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Review

Gliricidia sepium (Jacq.) Walp Applications for Enhancing Soil Fertility and Crop Nutritional Qualities: A Review

Emmanuel Oladeji Alamu [1,2,*], Michael Adesokan [2], Segun Fawole [2], Busie Maziya-Dixon [2], Tesfai Mehreteab [3] and David Chikoye [1]

1 International Institute of Tropical Agriculture, Southern Africa Research and Administration Hub (SARAH) Campus, Lusaka 10101, Zambia
2 Food and Nutrition Sciences Laboratory, International Institute of Tropical Agriculture (IITA), Ibadan 20001, Nigeria
3 Norwegian Institute of Bioeconomy Research (NIBIO), Oluf Thesens vei 43, 1431 Ås, Norway
* Correspondence: o.alamu@cgiar.org

Abstract: *Gliricidia sepium* (*Jacq.*) *Walp* is a well-known agroforestry leguminous tree that provides multiple benefits in different agroecological zones. Its apparent versatility is seen in improving animal feed, cleaning environmental wastes, and healing inflammations. It was also found to have significant benefits in agroforestry due to its ability to enhance soil fertility through nitrogen fixation and green manure. However, this article reviews the use of *Gliricidia sepium* to improve soil fertility and crop agronomic and nutritional properties. Google Scholar, PubMed, and Science Direct were the databases consulted for the relevant articles used in this review. Trees and leaves of *G. sepium*, either used as mulch, biochar, or intercropped, have enhanced soil fertility indicators, such as total soil carbon, nitrogen, phosphorus, available phosphorus, pH, cation exchange capacity, and soil organic matter in different farming systems. Its immense positive performance in improving the yield of crops led to an economic advantage for low-income farmers. *G. sepium* can also lower the use of mineral fertilizer as its adoption grows, leading to a greener environment in the agricultural sector. The review concluded that there is a plethora of research on the effect of *Gliricidia* on maize yield enhancement; hence further investigations should be conducted on using *Gliricidia sepium* as a green fertilizer to improve yields and the nutritional properties of other crops.

Keywords: *Gliricidia*; agroforestry; intercropping; mulch; biochar; green fertilizer

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1. Introduction

Legume trees are essential in reforestation programs, soil preservation, and green manure. They were reported to have high growth capacity, providing ecosystem services such as biomass production, recycling of nutrients, nitrogen (N) fixation, and carbon (C) sequestration [1]. Using leguminous trees in biomass production in alley cropping systems shows excellent potential in enhancing agricultural production and sustainability [2]. They improve soil fertility, increase crop productivity, and ensure the sustainability of tropical agroecosystems through nitrogen fixation, shade provision, green manuring, and mulch production [3,4]. N-fixing leguminous trees and N-mineral fertilizers are used to recover heavily degraded soils [5]. Legume trees were also used for several other applications, including controlling pests and diseases, as supplements in animal feed, and as sustainable raw materials for electrical energy production [6–9].

Gliricidia sepium (*Jacq.*) *Walp* (*G. sepium*) is a medium-sized legume tree native to Central America but also grows naturally in Santa Rosa and Veracruz, Mexico. *G. sepium* is from the Fabaceae family, the most prominent family in the plant world, and is mainly considered a source of relatively valuable plant protein [10]. It is sometimes called the "alfalfa of the tropics" because it has better water usage efficiency than alfalfa and may be used as forage by livestock [11]. It is a well-known multipurpose tree due to its ability to adapt well to various soils, including alkaline, acidic, sandy, heavy clay, and limestone [12]. However, it thrives best in medium-textured, well-drained, and fertile soils with near-neutral acidity [13]. *Gliricidia* was reported as a non-aggressive invader because it is a light-demanding species and unlikely to invade dense plant communities. However, it is often plagued with *Aphis craccivora,* which blackens the leaves and makes them fall prematurely [13]. The use of *Gliricidia* in agroforestry is due to its ability to adapt very well to a wide range of soils and a very high level of soil salt stress. The adaptation to soil salinity stress is seen in its ability to produce new leaves about two weeks after losing all leaves due to abrupt salinity stress [12]. *G. sepium* is a dominant crop for alley cropping in tropical and subtropical regions [3]. Its biochar application for the removal of caffeine in water and detoxification of coir pith was also reported [14,15], while Grygier et al. [10] recommended *Gliricidia sepium* as an unconventional source of oil, with oil yields similar to that of soybean (*Glycine max*). Furthermore, several authors reported using *Gliricidia* leaves (Figure 1) and trees for anthelmintic purposes. The wound healing effect of *Gliricidia* leaves grown in Indonesia, and the Philippines was studied. The authors found that the leaves contain flavonoids, saponins, and tannins, which act as anti-inflammatory agents, enhancing the healing process [9]. The active effect of ethanolic leaf extract of *Gliricidia* against *Anopheles stephensi* and gastrointestinal nematodes was also reported [16,17], while acetonic extract was used to control the intestinal nematode of ruminants [18]. However, this article aimed to review the applications of *Gliricidia* trees and leaves in improving soil quality parameters and crop nutritional properties. This review article focuses on; (a) the different ways in which *Gliricidia* was applied to improve soil fertility components (soil microbial composition, soil carbon, and nitrogen fixing in soils), (b) the impact of *Gliricidia* on crop agronomic performance and nutritional components, and (c) the synthesis of the knowledge gaps in *Gliricidia sepium* utilization for crop production as it relates to the nutritional composition of different crops. A review of this kind is essential as it presents insight into the application of *Gliricidia* in agroforestry practice for improving food crops' yield and nutritional composition.

Figure 1. Photo of *Gliricidia sepium* leaves.

2. Impact of *Gliricidia sepium* on Soil Fertility

Legume trees that grow quickly are potentially valuable to farmers in the tropics and could improve soil productivity as they do not require extensive agronomic inputs [19]. The trees and leaves of G. sepium, used in different forms, found applications in enhancing soil fertility, which is indicated by total carbon, nitrogen, available phosphorus, pH, cation exchange capacity, base saturation, soil aggregation, bulk density, and phospholipid fatty acid (PLFA) composition [20].

2.1. Impact of G. sepium on Soil Microbial Composition

Silvopastoral systems are agroforestry management practices that integrate trees, forage, and livestock. The effect of silvopastoral systems with shrub tree legumes on the structure, diversity, and abundance of total bacterial, diazotrophic, and ammonium-oxidizing bacterial communities at different places around the legumes was evaluated [21]. The authors' findings affirmed that introducing *G. sepium* and *Mimosa caesalpiniifolia* into the silvopastoral system with *Brachiaria decumbens* improved soil physical quality by promoting the abundance and spatial heterogeneity of the nitrogen-cycling bacterial community. This results in better growth conditions for the soil microbes and aids diazotroph diversity [21]. A pot experiment was conducted to evaluate the effects of biochar produced from *Gliricidia sepium* stems (BC-Gly) and rice husks (BC-RiH) on the growth of coconut seedlings. BC-Gly significantly affected the soil microbial community structure influencing plant growth rate, though biochar application did not affect the estimated total microbial biomass. The concentration of fungal estimated by the total phospholipid fatty acids (PLFAs) was significantly ($p < 0.05$) increased by BC-Gly amendment, and this increase was more apparent under the dry soil condition.

Additionally, the BC-Gly amendment greatly affected the concentration of arbuscular mycorrhizal fungi (AMF) [22]. A study by Riyanto [23] aimed to determine the application of various local microorganisms (LMO) to the growth and yield of new rice varieties in rainfed rice fields. Local microorganisms from *Gliricidia* sp. leaves produced the highest populations of nitrogen-fixing bacteria in the soil. However, it was discovered that LMO *Gliricidia* sp. leaves achieved the lowest population of phosphate-solubilizing bacteria. In a no-tillage system, the soil was subjected to treatments with mixtures of leguminous trees to study their impact on soil macrofauna. *Gliricidia* + Acacia (G + A) treatment extended essential ecosystem functions in the no-tillage agrosystem due to the functional groups, including soil engineers, predators, and litter transformers. These fast-growing leguminous trees can increase soil acidity and decrease soil macrofauna diversity; however, the harmful effects of leguminous tree cover are minor relative to the environmental benefits [24].

2.2. Impact of G. sepium on Soil Carbon

The impact of the *Gliricidia*-maize intercropping system on soil properties was investigated. *Gliricidia*-maize intercrop positively affected soil organic matter, particulate organic matter (POM), and cation exchange capacity (CEC). *Gliricidia* increased POM-carbon by 62% over sole maize. Additionally, the POM-C value of *Gliricidia* treatment was significantly (p = 0.0001) greater than only maize treatment with 48 kg ha^{-1} nitrogen added [25]. In Brazil, an agrisilviculture system was used to enhance the quality of organic carbon and organic matter of clayey Oxisol soil. The system in which corn is intercropped with *Panicum maximum* cv. Massai and *Gliricidia sepium* improved soil quality and short-term carbon sequestration [26]. *Gliricidia* mulch from the leaves and twigs was reported to produce more crop biomass and recycled more soil C. Therefore, adopting no-till mulch (*G. sepium*) curtailed energy use, carbon footprint, and cultivation costs, thereby enhancing energy use efficiency [27,28]. Clay soil is characterized by its heavy weight, high porosity, and low dry bulk density. In assessing the soil nutrient under the *Gliricidia* agroforestry system in the maize district of Zambia, incorporating *Gliricidia sepium* leaf biomass into the farming system improved the soil health in eastern Zambia by improving the soil organic matter and soil carbon stocks. Additionally, the leaf biomass served as a source of cheap organic fertilizer as an alternative to the more expensive inorganic fertilizers. This alternative source of fertilizer presented by *Gliricidia sepium* will mitigate the environmental contamination caused by nitrous oxide emissions by reducing the need for inorganic fertilizers [29]. *G. sepium* can be used as live support for restoring degraded black pepper plantations and overall improvement in soil quality in the plains of the tropics. *G. sepium* registered more excellent soil organic carbon, dissolved organic carbon, dissolved organic nitrogen, and mineral nitrogen in its rhizosphere, improving soil fertility [30]. A study on the effects of shade trees and spacing regimes on the availability of soil and plant nutrients showed that total soil carbon and total nitrogen were significantly higher in the Theobroma + *Gliricidia* plantation with 12 m × 12 m spacing [31]. In a *Gliricidia* + maize intercropping system, *Gliricidia* tree prunings were applied to the soil continuously for ten years. The sequestered carbon in the topsoil (0–20 cm) in *Gliricidia* + maize was 1.6 times more than in sole maize, while soil carbon dioxide evolution also improved in the *Gliricidia*-maize plot [32].

2.3. Impact of G. sepium on Soil Nitrogen Fixation

The application of nitrogen (N) fixing tree species affects, to a great extent, the rates of N mineralization and other N transformations [33]. In a study to evaluate the effect of leaf extracts of neem and *G. sepium* on emissions of methane (CH_4), carbon (IV) oxide (CO_2), and nitrogen (I) oxide (N_2O) in urea amended and unamended soil samples, and to study the dynamics of inorganic nitrogen (N) in the soil samples; it was observed that the application of aqueous extracts of the leaves improved the soil quality by increasing the available N for crop growth and controlling the pests in the soil, even though extracts of *Gliricidia* leaves did not reduce the emission of CH_4 by the evaluated soil samples [34]. The *Gliricidia*-maize intercrop was reported to affect soil organic matter significantly, particulate organic matter (POM), and cation exchange capacity (CEC). CEC, a significant factor in soil nitrogen fertility, was maintained in coarse-textured soils over 14 years by the *Gliricidia*-maize intercrop. *Gliricidia* positively affected the soil's nitrogen (N) parameters as it increased inorganic N from 7.93 g kg^{-1} in sole maize to 12.8 in the intercrop; however, the *Gliricidia* intercrop decreased soil phosphorus. By improving soil fertility, the *Gliricidia sepium*/maize intercropping system can increase productivity in maize-based cropping systems [25]. In Ghana, Omari et al. [35] enhanced soil fertility using mixtures of eight different tropical plant materials with chicken manure as soil amendments for growing tomatoes. Of all the treatments, *Gliricidia* + chicken manure improved soil fertility significantly by releasing more mineral N; however, this did not translate to more yield for the tomato plant. Additionally, Partey et al. [36] determined how the residue quality and decomposition of *Acacia auriculiformis*, *Albizia zygia*, *Azadirachta indica*, *Baphia nitida*, *Gliricidia sepium*, *Leucaena leucocephala*, *Tithonia diversifolia*, *Senna spectabilis*, and *Zea mays* influence soil nitrogen availability, microbial biomass, and β-glucosidase activity. It was then concluded that the decomposed biomass of *Tithonia diversifolia*, *Gliricidia sepium*, *Leucaena leucocephala*, *Senna spectabilis*, and *Azadirachta indica* leaves might improve soil fertility in the short term. Still, a long-term build-up of organic matter may be restricted due to accelerated decomposition. However, the long-term build-up of soil organic matter may be constrained due to the accelerated decomposition of the plant materials. This could lead to high economic costs for small-scale farmers because they must apply these organic materials every planting season. Méndez-Bautista et al. [37] reported that applying the extract of *G. sepium* leaves to beans favoured their development compared to untreated plants but had no significant effect on soil nitrification.

2.4. Impact of G. sepium on Other Soil Fertility Components

Serpentine soil is known to limit the growth of plants as it is characterized by a high natural abundance of heavy metals, such as nickel (Ni), manganese (Mn), cobalt (Co), and chromium (Cr), and is low in plant nutrients, such as nitrogen (N), phosphorus (P), and potassium (K) [38]. The immobilization of heavy metals in serpentine soil and enhancement of the soil calcium (Ca) uptake using woody biochar of *Gliricidia sepium* biomass were effectively achieved, thereby improving the growth of tomatoes on the amended soil. The woody biochar was produced by slow pyrolysis of ground *Gliricidia* biomass in a muffle furnace at 300 °C and 500 °C at 7 °C min^{-1}. However, it was observed that the woody biochar pyrolyzed at 500 °C and used at a high application rate effectively immobilized heavy metals in the soil [39]. Biochar is a carbon-rich material synthesized by burning organic biomass in the absence or partial absence of oxygen at high temperatures (usually from 300 to 1000 °C) [40]. The qualities, properties and impacts of biochar on soils are primarily influenced by the type of feedstock used and pyrolysis conditions [41]. Kuntashula and Mafongoya [42] also investigated the use of participatory research methods in evaluating the application of legume trees in improving soil fertility by engaging farmers in eastern Zambia. During the experiment, 112 farmers rated 11 agroforestry trees, and the result shows that over 90% of the farmers gave *G. sepium* a maximum score for soil fertility improvement. The woody biochar of *Gliricidia* sepium decreased the soil's bulk density and air capacity in a study meant to investigate the effect of biochar amendment on enhancing the quality of clay soil, primarily due to weight dilution generated by the biochar. Additionally, soil porosity, moisture at field capacity, and available water capacity were affected by biochar amendment [43]. A decomposition innovation to improve soil nutrients in a cocoa plantation was developed. It was reported that adding *Gliricidia* leaf waste improved cocoa leaf waste's decomposition and nutrient release rate [44].

Agroforestry trees improve the physical properties of soils by adding large quantities of litterfall, root biomass, root activity, biological activities, and roots, leaving macropores in the soil following their decomposition [45]. As highlighted in the reviewed articles, woody biochar biomass, intercropping, leaf extract, leaf mulching, and biomass are the various forms in which *Gliricidia sepium* is utilized for improving soil fertility components, such as soil microbial population, soil bulk density, soil organic carbon, soil inorganic N fixation, and heavy metals immobilization. The various forms in which agroforestry legume trees can be used (Table 1) indicate their versatility in agricultural applications, as this was also confirmed by farmers' practice of continuously keeping *G. sepium* in their farmlands because they are aware of the value of the tree crop in improving soil fertility [46] and by the positive response from farmers in a participatory study [42]. *Gliricidia sepium* is a fast-growing agroforestry tree with a significant characteristic of a relatively deep root system that enables it to capture leached nutrients along the soil profile, thereby accumulating nutrients that otherwise could not be accessed by other crops. These nutrients are made available to the soil surface from leaf biomass and other forms in which the agroforestry tree is utilized, thereby increasing soil fertility [29]. The adaptability of *Gliricidia sepium* in improving the nutrients of different soil types (in various locations) makes it a green and environmentally friendly alternative to inorganic fertilizers.

Table 1. Summary of the application of *Gliricidia* for soil quality improvement.

Soil Traits Evaluated	*Gliricidia* Application Mode	*Gliricidia* Application Effect	Reference
Emissions of CH_4, CO_2, and N_2O	Aqueous leaf extracts	Soil available N increased	[9]
Heavy metals	Woody biochar of *Gliricidia* biomass	Calcium uptake improved, and heavy metals immobilized	[39]
Microbial population	Intercropping	Improved the population and heterogeneity of the soil nitrogen-cycling bacterial	[21]
Organic carbon and organic matter	Intercropping	Improved soil organic matter and carbon sequestration	[26]
Soil fertility	Plant pruning	Increased soil mineral nitrogen	[35]
Soil fertility	Plant biomass	Improved soil fertility	[36]
Soil fertility	*Gliricidia* mulch	Curtailed energy use, carbon footprint	[27]
Soil health	*Gliricidia* leaf biomass	Improved soil organic matter and soil carbon stocks.	[29]
Soil properties	Intercropping	An improvement in soil organic matter, particulate organic matter, and cation exchange capacity.	[25]
Soil quality	Intercropping	Enhanced soil organic carbon, dissolved organic carbon, -nitrogen, and mineral nitrogen in black pepper rhizosphere	[30]
Availability of soil nutrients	Intercropping	Soil total carbon and total nitrogen improved	[31]
Carbon sequestration	Intercropping	Soil carbon sequestered and carbon (IV) oxide evolution also improved	[32]
Cocoa leaf decomposition and soil nutrients	*Gliricidia* leaves	Cocoa leaf waste decomposition and nutrient released rate improved	[44]

3. Impact of *Gliricidia sepium* on Crop Performance and Crop Nutritional Properties

Gliricidia sepium tremendously impacted food crops' yield and nutritional composition, especially maize, as shown in Tables 2 and 3. Bandara et al. [39] experimented with immobilizing heavy metal using woody biochar of *Gliricidia sepium* biomass. Pyrolysing *G. sepium* biochar at 500 °C and applying it to the soil at 110 t/ha immobilized toxic chromium, nickel, and manganese, increased the calcium/magnesium ratio, and facilitated the uptake of essential nutrients (nitrogen, potassium, and sodium); thereby increasing tomato plant growth associated with increased plant biomass. The effect of the amendment of biochar on saturated hydraulic conductivity (Ksat), soil aeration, available water capacity, and biomass and grain yields of maize was also investigated by Obia et al. [43]. They reported significantly higher maize biomass and grain yields in plots treated with biochar compared to the control plots. In contrast, Omari et al. [35] said in their experiment that the *Gliricidia* treatment (coupled with chicken manure) did not enhance the yield of tomato fruit.

Coulibaly et al. [47] found that adopting *Gliricidia sepium* as fertilizer trees in Malawi increased the value of food crops by 35%, positively affecting household food security. At the same time, it was also reported that *Gliricidia sepium* intercropped with maize in Malawi enhanced soil health renewal and maize yield and significantly increased the nutritional composition of the crop [48]. Makumba et al. [49] demonstrated the *Gliricidia*-maize intercropping system to be a suitable option for soil fertility improvement and maize yield increase in sub-Saharan Africa, where inorganic fertilizer use is minimal. They found that applying *Gliricidia* prunings increased maize yield three-fold over sole maize cropping without soil amendments and improved topsoil nutrients. Additionally, the use of *Gliricidia* leaves in alley cropping to improve the nitrogen uptake of sweet corn was reported [50]. *G. sepium* can improve nitrogen use efficiency, increase soil organic matter, and maintain the cations base, thereby enhancing maize grain yield in infertile tropical soil [51]. Coe et al. [52] reported increased maize yield with *Gliricidia* intercropping, though they raised concerns about the applicability of agroforestry techniques in diverse locations with different environmental properties. A two-year experiment assessed the impact of shrub and herbaceous mulch types on soil characteristics and maize nutritional content. Awopegba et al. [53] reported that *Gliricidia sepium*, one of the shrub mulches evaluated, enhanced maize's nutrient composition and yield when applied at 5 t/ha. They also observed that adopting *Gliricidia sepium*, *Tithonia diversifolia*, and *Calopogonium mucunoides* mulches could meet the maize nutritional requirement of the people and improve soil properties on a tropical alfisol. In Brazil, *Gliricidia* manure increases maize grain yield and soil organic matter content by enhancing soil chemical properties, such as pH, available phosphorus, exchangeable potassium, calcium, and magnesium, cation exchange capacity, and base saturation in the upper soil layer [54]. Applying *Gliricidia* leaf biomass as mulch with supplemental phosphorus fertilizer systematically increased the total dry weight of maize in maize + *Gliricidia* intercropping. Additionally, *Gliricidia* leaf biomass as mulch reduced weed dry weight compared with the control experiment [55].

The potential of intercropping maize with *Gliricidia* to control weeds was evaluated [56–58]. The authors observed that although maize-*Gliricidia* showed good potential in enhancing grain yield, it was not a viable option for weed control. However, hoeing was reported to be a better option. Although *Gliricidia*-maize intercropping was reported to increase maize yield, Sileshi et al. [59] evaluated the yield stability of maize–*Gliricidia* intercropping and fertilized monoculture maize. It was reported that maize yields remained more stable in maize–*Gliricidia* intercropping than in fertilized maize monoculture in the long term. However, average yields may be higher with complete fertilization. Therefore, considering the long-term yield stability and the accessibility of *Gliricidia* to low-income farmers, *Gliricidia*-maize intercropping is recommended. An agroecological study was conducted in Zambia in which the effect of the agroforestry system involved utilizing *Gliricidia sepium* to improve soil nutrients, crop yield, and nutritional properties of food crops. *Gliricidia sepium* was cultivated in alley cropping with maize, soybean, and groundnut. It enhanced the yield of the cultivated crops by more than twofold and improved the crops' nutritional properties. Intercropping maize with soybean and groundnut with *Gliricidia* improved crop diversification, enhancing crop resistance to climate change [29].

Swamila et al. [60] investigated the willingness and ability of farmers to adopt the *Gliricidia* agroforestry technology on their farms. Results of the experiment show that the most critical factor affecting the technology is the upfront cost because most of the production cost of investing in *Gliricidia* agroforestry technology is incurred in the first year of project establishment but has long-term biophysical and economic benefits. The authors also argued that based on the other environmental benefits attributed to the adoption of *Gliricidia* agroforestry technology, it has a high adoption potential among farmers in Tanzania. In the same vein, the profitability of the *Gliricidia*-maize system relative to an unfertilized sole maize system was assessed, and it was found that the *Gliricidia*-maize intercropping technology is profitable with time. It can potentially boost household income and food security because the monetary benefits accrued after the first year of the establishment can offset the initial investment costs. However, helping farmers overcome initial investment costs will aid the rapid adoption of *Gliricidia*-maize intercropping, especially among low-income farmers [61].

Cotton and sunflower nutrient (nitrogen, phosphorus, and potassium) accumulation and biomass productivity were enhanced by adding *Gliricidia* pruning mixed with cattle manure. In contrast, *Gliricidia*-cotton intercropping is a cost-effective option for smallholder cotton farmers [62,63]. The development of beans was favored when the soil was treated with extracts of *G. sepium* [37]. The insecticidal effect of *G. sepium* leaf extracts was demonstrated. This extract repelled insects from the plants, increased the overall yield of maize and stimulated the growth of tomato plants [64,65].

The application of *Gliricidia* in cocoa production was also reported [66–69]. In Indonesia, cacao plants were shaded with *G. sepium*, and it was reported that contrary to general belief, cacao bean yield was not decreased by shading. However, the shading of cacao plants resulted in greater leaf longevity due to reduced exposure of cacao to atmospheric drought [67]. Bai et al. [69] reported that the leaf litter of *G. sepium* enhanced the growth of cacao trees by showing a higher average concentration of total nitrogen, boron, iron, and phosphorus. The debris of *G. sepium* leaves also showed a rapid release of potassium after one month of decomposition and a low carbon-to-nitrogen ratio.

The effect of *G. sepium* mulch from whole leaves and chopped leaves and branches on yields and the water use efficiency of carrot plants were investigated. It was found that *G. sepium* mulch from entire leaves and mineral fertilization led to higher yields and water use efficiency of the carrot plants [70]. As reported by Ilangamudali et al. [71], a study in Sri Lanka assessed the potential of using coconut-based *G. sepium* agroforestry systems to improve the soil fertility of degraded coconut lands. The study revealed that *G. sepium* replenished soil fertility of degraded coconut-growing soils by giving higher soil organic matter, total nitrogen, potassium, magnesium, and microbial activity. Additionally, in Sri Lanka, the effects of different mulching materials on growth, yield, quality parameters of ginger, and soil parameters were assessed. Soil treatment with *Gliricidia* mulch gave the maximum number of sprouted plants, the highest plant height, and the highest number of pseudostems per clump. The authors concluded that *Gliricidia* is the best mulch for ginger cultivation in the low country intermediate zone of Sri Lanka [72]. Incorporating 75% nitrogen, 100% phosphorus, 50% potassium by chemical fertilizer, and 50% potassium via *Gliricidia* green leaf manuring improved soil fertility and yield of soybean cultivated in Vertisols [73].

Cassava genotype TMS 4(2)1425 was reported by Okon et al. [74] to respond positively to *Glomus deserticola* inoculation in conjunction with a mixture of *Gliricidia sepium* + *Senna siamea* mulch. The *Gliricidia* mulch significantly enhanced the yield of the cassava sample due to its ameliorating effects on soil structure and nutrient content. A *G. sepium* substrate formulated based on 50% mill compost with 50% *Gliricidia sepium* effectively produced yellow passion fruit seedlings with excellent vegetative growth rates [75]. Carpenter et al. [76] investigated the effect of mineral fertilization on interplanting two species of legume trees

(*Inga edulis* and *Gliricidia sepium*) on the growth of *Terminalia amazonia*. *G. sepium* intercropped with *Terminalia amazonia* was reported to increase yield and restore forestry. In contrast, sweet potato yield was not enhanced at the second planting on soil fallowed by *G. sepium* [77]. This could be a result of the method of application in which the leguminous crops were used as fallow and were cleared off the field before planting.

Table 2. Summary of the application of *Gliricidia* for improving crop quality.

Crop	*Gliricidia* Application Mode	*Gliricidia* Application Effect	Location	Reference
Maize	Intercropping	Enhanced soil health and maize yield	Malawi	[48]
Maize	Intercropping	Soil fertility and maize yield improved	Malawi	[49]
Maize	***	Improved food crops and household food security	Malawi	[47]
Maize	Intercropping	Yield enhanced	Malawi	[52]
Quality Protein Maize	Intercropping	Nutritional value improved	Brazil	[78]
Maize	Intercropping	Improved yield	Brazil	[79]
Maize	Intercropping	Improved yield	Brazil	[54]
Maize	Intercropping	Improved yield	Brazil	[51]
Maize	Mulching	Improved Yield	Nigeria	[53]
Sweet corn	Leaf pruning	Nitrogen uptake improved	Malaysia	[50]
Tomato	Woody biochar	Facilitated nutrient uptake and increased plant biomass	Sri Lanka	[39]
Cotton	Intercropping	Nutrient accumulation and biomass productivity was enhanced	Malawi	[62]
Cacao	Intercropping	Leaf longevity	Indonesia	[69]
Maize, soybean and groundnut	Intercropping	Improved yield and nutritional properties	Zambia	[29]

*** Review article.

Table 3. Application of *Gliricidia* to improve maize yield.

		Yield		
Crop	***Gliricidia* Plot**	**Sole Maize Plot**	**Inorganic Fertilizer Plot**	**Reference**
Maize	5.52 t ha^{-1}	1.48 t ha^{-1}	NE	[48]
Maize	597.67 kg acre^{-1}	478.75 kg acre^{-1}	NE	[47]
Maize	3.62 t ha^{-1}	2.73 t ha^{-1}	NE	[52]
Maize	* 2.5 Mg ha^{-1}(GA)/ 2.6 Mg ha^{-1} (GC)	0.4 Mg ha^{-1}	0.6 Mg ha^{-1}	[78]
Maize	5.618 kg ha^{-1}	6.714 kg ha^{-1}	NE	[79]
Maize	5.21 Mg ha^{-1}	3.03 Mg ha^{-1}	2.81 Mg ha^{-1}	[54]
Maize	1.41 t ha^{-1}	0.63 t ha^{-1}	2.19 t ha^{-1}	[53]
Maize	4520 kg ha^{-1}	1227 kg ha^{-1}	5954 kg ha^{-1}	[29]

* alley cropping; NE-not evaluated; GA—*Gliricidia* + Acacia; GC—*Gliricidia* + Clitoria.

4. Knowledge Gaps and Recommendations

Gliricidia sepium tremendously impacted food crops' yield, and nutritional composition, especially maize. However, more studies need to be conducted to establish the effect of applying *Gliricidia sepium* on other essential crops' yield and nutritional composition. Cocoa, cotton, tomato, black pepper, soybean, and groundnut are a few of the crops for which the effect of *Gliricidia sepium* on their agronomic and nutritional components was scarcely investigated. Therefore, the impact of *Gliricidia sepium* on the agronomic and nutritional composition of food crops, especially roots and tubers, should be investigated. In studying the application of *G. sepium* on the nutritional composition of food crops, it is vital to explore the various forms of *Gliricidia* application, such as mulching, biochar, intercropping, and using leaf extracts. This will lead to having a plethora of scientific knowledge on the best form of *Gliricidia* application for the different crops. A bottleneck for the widespread adoption of *Gliricidia sepium* is the initial cost of the establishment, even though its profit for farmers is in the long term. This upfront investment in agroforestry technology poses a challenge for low-income farmers who may need more financial strength for such an investment. However, they know the long-term benefits. Therefore, it is recommended that governmental bodies and research organizations work in tandem with low-income farmers to subsidize the initial cost of implementing the *Gliricidia* agroforestry technology; this will increase the adoption rate of the technology. Training smallholder farmers on agroforestry practices should also be intensified to increase the adoption rates of *Gliricidia* fertilizer trees. Information on the differences between *Gliricidia* biochar and biochar produced from other materials might be lacking and recommended for study.

5. Method Summary

The articles (2012 to 2022) for this review were obtained from three different databases (PubMed, Science Direct, and Google Scholar). The PubMed database was searched using the term "*Gliricidia*," and relevant articles for our study were extracted. The Science Direct database was also used, with the search term "*gliricidia*" used. An advanced search was also carried out, with the terms "*gliricidia*" and "legumes" being looked up in manuscript abstracts and titles. The agricultural, biological, and environmental sciences were the subject areas that were searched. The search results provide relevant reviews and research articles for our study. The Google Scholar database was searched using the terms "*gliricidia* intercropping" + "maize," "*gliricidia* intercropping" + "soybean," and "*gliricidia* intercropping" + "groundnut". The search results were examined, and pertinent articles were extracted based on the following inclusion criteria: Information based on evidence on *Gliricidia* (soil quality/fertility, crop yield/performance, and crop nutritional quality and safety). A preliminary screening of the retrieved literature's abstracts and contents was performed to determine its suitability for inclusion in the more in-depth reviews that followed. After removing duplicates and accounting for the scope of this study, we narrowed the list of potential literature reviews down to 79 articles. The review and revision were completed in about four months (November 2022 to February 2023), with five authors involved in the literature search, extraction, and review.

6. Conclusions

This review highlighted the importance of *G. sepium* as a leguminous plant used in various agroforestry practices to improve many food crops' yield and nutritional composition. Trees and leaves of *G. sepium*, either used as mulch, biochar, or intercropped, have improved soil fertility components and the yield of maize grains (up to a threefold yield). *Gliricidia* trees, when intercropped, have a tremendous impact on fixing nitrogen components in the soil, improving sequestered soil carbon, reducing the negative impacts of heavy metals on soil fertility, and, by extension, enhancing the proper development of crops. Low-income farmers have benefited economically due to *G. sepium's* positive impacts in increasing crop yields because it decreased their demand for mineral fertilizers, which are frequently out of reach due to their expensive cost. In addition, the leaf of *G. sepiun* has been found to have an anti-inflammatory function due to the high content of flavonoids and saponins, thereby aiding the healing process. In addition to the benefits of *G. sepium* on soil and crops, widespread use of *G. sepium* intercropping will contribute to a greener environment by reducing the use of chemicals that release greenhouse gases into the atmosphere in the agricultural sector.

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References

1. Medinski, T.; Freese, D. Soil carbon stabilization and turnover at alley-cropping systems, Eastern Germany. *Geophys. Res. Abstr.* **2012**, *14*, 9532.
2. De Moura, E.G.; Portela, S.B.; Macedo, V.R.A.; Sena, V.G.L.; Sousa, C.C.M.; Aguiar, A.D.C.F. Gypsum and legume residue as a strategy to improve soil conditions in the sustainability of agrosystems of the humid tropics. *Sustainability* **2018**, *10*, 1006. [CrossRef]
3. Wolz, K.J.; DeLucia, E.H. Alley cropping: Global patterns of species composition and function. *Agric. Ecosyst. Environ.* **2018**, *252*, 61–68. [CrossRef]
4. Sena, V.G.L.; de Moura, E.G.; Macedo, V.R.A.; Aguiar, A.C.F.; Price, A.H.; Mooney, S.J.; Calonego, J.C. Ecosystem services for intensification of agriculture, with emphasis on increased nitrogen ecological use efficiency. *Ecosphere* **2020**, *11*, e03028. [CrossRef]
5. Aleixo, S.; Gama-Rodrigues, A.C.; Gama-Rodrigues, E.F.; Campello, E.F.C.; Silva, E.C.; Schripsema, J. Can soil phosphorus availability in tropical forest systems be increased by nitrogen-fixing leguminous trees? *Sci. Total Environ.* **2020**, *712*, 136405. [CrossRef]
6. Nyoka, B.I.; Simons, A.J.; Akinnifesi, F.K. Genotype–environment interaction in *Gliricidia* sepium: Phenotypic stability of provenances for leaf biomass yield. *Agric. Ecosyst. Environ.* **2012**, *157*, 87–93. [CrossRef]
7. Edwards, A.; Mlambo, V.; Lallo, C.H.O.; Garcia, G.W. Yield, chemical Composition and In Vitro Ruminal Fermentation of the Leaves of Leucaena Leucocephala, *Gliricidia* Sepium and Trichanthera Gigantea as Influenced by Harvesting Frequency. *J. Anim. Sci. Adv.* **2012**, *2* (Suppl. 3.2), 321–331.
8. Susanto, D.; Auliana, A.; Amirta, R. Growth evaluation of several types of energy crops from tropical shrubs species. *F1000Research* **2019**, *8*, 329. [CrossRef]
9. Aulanni'am, A.; Ora, K.M.; Ariandini, N.A.; Wuragil, D.K.; Permata, F.S.; Riawan, W.; Beltran, M.A.G. Wound healing properties of *Gliricidia* sepium leaves from Indonesia and the Philippines in rats (Rattus norvegicus). *Vet. World* **2021**, *14*, 820–824. [CrossRef]
10. Grygier, A.; Chakradhari, S.; Ratusz, K.; Rudzinska, M.; Patel, K.S.; Lazdin, D.; Gornas, P. Seven underutilized species of the Fabaceae family with high potential for industrial application as alternative sources of oil and lipophilic bioactive compounds. *Ind. Crops Prod.* **2022**, *186*, 115251. [CrossRef]
11. Rahman, M.; Das, A.; Saha, S.; Uddin, M.; Rahman, M. Morphophysiological response of *Gliricidia* sepium to seawater-induced salt stress. *Agriculturists* **2019**, *17*, 66–75. [CrossRef]
12. Braga, Í.O.; Carvalho da Silva, T.L.; Belo Silva, V.N.; Rodrigues Neto, J.C.; Ribeiro, J.A.A.; Abdelnur, P.V.; de Sousa, C.A.F.; Souza, M.T., Jr. Deep Untargeted Metabolomics Analysis to Further Characterize the Adaptation Response of *Gliricidia* sepium (Walp.) to Very High Salinity Stress. *Front. Plant Sci.* **2022**, *13*, 869105. [CrossRef]
13. Elevitch, C.R.; Francis, J.K. Gliricidia sepium (*Gliricidia*), ver. 2.1. In *Species Profile for Pacific Island Agroforestry*; Elevitch, C.R., Ed.; Permanent Agriculture Resources (PAR): Holualoa, HI, USA, 2006; Available online: https://www.traditionaltree.org (accessed on 28 February 2023).
14. Keerthanan, S.; Rajapaksha, S.M.; Trakal, L.; Vithanage, M. Caffeine removal by *Gliricidia* sepium biochar: Influence of pyrolysis temperature and physicochemical properties. *Environ. Res.* **2020**, *189*, 109865. [CrossRef]
15. Jayakumar, M.; Emana, A.N.; Subbaiya, R.; Ponraj, M.; Kumar, K.K.A.; Muthusamy, G.; Kim, W.; Karmegam, N. Detoxification of coir pith through refined vermicomposting engaging Eudrilus eugeniae. *Chemosphere* **2022**, *291*, 132675. [CrossRef]
16. Krishnappa, K.; Dhanasekaran, S.; Elumalai, K. Larvicidal, ovicidal and pupicidal activities of Gliricidia sepium (Jacq.) (Leguminosae) against the malarial vector, Anopheles stephensi Liston (Culicidae: Diptera). *Asian Pac. J. Trop. Med.* **2012**, *5*, 598–604. [CrossRef]
17. Romero, N.; Areche, C.; Cubides-Cárdenas, J.; Escobar, N.; García-Beltrán, O.; Simirgiotis, M.J.; Céspedes, Á. In vitro anthelmintic evaluation of *Gliricidia* sepium, Leucaena leucocephala, and Pithecellobium dulce: Fingerprint analysis of extracts by UHPLC-orbitrap mass spectrometry. *Molecules* **2020**, *25*, 3002. [CrossRef]
18. Wabo Poné, J.; Kenne, T.F.; Mpoame, M.; Pamo, T.E.; Bilong, C.F. In vitro activities of acetonic extract from leaves of three forage legumes (Calliandra calotyrsus, *Gliricidia* sepium and Leucaena diversifolia) on Haemonchus contortus. *Asian Pac. J. Trop. Med.* **2011**, *4*, 125–128.

19. Amodu, J.T.; Onifade, O.S.; Adeyinka, I.A.; Jegede, J.O.; Afolayan, S.B. The effect of stocklength, stock diameter and planting angle on early establishment of *Gliricidia* sepium. *Pak. J. Biol. Sci.* **2007**, *10*, 632–636. [CrossRef]
20. Wartenberg, A.C.; Blaser, W.J.; Gattinger, A.; Roshetko, J.M.; Van Noordwijk, M.; Six, J. Does shade tree diversity increase soil fertility in cocoa plantations? *Agric. Ecosyst. Environ.* **2017**, *248*, 190–199. [CrossRef]
21. Barros, F.M.; Fracetto, F.J.C.; Lira Junior, M.A.; Bertini, S.C.B.; Fracetto, G.G.M. Spatial and seasonal responses of diazotrophs and ammonium-oxidizing bacteria to legume-based silvopastoral systems. *Appl. Soil Ecol.* **2021**, *158*, 103797. [CrossRef]
22. Nirukshan, G.S.; Ranasinghe, S.; Sleutel, S. The effect of biochar on mycorrhizal fungi mediated nutrient uptake by coconut (*Cocos nucifera* L.) seedlings grown on a Sandy Regosol. *Biochar* **2022**, *4*, 68. [CrossRef]
23. Riyanto, D. The utilization of agricultural and livestock waste and the effect on new rice varieties yield on rainfed rice land of Ponjong—Gunungkidul. *BIO Web Conf.* **2021**, *33*, 05004. [CrossRef]
24. Moura, E.G.; Aguiar, A.C.F.; Piedade, A.R.; Rousseau, G.X. Contribution of legume tree residues and macrofauna to the improvement of abiotic soil properties in the eastern Amazon. *Appl. Soil Ecol.* **2015**, *86*, 91–99. [CrossRef]
25. Beedy, T.L.; Snap, S.S.; Akinnifesi, F.K.; Sileshi, G.W. Impact of *Gliricidia* sepium intercropping on soil organic matter fractions in a maize-based cropping system. *Agric. Ecosyst. Environ.* **2010**, *138*, 139–146. [CrossRef]
26. Coser, T.R.; de Figueiredo, C.C.; Jovanovic, B.; Moreira, T.N.; Leite, G.G.; Cabral Filho, S.L.S.; Kato, E.; Malaquias, J.V.; Marchão, R.L. Short-term build-up of carbon from a low-productivity pastureland to an agrisilviculture system in the Brazilian savannah. *Agric. Syst.* **2018**, *166*, 184–195. [CrossRef]
27. Yadav, G.S.; Das, A.; Lal, R.; Babu, S.; Datta, M.; Meena, R.S.; Patil, S.B.; Singh, R. Impact of no-till and mulching on soil carbon sequestration under rice (*Oryza sativa* L.)-rapeseed (*Brassica campestris* L. var. rapeseed) cropping system in hilly agroecosystem of the Eastern Himalayas, India. *Agric. Ecosyst. Environ.* **2019**, *275*, 81–92. [CrossRef]
28. Yadav, G.S.; Babu, S.; Das, A.; Mohapatra, K.P.; Singh, R.; Avasthe, R.K.; Roy, S. No Till and mulching enhance energy use efficiency and reduce the carbon footprint of a direct-seeded upland rice production system. *J. Clean. Prod.* **2020**, *271*, 122700. [CrossRef]
29. Tesfai, M.; Emmanuel, A.O.; Njoloma, J.B.; Nagothu, U.S.; Ngumayo, J. Agroecological farming approaches that enhance resilience and mitigation to climate change in vulnerable farming systems. In *Climate Neutral and Resilient Farming Systems*; Routledge: London, UK, 2022; pp. 147–168.
30. Dinesh, R.; Srinivasan, V.; Hamza, S.; Parthasarathy, V.A.; Aipe, K.C. Physico-chemical, biochemical and microbial properties of the rhizospheric soils of tree species used as supports for black pepper cultivation in the humid tropics. *Geoderma* **2010**, *158*, 252–258. [CrossRef]
31. Bai, S.H.; Trueman, S.J.; Nevenimo, T.; Hannet, G.; Bapiwai, P.; Poienou, M.; Wallace, H.M. Effects of shade-tree species and spacing on soil and leaf nutrient concentrations in cocoa plantations at 8 years after establishment. *Agric. Ecosyst. Environ.* **2017**, *246*, 134–143. [CrossRef]
32. Makumba, W.; Janssen, B.; Oenema, O.; Akinnifesi, F.K.; Mweta, D.; Kwesiga, F. Long-term impact of a *Gliricidia* + maize intercropping system on carbon sequestration in southern Malawi. *Agric. Ecosyst. Environ.* **2007**, *118*, 237–243. [CrossRef]
33. Faming, W.; Li, Z.; Xia, H.; Zou, B.; Li, N.; Liu, J.; Zhu, W. Effects of nitrogen-fixing and non-nitrogen-fixing tree species on soil properties and nitrogen transformation during forest restoration in southern China. *Soil Sci. Plant Nutr.* **2010**, *56*, 297–306. [CrossRef]
34. Méndez-Bautista, J.; Fernández-Luqueño, F.; López-Valdez, F.; Mendoza-Cristino, R.; Montes-Molina, J.A.; Gutierrez-Miceli, F.A.; Dendooven, L. Effect of pest controlling neem (*Azadirachta indica* A. Juss) and mata-raton (*Gliricidia* sepium Jacquin) leaf extracts on emission of greenhouse gases and inorganic-N content in urea-amended soil. *Chemosphere* **2009**, *76*, 293–299. [CrossRef]
35. Omari, R.A.; Aung, H.P.; Hou, M.; Yokoyama, T.; Onwona-Agyeman, S.; Oikawa, Y.; Fujii, Y.; Bellingrath-Kimura, S.D. Influence of different plant materials in combination with chicken manure on soil carbon and nitrogen contents and vegetable yield. *Pedosphere* **2016**, *26*, 510–521. [CrossRef]
36. Partey, S.T.; Zougmore, R.B.; Thevathasan, N.V.; Preziosi, R.F. Effects of plant residue decomposition on soil N availability, microbial biomass and β-glucosidase activity during soil fertility improvement in Ghana. *Pedosphere* **2019**, *29*, 608–618. [CrossRef]
37. Méndez-Bautista, J.; Fernández-Luqueño, F.; López-Valdez, F.; Mendoza-Cristino, R.; Montes-Molina, J.A.; Gutierrez-Miceli, F.A.; Dendooven, L. Effect of pest controlling neem and mata-raton leaf extracts on greenhouse gas emissions from urea-amended soil cultivated with beans: A greenhouse experiment. *Sci. Total Environ.* **2010**, *408*, 4961–4968. [CrossRef]
38. Vithanage, M.; Rajapaksha, A.U.; Oze, C.; Rajakaruna, N.; Dissanayake, C. Metal release from serpentine soils in Sri Lanka. *Environ. Monit. Assess.* **2014**, *186*, 3415–3429. [CrossRef]
39. Bandara, T.; Herath, I.; Kumarathilaka, P.; Hseu, Z.-Y.; Ok, Y.S.; Vithanage, M. Efficacy of woody biomass and biochar for alleviating heavy metal bioavailability in serpentine soil. *Environ. Geochem. Health* **2016**, *39*, 391–401. [CrossRef]
40. Lehmann, J. A handful of carbon. *Nature* **2007**, *447*, 143–144. [CrossRef]
41. Luo, L.; Xu, C.; Chen, Z.; Zhang, S. Properties of biomass-derived biochars: Combined effects of operatingconditions and biomass types. *Bioresour. Technol.* **2015**, *192*, 83–89. [CrossRef]
42. Kuntashula, E.; Mafongoya, P.L. Farmer participatory evaluation of agroforestry trees in eastern Zambia. *Agric. Syst.* **2005**, *84*, 39–53. [CrossRef]
43. Obia, A.; Mulder, J.; Hale, S.E.; Nurida, N.L.; Cornelissen, G. The potential of biochar in improving drainage, aeration and maize yields in heavy clay soils. *PLoS ONE* **2018**, *13*, e0196794. [CrossRef] [PubMed]

44. Kaba, J.S.; Yamoah, F.A.; Acquaye, A. Towards sustainable agroforestry management: Harnessing the nutritional soil value through cocoa mix waste. *Waste Manag.* **2021**, *124*, 264–272. [CrossRef] [PubMed]
45. Akinnifesi, F.K.; Ajayi, O.C.; Sileshi, G.; Chirwa, P.W.; Chianu, J. Fertiliser trees for sustainable food security in the maize-based production systems of East and Southern Africa. A review. *Agron. Sustain. Dev.* **2010**, *30*, 615–629. [CrossRef]
46. Aweto, A.O. Trees in shifting and continuous cultivation farms in Ibadan area, southwestern Nigeria. *Landsc. Urban Plan.* **2001**, *53*, 163–171. [CrossRef]
47. Coulibaly, J.Y.; Chiputwa, B.; Nakelse, T.; Kundhlande, G. Adoption of agroforestry and the impact on household food security among farmers in Malawi. *Agric. Syst.* **2017**, *155*, 52–69. [CrossRef]
48. Nyirenda, H. Achieving sustainable agricultural production under farmer conditions in maize-*Gliricidia* intercropping in Salima District, central Malawi. *Heliyon* **2019**, *5*, e02632. [CrossRef]
49. Makumba, W.; Janssen, B.; Oenema, O.; Akinnifesi, F.K.; Mweta, D.; Kwesiga, F. The long-term effects of a *Gliricidia*–maize intercropping system in Southern Malawi, on *Gliricidia* and maize yields, and soil properties. *Agric. Ecosyst. Environ.* **2006**, *116*, 85–92. [CrossRef]
50. Bah, A.R.; Rahman, Z.A. *Gliricidia* (*Gliricidia* sepium) green manures as a potential source of N for maize production in the tropics. *Sci. World J.* **2001**, *1*, 90–95. [CrossRef]
51. Moura, E.G.; Sousa, R.M.; Campos, L.S.; Cardoso-Silva, A.J.; Mooney, S.J.; Aguiar, A.C.F. Could more efficient utilization of ecosystem services improve soil quality indicators to allow sustainable intensification of Amazonian family farming? *Ecol. Indic.* **2021**, *127*, 107723. [CrossRef]
52. Coe, R.; Njoloma, J.; Sinclair, F. Loading the Dice in Favour of the Farmer: Reducing the Risk of Adopting Agronomic Innovations. *Exp. Agric.* **2016**, *55*, 67–83. [CrossRef]
53. Awopegba, M.; Oladele, S.; Awodun, M. Effect of mulch types on nutrient composition, maize (Zea mays L.) yield and soil properties of a tropical Alfisol in Southwestern Nigeria. *Eurasian J. Soil Sci.* **2017**, *6*, 121–133. [CrossRef]
54. Feitosa, A.L.P.M.; Siqueira, G.M.; Moura, E.G.; Silva, A.J.C.; Aguiar, A.C.F. Effect of different soil fertilization regimes on soil chemical properties and maize grains yield in humid tropic. *Res. Soc. Dev.* **2022**, *11*, e4511527635. [CrossRef]
55. Oke, D.O. Weed Suppression and Maize Growth in *Gliricidia* + maize Intercrop as Influenced by Leaf Mulch Application and Inorganic Phosphorus Fertilization. *Int. J. Appl. Agric. Res.* **2012**, *7*, 119–127.
56. Araújo, B.B., Jr.; Silva, P.S.L.; Oliveira, O.F.; Espinola Sobrinho, J. Weed control in maize crop with *Gliricidia* intercropping. *Planta Daninha* **2012**, *30*, 767–774.
57. Silva, P.S.L.; Silva, E.M.; Silva, P.I.B.; Fernandes, J.P.P.; Chicas, L.S. Intercropping Corn with a Combination of Tree Species to Control Weeds. *Planta Daninha* **2015**, *33*, 717–726. [CrossRef]
58. Tavella, L.B.; Silva, P.S.L.; Monteiro, A.L.; Oliveira, V.R.; Siqueira, P.L.O.F. Weed Control in Maize with *Gliricidia* Intercropping. *Planta Daninha* **2015**, *33*, 249–258. [CrossRef]
59. Sileshi, G.W.; Debusho, L.K.; Akinnifesi, F.K. Can Integration of Legume Trees Increase Yield Stability in Rainfed Maize Cropping Systems in Southern Africa? *Agron. J.* **2012**, *104*, 1392–1398. [CrossRef]
60. Swamila, M.; Philip, D.; Akyoo, A.M.; Sieber, S.; Bekunda, M.; Kimaro, A.A. *Gliricidia* Agroforestry Technology Adoption Potential in Selected Dryland Areas of Dodoma Region, Tanzania. *Agriculture* **2020**, *10*, 306. [CrossRef]
61. Swamila, M.; Philip, D.; Akyoo, A.M.; Manda, J.; Mwinuka, L.; Smethurst, P.J.; Sieber, S.; Kimaro, A.A. Profitability of *Gliricidia* + maize System in Selected Dryland Areas of Dodoma Region, Tanzania. *Sustainability* **2022**, *14*, 53. [CrossRef]
62. Mngomba, S.A.; Akinnifesi, F.K.; Kerr, A.; Salipira, K.; Muchugi, A. Growth and yield responses of cotton (Gossypium hirsutum) to inorganic and organic fertilizers in southern Malawi. *Agrofor. Syst.* **2016**, *91*, 249–258. [CrossRef]
63. Primo, D.C.; Menezes, R.S.C.; Oliveira, F.F.D.; Dubeux Júnior, J.C.B.; Sampaio, E.V.S.B. Timing and placement of cattle manure and *Gliricidia* affects cotton and sunflower nutrient accumulation and biomass productivity. *An. Acad. Bras. Ciências* **2018**, *90*, 415–424. [CrossRef] [PubMed]
64. Montes-Molina, J.A.; Luna-Guido, M.L.; Espinoza-Paz, N.; Govaerts, B.; Gutierrez-Miceli, F.A.; Dendooven, L. Are extracts of neem (*Azadirachta indica* A. Juss. (L.)) and *Gliricidia* sepium (Jacquin) an alternative to control pests on maize (*Zea mays* L.)? *Crop Prot.* **2008**, *27*, 763–774. [CrossRef]
65. Montes-Molina, J.A.; Nuricumbo-Zarate, I.H.; Hernández-Díaz, J.; Gutiérrez-Miceli, F.A.; Dendooven, L.; Ruíz-Valdiviezo, V.M. Characteristics of tomato plants treated with leaf extracts of neem (*Azadirachta indica* A. Juss. (L.)) and mata-raton (*Gliricidia* sepium (Jacquin)): A greenhouse experiment. *J. Environ. Biol.* **2014**, *35*, 935–942. [PubMed]
66. Utomo, B.; Prawoto, A.A.; Bonnet, S.; Bangviwat, A.; Gheewala, S.H. Environmental performance of cocoa production from monoculture and agroforestry systems in Indonesia. *J. Clean. Prod.* **2016**, *134*, 583–591. [CrossRef]
67. Abou Rajab, Y.; Leuschner, C.; Barus, H.; Tjoa, A.; Hertel, D. Cacao Cultivation under Diverse Shade Tree Cover Allows High Carbon Storage and Sequestration without Yield Losses. *PLoS ONE* **2016**, *11*, e0149949. [CrossRef]
68. Bai, S.H.; Trueman, S.J.; Nevenimo, T.; Hannet, G.; Randall, B.; Wallace, H.M. The effects of tree spacing regime and tree species composition on mineral nutrient composition of cocoa beans and canarium nuts in 8-year-old cocoa plantations. *Environ. Sci. Pollut. Res.* **2019**, *26*, 22021–22029. [CrossRef]
69. Bai, S.H.; Gallart, M.; Singh, K.; Hannet, G.; Komolong, B.; Yinil, D.; Field, D.J.; Muqaddas, B.; Wallace, H.M. Leaf litter species affects the decomposition rate and nutrient release in a cocoa plantation. *Agric. Ecosyst. Environ.* **2022**, *324*, 107705. [CrossRef]

70. Carvalho, D.F.; Gomes, D.P.; Oliveira, N.D.H.; Guerra, J.G.M.; Rouws, J.R.C.; Oliveira, F.L. Carrot yield and water-use efficiency under different mulching, organic fertilization and irrigation levels. *Rev. Bras. Eng. Agrícola E Ambient.* **2018**, *22*, 445–450. [CrossRef]
71. Ilangamudali, I.M.P.S.; Senarathne, S.H.S.; Egodawatta, W.C.P. Evaluation of Coconut Based *Gliricidia sepium* Agroforestry Systems to Improve the Soil Properties of Intermediate and Dry Zone Coconut Growing Areas. *Int. J. Res. Agric. Sci.* **2014**, *1*, 34–42.
72. Kumara, R.P.D.N.; De Silva, C.S. The Efficacy of Different Mulching Materials in Influencing Growth, Yield, Soil and Quality Parameters of Ginger Cultivated in Low Country Intermediate Zone (IL1) of Sri Lanka. *OUSL J.* **2019**, *14*, 7–29. [CrossRef]
73. Yadav, J.; Gabhane, V.V.; Shelke, A.; Rathod, A.; Satpute, U.; Chandel, A. Effect of potash management through *Gliricidia* green leaf manuring on soil fertility and yield of soybean in Vertisols. *J. Pharmacogn. Phytochem.* **2020**, *9*, 1033–1037.
74. Okon, I.E.; Solomon, M.G.; Osonubi, O. The Effects of Arbuscular Mycorrhizal Fungal Inoculation and Mulch of Contrasting Chemical Composition on the Yield of Cassava under Humid Tropical Conditions. *Sci. World J.* **2010**, *10*, 505–511. [CrossRef]
75. Antunes, L.F.d.S.; Vaz, A.F.d.S.; Martelleto, L.A.P.; Leal, M.A.d.A.; Alves, R.d.S.; Ferreira, T.d.S.; Rumjanek, N.G.; Correia, M.E.F.; Rosa, R.C.C.; Guerra, J.G.M. Sustainable organic substrate production using millicompost in combination with different plant residues for the cultivation of Passiflora edulis seedlings. *Environ. Technol. Innov.* **2022**, *28*, 102612. [CrossRef]
76. Carpenter, F.L.; Nichols, J.D.; Pratt, R.T.; Young, K.C. Methods of facilitating reforestation of tropical degraded land with the native timber tree, Terminalia amazonia. *For. Ecol. Manag.* **2004**, *202*, 281–291. [CrossRef]
77. Hartemink, A.E. Sweet potato yields and nutrient dynamics after short-term fallows in the humid lowlands of Papua New Guinea. *NJAS* **2003**, *50*, 297–319. [CrossRef]
78. De Moura-Silva, A.G.; das Chagas Ferreira Aguiar, A.; de Moura, E.G.; Jorge, N. Influence of soil cover and N and K fertilization on the quality of biofortified QPM in the humid tropics. *J. Sci. Food Agric.* **2016**, *96*, 3807–3812. [CrossRef]
79. Oliveira, V.R.D.; Silva, P.S.L.; Paiva, H.N.D.; Antonio, R.P. Crescimento De Leguminosas Arbóreas E Rendimento Do Milho Em Sistemas Agroflorestais. *Rev. Árvore* **2016**, *40*, 679–688. [CrossRef]