The long-term effects of a gliricidia–maize intercropping system in Southern Malawi, on gliricidia and maize yields, and soil properties

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Abstract

A gliricidia–maize (Gliricidia sepium (Jacq.)–Zea mays L.) simultaneous intercropping agroforestry system has shown to be a suitable option for soil fertility improvement and yield increase in highly populated areas of sub Saharan Africa where landholding sizes are very small and inorganic fertilizer use is very low. An 11 year old field experiment, gliricidia–maize simultaneous intercropping, with and without a small application of inorganic fertilizer was studied to increase our understanding of the long-term effects of continuous applications of gliricidia prunings on maize yield and soil chemical properties. The main objectives were to assess: (1) the yield of gliricidia prunings under intensive pruning management, (2) the effect of continuous applications of gliricidia prunings and fertilizer on maize yield and soil properties. During 11 years of intensive pruning, gliricidia trees maintained high levels of leafy biomass production (4–5 Mg DM ha−1). Application of gliricidia prunings increased maize yield three-fold over sole maize cropping without any soil amendments (3.8 and 1.1 Mg ha−1, respectively). Maize yield declined with time under sole maize cropping system in both treatments with and without inorganic N fertilizer. Application of inorganic fertilizer (46 kg N ha−1) in agroforestry systems increased maize yield by 29% (P = 0.002). Application of inorganic P did not significantly increase maize yield implying that the native P in the topsoil and P recycled through gliricidia prunings application was enough to support maize growth. The trees took up “native” soil nutrients (P, Ca, Mg and K) from the depth and pumped these to the surface soil. A net soil nutrient decrease in the gliricidia–maize simultaneous intercropping system was observed due to increased nutrient export.

Keywords: Gliricidia; Maize; Inorganic fertilizer; Intercropping; Agroforestry; Smallholder farmer

1. Introduction

In the sub-Saharan Africa, soil infertility is a major problem constraining agricultural production. Inorganic fertilizers are the first option for soil amelioration, but due to exorbitant prices most farmers cannot set aside sufficient money to buy them. Hence, farmers are encouraged to enrich the soils through planting of desirable woody or herbaceous species as improved fallows or simultaneously with the crops. Woody or herbaceous species in agroforestry systems can enrich topsoil through enabling nutrient cycling from the subsoil, and through biological N2 fixation by legume species (Kang and Shannon, 2001). The positive effects of planted improved fallows and hedgerow intercropping on soil fertility and on yields of succeeding or associated crops have already been documented (Kwesiga and Coe, 1994; Wendt et al., 1996; Akondé et al., 1997; Kang et al., 1999).

Several authors have expressed their fear that competition between trees and crops in a hedgerow cropping system for resources, e.g. for light, water and mineral elements, will reduce the yields of the associated crops (Ruhigwa et al., 1992; José et al., 2000a,b; Miller and Pallardy, 2001). Smithson and Giller (2002) reviewed different agroforestry

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systems and pointed out that the system of gliricidia–maize mixed (Gliricidia sepium (Jacq.)–Zea mays L.) intercropping (also known as gliricidia–maize simultaneous intercropping) developed at Makoka, Zomba, in Malawi, was more successful than system of hedgerow intercropping. In Malawi alley cropping was unsuccessful because of low tree biomass production and competition for resources between trees and crops (Itimu, 1997), while gliricidia–maize mixed intercropping has shown to be successful (Ikerra et al., 1999). Gliricidia–maize simultaneous intercropping system is a variant of alley cropping in which the trees are kept short by intensive pruning. Tree rows are closely spaced with only two rows of maize between the tree rows. In standard alley cropping there are five maize rows in the alleys. In the gliricidia–maize simultaneous intercropping we need more information on the value of the prunings as N and P fertilizer, on the effects of intensive pruning management on long-term tree biomass production, and on nutrient availability in both topsoils and subsoils. In this study we set the following objectives: (1) to compare the effects of gliricidia prunings on maize yield with those of inorganic N fertilizer, (2) to study long-term gliricidia biomass production under intensive pruning management and (3) to assess the long-term effect of repeated application of gliricidia prunings on soil fertility and crop yield.

2. Materials and methods

2.1. Site description

The study was conducted at Makoka Agricultural Research Station near Zomba in Southern Malawi (15° 30' S, 35° 15' E, altitude of 1029 m asl). The soil had 42% clay, 46% sand and 1.42 g/cm³ bulk density. The chemical characteristics of the soil were: pH(H₂O) = 6, organic C = 9 g/kg, P-olsen = 26 mg/kg, exchangeable K = 3 mmol (+)/kg, exchangeable Ca = 44 mmol (+)/kg and exchangeable Mg = 16 mmol (+)/kg soil. The soil is classified as ferric lixisol (FAO) (Ikerra et al., 1999). The rainfall is unimodal, most of it falling between November and March, and the growing season of maize is usually from November/December till May. The mean rainfall for the 11 years was 937 mm. The highest total annual rainfall was 1706 mm in 1997 and the lowest was 552 mm in 1993. During the 11 years we experienced two major droughts (1994 and 1995, see Fig. 1) and one season of excessive rainfall (1997).

2.2. Experimental design and management

Previously, on the experimental plot was a cotton (Gossypium sp.) agronomy trial with inorganic N fertilizer management. This agroforestry experiment was established in 1992 and since establishment the plots have been continuously cropped with maize as a test crop. The trial was designed as a 2 x 3 factorial in three replicates with the following factors: (1) with and without Gliricidia sepium intercropping (2) three rates of inorganic N fertilizer (0, 24 and 48 kg N ha⁻¹), and (3) three rates of P fertilizer (0, 20 and 40 kg P₂O₅ ha⁻¹). Calcium ammonium nitrate (CAN) fertilizer was used as a source of inorganic N fertilizer and was applied at 4 weeks after planting. Triple super phosphate (TSP) was used as a source of inorganic P and was applied at time of planting. The P treatments were discontinued from 1993/1994 to 2001/2002 because there was no response. They were reintroduced in 2002/2003 season because we thought that after 10 years of continuous cropping without P amendment might have depleted the soil native P via crop harvest and tree wood biomass removal.

Plot size was 6.7 m x 5.1 m, separated by 1 m wide path. In order to minimize tree root encroachment into the neighboring plots, iron sheets were installed vertically to 1 m deep in the borders of the tree plots.

The agroforestry species was Gliricidia sepium (Jacq.) Walp ex Reltahaleu, Guatemala. The trees were planted in rows in every other furrow at spacing of 90 cm within row

Fig. 1. Total annual rainfall, monthly rainfall means for 11 years and monthly temperature means from 1993 to 2003.
and 150 cm between rows (7400 trees ha\(^{-1}\)). In the first year (1992) during their establishment the trees were not pruned. From the second season onwards, gliricidia was pruned to about 30 cm height, three times per season, in October (i.e. 2–4 weeks before the rain onset), December and February. Sometimes a pre-cut in July/August was necessary to remove the old woody biomass and encourage new growth for the cut of October and also to stop the trees from producing seed so that the nitrogen should not be lost in seed production. Only tender twigs and leaves henceforth referred to as prunings were incorporated into the soil. The ridges were split and the prunings were arranged in the split ridges, and thereafter the ridges were reconstituted burying the prunings to a depth of 15 cm. The leaves from the pre-cut were also incorporated in the soil. At each cutting, the tree biomass was weighed and a sample was collected for dry-matter determination.

Soon after the onset of the rainy season, maize (\textit{Zea mays} L.) hybrid NSCM 41 was planted on the ridges at a rate of one seed per hole at 30 cm apart within ridge and 75 cm between ridges giving a maize population of 44 400 plants ha\(^{-1}\). Maize population in plots with gliricidia trees was the same as in sole maize plots. Weeding was done twice by hand using a hand hoe, the first weeding in December and the second weeding in January/February corresponding with the time of the second and third gliricidia pruning, respectively. Maize was harvested in May. All the maize stover was incorporated into the soil soon after harvesting.

### 2.3. Soil sampling and analysis

Soil samples were collected for the first time during land preparation in 1992. Ten soil samples from the top 20 cm were augured per plot, and bulked. After 10 years of continuous cropping soil nutrient status was determined to 200 cm soil depth. Soil profile pits were dug 8 weeks after planting maize in all the treatments without inorganic fertilizer and soil samples were collected along the soil profile at 20 cm depth intervals. The soil samples were air-dried and sieved through 2 mm mesh and analyzed for organic carbon (OC), available P, K, Ca and Mg.

Total organic carbon in soil was analyzed following the “wet” oxidation by acidified dichromate method according to \textit{Anderson and Ingram} (1993). Available P was determined in the soil according to \textit{Watanabe and Olsen} (1965) method in 0.5 M \textit{NaHCO\(_3\)} solution buffered at pH 8.5. Exchangeable cations, K, Ca and Mg were extracted from the soil using 1 M ammonium acetate buffered at pH 7. In the extract K was determined on a flame photometer. Calcium and Mg were determined on atomic absorption spectrophotometer (AAS).

### 2.4. Plant sampling and analysis

Samples of gliricidia prunings were collected at every time of cutting. The fresh samples were pre-weighed and then dried in an oven at 75 °C to constant weight and their dry matter contents were determined. The dried samples were finely ground and analyzed for P, K, Ca and Mg following the method of \textit{Temminghoff et al.} (2000). The nutrient mass fractions were multiplied by the biomass (DM) to determine the amounts of nutrients recycled via gliricidia prunings application.

### 2.5. Soil moisture determination

Soil moisture was measured in April 2002 soon after the rain had tailed off (i.e. at the end of rain season). In the sub-Saharan countries there are frequent dry spells (mid rainy season short drought) during the seasons during which crops suffer much from water stress. Therefore, improving soil moisture retention capacity would help to sustain the crop longer during the dry spells. Gravimetric method was used to determine soil moisture contents in the two land-use systems of sole maize and gliricidia–maize simultaneous intercropping. Soil samples were collected from all three replicates. Soil samples were taken at 20 cm soil depth intervals to 200 cm deep, using an Edelman type auger, and placed in plastic bags. The soil samples were weighed in pre-weighed beakers and then dried in an oven at 105 °C. After 72 h of drying the dry weights were recorded.

### 2.6. Data analysis

The data was subjected to analysis of variance (ANOVA) using GENSTAT discovery version 1 (Library release PL12.2). Simple correlation coefficients were determined for the linear relationship between maize grain yield increase and applied inorganic N fertilizer.

### 3. Results

#### 3.1. Nutrient contents of tree prunings

Gliricidia prunings production varied between 2 Mg ha\(^{-1}\) in 1993 and 6 Mg ha\(^{-1}\) in 1998. Out of the three main cutting the highest biomass yield is obtained in the October cut, contributing on average 35% of the total biomass and the other 65% is from the December, February and July/August cut. The average nutrients content of the prunings were: 29 mg N/g, 4 mg P/g, and 12 mg K/g. The tree biomass yield was highest in 1998 corresponding with the highest rainfall in the preceding season (Fig. 2). The midseason droughts lasting about 2–3 weeks also affected the tree biomass yields especially for the cut of December and/or January. The midseason droughts reduced the gliricidia biomass in 2000 and 2003.

#### 3.2. Maize yields

In a test of inorganic P fertilizer response in 2003, application of inorganic P to agroforestry system did not
give a significant main effect, or a significant interaction with gliricidia prunings. Therefore, maize grain yields given are only for the treatments of the gliricidia prunings with and without inorganic N fertilizer (Fig. 3). For the sake of legibility and the fact that the effects of gliricidia prunings compare very well with 48 kg N ha\(^{-1}\) the treatment of 24 kg N ha\(^{-1}\) has been deliberately omitted from Fig. 3. Maize grain yield in sole maize receiving no fertilizer N was highest in the first season, 1993 and declined with time. In the treatments of sole maize with inorganic N, and in all treatments with gliricidia, highest maize yields were obtained in 1996. In the first season (in 1993), mean maize grain yield did not significantly differ between the systems of gliricidia intercropping (2.9 Mg ha\(^{-1}\)) and sole maize (3.2 Mg ha\(^{-1}\)). After 11 years of continuous cropping, the grand mean of maize grain yield with gliricidia intercropping was 1.9 times as high as that in sole maize cropping.

3.3. Inorganic N fertilizer equivalent

The response of maize to gliricidia N was compared with the response to inorganic N fertilizer with the method of "horizontal comparison" (Fig. 4). Via the response curve to inorganic N fertilizer, the amount of inorganic N fertilizer required to get the same maize grain increase for gliricidia treatment was read. The broken line demonstrates translation of 3.2 Mg of maize yield due to gliricidia prunings to 29 kg N ha\(^{-1}\). The regression equation, \(y = 0.1103x\) (where \(Y = \) maize yield increase and \(X = \) equivalent N fertilizer), was deployed to translate the effects of prunings into 'equivalent fertilizer N' by substituting into the equation ‘Y’ with the values of maize yield increase due to prunings application. The data calculated using this method is presented in Fig. 5. The N fertilizer equivalent for 1993 has not been calculated because maize response was largely due to residual fertilizer from the former trials. The inorganic N fertilizer equivalent was low during major drought year (1994) and also high rainfall decreased the N fertilizer equivalency. Years following droughts had high N fertilizer equivalency e.g. in 1996 and 2001.

3.4. Soil organic carbon

Soil organic carbon in the topsoil (0–20 cm depth) after 11 years of addition of gliricidia prunings was 3 g/kg higher in the system of gliricidia–maize intercropping than in the sole maize system. Soil organic carbon decreased with depth.
In sole maize, organic carbon was detected to 120 cm soil depth and in the gliricidia–maize intercropping system soil to 200 cm.

3.5. Soil nutrients status

In 0–60 cm soil layer the quantities of P, K and Mg were higher in agroforestry system than in sole maize cropping, whereas in the deeper soil layer (60–200 cm) there was a net depletion of K, Ca and Mg in the agroforestry system (Table 1). The increases of P and K in 0–60 cm were greater and those of Ca and Mg were smaller than the decreases in 60–200 cm soil layer (Table 2).

### Table 1
Soil chemical and physical along the soil profile wall under sole maize and gliricidia–maize

<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>pH</th>
<th>Organic C (mg g⁻¹)</th>
<th>Extract P (mg kg⁻¹)</th>
<th>Exchangeable cations (mmol kg⁻¹)</th>
<th>Soil texture (g kg⁻¹)</th>
<th>Bulk density (g cm⁻³)</th>
</tr>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>K</td>
<td>Ca</td>
<td>Mg</td>
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<td>Baseline date (taken in 1992)</td>
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<tr>
<td>0–20</td>
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<td>8.8</td>
<td>26</td>
<td>3.0</td>
<td>44</td>
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<td>Sole maize</td>
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<tr>
<td>0–20</td>
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<td>2.3</td>
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<td>60–80</td>
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<td>2.2</td>
<td>48</td>
<td>24</td>
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<tr>
<td>120–140</td>
<td>6.2</td>
<td>trace</td>
<td>5</td>
<td>2.8</td>
<td>52</td>
<td>28</td>
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<tr>
<td>140–160</td>
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<td>trace</td>
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<td>2.8</td>
<td>49</td>
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<td>trace</td>
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<td>4.3</td>
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<td>180–200</td>
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<td>3.3</td>
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<td>10.9</td>
<td>26</td>
<td>3.7</td>
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<td>2.7</td>
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<td>3.6</td>
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<td>2.8</td>
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<td>2.9</td>
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<td>2.7</td>
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<td>2.5</td>
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<td>1.2</td>
<td>3</td>
<td>2.6</td>
<td>42</td>
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</tr>
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</table>
3.6. Soil moisture

Soil moisture content in April, 2 weeks after rain had stopped, was higher in gliricidia–maize intercropping system than in sole maize cropping system in 0–120 cm soil layers (Fig. 7). In the deeper soil layers soil moisture contents in the two land use systems did not differ. Soil moisture increased down the soil profile. Statistical analysis showed that soil moisture in gliricidia–maize was significantly higher than in sole maize at $P < 0.001$.

4. Discussion

4.1. Prunings as a source of N

The applied quantities of gliricidia prunings were 'translated' into equivalent amounts of inorganic fertilizer N via their effects on maize yields. The comparison of the effects of prunings with the effects of fertilizer N for each of the seasons shows that N fertilizer equivalency did not directly increase due to increased application of organic N. The relationship between the thus found equivalent fertilizer N and rainfall during the season (Fig. 8) shows that fertilizer equivalent N varied with varying rainfall. Decomposition of the organic materials might have been slow during the drier conditions whereas under excessive rainfall denitrification process might have dominated resulting in high gaseous N losses and also leaching. Mid rain season droughts and poor rainfall distribution also affected the decomposition of the gliricidia prunings resulting in low equivalent fertilizer N. High fertilizer N equivalence was obtained between 900 and 1200 mm with normal distribution during the season. It is concluded that under low (<600 mm) and excessive rainfall (>1600 mm) conditions the equivalent fertilizer N of gliricidia prunings decreased. These results emphasize the importance of soil moisture that facilitates the decomposition of the applied organic materials and also uptake of released nutrients by the crop.

The progressive increase of maize yield in the studied agroforestry system must be ascribed to the nutrients in the built-up organic matter in the topsoil during the 11 years of continuous tree prunings application. This finding is in line with the organic carbon increases reported by other authors (e.g. Wendt et al., 1996; Kang et al., 1999; Aulakh and Doran, 2002) in various agroforestry systems. The decomposing fine roots that die during the dry season (Rowland, W. Makumba et al. / Agriculture, Ecosystems and Environment 116 (2006) 85–92

Table 2
Soil nutrients (P, K, Ca and Mg) increases in gliricidia–maize intercropping systems relative to sole maize (control) in 0–60, 60–200 and 0–200 cm soil profiles

<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>Extractable P (mg kg$^{-1}$)</th>
<th>K (mmol kg$^{-1}$)</th>
<th>Ca (mmol kg$^{-1}$)</th>
<th>Mg (mmol kg$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–60</td>
<td>9</td>
<td>4</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>60–120</td>
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<td>0</td>
<td>11</td>
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<td>0–200</td>
<td>10</td>
<td>1</td>
<td>−35</td>
<td>−52</td>
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</table>

Fig. 7. Soil moisture content as influenced by sole maize and gliricidia–maize cropping systems determined at the end of rain season. The horizontal bars are the least significant difference ($P = 0.05$) at various soil depths.

Fig. 8. Relationship between estimated equivalent fertilizer N in gliricidia prunings and rainfall from 1994 to 2003. (Data for 1993 was not included because in the first season trees competed with the crops for belowground resources hence the effect was negative).
are responsible for the increase of soil organic carbon in the subsoil under gliricidia–maize intercropping. Increases of soil organic matter provides more sites for nutrient adsorption hence reduce losses via leaching.

4.2. Prunings as a source of other nutrients than N

Soil application of inorganic N could have enhanced the depletion of the other nutrients than N in the soil via crop offtake due to increased crop yield hence other nutrients other than N might have become limiting. The increase of nutrients in the upper soil layer (0–60 cm) indicates that there is a build up of nutrients in the agroforestry system due to repeated application of the tree prunings. Mendham et al. (2003) found that K increased in the topsoil in Eucalyptus globus 4 years after establishment. Whether those other nutrients have become yield limiting is not certain. Statistical analysis of maize grain yield response to P application had shown that P was certainly not limiting after 11 years.

Although Jones et al. (1996) found a large response to P even with the application of prunings, there was no response to P in our experiments. The lack of P response must be attributed in the first place to high soil P (26 in the beginning and still 20 mg kg\(^{-1}\)) in the topsoil after 11 years in sole maize (Table 1). In view of these values it is not likely that P cycling from the subsoil by gliricidia was really needed to get maize yields between 1 and 4 Mg ha\(^{-1}\). The high soil P is from former P application in the field trials by the research station and the native soil P.

4.3. Subsoil exploitation

The amounts of nutrients applied annually (Fig. 2) through gliricidia prunings give an approximation of the quantities of nutrients that are pumped from the subsoil layers to the topsoil. This is not true for N because most of biomass N is derived from biological fixation.

Significant interaction of gliricidia and fertilizer N was obtained. The effect of fertilizer N was stronger in the absence than in the presence of gliricidia. This shows that the N applied through gliricidia prunings supported the maize growth and high yields. In Tables 1 and 2, it is shown that P had increased in the topsoil layer (0–60 cm) in the agroforestry system by about 80 kg ha\(^{-1}\). Kang et al. (1999) reported that P recycled through tree prunings application was inadequate to meet the needs of a high yielding crop. Again the high P status of the soils make the effect of pumping of P rather irrelevant, even though the quantities of P being recycled per year through gliricidia prunings are a little less, 20 kg ha\(^{-1}\) on average, than the recommended P rate of 40 kg P ha\(^{-1}\) for the hybrid maize (Ministry of Agriculture, 1990).

Calcium in the topsoil under gliricidia–maize did not change at all and Mg did not change much, possibly because the amounts of Ca and Mg being recycled were equivalent to the extra amounts taken up by the crops. The deep rooting gliricidia trees contribute more to effective nutrient cycling than annual crops as in sole maize cropping systems (Nair et al., 1995; Buresh and Tian, 1998). On the other hand, the pumping of nutrients from the subsoil implies that sub-soils are being mined. The stock of nutrients in the whole profile decreases more in a gliricidia system than under annual crops because of the removal of nutrients from the soil increases via extra crop yields and via storage in tree wood.

4.4. Above and below-ground competition

Above-ground competition for sunlight between the trees and crops is minimized through regular pruning of the trees during the maize growing period. Makumba (2003) reported that gliricidia had lower root density (460 cm dm\(^{-3}\)) within 0–30 cm than maize roots density (1200 cm dm\(^{-3}\)). The low roots density within the 0–30 cm soil depth where the nutrients are applied and the high maize yielding in gliricidia–maize simultaneous system indicate that gliricidia does not compete much with maize for the below-ground resources. Soil moisture retention was significantly (\(P < 0.001\)) higher in gliricidia–maize than in sole maize because of the increased soil organic matter in the gliricidia–maize. During the midseason droughts experienced almost every season we observed that the maize in gliricidia–maize system withstood the water stress for about 2 weeks while the maize in sole maize was withering. Despite the occurrence of major droughts and midseason short droughts, the maize grain yield remained higher in gliricidia maize system than in sole maize showing that competition for water between the tree and maize was not much. In the study of moisture dynamics in gliricidia–maize system Chirwa (2002) found that the soils under gliricidia–maize system had 20% more soil moisture than sole maize system at depths greater than 30 cm, in the driest month of September.

5. Conclusion

In spite of intensive pruning, gliricidia leaf biomass yield was maintained at an average of 4.8 Mg ha\(^{-1}\). Eleven years evaluation of gliricidia intercropping with maize has shown that gliricidia prunings could increase maize yield by 2–3 Mg ha\(^{-1}\) year\(^{-1}\) compared to sole maize cropping. The effect of the prunings was a nitrogen effect. The equivalent N fertilizer of the gliricidia prunings decreased under excessive rainfall and drought years. Repeated application of gliricidia prunings increased soil nutrients in the topsoil a little but mining of nutrients from the subsoil by the tree roots was evident. These other nutrients than N were not yield limiting in this experimental station with soils having been made fertile through applications of fertilizer P and K in fertilizer management trials prior to the start of the long-term gliricidia intercropping trial discussed in this paper. The stock of exchangeable Ca and Mg in the 0–200 cm soil profile decreased as a result of extra nutrient export by the extra maize yields.
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