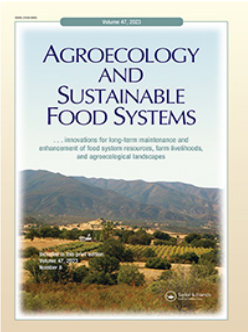

Taylor & Francis
Taylor & Francis Group

Agroecology and Sustainable Food Systems

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/wjsa21

Assessing the impact of *Gliricidia* agroforestry-based interventions on crop nutritional, antinutritional, functional, and mineral compositions in eastern Province, Zambia

Emmanuel Oladeji Alamu, Njoloma Joyce, Akello Juliet, Ngumayo Joel, Ray Chazangwe, Mehreteab Tesfai, Chikoye David, Nyoka Isaac, Dale Lewis & Nagothu Udaya Sekhar

AGROECOLOGY AND SUSTAINABLE FOOD SYSTEMS
https://doi.org/10.1080/21683565.2023.2254711

Assessing the impact of *Gliricidia* agroforestry-based interventions on crop nutritional, antinutritional, functional, and mineral compositions in eastern Province, Zambia

Emmanuel Oladeji Alamu [a], Njoloma Joyce [b], Akello Juliet[a], Ngumayo Joel [c], Ray Chazangwe[c], Mehreteab Tesfai [d], Chikoye David [a], Nyoka Isaac [b], Dale Lewis[c], and Nagothu Udaya Sekhar [d]

[a]International Institute of Tropical Agriculture (IITA), Southern Africa Hub, Lusaka, Zambia; [b]International Centre for Research in Agroforestry (ICRAF), Lilongwe, Malawi; [c]Community Markets for Conservation (COMACO), Lusaka, Zambia; [d]Norwegian Institute of Bioeconomy Research (NIBIO), ÅS, Norway

ABSTRACT

Agroforestry practices improve soil health which in turn improves crop nutrient concentrations and quality. This study examined how the agroforestry tree *Gliricidia sepium* intercropped with soybean, groundnuts, or maize affects crop nutrient compositions. The study was conducted in five Zambian chiefdoms for three crop-growing seasons (2019–2022) on 13 farmer-led demonstration trial sites. Seven treatments were tested that included maize, soybean, and groundnut plots with and without *Gliricidia* interventions. Grain samples were analyzed for crop nutrient contents using standard laboratory methods. Results showed that the treatments significantly ($P <$ 0.05) improved maize nutritional properties except for crude fiber, total carbohydrate, and metabolizable energy. *G. sepium* intercropping with maize and soybean decreased the antinutritional contents and displayed better functional qualities. All elemental mineral components (except potassium, calcium, and sodium) were higher in the *Gliricidia* + maize intercrop than in the control treatment. The *Gliricidia*+soybean intercrop had lower mean mineral concentrations than the control (soybean only) except for Mg, Cu, and Zn. The *Giliricidia*+groundnut intercrop significantly increased groundnut mineral components except for Nitrogen, Phosphorus, Potassium, and Iron. It can be concluded that *G. sepium* intercropped with maize, soybean, and groundnuts significantly improved the crops' nutritional quality.

KEYWORDS
Agroforestry; Zambia; Gliricidia sepium; legumes; nutritional quality; mineral

Introduction

Gliricidia sepium (Jacq.) is a well-known agroforestry leguminous tree growing in different agroecological zones and provides multiple environmental benefits (e.g., soil health, crop yields/quality) (Alamu et al. 2023; Tesfai et al. 2022);

CONTACT Emmanuel Oladeji Alamu o.alamu@cgiar.org International Institute of Tropical Agriculture (IITA), Southern Africa Hub, Lusaka, Zambia

Supplemental data for this article can be accessed online at https://doi.org/10.1080/21683565.2023.2254711.

social benefits (e.g., improved farmer livelihoods and food security) (Akinnifesi et al. 2010; Romero et al. 2020); and economic benefits (e.g., increase farmer income) (Alamu et al. 2023). *Gliricidia* is a medium-sized leguminous tree belonging to the *Fabaceae* family, and it is considered a source of relatively valuable plant protein (Grygier et al. 2022). The underlying hypothesis of the agroforestry fertilizer tree system is that available plant N is the most limiting macronutrient in the soil. However, since the unreactive N is highly abundant in the atmosphere, agroforestry practices using legumes can replenish soil fertility through biological fixation and recycling of nutrients in the soil and incorporation of the nitrogen-rich leaves of the legume trees, thus contributing to improved crop productivity. Trees produce large quantities of leaf biomass compared to legume crops. By incorporating nitrogen-rich leaves as green manure, *G. sepium* can replenish soil fertility through biological nitrogen fixation and improve nutrient recycling (Kim and Isaac 2022). The *Gliricidia* trees produce high-quality green manure as their leaves contain up to 4% total N. Furthermore, the trees provide a large amount of leaf biomass, increasing soil productivity and crop yields (da Costa Leite et al. 2019). In addition, the trees have a deep root system that can intercept and access nutrients percolating through the soil profile and drawing moisture. Thus, nutrients absorbed by the tree's deep root system are transferred to the soil surface through litter and other plant residues. Several studies have shown that the tree has been used in several applications, from being used as a supplement in animal feed (Castrejon et al. 2016; Oloruntola 2018) to improving soil fertility (Kuntashula and Mafongoya 2005; Vithanage et al. 2014; Wartenberg et al. 2017) to enhancing the yield and nutritional composition of crops (Ogunyemi, Otegbayo, and Fagbenro 2018; Yadav et al. 2020). Incorporating nutrient-rich tree leaves into the soil, especially leaves of leguminous plants like *G. sepium*, has shown positive results in improving soil fertility due to its profuse growth, deciduous nature, rapid decomposition rate, and higher crop nutrient content properties (Mehreteab et al. 2022; Méndez-Bautista et al. 2009; Rahman et al. 2019).

Maize (*Zea mays* L.) is a staple crop widely cultivated and consumed globally. It is an essential dietary energy and protein source in human diets, with an annual global production of approximately 967 million metric tons (Alamu, Olaniyan, and Maziya-Dixon 2021). Maize, Groundnut, and Soybean are the nutritional backbone of central, southern, and eastern Zambia (Alamu, Olaniyan, and Maziya-Dixon 2021). Groundnut seeds are high in protein and edible oil and contribute to diets (Asibuo et al. 2008). Soybean (*Glycine max*. L.) is reported to be the cheapest and richest source of protein and is in the diets of individuals and animals because soybean protein contains all the required essential amino acids (Alamu, Popoola, and Maziya-Dixon 2018).

To a large extent, agroforestry's role in enhancing soil quality and health has been demonstrated, making it a viable, sustainable land management practice.

Soil nutrient uptake and utilization are crucial for healthy development, increased harvest yields, and improved crop quality.

The adoption of *G. sepium* as fertilizer trees in Malawi was analyzed by Coulibaly et al. (2017) to increase the value of food crops by 35%, positively affecting household food security. In addition, *G. sepium* intercropped with maize enhanced soil health renewal and significantly increased the crop's nutritional composition (Nyirenda 2019). De Moura-Silva et al. (2015) evaluated the effect of combining *Gliricidia* with other shrubs in an alley cropping system to improve the productivity and nutritional value of quality protein maize. A two-year experiment evaluated the influence of shrub and herbaceous mulch types on soil characteristics and maize nutrient content. Awopegba, Oladele, and Awodun (2017) reported that 5 t/ha of *G. sepium*, one of the evaluated shrub mulches, improved maize's nutrient composition and yield.

G. sepium trees and leaves improve soil fertility by increasing total carbon, nitrogen, available phosphorus, pH, cation exchange capacity, base saturation, soil aggregation, bulk density, and phospholipid fatty acid (PLFA) composition (Barros et al. 2021). The mineral nutrient composition and availability in soil significantly affect a crop's yield and quality. Plants employ several mechanisms to maintain internal nutrient balance, including mobilization, uptake, chelation, transport between cells and organs, and storage (Mafongoya, Kuntashula, and Sileshi 2006; Nyirenda 2019). A simple possible mechanistic pathway between the high Nitrogen-litter deposition from *Gliricidia*, nutrition transformation in the soil and subsequent uptake, and the then transformation to nutrient crop enrichment is shown in Figure 1.

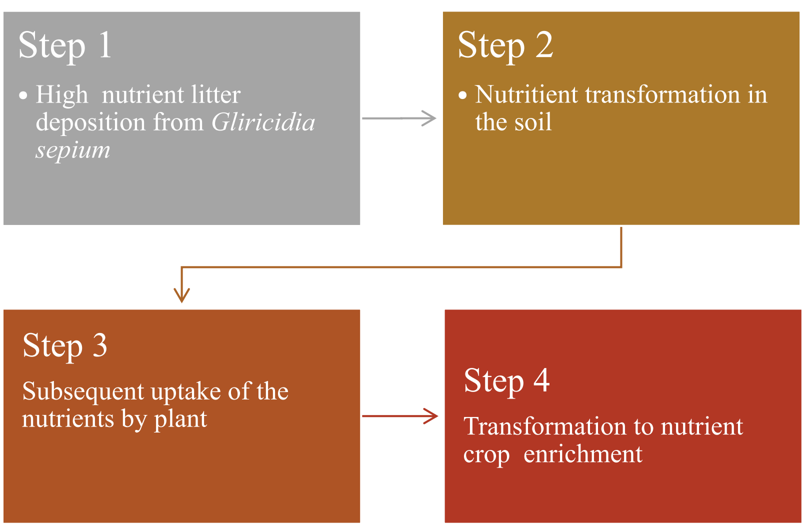

Figure 1. Mechanistic pathway of soil and crop enrichment using Gliricidia sepium.

Therefore, it is essential to determine how agroforestry as a soil management practice affects the nutrient composition of crops, as well as understanding whether crops produced under agroforestry systems are more nutritious than conventional ones.

Despite comprehensive studies on *Gliricidia* for soil and crop improvement (Alamu et al. 2023; Dinesh et al. 2010; Sileshi, Debusho, and Akinnifesi 2012; Yadav et al. 2020), there is a shortage of knowledge on the effect of intercropping of *Gliricidia* trees on the nutritional, antinutritional, functional, and mineral contents of field crops. The nutritional and mineral parameters are the chemical compounds found in crops/foods that the human body uses to function correctly and stay healthy. At the same time, antinutritional properties are unwanted chemical compounds that hinder the absorption or usage of nutrients in the body. However, the functional properties define how the crop components react during preparation and cooking and how they affect the completed food product's appearance, taste, and texture. Our research questions are: Do agroforestry practices by *Gliricidia* trees produce healthier and more nutrient-rich crops? If yes, in which crops? This study investigated the effect of *Gliricidia sepium* agroforestry intercropping on the nutritional, antinutritional, functional, and mineral properties of maize, soybean, and groundnut.

Materials and method

General description of the study sites

The study was implemented in the Eastern Province of Zambia (Chipata and Lundazi districts) in five selected Chiefdoms (an area/region governed by a chief), namely Magodi, Zumwanda, Chikomeni, Mwasemphangwe, and Mkanda. Zambia is subdivided into 36 agroecological zones and subdivided into 3 Agroecological regions mainly based on rainfall, and this study was implemented within the Agroecological Region II. Region II has an average annual rainfall of 800–1000 mm, and the growing season lasts between 100 to 140 days. The distribution of rain is not as erratic as in Regions I and III. Dry spells contribute to low crop yields, especially on sandy soils. Average daily air temperatures range from 23–26°C in October to 16–20°C in June and July. Chipata lies 1140 m above sea level with a typical tropical climate regime. The average annual rainfall is about 1023 mm, while the other study site (Lundazi) experiences extreme seasonal variation in monthly rainfall with an average annual rainfall of 923 mm. The rainy period lasts up to 6 months, spanning from October to May. The primary farming system in the study areas is maize-legume (groundnuts, beans) cropping systems with agroforestry trees such as *G. sepium* (Table 1).

Table 1. Main farming characteristics of the study districts in the eastern Province of Zambia.

	Project districts	
Characteristics	*Lundazi/Lumezi/Chasefu*	*Chipata/Chipangali*
Climate	Tropical Savanna	Tropical Savanna
Precipitation (mm/yr)	923	1023
Air temperature (°C)	19–27	18–25
Altitude (meters above sea level)	1143	1140
Population density (persons/km^2)	22.4	67.6
Food crops (in their order)	Maize > Groundnut > Beans	Maize > Groundnut > Beans

The dominant soils in the project areas are red-brownish clayey to loamy textured soils with moderate to strong leaching characteristics. Due to low organic matter contents, the soils are characterized by strong acidity, low nutrient retention, and low water-holding capacity. The topsoil is dominantly coarse-textured and has severe capping that hinders seedling emergence. Soil fertility declines over time and is exacerbated by burning crop residues and weeds. This has led to low organic matter levels in the soils.

Field layout/design (including treatments and replications)

The plots were established in five Chiefdoms: *Magodi, Zumwanda, Chikomeni, Mwasemphangwe, and Mkanda*, for the three crop-growing seasons (2019 to 2022). In each Chiefdom, 2–3 farmers participated in implementing the study treatments. In total, 13 demonstration trial plots were led by 13 farmers guided by researchers from the project team. The seven treatments (T) are shown in Figure 2.

Each farmer prepared seven plots measuring 5 m × 10 m (50 m^2). Each farmer in a Chiefdom was treated as a replicate, and the Chiefdoms were treated as blocks (Figure 1). The treatment plots were laid out in a Completely Randomized Design (CRD) and replicated three times, assuming that the pedoclimatic and socioeconomic conditions within each Chiefdom are homogeneous. In the maize plots, the net plot size was 3 inner rows 5 m long. The

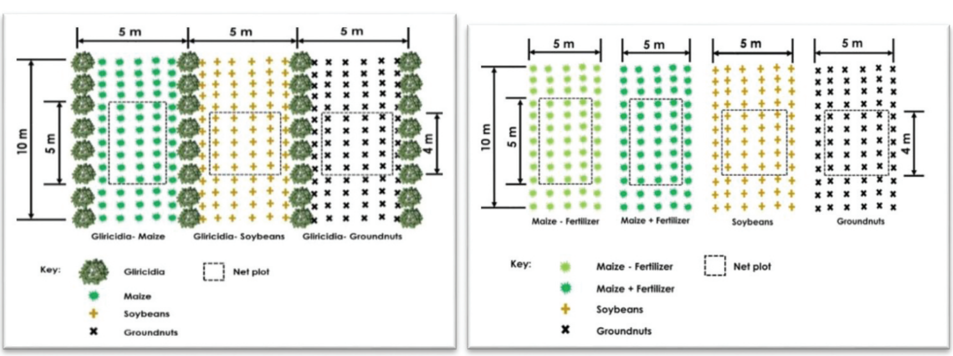

Figure 2. Illustration of the plot layout for the seven treatments.

net plot for groundnuts and soybeans was 4 inner rows 4 m long (Figure 1). All treatment combinations were compared to the control plot (T3), representing farmer practice without mineral fertilization.

Gliricidia trees management

This study was superimposed on a field previously planted with the *Gliricidia* agroforestry alley system. The *Gliricidia* ages ranged from 4 to 7 years at the start of the project. The initial objective of the planted *Gliricidia* was also soil conservation, but how the green leaf biomass was managed differed. Before this study, the farmers used pit incorporation, and only two handfuls were used per planting station, while some only applied the *Gliricidia* as mulch. In this study, after the first year, the application of the *Gliricidia* green manure was standardized as described below (Figure 3). *Gliricidia* is a coppicing agroforestry tree; as such, under this type of agroforestry system, the tree is typically cut back at three years from the transplanting year to develop a bush-like regrowth from which the green leaf biomass is harvested for incorporation.

Gliricidia green manure management consists of three Prunings

1st Pruning: At the start of land preparation, *Gliricidia* tree branches were cut 30–50 cm above the ground. During land preparation, pruned leaves were incorporated into the soil (ripper line) as green manure (Figure 3). The first Pruning occurred between October and November in readiness for the growing season.

Figure 3. Farmers incorporating the *Gliricidia* tree leaves into the soils.

The first Pruning and incorporation were done as follows:

- Split the planting line with a ripper creating a furrow deep enough to hold the leaves and young tender stems of *Gliricidia*.
- Prune the *Gliricidia* trees by removing all biomass above 30 cm with a panga knife or hand-held saw.
- Set aside any woody branches for firewood or poles. Wood should not be incorporated into the soil, as wood will not decompose fast enough.
- Evenly distribute the leaves and young, tender branches in the planting ripper line.
- Cover the green manure (leaves and young branches) by putting back some soil.

2^nd^ Pruning: After the first cut-back, the *Gliricidia* trees coppice producing much new growth in the wet season (December-January). This 2nd green manure is the equivalent of the 1st dose of top dressing (inorganic fertilizer). The second pruning operation was best combined with the first weeding.

- Prune all biomass above 30 cm. Pruning is done by cutting all the branches that have grown from the stump from 30 cm above the ground.
- Remove any woody biomass, i.e., the brown branch part, which is not tender (not greenish).
- Arrange the tree prunings on the sides of the planting row and cover them with some soil during the weeding. Thus, the first weeding and second pruning incorporation must be done simultaneously. Avoid placing the leaves too close to the maize plant in termite-prone fields as this may induce termite attack on the maize.

3rd Pruning: The third Pruning was done during the second weeding (in February).

- The procedure is the same as the 2nd Pruning except that the leaves are left on the surface around the maize plants rather than being incorporated.
- Consequently, the third Pruning requires less labor, as the biomass is placed on the surface along the planting row.
- The third Pruning will act as mulch and help the soil to retain moisture.

Tested crops management

The primary test cereal crop was maize (*Zea mays L, variety ZM 521*); along-side the maize trials, groundnut variety *Mgv5* and soybean variety *OPV* were planted under rainfed conditions.

Gliricidia tree leaves in the first year were used as mulch, while in the second year, *Gliricidia* green manure quantities ranging from 2.4 to 15 tons/ha, and in the third year, incorporated *Gliricidia* green manure was standardized at 12 tons across all the trial plots. *Gliricidia* green manure was incorporated a month before planting maize and soybeans on rotation with groundnuts in the alleys. We assessed the yields against the crop seed yield potential. The soils of the region are characterized as poor for supporting optimal crop yields. With the intervention we were demonstrating, the yields had improved toward achieving the potential yields described for the crop seed.

Soybeans and groundnuts were planted in rotation under *Gliricidia* alley or on a non-agroforestry plot. At the same time, it may be understood that all legume roots contain rhizobia; positive results of using legumes in rotation are not entirely due to nitrogen credits. Using legumes in rotation may break insect and disease cycles which are problems in monocultures. Many other insects and some diseases are indirectly affected by crop rotations. In general, if a management practice provides a deterrent to the life cycle of a pest or a benefit to the life cycle of a predator, it will decrease that pest's effects on the economic return of the practice. Legume rotation systems also help manage weeds (Leikam et al. 2007). Soya growth suppresses weeds more than would groundnuts. In our case, we were also dealing with soils devoid of organic matter such that in addition to breaking other cycles, it was meant to improve soil organic matter that would support the soil microbes and crop productivity. We also demonstrated that continuous maize cultivation with *Gliricidia* would sustain maize productivity even without the crop legume-cereal rotation.

Data collection of crops/Gliricidia: sampling, measurements &analysis

Two hundred seventy-nine (279) crop grain samples (maize (111), soybean (84), and groundnuts (84)) were collected from the fields in three growing seasons (2019 to 2022) using a standard sampling protocol (Mehreteab et al. 2022). The crop grain samples were cleaned, subsampled, and milled to a 0.5 mm particle size (flour) using Laboratory Mill 3100 from PERTEN Inc. For analysis, the milled samples (Table 2) were packed in a well-labeled Ziplock polythene bag and shipped to the Food and Nutrition Sciences Laboratory at IITA, Nigeria. The parameters were evaluated using standard laboratory methods of analysis of the Association of Analytical Chemist International (AOAC) as follows in the next sections.

Table 2. Crop nutrients and functional properties analyzed.

Properties	Parameter analyzed
• *Nutritional properties*	Fat, Ash, Protein, Starch, Crude Fiber, Sugar, Amylose, Total carbohydrate
• *Antinutritional properties*	Phytates and Tannins
• *Functional properties*	Water absorption capacity, Oil Absorption Capacity, Bulk Density of grains, Swelling power, and Solubility
• *Mineral properties*	Nitrogen, Sodium, Potassium, Magnesium, Manganese, Copper, Iron, and Zinc

Determination of nutritional and antinutritional properties

The samples' moisture, fat, and ash contents were determined using approved methods 925.09, 920.87, and 920.39 of the Association of Official Analytical Chemists (AOAC 2005). The Kjeldahl method was used to determine crude protein as described in FOSS Manual using Kjeltec™ model 2300 (FOSS, 2003). The method involved the sample digestion at 420°C for 1 h to liberate the organically bound nitrogen in the form of ammonium sulfate.

Starch was determined using the method by Alamu et al. (2019). The samples were extracted for starch and free sugar with 95% ethanol, and the starch residue was hydrolyzed to sugars with perchloric acid. After hydrolyzing the residue, the sugar was converted to starch by multiplying by 0.9, and the UV-Vis absorbance of both starch and sugar was measured at 490 nm. Amylose content was also determined using a spectrophotometric method based on forming a deep, blue-colored complex of amylose with iodine and UV-Vis absorbance read at 620 nm (Williams et al., 1985). Total tannin and phytic acid were also determined by spectrophotometric procedures described by Ndidi et al. (2014).

Determination of functional properties

The procedure determined the bulk density (BD) of the samples by Ashraf et al. (2012). 10 g of flour sample was weighed into a 50 ml graduated measuring cylinder and gently tapped on the bench 10 times to achieve a constant height. The sample volume was recorded, and BD was expressed as g/mL. Water absorption capacity (WAC) and oil absorption capacity (OAC) were determined using methods by Oyeyinka et al. (2013) and Sosulski et al. (1976), respectively; however, swelling power (SP) and solubility index (SI) were determined by methods reported by Alamu et al. (2021). Dispersibility was measured by dispersing 10 g of the sample in distilled water in a 100 ml measuring cylinder. The solution was made up to the 50 mL mark using distilled water. The mixture was stirred vigorously and allowed to settle for 3 hr, after which the volume of settled particles was noted, and the percentage was calculated (Asaam et al., 2018).

Determination of mineral content

The mineral contents were analyzed using the validated inductively coupled optical emission spectrometry (ICP-OES) method described by Wheal et al., 2011. 0.03 g of the dried flour sample was weighed into a 50 ml screw-cap polypropylene tube and digested using 2 ml of HNO_3 and 0.5 ml of H_2O_2 at 125°C for 120 min. The digest was made up to 25 ml with 18 MΩ.cm of water before aspiration into a radial view Spectro Ciros CCD ICP-OES (Spectro

Analytical Instruments, Kleve, Germany). The sample solution was injected at the flow rate of 2.0 ml/min, and the total analysis time per sample was approximately 2.5 min. High-purity single-element standard solutions in a 4% (v/v) HNO_3 matrix were used to construct the calibration curve for all the elements.

Statistical analysis

The data generated in this study for the three growing seasons (2019 to 2022) were pooled and subjected to descriptive and inferential statistical analysis using the XLSTAT (Addinsoft 2021). Fisher's least significant difference test at $P < 0.05$ was used for the means separation. There was no year-over-year data analyzed.

Results and discussion

Effect of treatment on nutrient composition of maize

Table 3 and Figure 4 show the nutritional properties (NPs), antinutritional properties (ANPs), and functional properties (FPs) of maize samples by treatment. Treatment has significant effects ($P < 0.0001$) on all NPs, ANPs, and FPs

Table 3. Nutritional, antinutritional, and functional properties of maize by treatment (N = 111).

	Gliricidia+Maize (T1)		Maize + mineral fertilization (T2)		Maize only (T3)			
Parameters	Mean	SD (*n*-1)	Mean	SD (*n*-1)	Mean	SD (*n*-1)	Pr > F(Treatment)	Pr > F (Farmer *Treatment)
Nutritional								
% MC	6.66 b	0.88	6.70 b	0.71	5.82 a	1.30	<0.0001	<0.0001
%Ash	1.29 a	0.02	1.35 b	0.01	1.29 a	0.02	<0.0001	0.001
%Fat	4.88 a	0.45	5.05 a	0.36	4.85 a	0.15	<0.0001	0.042
%Protein	7.57 a	1.63	8.28 c	2.52	7.68 b	2.01	<0.0001	<0.0001
%Sugar	3.09 a	0.40	3.51 c	0.50	3.36 b	0.39	<0.0001	<0.0001
%Starch	72.23 b	1.09	71.49 a	0.47	71.70 a	0.21	<0.0001	<0.0001
%Crude Fiber	2.57a	0.95	2.71a	0.61	2.83a	0.75	0.220	0.511
%CHO	78.36a	3.11	77.31a	6.59	78.38a	5.47	0.064	0.400
%ME	387.74a	55.31	387.61a	53.62	388.26a	88.32	0.927	0.298
%Amylose	25.04 b	4.07	24.19 a	5.04	25.64 c	4.08	<0.0001	<0.0001
%Amylopectin	74.96 b	4.07	75.81 c	5.04	74.36 a	4.08	<0.0001	<0.0001
Antinutritional								
%Phytic acid	6.04 a	0.61	5.41 a	1.38	5.82 a	1.30	<0.0001	<0.0001
Tannin (mg/g)	6.27 b	1.04	6.78 a	1.49	6.34 b	0.94	<0.0001	<0.0001
Functional								
% WAC	159.53 a	265.35	163.81 b	258.77	163.78 ab	272.85	<0.0001	<0.0001
BD (g/ml)	1.61 c	0.01	1.51 b	0.14	1.25 a	0.02	<0.0001	<0.0001
SP	7.68 b	0.20	7.46 a	0.26	7.20 a	0.15	<0.0001	<0.0001
%Soluble	14.59a	8.43	15.81 ab	11.91	18.38 b	16.87	<0.0001	<0.0001
Dispersibility	70.64 b	22.39	67.369 a	20.54	66.32 a	6.09	<0.0001	<0.0001

MC= moisture content; CF= crude fiber; CHO = Total carbohydrate; ME; Metabolizable Energy, WAC= Water Absorption Capacity; BD= bulk density; SP=swelling power; OAC= Oil Absorption Capacity. Mean values with different letters in the same row are significantly different ($P < 0.05$)

except %Crude fiber, % Total carbohydrate (CHO), and % Metabolizable Energy (ME). Also, considering the second level interaction of the factors (farmer and treatment), there was a significant effect($P < 0.05$) of the farmer-by-treatment interaction effect on all the studied parameters except for fat content, crude fiber, %CHO, %ME. It was concluded that the CHO, ME, and fat content of maize were unaffected by the treatment and planting environment (farmer). However, it impacted ANPs, FPs, and other NPs (protein, sugar, starch, amylose, and amylopectin). Maize with mineral fertilizer (T2) showed the highest moisture, ash, fat, protein, sugar, and amylopectin content with mean values of 6.70, 1.35, 5.05, 8.28, 3.51, and 75.81%, respectively and followed by *Gliricidia*+maize intercrop(T1) respectively. The mean values of these parameters increased significantly compared to the control treatment – Maize only (T3). A similar study by Awopegba, Oladele, and Awodun (2017) also reported increased protein and ash contents of maize grains cultivated in soil under shrub and herbaceous mulch treatments. However, the study by Ogunyemi, Otegbayo, and Fagbenro (2018) did not observe any significant difference in the ash content of maize samples subjected to mineralization with different levels of NPK and Biochar fertilizers. However, *Gliricidia*-maize intercrop treatment (T1) also showed

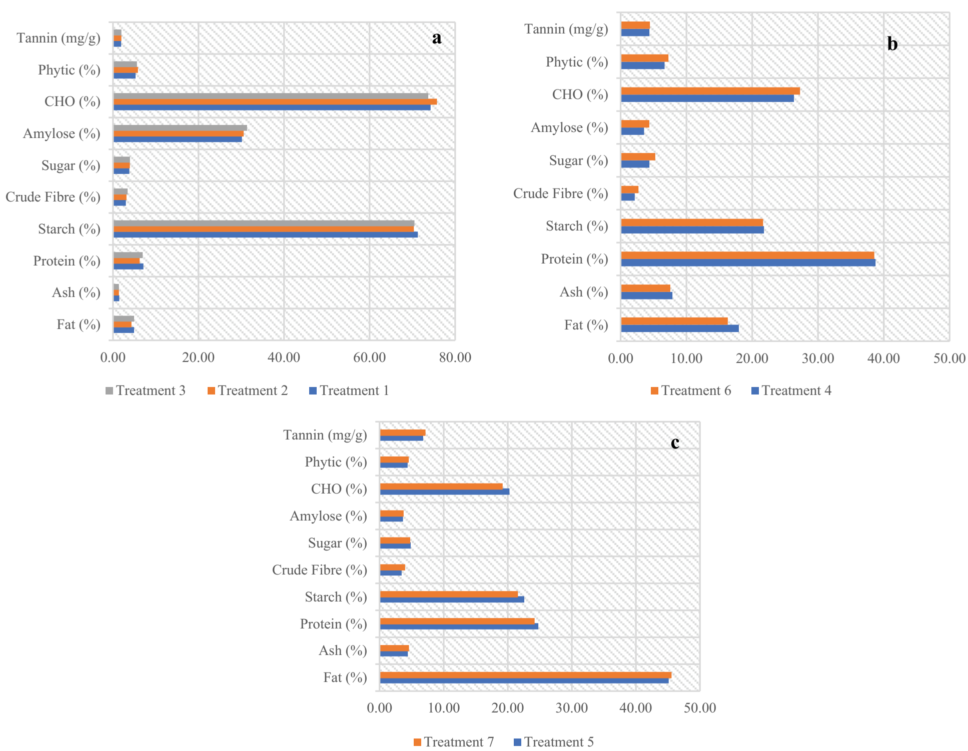

Figure 4. Effects of treatment on the nutritional & antinutritional properties of (a) maize, (b) Soybean, (c) groundnuts.

a higher mean value for starch (72.23%) and protein (7.57%), although not significantly different from the mean values obtained for T2. High starch is a desirable trait for maize consumers. The higher the starch content, the greater the quantity and quality of maize-based products such as Nshima (the most important maize-based food in Zambia). We can conclude that *Gliricidia*+maize intercrop (T1) improved the basic nutritional properties of maize compared to Maize-mineral fertilizer(T2) and the control (T3). This could be attributed to increased soil nutrient availability and maize absorbing more nutrients, which would boost the development of critical nutritional components. This is in line with the recent study by Nyirenda (2019), which concluded that *Gliricidia sepium* intercropped with maize enhanced soil health renewal and yield and significantly increased the nutritional composition of the crop.

There were no significant differences ($p > 0.05$) in the treatments' overall mean values of phytic acid, but T1 had the highest (6.04%) compared to T2, with the lowest (5.41%). In contrast, T1 had the lowest tannin mean value (6.27 mg/g), and T2 had the highest (6.78 mg/g). This implies that the *Gliricidia* treatment significantly reduced the tannin contents of maize samples compared with the T2 (mineral fertilizer) and T3 (maize only). Reducing ANPs such as tannin improves the solubility of minerals in cereal foods and their bioavailability (Chauhan et al., 2022). For the FPs, T1 had the highest mean values except for water absorption capacity (WAC) and solubility. The high values of bulk density and swelling power show the superior quality of the flour from the *Gliricidia*+maize intercrop (T1) experimental field compared to flours from other treatment fields (T2 and T3). The swelling power of flour is an indicator of the flour's swelling capacity in water; the higher the swelling power, the better the flour. The end-users preferred maize with high swelling power. In conclusion, the *Gliricidia* +maize intercrop (T1) showed higher mean values than the control (T3) for starch (72.23%), amylopectin (74.96%), protein (7.57%) and the lowest value for Tannin content. This implies that *Gliricidia*+maize intercrop improved the basic nutritional properties and reduced the antinutritional component of maize compared to maize only (Control). This finding buttressed the report of Coulibaly et al. (2017) that using *Gliricidia sepium* as fertilizer trees increased the value of food crops by 35%, positively affecting household food security.

Table 4 presents the effect of various treatments on the elemental composition of the maize samples. The 2-way interaction of farmer x treatment had a highly significant impact on all the elemental components studied. The results imply that the applied treatments affected all the elements. Also, the interaction of the environment (farmers) by treatment influenced all the elements measured. In addition to the treatments used,

Table 4. Effect of treatment on the mineral composition of maize (N = 111).

	Gliricidia+Maize (T1)		Maize + mineral fertilization (T2)		Maize only (T3)			
Parameter	Mean	SD (*n*-1)	Mean	SD (*n*-1)	Mean	SD (*n*-1)	Pr > F (Treatment)	Pr > F(Farmer*Treatment)
N (%)	1.21 b	0.12	1.40 c	0.1	1.21 b	0.06	<0.0001	<0.0001
P (mg/100g)	253.06 b	1544.89	237.12 a	1922.25	240.90 b	2113.57	<0.0001	<0.0001
Ca (mg/100g)	133.48 a	957.94	184.00 b	3671.14	229.58 c	1118.29	<0.0001	<0.0001
Mg (mg/100g))	73.60 c	22.23	71.45 b	73.99	59.78 a	15.29	<0.0001	<0.0001
K (mg/100g)	351.61 c	1567.6	275.21 a	6636.8	220.38 a	9621.79	<0.0001	<0.0001
Na (mg/kg)	20.57 a	86.83	24.17 b	40.15	25.88 c	31.99	<0.0001	<0.0001
Mn (mg/kg)	15.51 c	7.29	11.91 b	51.38	6.15 a	16.20	<0.0001	<0.0001
Fe (mg/kg)	20.22 c	28.75	18.85 b	31.77	16.44 a	12.39	<0.0001	<0.0001
Cu (mg/kg)	3.35 a	0.98	3.78 b	0.79	3.52 b	0.49	<0.0001	<0.0001
Zn (mg/kg)	14.19 a	1.99	22.90 b	162.74	31.61 c	16.94	<0.0001	<0.0001

Mean values with different letters in the same row are significantly different ($P < 0.05$)

this can be because each farmer has distinct weather circumstances and soil types. The *Gliricidia*+maize intercrop (T1) had higher values than the control (T3) for all the elemental components except for Potassium, Calcium, and Sodium.

The T1 showed higher values for Potassium, Magnesium, and Manganese content than the Maize+mineral fertilization (T2). This agrees with the conclusion made by de Moura-Silva et al. (2016) and Diouf et al. (2017) that incorporating *Gliricidia* organic matter improves the mineral nutrition of cultivated maize crops. There was a highly significant ($P < 0.0001$) effect of treatment and farmer x treatment on all the elements evaluated. This implies that the treatment applied impacted the mineral content of maize, as *Gliricidia* contributed slightly to the increased level of the selected elements relative to the control (T3), especially nitrogen content that indicates a higher protein value. However, Maize+mineral fertilization (T2) gave a higher %N than other treatments. This observation is unlike what Nyirenda (2019) reported, where there was no significant difference between the maize samples from integrated soil management practices treatment and the control.

However, the range of values for Sodium and Iron obtained in this study is lower than the results reported by Ogunyemi, Otegbayo, and Fagbenro (2018). In this study, the magnesium and calcium contents were higher. The disparity in the results could be due to the genotype-by-environment effect. However, our results agree with Etiosa, Chika, and Benedicta (2017) and Swamila et al. (2021), who reported maize samples from the *Gliricidia* field had a significantly increased mineral content and decreased antinutrient content, making them an affordable source of essential nutrients for human and animal use. We can conclude that *Gliricidia*+maize intercropping improved the mineral composition of the maize samples by showing higher values of some minerals than the control (T3), except for Potassium, Calcium, and Sodium.

Effect of treatment on nutrient composition of soybean

Table 5 and Figure 4 present the effect of *Gliricidia*+soybean intercropping (T4) on Soybeans' NPs, ANPs, and FPs. The effect of treatment was significant ($p < 0.05$) on all the NPs, ANPs, and FPs except moisture content (MC), protein content, crude fiber, % total carbohydrate (CHO), % metabolizable Energy (ME), Bulk density (BD) and Solubility. Also, treatment by farmer interaction had a significant effect ($p < 0.05$) on all NPs, ANPs, and FPs except for MC, crude fiber, %CHO, % ME, BD, swelling power (SP), and Solubility. The non-significant effect ($p > 0.05$) of treatment and farmer-by-treatment interactions on MC, BD, and Solubility indicate that these parameters were neither affected by treatment nor the planting environment. Treatment 4 (*Gliricidia*/soybean intercropping) significantly increased the average concentration of sugar (5.74%), starch (22.09%), and amylose (3.00%) when compared with T6 (control).

Also, T4 showed a significantly higher average concentration of WAC (180.09%) and SP (2.45%) compared to the control 171.63% and 2.31%. *Gliricidia* treatments improved the nutritional and functional properties of soybean. However, ash content was lower in the *Gliricidia*+soybean intercropping, which might imply a lower mineral load of these soybean samples with the *Gliricidia* intercrop treatment. However, lower phytate content achieved by T4 is desirable because phytates in diets decrease the availability of minerals, mainly calcium, phosphorus, and zinc (Alamu et al. 2019). *Gliricidia*+soybean intercropping significantly increased the soybean's

Table 5. Nutritional, antinutritional, and functional properties of soybean by treatment (N = 84).

	Gliricidia+soybean (T4)		Soybean only (T6)			
Parameters	Mean	SD (*n*-1)	Mean	SD (*n*-1)	Pr > F(Treatment)	Pr > F (Farmer *Treatment)
Nutritional						
%MC	6.30a	0.16	6.13a	0.14	0.062	0.122
%Ash	5.07a	0.16	5.28b	0.06	<0.0001	<0.0001
%Fat	20.54a	2.83	21.33b	3.11	0.007	0.004
% Protein	38.46a	2.69	38.72a	1.86	0.102	<0.0001
%Sugar	5.74b	1.37	4.74a	0.21	<0.0001	<0.0001
%Starch	22.09b	2.11	21.86a	0.95	0.001	<0.0001
% Amylose	3.00b	1.07	2.04a	0.07	<0.0001	<0.0001
%Crude Fiber	6.91 a	0.602	6.94 a	0.630	0.783	0.804
%CHO	26.15 a	3.798	25.09 a	4.458	0.409	0.996
%ME	304.18a	14.616	302.70a	16.244	0.765	0.999
%Amylopectin	97.00a	1.07	97.96b	0.07	<0.0001	<0.0001
Antinutritional						
% Phytate	8.36a	2.86	9.24b	2.98	<0.0001	<0.0001
Tannin (mg/g)	12.31b	3.17	12.00a	0.88	<0.0001	<0.0001
Functional						
% WAC	180.09b	299.13	171.63a	380.18	<0.0001	<0.0001
B D (g/ml)	1.67a	0.03	1.68a	0.01	0.867	0.218
S P	2.45b	0.05	2.31a	0.02	0.008	0.190
%Soluble	51.14a	18.00	52.60a	7.56	0.083	0.132
% OAC	143.47a	201.73	152.19b	209.17	<0.0001	<0.0001
Dispersibility	47.68a	20.37	51.00b	20.81	0.0001	0.002

MC = moisture content; WAC= Water Absorption Capacity; BD= bulk density; SP= swelling power; OAC= Oil Absorption Capacity, Mean values with different letters in the same row are significantly different (P <0.05) nutritional and vital functional properties (WAC and SP), performing better than the control. T4 also produced soybean with reduced antinutritional properties.

Table 6 shows the effect of treatment 4 (*Gliricidia*+soybean intercrop) and treatment 6 (control) on the elemental composition of Soybean samples. Treatments significantly impacted ($p < 0.05$) the soybean's N, Mg, Na, Fe, and Zn concentrations. In contrast, the second level interaction of treatment and farmer significantly affected all the mineral elements except Ca. The implication is that differences in planting environment had more effect on the mineral composition of soybean than the effect of the difference in treatments (Yadav et al. 2020). also reported the significant influence of *Gliricidia* leaf manuring on the mineral content of soybeans. T4 had a lower average concentration for all the minerals except for Mg, Cu, and Zn, which implies that *Gliricidia*+soybean intercropping does not significantly improve the mineral composition of the samples when compared with the control. The lower average concentration of most minerals with T4 is also reflected in the lower average ash content, as shown in Table 3 above for the nutritional properties. Although *Gliricidia*+soybean intercropping significantly impacts the mineral composition of soybean, the effect does not improve their concentrations except for Ma, Cu and Zn.

Effect of treatment on nutrient composition of groundnuts

Table 7 and Figure 4 show the nutritional properties (NPs), antinutritional properties (ANPs), and functional properties (FPs) of groundnut samples by treatment. Treatment had significant effects ($P < 0.05$) on the primary NPs such as starch, amylose, amylopectin, crude fiber, CHO, and ME. This trend is also noticeable in all FPs like bulk density (BD), water absorption capacity (WAC), and Oil absorption capacity (OAC), except swelling power at $P > 0.05$. The result for NPs of groundnut reported agrees with previously published studies on the proximate composition of groundnut samples (Asibuo et al.

Table 6. Effect of treatment on the mineral composition of soybean (N = 84).

	Gliricidia+soybean (T4)		Soybean only (T6)			
Parameter	Mean	SD (*n*-1)	Mean	SD (*n*-1)	Pr > F(Treatment)	Pr > F(Farmer*Treatment)
Nitrogen(%)	6.40 a	0.10	6.47 b	0.06	0.022	<0.0001
Phosphorus (%)	585.03 a	3571.19	594.22 a	5679.98	0.236	0.003
Calcium(%)	1275.68a	27014.73	1327.94 a	41115.50	0.213	0.080
Magnesium(%)	179.47 b	32.99	174.77 a	35.60	<0.0001	0.031
Potassium (%)	2907.27a	36987.41	2949.30a	20863.58	0.098	0.036
Sodium(ppm)	22.33 a	18.86	23.74 b	23.42	<0.0001	<0.0001
Manganese(ppm)	24.60 a	15.48	24.83 a	15.76	0.093	<0.0001
Iron(ppm)	40.58 a	23.72	42.45 b	21.61	0.008	<0.0001
Copper(ppm)	7.51 a	2.09	7.44 a	1.86	0.423	<0.0001
Zinc(ppm)	80.57 b	90.70	74.77 a	261.34	0.011	0.027

Mean values with different letters in the same row are significantly different ($P < 0.05$)

2008; Atasie, Akinhanmi, and Ojiodu 2009a). Farmer x treatment interaction had a highly significant ($p < 0.001$) effect on the NPs and FPs of groundnut samples except for Moisture content, Ash, Fat, CHO, Bulk Density, and Swelling power, respectively.

The mean values of the samples from the *Gliricidia*-groundnut intercropping treatment (T5) were higher for Fat, Crude fiber, CHO, and ME only when compared to the control (T7). The *Gliricidia*+groundnut intercropping did not significantly improve other nutritional properties such as protein, ash, and starch. Also, the *Gliricidia*+groundnut intercropping did not suppress the antinutritional properties (phytic and tannin). This implies that the effect of T4 is not pronounced as it only improves a few of the nutritional properties and there was no reduction in the antinutritional properties.

Goudiaby et al. (2020) also reported a non-significant effect of *Eucalyptus camaldulensis* intercropping with groundnut on the proximate content of the crop except for the grain yield. This implies that the *Gliricidia*+groundnut intercrop is better in improving groundnut nutritional parameters when compared to a treatment like the use of *E. camaldulensis*. In conclusion, the impacts due to *Gliricidia*+groundnut intercropping do not differ much from the control (groundnut only), as the treatment's essential nutritional properties were unaffected, and the treatment did not suppress the antinutritional factors.

Table 8 shows the effect of Treatment 5 (*Gliricidia*+groundnut intercrop) and Treatment 7 (control) on the mineral composition of groundnut. *Gliricidia* intercropping with groundnut significantly affects all groundnut mineral components except Nitrogen, Phosphorus, Potassium, and Iron. However, Sodium,

Table 7. Nutritional, antinutritional, and functional properties of groundnut by treatment (N = 84).

	Gliricidia+groundnut intercrop (T5)		Groundnut only (T7)			
Parameters	Mean	SD (*n*-1)	Mean	SD (*n*-1)	Pr > F(Treatment)	Pr > F(Farmer *Treatment)
Nutritional						
%MC	3.86a	0.14	3.85 a	0.14	0.878	0.071
%Ash	3.01a	0.05	3.00 a	0.11	0.850	0.144
%Fat	45.38a	13.50	43.95 a	16.01	0.057	0.013
% Protein	24.23a	3.94	24.23 a	4.74	0.973	<0.0001
%Sugar	3.97a	0.61	3.98 a	0.49	0.550	<0.0001
%Starch	12.73a	3.64	13.93 b	2.72	<0.0001	<0.0001
% Amylose	2.70a	0.55	2.91 b	0.38	<0.0001	<0.0001
%Amylopectin	97.30b	0.55	97.08 a	0.38	<0.0001	<0.0001
%Crude Fiber	2.85 b	0.913	2.42 a	0.487	<0.0001	<0.0001
%CHO	20.66 a	4.479	22.54 b	4.246	0.021	0.141
%ME	588.01a	18.22	582.67 a	20.47	0.004	0.008
Antinutritional						
% Phytate	15.19b	28.15	8.485 a	1.53	<0.0001	<0.0001
Tannin (mg/g)	29.94b	6.26	29.286 a	6.99	0.0002	<0.0001
Functional						
% WAC	135.441 a	604.14	141.21 b	522.48	0.034	<0.0001
BD (g/ml)	1.407 b	0.03	1.33 a	0.01	0.030	0.073
Swelling power	2.135 a	0.17	2.06 b	0.19	0.236	0.011
%Soluble	48.918a	22.86	50.65a	20.83	<0.0001	<0.0001
% OAC	93.608 a	132.57	101.38 a	59.77	<0.0001	<0.0001
Dispersibility	70.321a	5.26	69.61a	12.77	<0.0001	<0.0001

MC = moisture content; CHO = Total carbohydrate; WAC= Water Absorption Capacity; OAC= Oil Absorption Capacity, Mean values with different letters in the same row are significantly different ($P < 0.05$)

Table 8. Effect of treatment on the mineral composition of groundnut (N = 84).

	Gliricidia+groundnut intercrop (T5)		Groundnut only (T7)			
Parameter	Mean	SD (*n*-1)	Mean	SD (*n*-1)	Pr>F (Treatment)	Pr> F (Farmer*Treatment)
Nitrogen(%)	3.93 a	0.11	4.01 a	0.22	0.230	0.043
Phosphorus (%)	0.45 a	0.00	0.45 a	0.00	0.976	0.003
Calcium(%)	0.39 a	0.05	0.45 b	0.09	0.006	<0.0001
Magnesium(%)	0.19 b	0.00	0.18 a	0.00	0.0001	<0.0001
Potassium (%)	0.94 a	0.01	0.95 a	0.01	0.389	<0.0001
Sodium(ppm)	21.55 b	54.39	19.86 a	14.86	<0.0001	<0.0001
Manganese(ppm)	15.51 a	53.96	35.51 b	105.67	<0.0001	<0.0001
Iron(ppm)	18.36 a	16.05	18.87 a	10.54	0.195	<0.0001
Copper(ppm)	7.40 b	1.82	7.05 a	1.75	0.002	<0.0001
Zinc(ppm)	29.69 b	182.48	16.48 a	4.29	<0.0001	<0.0001

Mean values with different letters in the same row are significantly different (P <0.05)

Copper, and Zinc values increased with treatment 5 compared to Treatment 7 (control). Manganese concentration decreased from 35.51ppm (in T7) to 15.51ppm (in T5), while Zinc concentration increased from 16.48ppm (in T7) to 29.69ppm (in T5). This implies that *Gliricidia*+groundnut intercropping inhibits manganese uptake from the soil but promotes zinc uptake by the groundnut samples. Zinc is one of the critical micronutrients, and intercropping groundnut with *Gliricidia* trees could be an approach to address Zinc deficiency among the groundnut-consuming communities. The farmer x treatment interaction significantly affected all of the mineral parameters. This indicates environmental effects on groundnut sample mineral parameters, as Phan-Thien, Wright, and Lee (2010) reported. *Gliricidia*+groundnut intercropping improves the Zinc composition of groundnut samples, which implies it is a promising option to relieve Zinc deficiency amongst groundnut consumers.

Conclusion

Our findings from this study have shown that *Gliricidia sepium* influences the composition and concentration of nutrients in crops. *G sepium* intercropped with maize and soybean significantly improved the crops' nutritional composition. It shows a more pronounced effect on maize than soybean and groundnut. However, it decreases the antinutrients in soybean but not in groundnut. The potential of *G. sepium* on the agronomic and nutritional composition of other food crops, especially root and tuber crops, should be further explored. Mulching, biochar, intercropping, and leaf extracts must all be investigated to see how *G. sepium* affects food crop nutrition. This will result in a wealth of scientific knowledge about how to apply *Gliricidia* to various crops. Even though *G sepium* benefits farmers in the long run, its high initial cost prevents it from being widely adopted. To increase adoption, governments and research organizations should collaborate with low-income farmers to subsidize the initial cost of implementing the *Gliricidia* agroforestry technology. Agroforestry has the potential to increase smallholder farmers' resistance to climate change. Smallholders will likely experience a deterioration in food security because of climate change. Agroforestry is an option for enhancing climate change adaptation and contributing to food availability, income, health, and environmental stability. Agroforestry can be a good way for small-scale farmers to protect the environment and their finances by encouraging tree planting. It also creates more resilient agricultural systems in which the risk of crop failure is minimized and spread across various crops for food-insecure and food-starved communities.

Acknowledgments

The authors acknowledge the financial support from NORAD/Ministry of Foreign Affairs, Norway, and the support of all farmers participating in the study.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This project has received funding from the Norwegian Agency for Development Cooperation (Norad) under Saksnr: 1800165-18.

ORCID

Emmanuel Oladeji Alamu http://orcid.org/0000-0001-6263-1359
Njoloma Joyce http://orcid.org/0000-0002-5847-2604
Ngumayo Joel http://orcid.org/0009-0009-8191-8350
Mehreteab Tesfai http://orcid.org/0000-0001-9359-8723
Chikoye David http://orcid.org/0000-0002-6047-9821
Nyoka Isaac http://orcid.org/0000-0002-5118-5231
Nagothu Udaya Sekhar http://orcid.org/0000-0003-1273-8347

Data availability statement

The data supporting this study's findings are openly available at https://doi.org/10.25502/0fa9-dm27/d.

References

Addinsoft (2021). XLSTAT statistical and data analysis solution. New York, NY. accessed December 2022 https://www.xlstat.com/en.

Akinnifesi, F. K., O. C. Ajayi, G. Sileshi, P. W. Chirwa, and J. Chianu. 2010. Fertiliser trees for sustainable food security in the maize-based production systems of East and southern Africa. A review. *Agronomy for Sustainable Development* 30 (3):615–29. doi:10.1051/agro/2009058.

Alamu, E. O., M. Adesokan, S. Fawole, B. Maziya-Dixon, T. Mehreteab, and D. Chikoye. 2023. *Gliricidia sepium (Jacq.) Walp* applications for enhancing soil fertility and crop nutritional qualities: A review. *Forests* 14 (3):635. doi:https://doi.org/10.3390/f14030635.

Alamu, E. O., T. Gondwe, G. Akinwale, K. Suzuki, C. Chisonga, G. Chigeza, M.-D. Busie, and F. Yildiz. 2019. Impact of soil fertility management practices on the nutritional quality of soybean (Glycine max (l.) Merr.) varieties grown in eastern Zambia. *Cogent Food & Agriculture* 5 (1):10–13. doi:10.1080/23311932.2019.1671117.

Alamu, E. O., B. Maziya-Dixon, A. Menkir, M. Adesokan, and O. Olaofe. 2021. Assessment of functional and pasting properties of fresh orange maize hybrids and open-pollinated varieties as influenced by genotype, harvesting time, and growing location. *Frontiers in Nutrition* 8:757728. doi:10.3389/fnut.2021.757728.

Alamu, E. O., B. Olaniyan, and B. Maziya-Dixon. 2021. Diversifying the utilization of maize at household level in Zambia: Quality and consumer preferences of maize-based Snacks. *Foods* 10 (4):750. doi:10.3390/foods10040750.

Alamu, E. O., I. Popoola, and B. Maziya-Dixon. 2018. Effect of soybean (Glycine max (L.) Merr.) flour inclusion on the nutritional properties and consumer preference of fritters for improved household nutrition. *Food Science & Nutrition* 6 (7):1811–16. doi:10.1002/fsn3.751.

AOAC. 2005. Official methods of analysis. 18th. *Association of Official Analytical Chemists*. Washington, DC, USA: 10.1002/0471740039.vec028.

Asaam, E. S., J. Adubofuor, I. Amoah, and O. J. D. Apeku. 2018. Functional and pasting properties of yellow maize–soya bean–pumpkin composite flours and acceptability study on their breakfast cereals. *Cogent Food & Agriculture* 4 (1):1501932.

Ashraf, S., S. M. G. Saeed, S. A. Sayeed, and R. Ali. 2012. Impact of microwave treatment on the functionality of cereals and legumes. *International Journal of Agriculture & Biology* 14 (3):365–70.

Asibuo, J. Y., R. Akromah, O. Safo-Kantanka, H. K. Adu-Dapaah, S. Ohemeng-Dapaah, and A. Agyeman. 2008. Chemical composition of groundnut, *Arachis hypogaea* (L) landraces. *African Journal of Biotechnology* 7 (13):2203–08.

Atasie, V. N., T. F. Akinhanmi, and C. C. Ojiodu. 2009a. Proximate analysis and physico-chemical properties of groundnut (*Arachis hypogaea* L.). *Pakistan Journal of Nutrition* 8 (2):194–97. doi:10.3923/pjn.2009.194.197.

Awopegba, M., S. Oladele, and M. Awodun. 2017. Effect of mulch types on nutrient composition, maize (*Zea mays* L.) yield and soil properties of a tropical Alfisol in Southwestern Nigeria. *Eurasian Journal of Soil Science* 6 (2):121–33. doi:10.18393/ejss.286546.

Barros, F. M., R. Do, F. J. C. Fracetto, J. M. Lira, S. C. B. Bertini, and G. G. M. Fracetto. 2021. Spatial and seasonal responses of diazotrophs and ammonium-oxidizing bacteria to legume-based silvopastoral systems. *Applied Soil Ecology* 158:103797. doi:10.1016/j.apsoil.2020.103797.

Castrejon, F., P. Martínez-Pérez, L. Corona, J. Cerdán, and G. Mendoza. 2016. Partial substitution of soybean meal by *Gliricidia* sepium or Guazuma ulmifolia leaves in the rations of growing lambs. *Tropical Animal Health and Production* 48 (1):10.1007/s11250-015-0932–2. doi:10.1007/s11250-015-0932-2.

Chauhan, D., K. Kumar, N. Ahmed, P. Thakur, Q. U. E. H. Rizvi, S. Jan, and A. N. Yadav. 2022. Impact of soaking, germination, fermentation, and roasting treatments on nutritional, anti-nutritional, and bioactive composition of black soybean (glycine max L.). *Journal of Applied Biology and Biotechnology* 10 (5):186–92.

Coulibaly, J. Y., B. Chiputwa, T. Nakelse, and G. Kundhlande. 2017. Adoption of agroforestry and the impact on household food security among farmers in Malawi. *Agricultural Systems* 155:52–69. doi:10.1016/j.agsy.2017.03.017.

da Costa Leite, R., J. G. Donizetti dos Santos, R. da Costa Leite, L. Fernandes Sousa, G. O. de Sousa Soares, L. Fernandes Rodrigues, J. Santana da Silva Carneiro. 2019. Leguminous alley cropping improves the production. *Nutrition, and Yield of Forage Sorghum Agronomy* 9 (10):636. MDPI AG. doi:10.3390/agronomy9100636.

de Moura-Silva, A. G., A. D. C. F. Aguiar, E. G. de Moura, and N. Jorge. 2016. Influence of soil cover and N and K fertilization on the quality of biofortified QPM in the humid tropics. *Journal of the Science of Food and Agriculture* 96 (11):3807–12. doi:10.1002/jsfa.7574.

Dinesh, R., V. Srinivasan, S. Hamza, V. A. Parthasarathy, and K. C. Aipe. 2010. 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* 158 (3–4):252–58. doi:10.1016/j.geoderma.2010.04.034.

Diouf, A., M. Ndiaye, M. A. Fall-Ndiaye, and T. A. Diop. 2017. Maize crop N uptake from organic material of *Gliricidia sepium* inoculated with rhizobium and arbuscular mycorrhizal fungus in sub-Saharan Africa sandy soil. *American Journal of Plant Sciences* 8 (3):428–40. doi:10.4236/ajps.2017.83029.

Etiosa, O. R., N. B. Chika, and A. Benedicta. 2017. Mineral and proximate composition of soya bean. *Asian Journal of Physical and Chemical Sciences* 4 (3):1–6. doi:10.9734/AJOPACS/2017/38530.

Goudiaby, A. O. K., S. Diedhiou, Y. Diatta, A. Badiane, P. Diouf, S. Fall, M. D. Diallo, and N. Doyi. 2020. Soil properties and groundnut (*Arachis hypogea* L.) responses to intercropping with *Eucalyptus camaldulensis* Dehn and amendment with its biochar. *Journal of Materials and Environmental Sciences* 11:220–29.

Grygier, A., S. Chakradhari, K. Ratusz, M. Rudzinska, K. S. Patel, D. Lazdin, and P. Gornas. 2022. Seven underutilized species of the Fabaceae family with high potential for industrial application as alternative sources of oil and lipophilic bioactive compounds. *Industrial Crops & Products* 186:115251. doi:10.1016/j.indcrop.2022.115251.

Kim, D.-G., and M. E. Isaac. 2022. Nitrogen dynamics in agroforestry systems. A review. *Agronomy for Sustainable Development* 42 (4):60. doi:10.1007/s13593-022-00791-7.

Kuntashula, E., and P. L. Mafongoya. 2005. Farmer participatory evaluation of agroforestry trees in eastern Zambia. *Agricultural Systems* 84 (1):39–53. doi:10.1016/j.agsy.2004.06.009.

Leikam, D., L. C. Bonczkowski, J. S. Hickman, D. A. Whitney, and R. E. Lamond. 2007. *Using legumes in crop Rotations*. Kansas State University. http://www.ksre.ksu.edu/library/crpsl2/l778.pdf.

Mafongoya, P. L., E. Kuntashula, and G. Sileshi (2006). Managing soil fertility and nutrient cycles through fertilizer trees in southern Africa. ed. N. Uphoff, A. S. Ball, E. Fernandes, H. Herren, O. Husson, M. Liang, C. Palm, J. Pretty, P. Sanchez, N. Sanginga In *Biological Approaches to Sustainable Soil Systems*, 273–89. Taylor & Francis. doi:10.1201/9781420017113.ch19

Mehreteab, T., E. O. Alamu, J. B. Njoloma, S. N. Udaya, and J. Ngumayo. 2022. Agroecological farming approaches that enhance resilience and mitigation to climate change in vulnerable farming systems. In U. S. Nagothu, ed. *Climate Neutral and Resilient Farming Systems: Practical Solutions for Climate Mitigation and Adaptation*, 1st. Routledge. 10.4324/9781003273172.

Méndez-Bautista, J., F. Fernández-Luqueño, F. López-Valdez, R. Mendoza-Cristino, J. A. Montes-Molina, F. A. Gutierrez-Miceli, and L. Dendooven. 2009. 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* 76 (3):293–99. doi:10.1016/j.chemosphere.2009.04.007.

Nyirenda, H. 2019. Achieving sustainable agricultural production under farmer conditions in maize-*Gliricidia* intercropping in Salima District, central Malawi. *Heliyon* 5 (10):e02632. doi:10.1016/j.heliyon.2019.e02632.

Ogunyemi, A. M., B. O. Otegbayo, and J. A. Fagbenro. 2018. Effects of NPK and biochar fertilized soil on maize flour's proximate composition and mineral evaluation. *Food Science & Nutrition* 6 (8):2308–13. doi:10.1002/fsn3.808.

Oloruntola, O. D. 2018. *Gliricidia* leaf meal in broiler chickens diet: Effects on performance, carcass, and haemato-biochemical parameters. *Journal of Applied Life Sciences International* 18 (3):1–9. doi:10.9734/JALSI/2018/43813.

Oyeyinka, S. A., A. T. Oyeyinka, O. R. Karim, R. M. O. Kayode, M. A. Balogun, and O. A. Balogun. 2013. Qualitysttributes of Weevils (callosobruchus Maculatus)infested cowpea (Vigna Unguiculata) products. *Nig. J.Of Agric. Food. and Environ* 9 (3):16–22.

Phan-Thien, K.-Y., G. C. Wright, and N. A. Lee. 2010. Genotype-by-environment interaction affects the essential mineral composition of peanut (Arachis hypogaeaL.) Kernels. *Journal of Agricultural and Food Chemistry* 58 (16):9204–13. doi:10.1021/jf101332z.

Rahman, M., A. Das, S. Saha, and M. Uddin. 2019. Morphophysiological response of *Gliricidia sepium* to seawater-induced salt stress. *The Agriculturists* 17:66–75. doi:10.3329/agric.v17i1-2.44697.

Romero, N., C. Areche, J. Cubides-Cárdenas, N. Escobar, O. García-Beltrán, M. J. Simirgiotis, and Á. Céspedes. 2020. In vitro anthelmintic evaluation of *Gliricidia* sepium, Leucaena leucocephala, and Pithecellobium dulce: Fingerprint analysis of extracts by UHPLC-orbitrap mass spectrometry. *Molecules* 25 (13):3002. doi:10.3390/molecules25133002.

Sileshi, G. W., L. K. Debusho, and F. K. Akinnifesi. 2012. Can Integration of legume trees increase yield stability in rainfed maize cropping systems in southern Africa? *Agronomy Journal* 104 (5):1392–98. doi:10.2134/agronj2012.0063.

Sosulski, F. W., E. S. Humbert, E. S. Bui, and J. I. Jones. 1976. Functional properties of rapeseed flours concentrates and isolates. *Journal of Food Science* 41:1349–51. doi:10.1111/j.1365-2621.1976.tb01168.x.

Swamila, M., D. Philip, A. M. Akyoo, J. Manda, L. Mwinuka, P. J. Smethurst, and A. A. Kimaro. 2021. Profitability of *Gliricidia*+maize system in selected dryland areas of Dodoma region, Tanzania. *Sustainability* 14 (1):53. doi:10.3390/su14010053.

Tesfai, M., A. O. Emmanuel, J. B. Njoloma, U. S. Nagothu, and J. Ngumayo. 2022. Agroecological farming approaches that enhance resilience and mitigation to climate change in vulnerable farming systems. In *Climate Neutral and Resilient Farming Systems*, 147–68. Routledge.

Vithanage, M., A. U. Rajapaksha, C. Oze, N. Rajakaruna, and C. Dissanayake. 2014. Metal release from serpentine soils in Sri Lanka. *Environmental Monitoring and Assessment* 186 (6):3415–29. doi:10.1007/s10661-014-3626-8.

Wartenberg, A. C., W. J. Blaser, A. Gattinger, J. M. Roshetko, M. Van Noordwijk, and J. Six. 2017. Does shade tree diversity increase soil fertility in cocoa plantations? *Agriculture, Ecosystems & Environment* 248:190–99. doi:10.1016/j.agee.2017.07.033.

Wheal, M. S., T. O. Fowles, and L. T. Palmer. 2011. A cost-effective acid digestion method using closed polypropylene tubes for inductively coupled plasma optical emission spectrometry (ICP-OES) analysis of plant essential elements. *Analytical Methods* 3 (12):2854–63.

Yadav, J., V. V. Gabhane, A. Shelke, A. Rathod, U. Satpute, and A. Chandel. 2020. Effect of potash management through *Gliricidia* green leaf manuring on soil fertility and yield of soybean in Vertisols. *Journal of Pharmacognosy & Phytochemistry* 9 (2):1033–1037.s. doi:10.22271/chemi.2021.v9.i2l.11913.