elevation resulted in a 2.9 g kg^{-1}, or 14% increase in soil organic matter.

Soil organic matter in fields with the gliricidia/maize intercrop

When the gliricidia/maize intercrop fields were analyzed separately (Table 3.5), and soil was characterized by sand content, neither the age (Pr>F = 0.5440) nor the population (Pr>F = 0.9476) of gliricidia plantings had a significant influence on SOM. The number of soil fertility improvement methods used in a given field was added as a categorical variable, but proved to have little direct impact on SOM. Fertilizer N was associated with a slight positive trend in soil organic matter. At the mean rate of application, a 1 kg ha^{-1} increase in fertilizer N was associated with a 1.3% increase in SOM.

Soil type, elevation, and their interaction had a significant effect on soil organic matter (Table 3.5). Trendlines with positive slopes (Figure 3.5) indicate a positive relationship between soil organic matter and elevation in the two finer soil types, Makande and Katondo, while the relationship was negative in the coarser M'chenga soils.

For each 100m increase from the mean elevation, Katondo and Makande soils increased in soil organic matter 10 and 4 g kg^{-1} or 1.1% and 0.46% respectively, while M'chenga soils decreased in SOM 2.3 g kg^{-1} or 0.26%. Elevations among the fields in the study ranged from 760m to 1064m. Elevations in the Zomba district range from 300m to 2100, with most of the area in the surrounding the study fields ranging from 600m to 1200m (Benson et al., 2002).

Planting patterns of gliricidia showed evidence of having been established at the recommended population and spacing, and subsequently to have lost plants from this planting pattern without replacement by most smallholders. Mean population per hectare was 2300, or one-third of the recommended plant population (Table 3.2). Plant populations were markedly low in plantings from four to six years in age (Figure 3.6).

Soil organic matter in fields without the gliricidia/maize intercrop

Increasing elevation was associated with an increasing trend (Pr>F = 0.1836 to 0.0703) of SOM in fields without the gliricidia intercrop (Table 3.5, Figure 3.7) when soils were characterized by soil types. Soil organic matter averages in sole maize and maize/pigeonpea cropping systems were very similar in aggregate, 20.40 g kg^{-1} and 20.37 g kg^{-1} respectively. However, the addition of pigeonpea to the maize cropping system at elevations below 877 meters was associated with an increase of 1.8 g kg^{-1} or 11% in soil organic matter levels compared to the sole maize cropping system (Figure 3.7).

DISCUSSION

Ferralsols and Lixisols, which are common in southern Malawi, have comparatively low CECs and absolute levels of plant nutrients due to the predominance of high sand content (Figure 3.3) and low-activity clays (FAO, 1999a). This makes recurrent inputs of plant nutrients a pre-condition for continuous cultivation. Given the limited natural fertility of these soils, we would expect to be able to demonstrate the benefits of the gliricidia/maize intercrop, which provides a recurrent nutrient source, over sole maize. Though the expected SOM effect of the gliricidia intercrop was not evident, the expected biogeochemical drivers of SOM content were more evident in the gliricidia/maize intercrop fields than in the comparison fields without the intercrop.

However, multiple soil-fertility-enhancing practices were used in the fields studied, so that SOM effects from individual practices might interact with one another, making it difficult to separate individual effects. Tittonell et al. (2008) found that farmers reinforced soil fertility variability in their fields by investing more resources on already fertile fields. As in many on-farm studies the differences in SOM attributable to the treatment studied were smaller than differences in SOM between fields, due to differing biophysical characteristics, such as elevation and soil texture, and to differing management that stems from these characteristics. Mafongoya et al. (2006b) found that in Southern Africa within farm and within field variability of soil nutrients is sometimes greater than mean differences across districts. In our study, within farm variability of SOM was greater than the largest difference in SOM between EPA's in 22% of cases. Within farm variability of SOM was greater than the second largest difference in SOM among EPA's in 73% of cases. Tittonell et al. (2008) found that management and environmental effect may also be negatively reinforcing. For example, if a field with low soil fertility is planted late, it is also subject to greater soil erosion, lessening the soil fertility further. Study of such interactions requires multiple soil sampling at designated intervals and is beyond the scope of this study.

Sampling frame issues

The smallholders participating in this study are assumed to be representative of the larger population of smallholders in southern Malawi, However their villages were within ten kilometers of paved roads and within the same district as the Makoka research station, which should give them greater accessibility to gliricidia seedlings and knowledge of the cropping system.

Soil fertility enhancing practices

Makumba (2003) listed incorporation of crop residues in his description of typical cropping practices for maize-based cropping systems. These findings are consistent with our finding that 97% of sampled fields were managed with incorporation of crop residues in both maize/gliricidia intercrops and non-gliricidia fields. Because residue incorporation is used in all of the treatments, this important practice is not being reduced by the use of the gliricidia/maizer intercrop.

It has not usually been possible for smallholders to apply the recommended rates of N fertilizer to maize. Price ratios of nitrogen to maize in Malawi may be twice those in Mozambique, which borders Malawi on the east (Mafongoya et al., 2006a). One of the advantages of the gliricidia/maize intercrop is addition of N to the soil in green leaf manure. (add Chirwa, 2006 reference and make sure it is in the diss. Endnote file) (Also add Makumba on amount of N in gliricidia) . Because a lower proportion of maize/gliricidia fields received fertilizer N additions than the comparison fields (76% versus 89%), it is evident that some N fertilizer additions are being replaced with the gliricidia intercrop.

Nitrogen fertilizer additions did not have significant explanatory value for soil organic matter values when used in a model (Table 3.4). In 16% of households, however, the intercrop replaced fertilizer N additions, giving growers the option of covering more of their maize cropping area with N additions from either the intercrop or from fertilizer N. Seventy-six percent of households added fertilizer N to the maize/gliricidia intercrop and the paired maize fields at the same rate, which had the potential to increase yields more than either treatment alone. Although a synergy between fertilizer N additions and the gliricidia intercrop in maize grain production has been demonstrated at nearby Makoka research station (Akinnifesi et al., 2007), this synergy did not carry through to SOM values, and was not detectable in this on-farm study. Thus, the practice of intercropping maize with gliricidia seems to be additive to the most common two soil-practices of incorporation of crop residues and addition of fertilizer N, because most of the smallholders used both these with all cropping systems.

Pigeonpea is valued by smallholders as a food source during the dry season, and for soil enrichment (Snapp, 1998), though it was not classified as a soil improvement practice by either researcher or smallholders in this study. Chirwa (2003), found that the addition of the gliricidia to the maize/pigeonpea intercrop did not decrease the yield of pigeonpea grain, and predicted that gliricidia would not replace pigeonpea in local cropping systems. The fact that pigeonpea was used in 78% of paired maize fields and only 38% of the gliricidia/maize fields might contradict Chirwa's expectations, or it might reflect the smallholder's tendency to place gliricidia more often on finer-textured Katondo and Makande soils, leaving the maize/pigeonpea intercrops to predominate on the coarser M'chenga soils.

Soil organic matter and explanatory variables

The results reported in chapter two demonstrate the maize/gliricidia intercrop to significantly increase soil organic matter compared to sole maize cropping systems. The presence of the maize/gliricidia in the smallholder's fields in this study did not demonstrate a discernable effect on SOM (Table 3.3, Figure 3.3). However, the results reported in chapter two were reached after 15 years of intensive management at a research station, while the age of the gliricidia plantings in the fields averaged 8 years of age and less than half the recommended gliricidia population density.

Soil texture greatly influences decomposition of soil organic matter. Giller et al. (1997) note that while temperature and moisture availability control the rate of decomposition of SOM, texture controls the extent to which decomposition eventually proceeds. The tendency of clay colloids to slow decomposition of SOM may result both from adherence between colloid and organic molecules (Giller et al., 1997), and increased aggregation with increasing clay content (Vanlauwe et al., 1998). When the full set of fields studied were included in analysis, increasing sand content, and corresponding decrease of clay content of the soil was very strongly and negatively related to SOM content (Table 3.4, Figure 3.3).

Descriptors of soil type common in central and southern Malawi were chosen to classify soil types to facilitate descriptions of current placement of the gliricidia/maize intercrop and to simplify communication of any possible recommendations arising from this research. Kamanga (2002), interviewing smallholders in central and southern Malawi, characterized Katondo soils as similar to alfisols (USDA), M'chenga soils as very sandy and Makande soils as having vertic properties. When the sand content of the of the three soils was compared (Figure 3.4), the M'chenga and Katondo soils clustered in the high and low sand contents, respectively, as expected. The Lixisols (FAO, 1999b) listed as the most common soil type in Malawi (Kamanga, 2002) correspond roughly to the Alfisol soil order in the USDA classification system. The soils classified as M'chenga by smallholders may correspond to an Alfisol with a thick, sandy A horizon. The Katondo soils may correspond to a Alfisol, in which the A horizon is partially or wholly eroded, and the B horizon is part of the layer annually tilled for production. The fact that the soils described as Makande extend across the range of sand contents was not expected. Soils with vertic properties, such as Makande, having high-activity clays, should have a greater protective effect on SOM than the low activity clays found in the Katondo soils or alfisols.

In moisture-limited cropping systems (Figure 3.1), such as those in this study, increased rainfall leads to greater yields of plant biomass, which is returned to the soil as crop residues. Thus, the increasing SOM values with increasing rainfall may be liked to increased biomass additions. However, rainfall values above 830mm in this study were correlated with decreasing SOM. At higher rainfall values, both rate of biomass addition and rate of SOM breakdown are important influences on SOM values. Agehara et al.(2005) found that soil moisture levels between 50% and 70% maximized microbiological activity during incubations, maximizing mineralization of nutrients, and speeding microbial breakdown of SOM. Therefore increased rainfall above 830mm may have increased the rate of SOM decomposition and resulted in decreased SOM values.

Statistical analyses similar to those for SOM were carried out for Bray P and exchangeable K values and for CEC. In the few instances that discernable trends were identified, the trends were in contradiction to typical biological drivers and are not reported.

Soil organic matter in fields with the gliricidia/maize intercrop

The fields with the maize/gliricidia intercrop were analyzed separately so as to be able to include age and population of the gliricidia planting as potential factors in SOM values. Gliricidia plantings showed evidence of having originally been established in the recommended planting patterns, then reduced in population. The markedly low populations of gliricidia planted from the years 2000 to 2002 may have resulted from insufficient rainfall for establishment. Akinnifesi et al. (2007) have reported below-average rainfall in this district in 2001/2 and 2002/3. This could have reduced the survival rate of trees in gliricidia plantings that were not well established, corresponding to plantings from four to six years of age in our study. Gliricidia population and age had no significant effect on SOM. However, this result is consistent with the findings of Akinnifesi et al. (2007), in which SOM values were slightly reduced after nine years of monocropped maize, while they were stable after nine years of the maize/gliricidia intercrop.

Sand content had a strong negative effect on soil organic matter. (Table 3.3) The most pronounced trend in SOM values of fields with the maize/gliricidia intercrop was found when soils were characterized by soil type (Table 3.5). Soil type and the interaction of elevation and soil type show strong trends, and the effect of elevation on SOM approaches statistical significance.

Giller et al. (1997) listed temperature and moisture availability as factors that controlled the rate of decomposition of SOM, and reviewed comparative research in England and Nigeria that determined that rates of SOM decomposition were doubled with an 8° to 9° C increase in temperature independent of differences in rainfall and temperature patterns. Lovett (1999) found a strong correlation between elevation and temperature in Tanzania, and measured a 0.5° to 0.6° C decrease in mean monthly maximum and minimum temperatures for each 100m increase in elevation. Given a similar lapse rate in Zomba district, the 300m elevation range in this study would generate a difference in temperature only one-fourth that described by Giller. If the relationship of decomposition rates and temperature is linear, this could result in differences of 25% in rates of decomposition between soils at higher and lower elevations, based solely on temperature differences.

Increasing clay content would be expected to increase SOM. Soils with vertic properties, such as Makande soils (Kamanga, 2002), would be expected to have a greater protective effect on SOM than the low-activity clays found in Katondo soils. The effect of soil type on the influence of elevation on SOM values is clear in Figure 3.5. The strongest effect of increasing elevation on SOM values is among the soils characterized as Makande. The effect of elevation on SOM is positive with Katondo soils containing low-activity clays, but the magnitude of the effect is lower, while the effect of elevation is reversed with sandy M'chenga soils. It may be that in Malawi's ustic environment that evapotranspiration is decreased with increasing elevations, leading to increased maize yields, and increased mining of soil nutrients and SOM.

Soil organic matter in fields without the gliricidia/maize intercrop

The effect of elevation on SOM in fields without the gliricidia intercrop is similar to the effect of elevation in fields with the intercrop (Table 3.4, Table 3.6). The interaction with soil type is not evident, however, in fields without the gliricidia intercrop. The pigeonpea plant is of smaller stature than the gliricidia plant, and average populations of pigeonpea were only 60% of populations of gliricidia. Thus the biomass contributions and resulting SOM values would be expected to be lower. The SOM values, however, are similar (Figure 3.5, Figure 3.7). Aggregate SOM values for the sole maize and maize/pigeonpea cropping systems are also similar. But at elevations below 877m, addition of pigeonpea to the cropping system resulted in an increase of 11% in SOM over the sole maize system. This may be a result of the higher C:N values typical of pigeonpea leaf biomass. Makumba (2003) found that pigonpea leaf plus root biomass had a C:N ratio of 19 , compared to 16 for gliricidia leaf biomass.

CONCLUSIONS

Among the explanatory variables, sand content had the most pronounced effect on SOM values followed by elevation and soil type. Use of the gliricidia intercrop did not result in discernable effect on SOM when all fields were included. The effect on SOM of elevation and soil type and their interaction were more discernable when only the fields including the gliricidia/maize intercrop were included. This suggests that the gliricidia is supplying a recurrent source of plant nutrients and SOM and that this supply of SOM allowed gradients of increasing SOM to develop with increasing elevation and fineness of soil texture. These results suggest that maize yield increases, when present, should form the first incentive for the use of the gliricidia intercrop, for these yield increases may be generally operative and more immediately valuable. The second incentive, recapitalization of SOM, should be described when combinations of increasing site elevation and increasing fineness of soil textures will maintain increased SOM values.

TABLES

Table 3.1 Sampling frame for the on-farm study.

EPA	Cropping System	No. villages	No. households	No. fields
Thondwe	gliricidia	2	4	4
	paired maize			4
	non-gliricidia		3	3
Total			*7*	*11*
Dzaone	gliricidia	7	14	14
	paired maize			14
	non-gliricidia		11	11
Total			*25*	*39*
Mpokwa	gliricidia	4	8	8
	paired maize			8
	non-gliricidia		7	7
Total			*15*	*23*
Malosa	gliricidia	6	11	11
	paired maize			11
	non-gliricidia		7	7
Total			*18*	*29*
Grand total			19	65 102

Table 3.2 Mean and standard deviation of environmental, management, and response variables, divided by extension planning area.

Variable	Thondwe	Dzaone	Mpokwa	Malosa
Environmental variables				
Sand content (%)	66 (9.7)*	69.4 (11.0)	71.8 (7.3)	69.6 (9.5)
Elevation (m)	1053 (8.1)	925 (50.2)	822 (37.8)	808 (25.4)
Rainfall (mm)	565 (55.0)	1099 (4.0)	904 (131.8)	1315 (90.5)
Katondo soil (%)	63.6	31.6	8.7	51.7
Makande soil (%)	18.2	26.3	65.2	34.5
M'chenga soil (%)	18.2	42.1	26.1	13.8
Management variable				
Fertilizer (kg N ha^{-1})	11.0 (6.8)	5.6 (6.5)	4.1 (2.8)	6.2 (5.0)
Gliricidia pop. (plants ha^{-1})	1408 (2067)	926 (1751)	554 (787)	1080 (1939)
Gliricidia age (year)	5.0 (2.9)	7.6 (3.1)	11.0 (3.6)	8.7 (2.5)
Pigeonpea pop. (plants ha^{-1})	741 (1173)	1497 (8057)	1711 (4972)	1088 (5130)
Response variables				
Soil Organic Matter (g kg^{-1})	22.6 (6.7)	22.2 (10.4)	21.3 (7.4)	17.7 (5.8)
Bray P (mg kg^{-1})	28.0 (24.9)	29.2 (18.9)	43.5 (37.6)	35.9 (25.4)
Exchangeable K^+ (mg kg^{-1})	114 (48.7)	181 (88.7)	207 (88.6)	153 (65.9)
CEC (cmol kg^{-1})	5.6 (1.4)	8.3 (3.4)	8.1 (2.2)	5.8 (1.3)
pH	5.9 (0.23)	6.1 (0.28)	6.4 (0.43)	6.1 (0.35)

*Standard deviation is in parentheses following the mean of continuous variables

Table 3.3 Mean and standard deviation of soil organic matter above and below the mean elevation for the sub-group of fields, divided by soil type and cropping system

Soil Organic Matter (g kg^{-1})		
(maize/ gliricidia fields)	Elevation ≤ 877m	Elevation > 877m
Katondo	19.9 (6.7)	25.7 (9.4)
Makande	17.4 (2.9)	29.3 (12.8)
M'chenga	23.3 (3.7)	17.3 (6.8)
(fields without gliricidia)	Elevation ≤ 882m	Elevation > 882m
Sole maize	15.8 (4.8)	22.4 (10.8)
Maize/pigeonpea	19.2 (6.0)	22.8 (10.7)

Table 3.4 The effect of cropping system, sand content, soil type, elevation, fertilizer N, rainfall, village, household nested within village and residual variance on soil organic matter and CEC
in all fields

	Statistical Significance for Combinations of Variables		
Soil Organic Matter:			
Soil characterized by sand content		Pr > F:	
Cropping system	0.8245	0.5984	0.7954
Sand content	<.0001	<.0001	<.0001
Elevation	0.2453		
Fertilizer N		0.6709	
Rainfall			0.1454
Covariance parameters:		Pr > Z:	
Village	0.0140	0.0228	0.0720
Household(village)	0.0535	0.0739	0.0290
Residual	0.0003	0.0067	0.0002
Soil characterized by soil type		Pr > F:	
Cropping system	0.2591	0.7915	0.3189
Soil Type	0.2716	0.6936	0.2019
Elevation	0.1626		
Fertilizer N		0.5143	
Rainfall			0.7189
Significance of covariance parameters:		Pr > Z:	
Village	0.0539	0.0368	0.0865
Household(village)	<.0001	0.0007	<.0001
Residual	<.0001	0.0009	<.0001

Table 3.5 The effect of sand content, soil type, number of soil fertility methods, elevation, rainfall, fertilizer N, gliricidia population, and age of gliricidia on soil organic matter in fields with the gliricidia intercrop.

	Pr > F for Combinations of Variables				
Soil Organic Matter:					
Soil characterized by sand content					
Sand content	<.0001	0.0012	<.0001	<.0001	<.0001
Soil fertility methods	0.6658	0.8826	0.2705	0.6553	0.6643
Elevation	0.9124				
Rainfall		0.6179			
Fertilizer N			0.1472		
Gliricidia population				0.9476	
Age of gliricidia					0.5440
Soil characterized by soil types					
Soil Type	0.6164	0.6821	0.5941	0.6045	0.1241
Elevation	0.3094	0.2345	0.1860	0.1555	0.0746
Rainfall	0.8226				
Fertilizer N		0.7996			
Gliricidia population			0.4143		
Age of gliricidia				0.5440	
Soil Type x Elevation					0.1118

Table 3.6 The effect of sand content, soil type, elevation, rainfall, fertilizer N, pigeonpea population and age on SOM in fields without gliricidia.

Pr > F for Combinations of Variables					
Soils characterized by sand content					
Sand Content	<.0001	<.0001	<.0001	<.0001	<.0001
Cropping system	0.5569	0.4371	0.7499	0.6012	0.3944
Elevation	0.3611				
Rainfall		0.1681			
Fertilizer N			0.8246		
Pigeonpea population				0.8713	
Presence of pigeonpea					0.2600
Soils characterized by soil type					
Soil Type	0.4601	0.2492	0.9722	0.4581	0.3940
Elevation	0.1836	0.1586	0.0703	0.1743	0.1400
Cropping system	0.7680				
Rainfall		0.5227			
Fertilizer N			0.5430		
Pigeonpea population				0.6520	
Presence of pigeonpea					0.1235

FIGURES

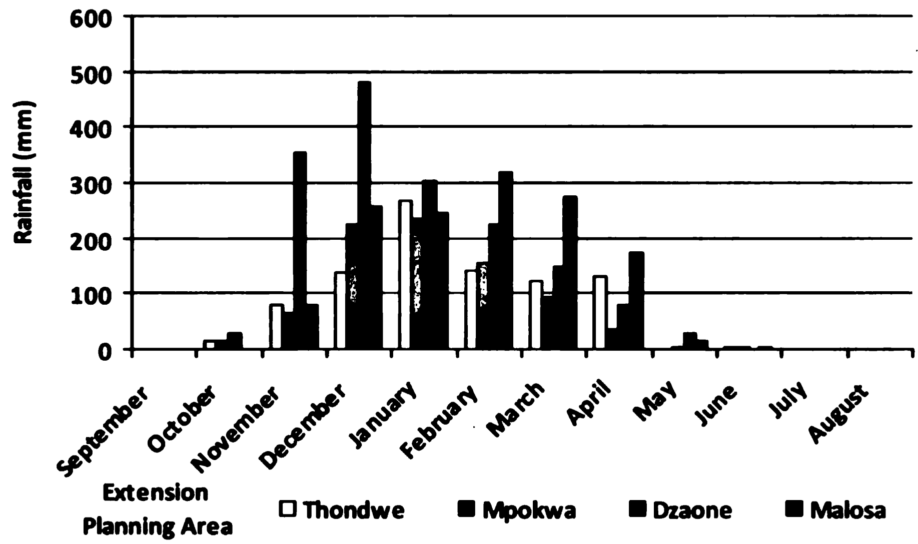

Figure 3.1 Three-year average annual rainfall from the 2003 to 2006 cropping seasons in the four extension planning areas.

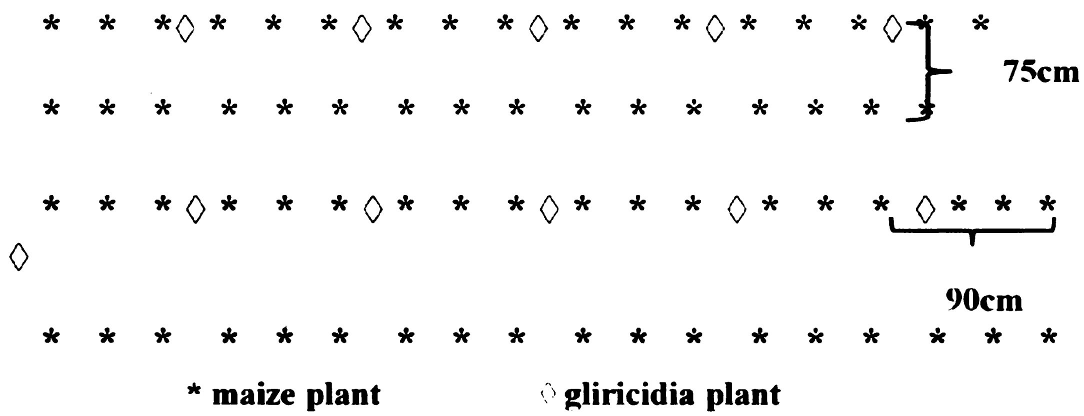

Figure 3.2 Planting pattern for the maize gliricidia intercrop given a 75cm spacing between rows and single-seeded planting pattern within rows.

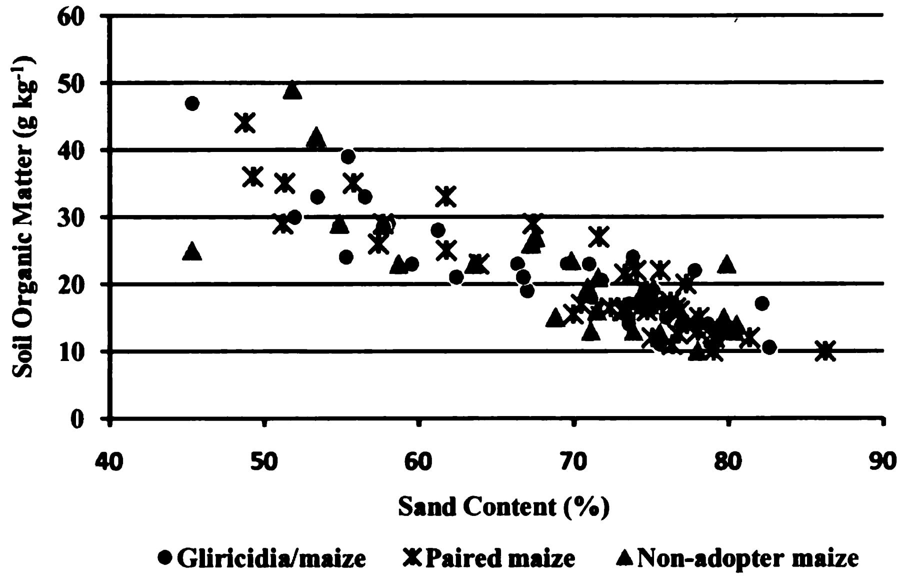

Figure 3.3 Soil organic matter as a function of sand content, by cropping system, including all fields.

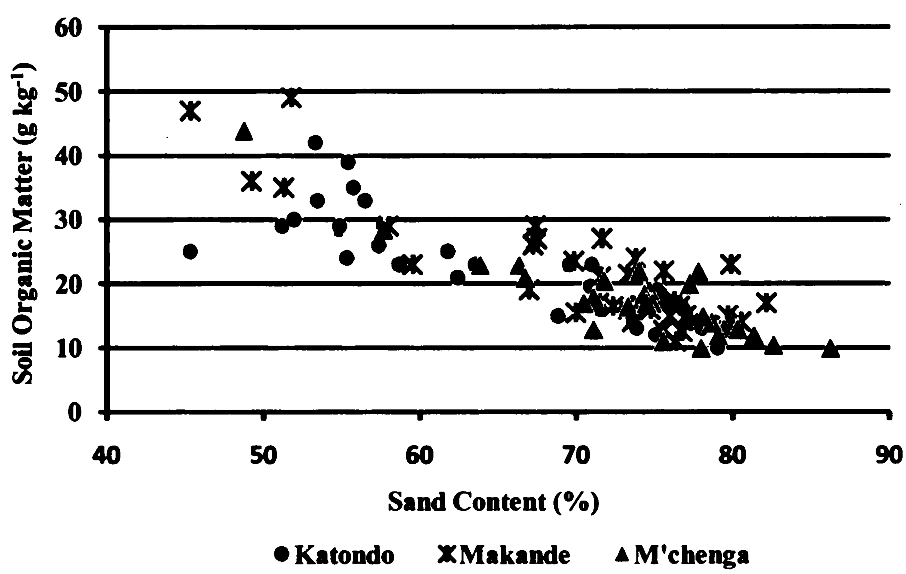

Figure 3.4 Soil organic matter as a function of sand content, by soil type, including all fields.

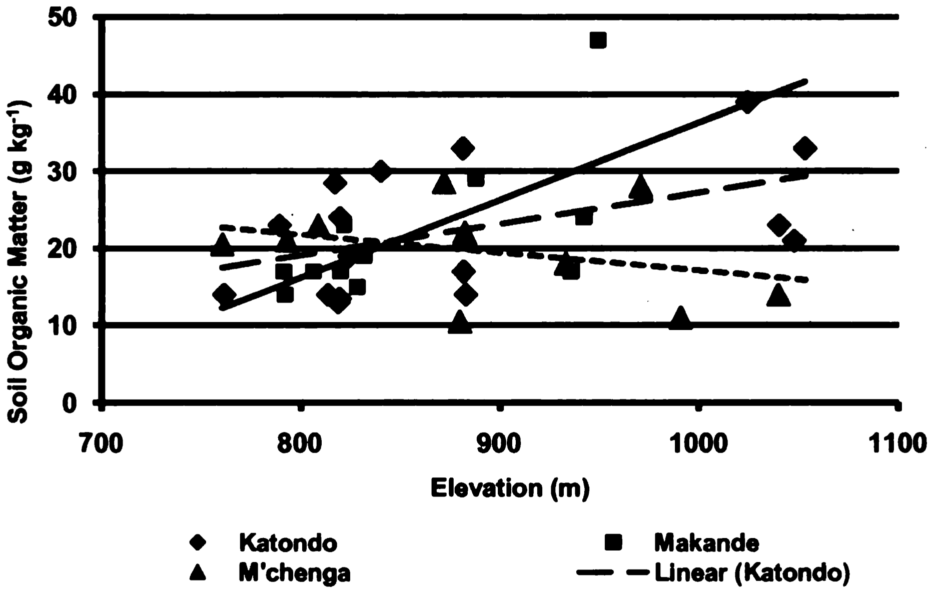

Figure 3.5 The effect of soil type and elevation on soil organic matter in fields containing the gliricidia/maize intercrop.

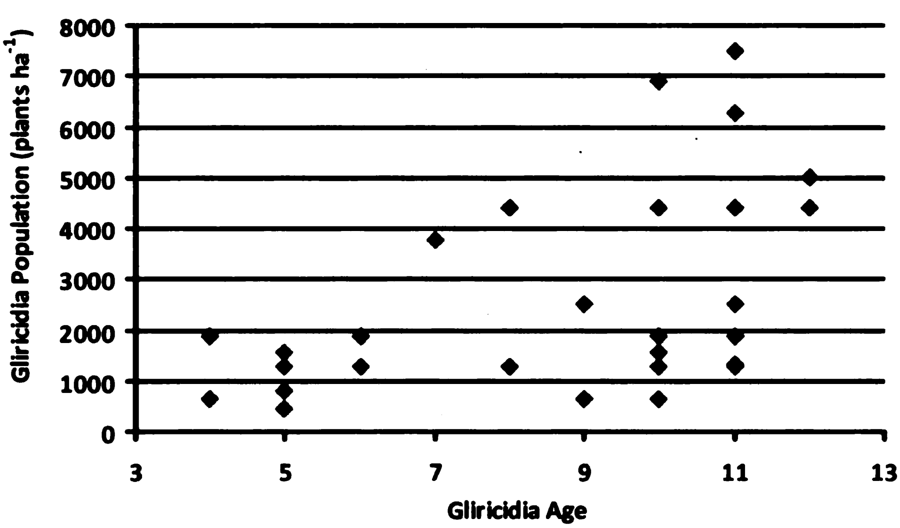

Figure 3.6 The effect of age of gliricidia planting on gliricidia population.

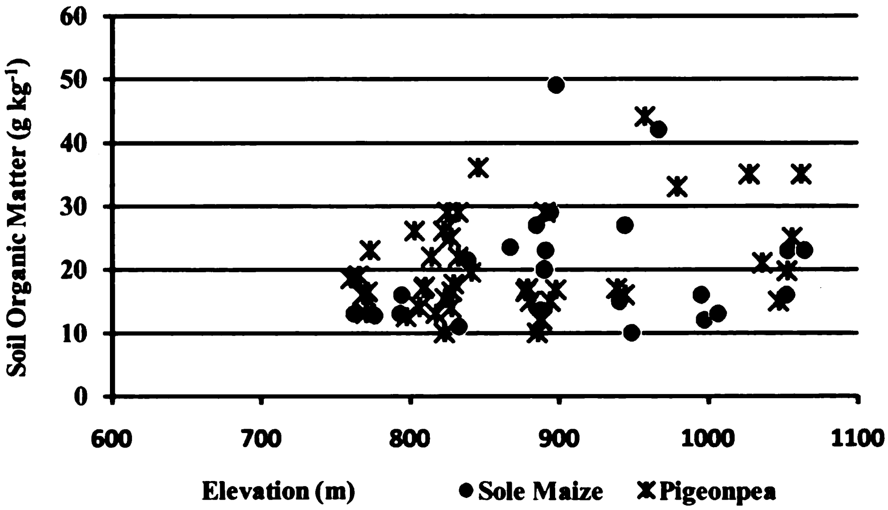

Figure 3.7 Soil organic matter as a function of elevation in fields without the gliricidia/maize intercrop, by cropping practice.

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APPENDIX

Evaluating the Impact of Gliricidia Sepium on Soil Quality with Smallholder Farmers in the Chinyanja Triangle

Household Survey Household code number___________(number consecutively, 1, 2, 3,…through the whole study)

May we ask you some questions about your household and farming practices ? □ yes □ no (tick) (We are not allowed to interview people less than 18 years of age.)

Farmer's name: _________________ Village: _______________ EPA: ____________

District: ____________Date: ____________ Interviewer's name: ______________________

General questions:

How many years have farmers in this village planted gliricidia?_________(# years) (May be less than perfectly precise, and may also be related to the year an important public event occurred.)

Have many farmers used gliricidia over these years? □ yes □ no

Of those farmers that began with gliricidia, how many have continued to use it?

□ almost all □ half □ quarter □ less than a quarter (tick one box)

Household questions:

House status (tick all that apply, do not ask): □ metal roof □ thatch roof

□ fired bricks □ unfired bricks □ Windows/glass panes □ Windows/wood shutters

Table 4.1 Household Members: (to be asked of the farmer or a knowledgeable elder).

Name of household member	Sex 1=M 2=F	Age (years)	Participates in fieldwork (on any plot) Please write the # of hours per day each person might work in the field, or write: 1 = too young or too old 2 = works off-farm
Name	Code	Age	Code

Household livestock: chickens ______goats ______pigs ______cattle ______(other) __________ (write in number of animals)

Land available for use by the household (May be asked while at the field being sampled)

Table 4.2 Field Size: (to be asked of the farmer or a knowledgeable elder).

Number of field (Please number: 1,2,3...in each household)	Size of Field May be in comparison to the size of the filed that we are sampling.	Dominant soil type in field 1=katondo, 2=makande, 3=mchenga, 4=mtsilo, 5= other names, please list	Typical crop, intercrop, or rotation on that field A = local maize variety B = improved maize variety 1 = sole maize 2 = maize/gliricidia intercrop 3 = maize/pigeonpea /gliricidia intercrop 4 = maize intercrop with pigeon pea or other annual legume 5 = vegetables 6 = tobacco 7 = other crops, please list	Typical soil fertility treatments on that field 1 = crop residues 2 = livestock manure 3 = fertilizer 4 = gliricidia 5 = other agroforestry 6 = compost 7= annual legume rotation or intercrop 8 = other, please list	Rating Please rate the fields (1 = best, 2 = next best...) according to the productive capacity of the soils in a moderate production year.
Number	percentages	Code	Code	Code	Rating

Evaluating the Impact of Gliricidia Sepium on Soil Quality with Smallholder Farmers in the Chinyanja Triangle

Farm Field Survey

Household code number______(from hh questionnaire) Farmer's name____________________

Field or garden code number _________(number consecutively, 1,2,3,...for each household)

Matching information from ICRAF survey? □ yes □ no

* questions that should be omitted for 'control' fields

** questions that should be omitted if ICRAF survey was done on this field.

GPS data: (from center of field)

Longitude:_________ Latitude:_________ Altitude:__________

**Measure the field sampled with the GPS, and draw a picture of the field on the back of this questionnaire.

Size of field: ________ ha

Field type:

□ gliricidia intercrop + inorganic N □ gliricidia intercrop – inorganic N □control/gliricidia adopter + inorganic N □ control/gliricidia adopter – inorganic N

□control/gliricidia non-adopter + inorganic N □control/gliricidia non-adopter – inorganic N (tick)
May we take a sample of the soil and tell you more about your soil type? □Yes, □No (tick)May we take some of this soil to the office to analyze further? □Yes, □No (tick)

Take soils samples the field (in 'X' pattern), sampling from the maize rows. Take 3 samples of 10 cores per sample.

Soil sampling is done in : □ rows from last year's crop, □ rows from next year's crop (tick)

Rows are: □ tops scraped to cover maize biomass, □ tops not scraped (tick)

Plate pH:________________________Texture:_________________________

Table 4.3 Soil Characteristics (of field sampled):

Name of soil Write the Chichewa names of the main soils in this field.	Dominant soil Mark an 'x' in the square of the dominant soil in this field	Tillage 1 = easy 2 = somewhat easy 3 = somewhat difficult 4 = difficult	Infiltration of rainfall 1 = very fast 2 = somewhat fast 3 = somewhat slow 4 = very slow	Runoff 1 = none 2 = small amount 3 = moderate amount 4 = much	Available water holding capacity 1 = high 2 = moderately high 3 = moderately low 4 = very low	Fertility 1 = highly fertile 2 = moderately fertile 3 = poorly fertile 4 = exhausted
Name	mark	code	code	code	code	code

Which type of soil is the best (farmer's point of view)? ________________________

**This field is: (1) relatively deep and fertile (2) shallow, rocky and/or exhausted

(point of view of the interviewer, do not ask, please circle)

Table 4.4. Soil Fertility methods (of field sampled):

Years	Methods	Advantages of the methods	Disadvantages of methods
2005/6 2004/5 2003/4	1 = crop residues 2 = livestock manure 3 = fertilizer (fill table below) 4 = gliricidia 5 = other agroforestry 6 = compost 7= annual legume rotation or intercrop 8 = other, please list **Enter each response on a separate line.**	1 = high maize yield 2 = fast maize growth 3 = permanent, cannot lose 4 = improves household nutrition 5 = low labor requirement 6 = suppresses weeds 7 = other, please list 8 = easy to till 9 = reduces pests May enter more than one response.	1 = slow maize growth 2 = shortage of livestock manure 3 = extra labor 4 = high price 5 = low cash flow at planting 6 = soil depletion 7 = dries the soil 8 = intercrop competes with maize 9 = other, please list 10=builds up pests May enter more than one response, in order of importance.

*Year that gliricidia was planted (please circle):

1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006

*Table 4.5. Gliricidia biomass cycle: (Please mark 'i' for years in which the tree was immature, 'm' for years in which the tree was mature, and 'd' for years in which the tree was declining due to age/disease.)

1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006

*Table 4.6 Gliricidia pruning:

Ye ar	Annual Pruning 1 = pruned once 2 = pruned twice 3 = pruned thrice 4 = not pruned 5 = other, please list	Pruning type 1 = branches cut, leaves separated 2 = branches left on tree, leaves taken 3 = other, please list May include different answers for different prunings, separated by commas	Leaf Processing and Incorporation 1 = Whole leaves applied over whole soil surface 2 =.Whole leaves, in or under planting ridge 3 = Whole leaves, spot applied 4 = Powdered leaves applied over whole soil surface 5 = Powdered leaves, in or under planting ridge 6 = Powdered leaves, spot applied 7 = Powdered, mixed with fertilizer, and spot applied.	Timing How many days passed between pruning and incorporation ? May include different answers for different prunings, separated by commas
200 5/6				
200 4/5				
200 3/4				

Table 4.7. Was fertilizer listed in table 3? (tick) □No □Yes, please fill table

Year	Type	Timing	Application	Amount
	1=compound D, 2=Urea, 3=CAN, 4=23.21.0.+4S, 5=Other (please list)	1 = basal 2 = top-dress May include both basal and top-dress	1 = spot applied 2 = applied to ridge 3 = broadcast on whole surface May include different answers for basal and top-dress, separated by commas.	1 = bottle-cap applied to each maize station 2 = spoonful applied to each maize station 3 = handful applied to each maize station 4 = fertilizer and manure mixed 5 = applied in a line along the ridge (please write how many kg for this field) 6 = broadcast over whole surface (please write how many kg for this field) 7 = other, please specify . May include different answers for basal and top-dress, separated by commas
2005/6				
2004/5				
2003/4				

Table 4.8. Please fill the following information about the cropping system(in field sampled):

Year	Crop or intercrop In addition to gliricidia, if present: 1= sole maize 2=maize + pigeon pea 3=maize + other legume 4= tobacco, 5=other (please list)	Variety name Please list variety name and/or the Chichewa name.	Spacing 1=25cm x 1m.; 2= 90cm x 90cm, 3=1mx1m, 4=other (please specify) May include different answers for intercrops, maize listed first.	Yield May include different answers for intercrops, maize listed first. 1 = 50 kg 2 = 70 kg 3 = 90 kg	Yield difference What would the yield of this field have been with sole maize? 1=quarter 2=half 3=same	Incorpo-ration What portion of crop residues were incorporated? 1=quarter 2=half 3=three quarter 4=all	Notes High or low rainfall Unable to weed Crop diseases Other cropping issues (please describe)
2005/6							
2004/5							
2003/4							

**Table 4.9. Please fill this table about weeding practices:

Year	Date of maize planting May be approximate in 2005 and 2004.	Number of weedings	Time of weeding		
			1st	2nd	3rd
2005/6					
2004/5					
2003/4					

Do you have any suggestions on how the agroforestry technologies can be improved?____

Do you any question to ask us?

Thank you very much for taking the time to give us this sample and information.

Farmer report sheet:

Name of farmer:

Plate pH:

Texture:

Size of the field