

# Effect of Agroforestry and Conventional Cropping Systems on Potato (*Solanum tuberosum* L.) Productivity and Pest Management in Menoua Division, West Cameroon

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## Abstract

This study assessed the agronomic performance, pest and disease dynamics, and economic profitability of three potato production systems—conventional system with chemical inputs (CS), agroforestry system with *Gliricidia sepium* biomass (AFS), and a control system without any inputs (CP)—in the Menoua Division of West Cameroon. A randomized complete block design was employed to evaluate growth parameters, tuber yield, pest and disease incidence, and financial returns over a single cropping cycle. The conventional system produced the highest tuber yield (38.97 t/ha), followed by AFS (25.42 t/ha), while the control system yielded the least (10.53 t/ha). Growth parameters, including plant height, crown diameter, leaf area, and number of lateral branches, were significantly superior under CS, although AFS gradually caught up at mid-growth stages due to sustained nutrient release from *Gliricidia* biomass. Downy mildew (*Phytophthora infestans*) severity and incidence were effectively suppressed in both CS and AFS, with no significant differences observed between them at 76 days after sowing (DAS), while CP exhibited the highest disease pressure. For insect pests, AFS consistently outperformed both CS and CP in minimizing incidence and severity of leaf-eating caterpillars and whiteflies. While CS achieved early pest suppression through chemical control, its effectiveness declined over time, resulting in pest levels similar to or exceeding those of the control by late growth stages. Economic analysis revealed that CS generated the highest absolute profit but incurred the highest production costs. In contrast, AFS demon-

strated highly competitive profitability (324.61%) and strong value-cost ratio (VCR 4.24), offering substantial economic benefits while reducing dependence on costly external inputs. These findings highlight agroforestry as a sustainable and economically viable alternative for smallholder potato producers, delivering strong agronomic performance, effective pest management, and improved financial returns under resource-limited conditions.

## Keywords

Potato, Agroforestry, *Gliricidia sepium*, Profitability, Pest Management

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## 1. Introduction

Potato (*Solanum tuberosum* L.) is the third most important food crop globally, after rice and wheat, and plays a vital role in food security and income generation, especially in developing countries [1]. As a staple crop rich in carbohydrates, vitamins, and minerals, potatoes are crucial for both subsistence and commercial agriculture in Sub-Saharan Africa, including Cameroon [2]. In Cameroon, potato cultivation has significantly expanded, particularly in the Western Highlands, where agro-ecological conditions are favorable [3]. However, smallholder farmers face multiple challenges, including declining soil fertility, pest and disease outbreaks, and the adverse effects of climate change, which compromise yields and sustainability [4]. To address these challenges, there is a growing interest in sustainable agricultural practices such as agroforestry, which integrates trees with crops and/or livestock [5]. Agroforestry systems have been shown to improve soil fertility through biological nitrogen fixation, enhance biodiversity, and provide microclimate regulation, which can suppress pest populations and reduce the need for chemical inputs [6]. In contrast, conventional agricultural systems, characterized by monocultures and high chemical input usage, often yield higher short-term productivity but may lead to long-term environmental degradation and increased vulnerability to pests and diseases [7]. In the Menoua Division of West Cameroon, where potato is widely cultivated, conventional farming systems are still dominant. Yet, the region is experiencing escalating pressure on land, coupled with erratic weather patterns and growing concerns about pesticide misuse. These issues have prompted researchers and policymakers to explore alternative production models that ensure productivity while maintaining ecological balance and economic viability. Despite growing literature on agroforestry and sustainable intensification, limited empirical evidence exists on the comparative performance of agroforestry and conventional systems in potato production in Cameroon. This study aims to fill that gap by evaluating the productivity, pest incidence, and economic performance of potato grown under three different production modes: agroforestry, conventional without chemical inputs, and conventional with chemical inputs. The results will provide valuable insights into the potential trade-offs and synergies between productivity, pest management, and profitability in different production modes,

thereby informing more sustainable agricultural practices for smallholder farmers in Cameroon and similar contexts.

## 2. Materials and Methods

### 2.1. Study Area

The experiment was conducted from March to July 2023 in Fokoué Subdivision, Menoua Division, Western Region of Cameroon. This area lies within the Western Highlands agro-ecological zone, characterized by volcanic soils, relatively mild temperatures, and high rainfall. The geographical coordinates range between 5°16'N-5°25'N and 10°15'E-10°30'E, with an average elevation of 1500 meters above sea level. The region experiences a bimodal rainfall pattern, with peaks in April-June and August-October, and annual precipitation between 1800 and 2000 mm. The mean annual temperature ranges from 20°C to 24°C. The predominant soil types are Andosols and Ferralsols, which are well-drained and fertile but susceptible to erosion on slopes [8] [9].

### 2.2. Experimental Design and Treatments

The experiment was conducted using a Randomized Complete Block Design (RCBD) comprising three treatments, each replicated three times, resulting in a total of nine plots. Each plot measured 12 meters by 5 meters (60 m<sup>2</sup>), with 1-meter alleys separating plots and blocks to minimize edge effects and facilitate farm operations.

The treatments were as follows:

- T1—Agroforestry System (AFS): Intercropping of potato with *Gliricidia sepium* hedgerows. Nutrient input was exclusively from green manure derived from *Gliricidia* biomass. No synthetic fertilizers or pesticides were applied.
- T2—Conventional System without Inputs (CP): Potato monoculture without the application of either organic or inorganic fertilizers or pesticides.
- T3—Conventional System with Inputs (CS): Potato monoculture receiving full recommended doses of chemical fertilizers and pesticides based on agronomic guidelines.

### 2.3. Land Preparation and Establishment

Land was manually cleared using machetes and hoes. Ridges were constructed 75 cm apart. For the agroforestry system, *Gliricidia sepium* stakes of approximately 1.5 meters in length were planted along the ridges at 2 m inter-row and 1.5 m intra-row spacing two months prior to potato planting to ensure sufficient biomass production for initial pruning. These hedgerows ran perpendicular to the slope to reduce erosion.

Seed tubers of the improved variety “Cipira” were sourced from the Institute of Agricultural Research for Development (IRAD) in Dschang. Tubers were cut into 40 - 60 g pieces with at least one viable eye and treated with wood ash to prevent fungal infections. Tubers were planted manually at a spacing of 30 cm within rows,

resulting in 120 plants per plot.

The management of *Gliricidia* hedgerows was standardized to ensure consistency across plots. Stakes were initially planted two months before potato planting. Pruning was carried out every two weeks during the potato growth cycle, maintaining hedgerow height at approximately 1.0 - 1.2 meters. This allowed sufficient light penetration and regular biomass supply for green manure application.

#### 2.4. Soil Fertility and Input Application

- In T1 (AFS), *Gliricidia* biomass was pruned and incorporated into ridges at planting at a rate of 6 tons/ha (fresh weight) and reapplied every two weeks during the growing season.
- In T2 (CP), no soil amendments were applied.
- In T3 (CS), NPK 20:10:10 was applied at 200 kg/ha during planting and Urea at 100 kg/ha split between hilling (30 DAP) and flowering (60 DAP).

#### 2.5. Pest and Disease Management

- T1 and T2 did not receive any chemical pest or disease control.
- In T3, disease control was done using Metalaxyl-based fungicide (Ridomil Gold) applied biweekly at 2.5 g/L, and insect control was provided with Lambda-cyhalothrin (Karate 5 EC) at 1.5 mL/L water, sprayed using a knapsack sprayer. All treatments were manually weeded at 15, 35, and 55 DAP using hoes. No irrigation was applied; the crop depended entirely on rainfall.

#### 2.6. Data Collection

##### 2.6.1. Agronomic Parameters

Growth parameters were recorded at 34, 48, 62 and 76 DAP using 10 randomly selected and tagged plants per plot:

- Plant height (cm): Measured from soil surface to apical meristem using a measuring tape.
- Stem diameter (mm): Measured using a digital caliper 5 cm above ground.
- Number of leaves: Counted from base to apex.
- Leaf area was measured using a portable leaf area meter (model LI-3000C, LICOR Biosciences, USA). Measurements were taken on fully expanded upper third leaves from 10 randomly selected and tagged plants per plot at each observation date. The leaf area meter directly provided values in cm<sup>2</sup>, which were recorded for analysis.

##### 2.6.2. Yield Parameters

At maturity (90 - 110 DAP), the following were recorded:

- Number of tubers per plant;
- Fresh tuber weight per plot (kg);
- Marketable tuber yield (kg): Tubers > 30 mm diameter, clean and undamaged.

Yields were converted to tons per hectare (t/ha) for comparison using the for-

mula:

$$\text{Yield} \left( \frac{\text{t}}{\text{ha}} \right) = \left( \frac{\text{Yield per plot (kg)} \times 10000}{\text{Plot area (m}^2\text{)}} \right) \div 1000 \quad (1)$$

### 2.6.3. Pest and Disease Incidence and Severity

Scouting for pests and diseases began at 30 DAP and was conducted weekly until harvest. Each plot was assessed using the International Potato Center (CIP) [10] Visual Rating Scale (0 - 5):

- 0 = no visible symptoms;
- 1 - 2 = mild;
- 3 = moderate;
- 4 - 5 = severe.

Visual inspection and hand lens identification were used to monitor for:

- Downy mildew;
- Leaf-eating caterpillar;
- Whitefly.

The severity scores (0 - 5) were converted into severity indices following the CIP Visual Rating Scale using the formula:

$$\begin{aligned} & \text{Pest Severity Index} \\ & = \frac{\sum (\text{Rating} \times \text{Number of plants at that rating})}{\text{Total number of plants observed} \times \text{Maximum rating scale of 5}} \end{aligned} \quad (2)$$

### 2.7. Economic Analysis

An economic evaluation was conducted to assess the profitability of each cropping system. Total production cost (CP) was calculated by summing all variable costs associated with the production process, including the costs of seeds, fertilizers (organic and chemical), phytosanitary products (insecticides and fungicides), labor (for land preparation, ridging, input application, harvesting, and packaging), and transportation of inputs and harvested produce.

Interest on investment (II) was calculated as 10% of the total production cost, reflecting the opportunity cost of capital and risk associated with production activities, using the formula:

$$\text{II} = \text{CP} \times 10\% \quad (3)$$

The 10% interest rate reflects local credit interest rates for smallholder farmers in Cameroon during the study period, incorporating both opportunity cost and production risk. The market price of 14,000 FCFA per 50 kg bag was based on the prevailing average farm-gate prices during the cropping season, gathered from local markets in Menoua Division.

The market price (MP) was computed as the sum of the total production cost and interest on investment:

$$\text{MP} = \text{CP} + \text{II} \quad (4)$$

Sales of yield (SOY) were determined by multiplying the total marketable yield,

expressed in number of 50 kg bags, by the prevailing local market price per bag, which was 14,000 FCFA:

$$\text{SOY} = \text{Number of 50 kg bags} \times 14000 \text{ FCFA} \quad (5)$$

The profit for each system was calculated as the difference between the sales revenue and market price:

$$\text{Profit} = \text{SOY} - \text{MP} \quad (6)$$

Profitability was expressed as a percentage, calculated by dividing the profit by the market price and multiplying by 100:

$$\text{Profitability}(\%) = \frac{\text{Profit}}{\text{MP}} \times 100 \quad (7)$$

The value-cost ratio (VCR), which measures the return on each unit of currency invested, was calculated as:

$$\text{VCR} = \frac{\text{SOY}}{\text{CP}} \quad (8)$$

This profitability assessment was applied to all three production systems: the Agroforestry System (AFS), Conventional System (CS), and Control Plot (CP). All monetary values were expressed in FCFA (Central African CFA franc).

## 2.8. Statistical Analysis

Data were analyzed using R version 4.2.2. A Shapiro-Wilk test checked for normality, and Levene's test assessed homogeneity of variance. Parametric variables were subjected to One-way ANOVA, and significant differences were further tested using Tukey's HSD at  $\alpha = 0.05$ . Non-parametric data (e.g. pest severity scores) were analyzed using the Kruskal-Wallis H test, with pairwise comparisons using the Dunn test. Data visualization was performed with the ggplot2 and dplyr packages.

## 3. Results

### 3.1. Chemical Composition of Experimental Site Soil and *Gliricidia sepium* Biomass Prior to Trial Implementation

Prior to the implementation of the experiment, the chemical properties of the soils in the agroforestry and conventional plots were analyzed to determine baseline fertility conditions (**Table 1**).

The pH of the agroforestry soil was moderately acidic ( $\text{pH}_{\text{H}_2\text{O}} = 5.8$ ;  $\text{pH}_{\text{KCl}} = 4.7$ ), while the conventional plot exhibited slightly less acidity ( $\text{pH}_{\text{H}_2\text{O}} = 6.2$ ;  $\text{pH}_{\text{KCl}} = 5.0$ ). Organic matter content (MO) was higher in the agroforestry system at 5.19%, compared to 4.3% in the conventional plot. Similarly, the carbon content (CO) was 3.01% in the agroforestry plot and 2.5% in the conventional plot. However, total nitrogen (N) content was notably higher in the conventional soil (0.125%) than in the agroforestry system (0.063%), reflecting potentially greater nutrient reserves from past chemical inputs.

**Table 1.** Soil chemical properties prior to trial implementation.

Sample code	Agroforestry system	Conventional system
Sand (%)	39	38
Silt (%)	30	32
Clay (%)	31	32
p <sup>H</sup> eau	5.8	6.2
p <sup>H</sup> KCl	4.7	5
CO (%)	3.01	2.5
MO (%)	5.19	4.3
N (%)	0.063	0.125
C/N	48	20
Ca (meq/100g)	2.72	3.12
Mg (meq/100g)	1.04	1.2
K (meq/100g)	0.83	1.5
Na (meq/100g)	0.22	0.29
Sum of exchangeable bases	4.61	5.84
CEC (meq/100g)	14.25	13.75
Base Saturation	32.36	42.47
P (mg/kg)	12.22	17.66

Source: Soil Analysis and Environmental Chemistry Research Unit, FASA UDS, 2024.

The carbon-to-nitrogen (C/N) ratio was considerably higher in the agroforestry soil (48) than in the conventional soil (20), suggesting a higher amount of organic residue that could mineralize more slowly, hence supporting long-term soil fertility. In terms of exchangeable bases, calcium (Ca<sup>2+</sup>) was slightly higher in the conventional soil (3.12 meq/100g) than in the agroforestry system (2.72 meq/100g). Magnesium (Mg<sup>2+</sup>), potassium (K<sup>+</sup>), and sodium (Na<sup>+</sup>) concentrations followed a similar pattern, with higher values in the conventional soil: Mg<sup>2+</sup> = 1.2 vs. 1.04 meq/100g; K<sup>+</sup> = 1.5 vs. 0.83 meq/100g; Na<sup>+</sup> = 0.29 vs. 0.22 meq/100g for conventional and agroforestry soils, respectively.

The sum of base exchange (SBE) was 5.84 meq/100g for the conventional system and 4.61 meq/100g for the agroforestry system. Cation exchange capacity (CEC), which reflects the soil's ability to hold nutrients, was slightly higher in the agroforestry system (14.25 meq/100g) compared to the conventional system (13.75 meq/100g), indicating better potential for nutrient retention despite lower base saturation. Base saturation percentage (V%) was considerably higher in the conventional soil (42.47%) than in the agroforestry soil (32.36%). Finally, the concentration of available phosphorus (P) was 17.66 mg/kg in the conventional soil and 12.22 mg/kg in the agroforestry soil, indicating a richer phosphorus status in the former.

Overall, the conventional soil exhibited higher immediate nutrient availability, particularly for nitrogen, potassium, calcium, and phosphorus, while the agroforestry system showed higher organic matter content and a more favorable CEC, suggesting better long-term fertility sustainability.

### 3.2. Results on the Chemical Analysis of *Gliricidia sepium* Leaf Biomass

The chemical analysis of *Gliricidia sepium* leaf biomass revealed its potential as a valuable organic amendment (Table 2). The results showed that the dry biomass contained: Nitrogen (N): 3.72%, Phosphorus (P): 0.62%, Potassium (K): 2.27% and Organic matter (OM): 7.745%. These nutrient concentrations translate to substantial quantities of plant-available elements when biomass is applied to soil at field scale. Based on an average application rate of approximately 10.55 tons of fresh biomass per hectare, the corresponding fertilizing element contributions were estimated as follows: Nitrogen (N): 82.27 kg/ha, Phosphorus (P): 13.71 kg/ha, Potassium (K): 50.20 kg/ha Organic matter: 1712.85 kg/ha (approximately 1.71 tons/ha of organic matter). These figures demonstrate that *Gliricidia sepium* can serve as a low-cost and sustainable source of macro-nutrients, especially nitrogen and potassium, which are vital for vegetative growth and tuber development in potato. Its high organic matter content also contributes to improved soil structure, moisture retention, and microbial activity. The biomass thus plays a dual role—providing nutrients and enhancing long-term soil fertility.

**Table 2.** Average chemical element content (%) of *Gliricidia sepium* leaf biomass.

Parameter	Nitrogen	Phosphorus	Potassium	Organic matter
Value (%)	3.72	0.62	2.27	7.745

Prior to potato planting, *Gliricidia sepium* prunings were applied as green manure in the agroforestry plots. The average biomass production per tree was 5.38 kg of fresh biomass, which upon drying yielded 1.538 kg of dry biomass. When extrapolated to field scale, the fresh biomass contribution was estimated at 10,552.61 kg per hectare (10.55 t/ha), which corresponded to 3,165.62 kg per hectare (3.17 t/ha) of dry matter (Table 3).

**Table 3.** Quantity of *Gliricidia sepium* biomass applied.

Parameter	Fresh biomass (kg)	Dry biomass (kg)
Biomass per tree	5.38	1.538
Biomass per hectare	10552.61	3165.62

### 3.3. Agronomic Performance of Different Production Methods on Potato Growth and Productivity Variables

#### 3.3.1. Crown Diameter

The crown diameter, representing stem thickness at the base of the plant, was used

as a key indicator of vegetative vigor across different cropping systems. Measurements were taken at 34, 48, 62, and 76 days after planting (DAP), and the results revealed significant differences among the cropping strategies (Table 4).

**Table 4.** Crown diameter of potato plants under different cropping systems

Days after planting (DAP)	Contrast	Contrast value	Degree of freedom	T ratio	p-value
34	AFS vs CS	$-0.65 \pm 0.34$	69	-1.887	0.065 <sup>ns</sup>
	AFS vs CP	$1.20 \pm 0.34$	69	3.502	<0.001 <sup>***</sup>
	CS vs CP	$1.85 \pm 0.34$	69	-5.380	<0.001 <sup>***</sup>
	AFS and CS vs CP	$3.05 \pm 0.34$	69	5.128	<0.001 <sup>***</sup>
48	AFS vs CS	$-1.07 \pm 0.36$	69	-2.99	0.004 <sup>**</sup>
	AFS vs CP	$1.00 \pm 0.36$	69	2.80	0.007 <sup>**</sup>
	CS vs CP	$2.07 \pm 0.36$	69	5.78	<0.001 <sup>***</sup>
	AFS and CS vs CP	$3.08 \pm 0.62$	69	4.96	<0.001 <sup>***</sup>
62	AFS vs CS	$-0.94 \pm 0.39$	69	-2.40	0.019 <sup>*</sup>
	AFS vs CP	$1.50 \pm 0.39$	69	3.81	<0.001 <sup>***</sup>
	CS vs CP	$2.44 \pm 0.39$	69	6.21	<0.001 <sup>***</sup>
	AFS and CS vs CP	$3.94 \pm 0.68$	69	5.79	<0.001 <sup>***</sup>
76	AFS vs CS	$-1.54 \pm 0.41$	69	-3.49	<0.001 <sup>***</sup>
	AFS vs CP	$1.50 \pm 0.33$	69	4.58	<0.001 <sup>***</sup>
	CS vs CP	$3.04 \pm 0.45$	69	6.74	<0.001 <sup>***</sup>
	AFS and CS vs CP	$4.54 \pm 0.65$	69	6.95	<0.001 <sup>***</sup>

AFS: Corridor agroforestry system; CS: Conventional system; CP: Control plot. \* $p < 0.05$ ; \*\* $p < 0.01$ ; \*\*\* $p < 0.001$ ; ns: Not significant.

At 34 DAP, no significant difference was observed between the corridor agroforestry system (AFS) and the conventional system (CS) (Difference value =  $-0.65 \pm 0.34$  mm;  $p = 0.065$ ), indicating a similar early-stage growth response. However, the crown diameter in AFS was significantly greater than in the control plot (CP) by  $1.20 \pm 0.34$  mm ( $p = 0.001$ ), while CS significantly outperformed CP by  $1.85 \pm 0.34$  mm ( $p < 0.001$ ). Combined, both AFS and CS significantly outperformed CP at this stage (contrast =  $3.05 \pm 0.34$  mm;  $p < 0.001$ ).

By 48 DAP, clear distinctions were established among the systems. CS had a significantly greater crown diameter than AFS ( $-1.07 \pm 0.36$  mm;  $p = 0.004$ ), and both systems again significantly outperformed CP (AFS vs CP =  $1.00 \pm 0.36$  mm; CS vs CP =  $2.07 \pm 0.36$  mm;  $p < 0.01$  for both). The combined contrast of AFS and CS versus CP was  $3.08 \pm 0.62$  mm ( $p < 0.001$ ), reflecting substantial improvements in stem development under fertilized or organically enriched conditions.

At 62 DAP, crown diameter continued to favor CS over AFS ( $-0.94 \pm 0.39$  mm;

$p = 0.019$ ). AFS significantly outperformed CP by  $1.50 \pm 0.39$  mm ( $p < 0.001$ ), and CS exceeded CP by  $2.44 \pm 0.39$  mm ( $p < 0.001$ ). The cumulative contrast of AFS and CS over CP was  $3.94 \pm 0.68$  mm ( $p < 0.001$ ), showing sustained superiority of managed systems in enhancing stem robustness.

By 76 DAP, CS still had a significantly higher crown diameter than AFS ( $-1.54 \pm 0.41$  mm;  $p < 0.001$ ), while AFS significantly outperformed CP by  $1.50 \pm 0.33$  mm ( $p < 0.001$ ). The difference between CS and CP was even greater at  $3.04 \pm 0.45$  mm ( $p < 0.001$ ). Overall, AFS and CS together showed a  $4.54 \pm 0.65$  mm advantage over CP ( $p < 0.001$ ), highlighting the compounding benefits of nutrient input and integrated soil fertility management.

### 3.3.2. Plant Height

Plant height differed significantly across the three cropping systems—corridor agroforestry system (AFS), conventional system with fertilizer (CS), and the control plot (CP)—over the course of the growing season, measured at 34, 48, 62, and 76 days after sowing (DAS) (Table 5).

**Table 5.** Plant height of potato under different cropping systems.

Days after planting (DAP)	Contrast	Contrast value	Degree of freedom	T ratio	p-value
34	AFS vs CS	$-6.17 \pm 2.10$	69	-2.929	0.005**
	AFS vs CP	$4.67 \pm 2.10$	69	2.217	0.030*
	CS vs CP	$10.83 \pm 2.10$	69	5.146	<0.001***
	AFS and CS vs CP	$15.50 \pm 3.65$	69	4.251	<0.001***
48	AFS vs CS	$-9.17 \pm 2.19$	69	-4.178	<0.001***
	AFS vs CP	$10.92 \pm 2.19$	69	4.975	<0.001***
	CS vs CP	$20.08 \pm 2.19$	69	5.953	<0.001***
	AFS and CS vs CP	$31.00 \pm 3.80$	69	8.157	<0.001***
62	AFS vs CS	$0.00 \pm 2.86$	69	0.00	1.000 <sup>ns</sup>
	AFS vs CP	$31.06 \pm 2.89$	69	10.747	<0.001***
	CS vs CP	$31.06 \pm 2.89$	69	10.747	<0.001***
	AFS and CS vs CP	$62.11 \pm 5.02$	69	12.366	<0.001***
76	AFS vs CS	$12.42 \pm 4.20$	69	2.951	<0.001***
	AFS vs CP	$40.92 \pm 3.79$	69	10.792	<0.001***
	CS vs CP	$28.50 \pm 3.06$	69	9.299	<0.001***
	AFS and CS vs CP	$69.42 \pm 5.46$	69	12.710	<0.001***

AFS: Agroforestry system; CS: Conventional system; CP: Control plot. \* $p < 0.05$ ; \*\* $p < 0.01$ ; \*\*\* $p < 0.001$ ; ns: Not significant.

At 34 DAS, plant height in the CS system was significantly greater than in both AFS and CP. The difference between CS and CP was  $10.83 \pm 2.10$  cm ( $p < 0.001$ ),

while AFS also exceeded CP by  $4.67 \pm 2.10$  cm ( $p = 0.030$ ). However, CS significantly outperformed AFS by  $6.17 \pm 2.10$  cm ( $p = 0.005$ ), indicating that early vegetative growth was more pronounced in the fertilized conventional plots than in the agroforestry system, where nutrient release from biomass was likely slower.

By 48 DAS, the disparity among treatments became more evident. CS plants remained significantly taller than those in AFS, with a mean difference of  $9.17 \pm 2.19$  cm ( $p < 0.001$ ). AFS continued to maintain a significant lead over CP, registering a  $10.92 \pm 2.19$  cm advantage ( $p < 0.001$ ). The CS plants were  $20.08 \pm 2.19$  cm taller than those in CP ( $p < 0.001$ ), and the combined effect of AFS and CS compared to CP was highly significant, with a cumulative difference of  $31.00 \pm 3.80$  cm ( $p < 0.001$ ). This reflects the compounding influence of both organic and inorganic nutrient inputs on vegetative development during mid-growth.

Interestingly, at 62 DAS, plant heights in AFS and CS were statistically equivalent ( $p = 1.000$ ), both systems producing an identical increase of  $31.06 \pm 2.89$  cm over CP ( $p < 0.001$ ). This suggests that the nutrient release from *Gliricidia sepium* biomass in the AFS system had fully taken effect by this stage, resulting in vegetative performance comparable to that observed under chemical fertilization. The combined effect of AFS and CS relative to CP reached  $62.11 \pm 5.02$  cm ( $p < 0.001$ ), marking a significant divergence in growth performance from the control.

At 76 DAS, CS once again demonstrated superior plant height, surpassing AFS by  $12.42 \pm 4.20$  cm ( $p = 0.001$ ), likely due to the sustained availability of nitrogen from mineral fertilizers. Despite this, AFS maintained a strong advantage over CP, with a difference of  $40.92 \pm 3.79$  cm ( $p < 0.001$ ), while CS was  $28.50 \pm 3.06$  cm taller than CP ( $p < 0.001$ ). The joint comparison of AFS and CS with CP revealed a highly significant combined difference of  $69.42 \pm 5.46$  cm ( $p < 0.001$ ), confirming the overall positive influence of nutrient input—regardless of source—on final plant height.

These results demonstrate that while chemical fertilizers in the CS treatment provided a quicker and more sustained boost to plant height, the agroforestry system (AFS) was able to match and even approach the same level of vegetative performance at mid-season due to the delayed but effective nutrient release from *Gliricidia sepium* biomass. The control system consistently underperformed across all stages, reflecting the negative impact of nutrient deficiency on potato growth.

### 3.3.3. Number of Lateral Branches

The number of lateral branches per plant, an important morphological trait linked to canopy development and potential yield formation, showed variable responses to cropping systems across the different days after sowing (DAS) (**Table 6**).

At 34 DAS, there were no statistically significant differences among the three systems. The difference between AFS and CS was  $-0.62 \pm 0.74$  ( $p = 0.470$ ), between AFS and CP was  $0.17 \pm 0.74$  ( $p = 0.794$ ), and between CS and CP was  $0.79 \pm 0.74$  ( $p = 0.285$ ). Even the combined effect of AFS and CS compared to CP was not statistically significant ( $p = 0.371$ ), indicating that early branching was not influenced by treatment at this stage.

**Table 6.** Number of lateral branches in potato plants under different cropping systems.

Days after planting (DAP)	Contrast	Contrast value	Degree of freedom	T ratio	p-value
34	AFS vs CS	$-0.62 \pm 0.74$	69	-0.731	0.470 <sup>ns</sup>
	AFS vs CP	$0.17 \pm 0.74$	69	0.263	0.794 <sup>ns</sup>
	CS vs CP	$0.79 \pm 0.74$	69	1.086	0.285 <sup>ns</sup>
	AFS and CS vs CP	$0.96 \pm 1.29$	69	0.900	0.371 <sup>ns</sup>
48	AFS vs CS	$-3.62 \pm 1.17$	69	-3.152	0.03 <sup>**</sup>
	AFS vs CP	$-1.29 \pm 0.94$	69	-1.375	0.179 <sup>ns</sup>
	CS vs CP	$2.33 \pm 0.87$	69	2.668	0.012 <sup>**</sup>
	AFS and CS vs CP	$1.04 \pm 1.40$	69	0.741	0.46 <sup>ns</sup>
62	AFS vs CS	$-9.75 \pm 4.09$	69	-2.384	0.024 <sup>**</sup>
	AFS vs CP	$6.46 \pm 1.30$	69	4.981	<0.001 <sup>***</sup>
	CS vs CP	$16.20 \pm 3.94$	69	4.111	<0.001 <sup>***</sup>
	AFS and CS vs CP	$22.67 \pm 4.21$	69	5.382	<0.001 <sup>***</sup>
76	AFS vs CS	$-0.96 \pm 1.83$	69	0.524	0.603 <sup>ns</sup>
	AFS vs CP	$4.08 \pm 1.21$	69	3.378	0.002 <sup>***</sup>
	CS vs CP	$3.12 \pm 1.56$	69	2.004	0.055 <sup>ns</sup>
	AFS and CS vs CP	$7.21 \pm 2.11$	69	3.420	0.001 <sup>***</sup>

AFS: Agroforestry system; CS: Conventional system; CP: Control plot. \* $p < 0.05$ ; \*\* $p < 0.01$ ; \*\*\* $p < 0.001$ ; ns: Not significant.

However, by 48 DAS, a significant difference emerged between AFS and CS, with the conventional system recording a higher number of lateral branches than the agroforestry system, as shown by a difference of  $-3.62 \pm 1.17$  ( $p = 0.030$ ). AFS and CP remained statistically similar ( $p = 0.179$ ), while CS significantly outperformed CP by  $2.33 \pm 0.87$  branches ( $p = 0.012$ ). The combined contrast of AFS and CS versus CP was still not statistically significant ( $p = 0.468$ ), suggesting that although CS clearly promoted branching, the overall combined treatment effect had not yet differentiated enough from the control.

A more distinct pattern developed at 62 DAS. The number of lateral branches in the CS system was significantly greater than in both AFS and CP. The difference between AFS and CS reached  $-9.75 \pm 4.09$  ( $p = 0.024$ ), indicating a strong advantage of the fertilized conventional system over agroforestry in terms of lateral shoot production. AFS, however, significantly exceeded CP by  $6.46 \pm 1.30$  branches ( $p < 0.001$ ), and CS was  $16.20 \pm 3.94$  branches ahead of CP ( $p < 0.001$ ). These trends were reinforced by the combined contrast between AFS and CS versus CP, which showed a highly significant difference of  $22.67 \pm 4.21$  ( $p < 0.001$ ).

At 76 DAS, the trend continued, though with some leveling off between the two managed systems. The AFS and CS systems did not differ significantly in branch

number (difference =  $-0.96 \pm 1.83$ ;  $p = 0.603$ ). However, AFS maintained a significant lead over CP by  $4.08 \pm 1.21$  branches ( $p = 0.002$ ), and CS was marginally higher than CP with a difference of  $3.12 \pm 1.56$  ( $p = 0.055$ ), bordering statistical significance. The combined comparison of AFS and CS with CP was again highly significant, with a mean difference of  $7.21 \pm 2.11$  ( $p = 0.001$ ), suggesting that both cropping systems contributed meaningfully to enhanced branching at the end of the vegetative stage.

### 3.3.4. Leaf Area

Leaf area expansion, a critical determinant of photosynthetic capacity and overall biomass accumulation, varied significantly among the three cropping systems—corridor agroforestry system (AFS), conventional system with fertilizer (CS), and the control plot (CP)—across the growth stages evaluated at 34, 48, 62, and 76 days after sowing (DAS) (Table 7).

**Table 7.** Leaf area development under different cropping systems.

Days after planting (DAP)	Contrast	Contrast value	Degree of freedom	T ratio	p-value
34	AFS vs CS	$-75.00 \pm 33.85$	69	-2.216	0.033*
	AFS vs CP	$29.17 \pm 19.94$	69	1.462	0.154 <sup>ns</sup>
	CS vs CP	$104.17 \pm 29.47$	69	3.534	0.002**
	AFS and CS vs CP	$133.33 \pm 37.25$	69	3.580	0.001***
48	AFS vs CS	$-26.667 \pm 46.36$	69	-5.751	<0.001***
	AFS vs CP	$79.17 \pm 29.47$	69	2.686	0.011*
	CS vs CP	$345.83 \pm 39.92$	69	8.664	<0.001***
	AFS and CS vs CP	$425.00 \pm 52.67$	69	8.068	<0.001***
62	AFS vs CS	$-295.83 \pm 56.70$	69	-5.218	<0.001***
	AFS vs CP	$233.33 \pm 35.18$	69	6.632	<0.001***
	CS vs CP	$529.17 \pm 49.05$	69	10.789	<0.001***
	AFS and CS vs CP	$762.50 \pm 63.81$	69	11.949	<0.001***
76	AFS vs CS	$-33.33 \pm 61.29$	69	0.544	0.589 <sup>ns</sup>
	AFS vs CP	$529.17 \pm 43.40$	69	12.194	<0.001***
	CS vs CP	$495.93 \pm 49.50$	69	10.015	<0.001***
	AFS and CS vs CP	$1025.00 \pm 70.09$	69	14.624	<0.001***

AFS: Agroforestry system; CS: Conventional system; CP: Control plot. \* $p < 0.05$ ; \*\* $p < 0.01$ ; \*\*\* $p < 0.001$ ; ns: Not significant.

At 34 DAS, the CS system recorded significantly higher leaf area compared to CP, with a mean difference of  $104.17 \pm 29.47$  cm<sup>2</sup> ( $p = 0.002$ ). AFS also exhibited a modest increase over CP ( $29.17 \pm 19.94$  cm<sup>2</sup>), although the difference was not statistically significant ( $p = 0.145$ ). However, when compared directly with CS, the

AFS system showed significantly lower leaf area, with a reduction of  $75.00 \pm 33.85 \text{ cm}^2$  ( $p = 0.033$ ). The combined comparison of AFS and CS with CP revealed a cumulative difference of  $133.33 \pm 37.25 \text{ cm}^2$  ( $p = 0.001$ ), confirming the early influence of input-based systems on leaf surface development.

By 48 DAS, CS maintained its superiority, with significantly greater leaf area than AFS by  $266.67 \pm 46.36 \text{ cm}^2$  ( $p < 0.001$ ). AFS, in turn, significantly exceeded CP by  $79.17 \pm 29.47 \text{ cm}^2$  ( $p = 0.011$ ), while CS was  $345.83 \pm 39.92 \text{ cm}^2$  ahead of CP ( $p < 0.001$ ). The cumulative contrast between AFS and CS versus CP was highly significant at  $425.00 \pm 52.67 \text{ cm}^2$  ( $p < 0.001$ ), showing a compounding advantage in leaf development in the nutrient-enriched systems.

At 62 DAS, the difference between CS and AFS widened further. CS produced  $295.83 \pm 56.70 \text{ cm}^2$  more leaf area than AFS ( $p < 0.001$ ). AFS still retained a significant advantage over CP, with a difference of  $233.33 \pm 35.18 \text{ cm}^2$  ( $p < 0.001$ ), while CS produced a much larger increase over CP, with a mean difference of  $529.17 \pm 49.05 \text{ cm}^2$  ( $p < 0.001$ ). The combination of AFS and CS systems produced  $762.50 \pm 63.81 \text{ cm}^2$  more leaf area than CP ( $p < 0.001$ ), clearly demonstrating the positive impact of both organic and inorganic nutrient inputs on canopy expansion.

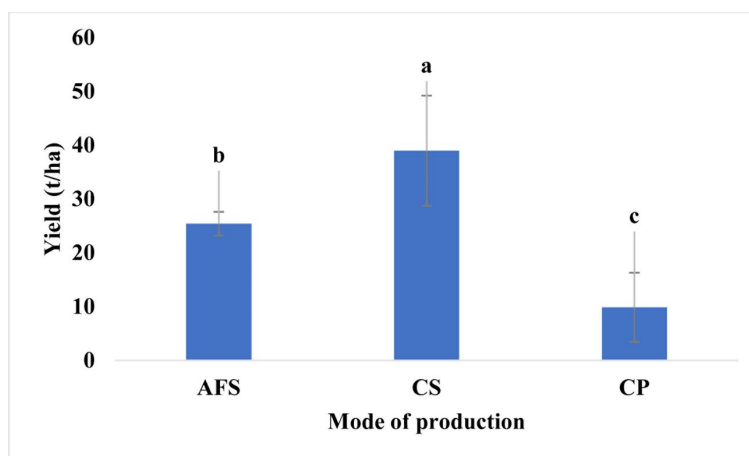
At 76 DAS, leaf area in AFS and CS systems remained significantly higher than in CP. Although the direct comparison between AFS and CS was not statistically significant at this stage ( $-33.33 \pm 61.29 \text{ cm}^2$ ;  $p = 0.589$ ), AFS maintained a strong advantage over CP with a difference of  $529.17 \pm 43.40 \text{ cm}^2$  ( $p < 0.001$ ), and CS also maintained superiority over CP by  $495.93 \pm 49.50 \text{ cm}^2$  ( $p < 0.001$ ). The combined effect of AFS and CS versus CP reached a peak cumulative difference of  $1025.00 \pm 70.09 \text{ cm}^2$  ( $p < 0.001$ ), indicating that leaf area benefits were maximized late in the growth cycle in nutrient-supported systems.

### 3.3.5. Tuber Yield

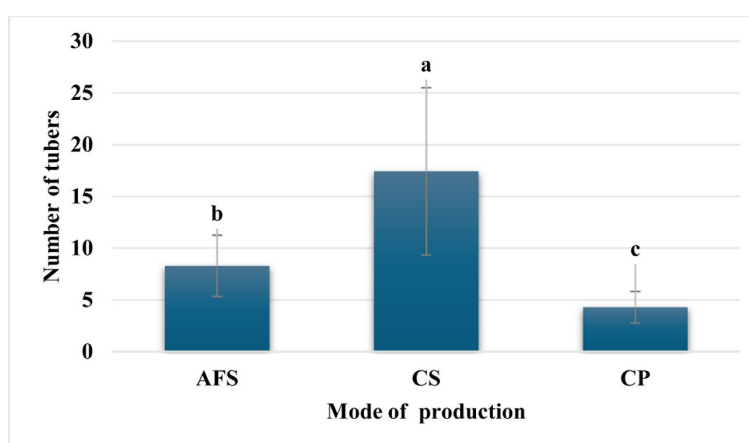
The average yield of potato tubers differed significantly among the three production systems: the agroforestry system (AFS), the conventional system with chemical inputs (CS), and the traditional control system without any inputs (CP). As illustrated in **Figure 1**, the highest yield was recorded under the conventional system (CS), with an average of approximately 40 tons per hectare, followed by the agroforestry system (AFS) with about 25 tons per hectare, while the lowest yield was observed in the control system (CP), which produced only around 10 tons per hectare.

Statistical grouping based on post hoc comparisons (indicated by different letters above the bars) showed that the yield in CS was significantly higher than that of both AFS and CP ( $p < 0.05$ ). The AFS system also yielded significantly more than the CP system, confirming the beneficial effect of organic nutrient input from *Gliricidia sepium* biomass.

The number of tubers per plant showed significant variation among the different production systems. The conventional system with chemical inputs (CS) produced the highest tuber number per plant, followed by the agroforestry system (AFS), while the control system (CP) recorded the lowest performance (**Figure 2**).



**Figure 1.** Average tuber yield under different production methods.



**Figure 2.** Average yield in number of tubers per potato plant by production method.

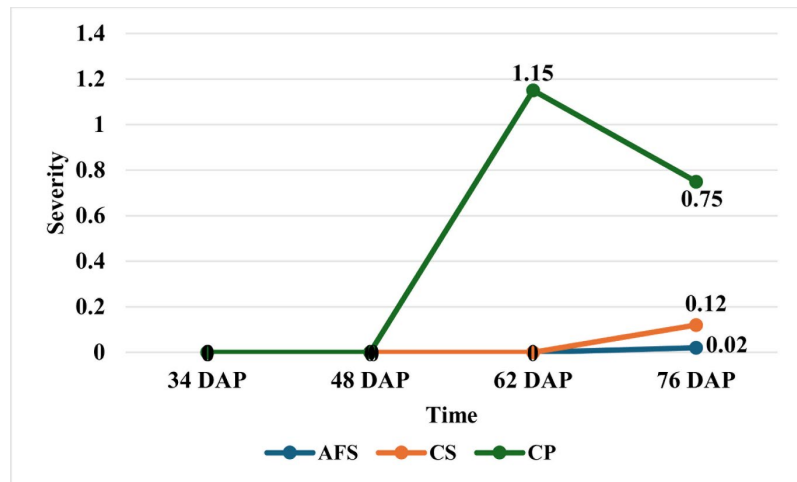
Under the CS system, the average number of tubers per plant reached approximately 17, which was significantly higher than the averages recorded in both AFS (8) and CP (4). The agroforestry system (AFS) produced an intermediate number of tubers per plant, averaging approximately 8 tubers, while the control system (CP) recorded the lowest tuber number, averaging approximately 4 tubers per plant. The differences among treatments were statistically significant, as indicated by the different letters assigned to each treatment group (a, b, and c), reflecting the results of multiple comparison tests at  $p < 0.05$ .

### 3.4. Performance of Different Production Methods on the Control of Pests and Diseases

#### 3.4.1. Potato Downy Mildew

The evolution of downy mildew (*Phytophthora infestans*) severity varied significantly among the three cropping systems over the entire crop cycle, as shown in **Figure 3**. Measurements were taken at 34, 48, 62, and 76 days after sowing (DAS) (**Figure 3**).

At 34 DAS, no significant difference was observed in mildew severity between



**Figure 3.** Progress of the severity of potato downy mildew under different production systems.

the three systems, with severity remaining close to zero in all treatments. This suggests that initial disease pressure was low across the field, likely due to environmental conditions not yet favouring infection or pathogen development.

By 48 DAS, disease severity remained minimal for both the conventional system (CS) and the agroforestry system (AFS), while the control system (CP) exhibited a slight increase, although differences were not yet statistically significant at this stage.

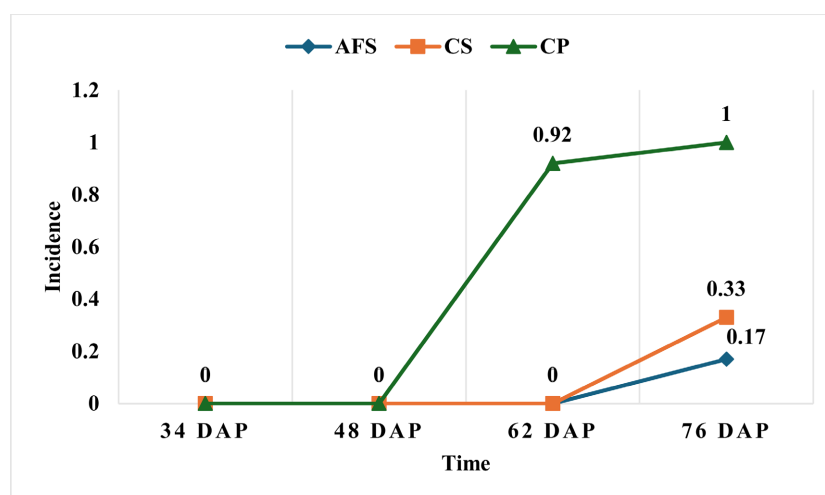
At 62 DAS, the first marked differences in disease severity were observed. The control system (CP) recorded the highest severity score of approximately 1.15, while both CS and AFS remained zero, indicating effective disease suppression under both managed systems.

At 76 DAS, disease pressure increased further, and significant differences emerged between the treatments. The agroforestry system (AFS) exhibited the highest mildew severity, reaching a score of 0.75. In contrast, the conventional system (CS) recorded a lower severity score of 0.12, while the control plot (CP) maintained the lowest severity level (0.02).

The incidence of downy mildew also varied among the three cropping systems throughout the crop cycle. At 34 and 48 days after sowing (DAS), no incidence of downy mildew was recorded in any of the systems, indicating that the disease only became established during the later stages of the crop development (**Figure 4**).

At 62 DAS, the first incidences of downy mildew were observed. The control system (CP) recorded the highest incidence, reaching a value of 0.92, while both the agroforestry system (AFS) and the conventional system (CS) maintained complete absence of disease at this stage (0 incidence for both). This reflects the early protective role provided by both chemical control in CS and the microclimatic or ecological benefits of the agroforestry system.

By 76 DAS, incidence increased further in the control system, reaching a peak value of 1.0. In contrast, the incidence in the CS and AFS systems remained substantially lower, with CS recording 0.33 and AFS recording 0.17.



**Figure 4.** Progress of the incidence of downy mildew under different production systems.

At 76 days after sowing (DAS), detailed pairwise statistical comparisons of downy mildew severity and incidence across the cropping systems further confirmed the differential performance of the production strategies in managing disease (**Table 8**).

**Table 8.** Statistical comparison of downy mildew incidence and severity at 76 days after planting (DAS).

Variable	Contrast	Contrast value	Degree of freedom	T ratio	p-value
Severity of mildew	AFS vs CS	$0.02 \pm 0.06$	69	-0.369	0.001***
	AFS vs CP	$-0.51 \pm 0.08$	69	-6.419	0.001***
	CS vs CP	$-0.53 \pm 0.07$	69	-7.352	0.001***
	AFS and CS vs CP	$-1.04 \pm 0.14$	69	-7.380	0.001***
Incidence of mildew	AFS vs CS	$-0.17 \pm 0.12$	69	-1.414	0.230 <sup>ns</sup>
	AFS vs CP	$-0.83 \pm 0.08$	69	-10.000	0.010**
	CS vs CP	$-0.67 \pm 0.08$	69	-8.000	0.015**
	AFS and CS vs CP	$-1.50 \pm 0.12$	69	-12.728	0.001***

AFS: Agroforestry system; CS: Conventional system; CP: Control plot. \*\* $p < 0.01$ ; \*\*\* $p < 0.001$ ; ns: Not significant.

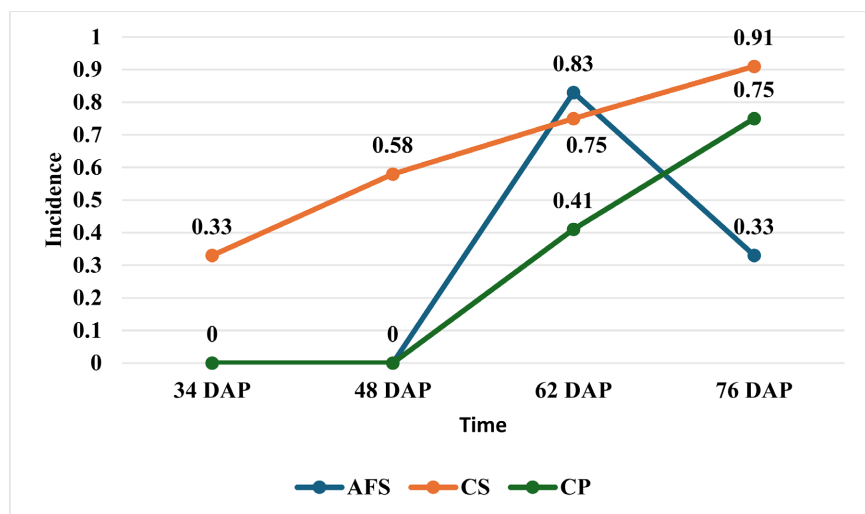
For severity of downy mildew, the comparison between AFS (corridor agroforestry system) and CS (conventional system with fertilizer) revealed no statistically significant difference (difference =  $0.02 \pm 0.06$ ;  $p = 0.001$ ), indicating that both systems performed similarly in suppressing disease severity at this stage. However, both AFS and CS exhibited significantly lower severity compared to the control system (CP). The severity difference between AFS and CP was  $-0.51 \pm 0.08$  ( $p < 0.001$ ), while the difference between CS and CP was  $-0.53 \pm 0.07$  ( $p < 0.001$ ). The combined effect of AFS and CS compared to CP produced a highly significant

cumulative difference of  $-1.04 \pm 0.14$  ( $p < 0.001$ ), confirming that both management strategies substantially reduced disease severity relative to the untreated control.

For incidence of downy mildew, similar trends were observed. There was no significant difference between AFS and CS (difference =  $-0.17 \pm 0.12$ ;  $p = 0.230$ ), suggesting that both systems offered comparable levels of disease prevention in terms of infection occurrence. However, AFS significantly outperformed CP by  $-0.83 \pm 0.08$  ( $p = 0.010$ ), and CS also significantly outperformed CP by  $-0.67 \pm 0.08$  ( $p = 0.015$ ). The combined AFS and CS treatments differed from CP by  $-1.50 \pm 0.12$  ( $p < 0.001$ ), confirming strong suppression of infection in both managed systems relative to the control.

### 3.4.2. Leaf-Eating Caterpillars

The incidence of leaf-eating caterpillars exhibited considerable variation among the three production systems throughout the growing period, as shown in **Figure 5**. Observations were recorded at 34, 48, 62, and 76 days after sowing (DAS) (**Figure 5**).



**Figure 5.** Progress of the incidence of leaf-eating caterpillars under different cropping systems.

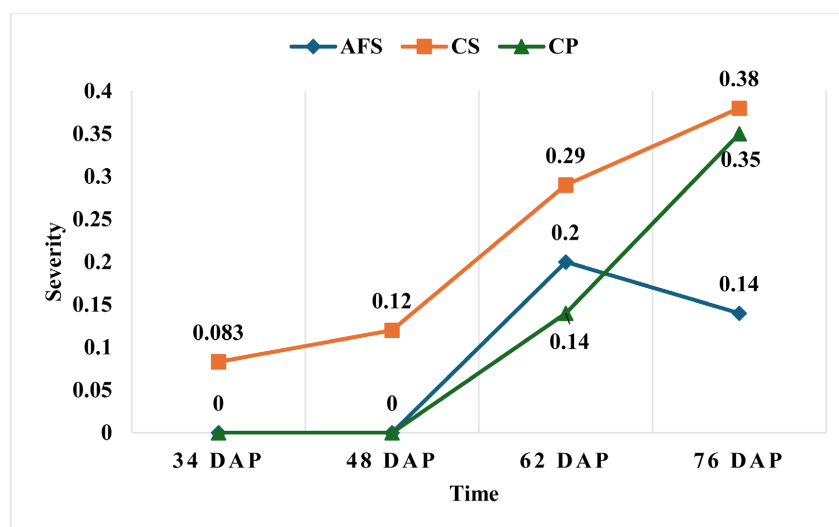
At 34 DAS, leaf-eating caterpillars were only detected in the conventional system with chemical inputs (SC), which recorded an initial incidence of 0.33. In contrast, no incidence was recorded in either the agroforestry system (SAF) or the control system (CP) at this early stage.

By 48 DAS, pest incidence increased across all systems but remained most pronounced in the SC system, which recorded an incidence of 0.58. The control system (CP) exhibited a lower incidence of 0.41, while the SAF system continued to suppress caterpillar infestation effectively, maintaining an incidence of zero. This suggests that the organic mulch and microclimatic buffering in the agroforestry system may have provided early-season protection against pest colonization.

At 62 DAS, the incidence reached its peak in the SC system, recording the highest value of 0.83. The SAF system recorded an increase to 0.75, while CP remained lower at 0.41. The sharp increase in caterpillar presence in SAF at this stage may reflect seasonal pest pressure combined with maturing plant tissue that is more attractive to larval feeding.

By 76 DAS, pest incidence declined in both SAF and SC but increased slightly in CP. The SC system recorded the highest final incidence at 0.91, followed by SAF at 0.75, while CP reached 0.33. These results indicate that even under chemical control, SC did not fully suppress caterpillar infestation, while the agroforestry system continued to provide relatively better control compared to the untreated control.

The severity of damage caused by leaf-eating caterpillars varied across the three cropping systems throughout the growing cycle, as illustrated in **Figure 6**. Measurements were taken at 34, 48, 62, and 76 days after sowing (DAS).



**Figure 6.** Progress of the severity of leaf-eating caterpillars under different production systems.

At 34 DAS, caterpillar severity was minimal across all systems. The conventional system (CS) recorded a low severity score of 0.083, while both the agroforestry system (AFS) and the control system (CP) recorded zero severity, indicating no noticeable damage at this early stage.

By 48 DAS, pest severity began to rise in the CS system, reaching 0.12, while both AFS and CP continued to record zero severity. This suggests that early in the crop cycle, *Gliricidia sepium* hedgerows may have helped suppress initial pest establishment in the agroforestry system, while the control system still remained unaffected.

At 62 DAS, both AFS and CP started to experience caterpillar damage. CS recorded the highest severity of 0.29, followed by AFS at 0.20, and CP at 0.14. This shift reflects the mid-season escalation of pest pressure across systems as leaf canopy expansion provided increased feeding surface.

By 76 DAS, pest severity reached its maximum levels in all systems. CS recorded the highest severity of 0.38, closely followed by CP at 0.35. In contrast, AFS recorded

the lowest severity of 0.14, highlighting the sustained capacity of the agroforestry system to suppress pest severity even under increased seasonal pest pressure.

At 76 days after sowing (DAS), the incidence and severity of leaf-eating caterpillars were statistically compared across the three cropping systems: corridor agroforestry system (AFS), conventional system with fertilizer (CS), and the control system (CP) (**Table 9**).

**Table 9.** Statistical comparison of incidence and severity of leaf-eating caterpillars at 76 days after planting.

Variable	Contrast	Contrast value	Degree of freedom	T ratio	p-value
Incidence leaf-eating caterpillar	AFS vs CS	$-0.58 \pm 0.15$	69	-3834	0.009**
	AFS vs CP	$-0.42 \pm 0.15$	69	-2739	0.034*
	CS vs CP	$-0.17 \pm 0.15$	69	-1095	0.315 <sup>ns</sup>
	AFS and CS vs CP	$-0.25 \pm 0.26$	69	-0949	0.379 <sup>ns</sup>
Severity of leaf-eating caterpillar	AFS vs CS	$-0.24 \pm 0.09$	69	-2536	0.016*
	AFS vs CP	$-0.21 \pm 0.09$	69	-2225	0.033*
	CS vs CP	$-0.03 \pm 0.09$	69	-0311	0.757 <sup>ns</sup>
	AFS and CS vs CP	$-0.18 \pm 0.12$	69	-1105	0.277 <sup>ns</sup>

AFS: Agroforestry system; CS: Conventional system; CP: Control plot. \* $p < 0.05$ ; \*\* $p < 0.01$ ; ns: Not significant.

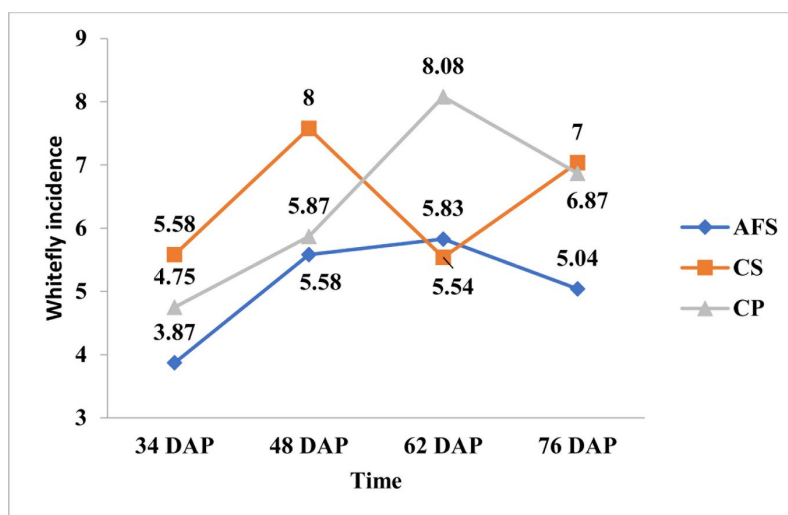
For incidence of leaf-eating caterpillars, the incidence in AFS was significantly lower than in CS, with a difference of  $-0.58 \pm 0.15$  ( $p = 0.009$ ). Similarly, AFS recorded significantly lower incidence compared to CP, with a difference of  $-0.42 \pm 0.15$  ( $p = 0.034$ ). However, there was no significant difference between CS and CP for incidence (difference =  $-0.17 \pm 0.15$ ;  $p = 0.315$ ), indicating that chemical fertilization did not significantly reduce pest incidence relative to the untreated control system. The combined comparison between AFS and CS versus CP was not significant either (difference =  $-0.25 \pm 0.26$ ;  $p = 0.379$ ), suggesting variability in pest incidence across the systems when considered together.

For severity of leaf-eating caterpillars, a similar trend was observed. AFS demonstrated significantly lower severity compared to CS (difference =  $-0.24 \pm 0.09$ ;  $p = 0.016$ ), and significantly lower severity compared to CP (difference =  $-0.21 \pm 0.09$ ;  $p = 0.033$ ). The difference between CS and CP was not significant (difference =  $-0.03 \pm 0.09$ ;  $p = 0.757$ ), confirming that chemical treatment did not confer an advantage over the control in reducing caterpillar damage severity. The combined AFS and CS vs CP comparison also remained non-significant (difference =  $-0.18 \pm 0.12$ ;  $p = 0.277$ ).

### 3.4.3. Whitefly

The incidence of whitefly populations varied among the production systems over the entire crop cycle. Observations were taken at 34, 48, 62, and 76 days after sow-

ing (DAS), with considerable fluctuations in pest pressure observed between the different systems and growth stages (**Figure 7**).



**Figure 7.** Incidence of whitefly populations under different cropping systems.

At 34 DAS, whitefly incidence was relatively low in all systems. The agroforestry system (AFS) recorded the lowest incidence at 3.87 individuals per plant, while the conventional system with chemical inputs (CS) recorded 5.58, and the control system (CP) recorded 4.75. This suggests that early-season whitefly pressure was minimal but already slightly elevated in the CS system.

By 48 DAS, the incidence increased sharply, particularly in the CS system, which peaked at 8 individuals per plant. The control system (CP) followed with 5.87, while the AFS system recorded 5.58, indicating some moderate buildup of whitefly populations but with more effective suppression under agroforestry.

At 62 DAS, the whitefly population peaked in the CP system, reaching its maximum incidence of 8.08 individuals per plant. Meanwhile, both the CS and AFS systems recorded relatively lower incidences of 5.83 and 5.54, respectively. These results suggest that the absence of any control strategy in the CP system allowed for continuous buildup of whitefly populations, while both management systems were able to moderate population growth during this stage.

At 76 DAS, incidence in the CP system declined slightly to 7 individuals per plant, while CS recorded 6.87 and AFS recorded the lowest incidence at 5.04. By the end of the growing period, the agroforestry system consistently maintained lower whitefly populations compared to both the chemically managed and control systems.

The incidence of whitefly populations differed significantly between cropping systems at multiple stages of the crop cycle. The data presented in **Table 10** provide a detailed pairwise comparison of these differences at 34, 48, 62, and 76 days after sowing (DAS).

At 34 DAS, a significant difference was observed between the agroforestry system (AFS) and the conventional system (CS), with AFS recording a lower incidence

**Table 10.** Statistical comparison of whitefly incidence across production systems and growth stages.

Days after planting (DAP)	Contrast	Contrast value	Degree of freedom	T ratio	p-value
34	AFS vs CS	$-1.71 \pm 0.50$	69	-3.401	0.003**
	AFS vs CP	$-0.88 \pm 0.50$	69	-1.742	0.115 <sup>ns</sup>
	CS vs CP	$0.83 \pm 0.50$	69	1.659	0.052 <sup>ns</sup>
	AFS and CS vs CP	$-0.04 \pm 0.87$	69	-0.48	0.959 <sup>ns</sup>
48	AFS vs CS	$-2.00 \pm 0.70$	69	-2.827	0.006**
	AFS vs CP	$-0.29 \pm 0.70$	69	-4.12	0.681 <sup>ns</sup>
	CS vs CP	$1.71 \pm 0.70$	69	2.415	0.018*
	AFS and CS vs CP	$1.42 \pm 1.22$	69	1.156	0.252 <sup>ns</sup>
62	AFS vs CS	$0.29 \pm 0.64$	69	0.458	0.648 <sup>ns</sup>
	AFS vs CP	$-2.25 \pm 0.64$	69	-3.537	<0.001***
	SC vs CP	$-2.54 \pm 0.64$	69	-3.995	<0.001***
	AFS and CS vs CP	$-4.79 \pm 1.10$	69	-4.348	<0.001***
76	AFS vs CS	$-2.00 \pm 0.63$	69	-3.165	0.002**
	AFS vs CP	$-1.83 \pm 0.63$	69	-2.902	0.005**
	CS vs CP	$-0.17 \pm 0.63$	69	0.264	0.793 <sup>ns</sup>
	AFS and CS vs CP	$-1.67 \pm 1.09$	69	-1.523	0.132 <sup>ns</sup>

AFS: Agroforestry system; CS: Conventional system; CP: Control plot. \* $p < 0.05$ ; \*\* $p < 0.01$ ; \*\*\* $p < 0.001$ ; ns: Not significant.

by  $-1.71 \pm 0.50$  ( $p = 0.003$ ). However, no significant differences were found between AFS and the control system (CP) ( $p = 0.115$ ), or between CS and CP ( $p = 0.052$ ), suggesting that at this early stage, only the agroforestry system offered statistically lower whitefly incidence compared to chemical control, while the control and conventional systems exhibited similar incidence levels.

At 48 DAS, the differences between AFS and CS remained statistically significant, with AFS showing lower incidence by  $-2.00 \pm 0.70$  ( $p = 0.006$ ). AFS vs CP remained non-significant ( $p = 0.681$ ), while CS exhibited significantly higher whitefly incidence compared to CP by  $1.71 \pm 0.70$  ( $p = 0.018$ ). These results indicate that at mid-season, whitefly populations escalated more rapidly in the conventional system than in both agroforestry and control plots.

At 62 DAS, the pattern shifted. There was no significant difference between AFS and CS ( $p = 0.648$ ), but AFS maintained significantly lower incidence compared to CP by  $-2.25 \pm 0.64$  ( $p < 0.001$ ). The CS system also showed significantly higher incidence than CP by  $-2.54 \pm 0.64$  ( $p < 0.001$ ), confirming that by 62 DAS, both managed systems (AFS and CS) controlled whitefly better than the control, but incidence levels between CS and AFS converged.

At 76 DAS, the difference between AFS and CS re-emerged as significant, with AFS recording a lower incidence by  $-2.00 \pm 0.63$  ( $p = 0.002$ ). AFS also maintained a significantly lower incidence compared to CP by  $-1.83 \pm 0.63$  ( $p = 0.005$ ), while the difference between CS and CP was non-significant ( $p = 0.793$ ). The combined effect of AFS and CS compared to CP remained non-significant at this stage ( $p = 0.132$ ).

### 3.5. Economic Profitability of Potato Production

The economic analysis revealed substantial differences in production costs, revenues, profits, and profitability indicators across the three cropping systems: Agroforestry System (AFS), Conventional System with chemical inputs (CS), and Control Plot (CP) (Table 11).

The marketable yield was highest under the conventional system (CS) at 38.97

**Table 11.** Economic profitability of potato production under different cropping systems.

Parameter	AFS	CS	CP
Yield (t/ha)	25.42	38.97	10.53
Seeds (FCFA)	675,000	675,000	675,000
Organic fertilizers (FCFA)	320,000	320,000	00
Chemical fertilizers (FCFA)	/	280,000	00
<b>Phytosanitary products</b>			
Insecticides	32,500	32,500	32,500
Fungicides	84,000	84,000	84,000
<b>Labour cost (FCFA)</b>			
Clearing	100,000	100,000	100,000
Ridging	30,000	/	/
Mowing and spreading of biomass	30,000	30,000	0
Organic fertilizer application	30,000	30,000	0
Labour cost for application chemical fertiliser (FCFA)	/	30,000	00
Sarclo-ridging workforce (FCFA)	60,000	60,000	60,000
Transportation of chemical fertilizer (FCFA)	/	21,000	00
Transportation of organic fertilizers (FCFA)	15,000	15,000	00
Labor for harvesting and packaging (FCFA)	40,000	40,000	40,000
Transportation of crops (FCFA)	178,250	366,100	120,000
CP (FCFA)	1,624,750	2,113,600	534,000
II (FCFA)	162,475	211,360	53,400
MP (FCFA)	1,787,225	2,324,960	587,400
SOY (FCFA)	7,588,000	10,911,600	728,000

**Continued**

Profit (FCFA)	5,801,575	8,586,640	140,000
Profitability % (RT)	324.61	369.32	23.83
VCR	4.24	4.69	

CP: Cost of production; MP: Market price; SOY: Sales of yield; II: Interest on investment; VCR: Value to cost ratio.

t/ha, followed by AFS with 25.42 t/ha, and the lowest yield recorded in CP at 10.53 t/ha. This yield performance directly translated into variations in both revenues and profitability across the systems.

The total production cost (CP) was highest in CS, amounting to 2,113,600 FCFA/ha due to the substantial cost of chemical fertilizers (280,000 FCFA/ha), phytosanitary products (insecticides and fungicides totaling 116,500 FCFA/ha), and additional labor costs for chemical application and input transportation. The production cost in AFS was lower at 1,624,750 FCFA/ha, while CP, which involved minimal input, recorded the lowest production cost of 534,000 FCFA/ha.

The total sales revenue (SOY) was highest under CS, reaching 10,911,600 FCFA/ha due to its superior yield. AFS achieved a sales revenue of 7,588,000 FCFA/ha, while CP produced the lowest revenue of 728,000 FCFA/ha.

When calculating profit, CS remained the most profitable, yielding 8,586,640 FCFA/ha. However, AFS also generated a strong profit of 5,501,575 FCFA/ha, while CP returned a minimal profit of 140,000 FCFA/ha, reflecting its limited productivity.

In terms of profitability ratios, the agroforestry system (AFS) achieved a profitability of 324.61% and a value-cost ratio (VCR) of 4.24. The conventional system (CS) recorded a slightly higher profitability of 369.32% and a VCR of 4.69. In contrast, the control system (CP) recorded a substantially lower profitability of only 23.83% and a VCR of 1.26.

Although the conventional system generated the highest absolute profit due to its superior yields, it also incurred the highest production costs. The agroforestry system, while yielding moderately lower production and revenues, exhibited a very competitive profitability ratio when considering its reduced input dependency and lower production costs. The control system, lacking both nutrient and pest management interventions, produced minimal financial returns and demonstrated poor profitability.

These findings suggest that the agroforestry system offers a highly promising economic alternative, delivering strong profitability while significantly reducing dependence on costly external inputs, making it a more sustainable and resilient option for resource-limited farmers.

## 4. Discussions

The present study evaluated the agronomic, phytosanitary, and economic performance of three potato production systems: the Agroforestry System (AFS), the

Conventional System with chemical inputs (CS), and the Control System without any inputs (CP). The findings demonstrate that while chemical inputs achieved the highest absolute yield, agroforestry offered substantial yield improvements with significantly lower input costs and considerable ecological and economic advantages.

Plant growth parameters, including crown diameter, plant height, number of lateral branches, and leaf area, were consistently superior under CS, particularly at the early stages of crop development. This can be attributed to the rapid nutrient availability associated with mineral fertilizers, which promoted vigorous vegetative growth during the critical early establishment period. However, as the season progressed, nutrient release from *Gliricidia sepium* biomass in AFS allowed the agroforestry system to catch up and, in some cases, achieve parity with the conventional system at mid-season growth stages. The slow but steady decomposition of organic residues likely contributed to sustained nutrient supply over time, as has been previously reported in agroforestry systems [11] [12].

Tuber yield and yield components followed a similar trend. The CS system produced the highest yield (38.97 t/ha), significantly exceeding that of both AFS (25.42 t/ha) and CP (10.53 t/ha). Nevertheless, the agroforestry system still achieved more than double the yield recorded under the control system, demonstrating its capacity to substantially improve productivity without reliance on costly external inputs. The superior performance of CS in tuber formation can be attributed to the immediate and continuous availability of nutrients throughout tuber bulking, while the gradual nutrient release from *Gliricidia sepium* biomass in AFS provided steady but slightly delayed support for yield development. These findings align with earlier work that has shown the complementary benefits of integrating organic and inorganic nutrient sources in potato production [13] [14].

In terms of pest and disease management, both CS and AFS demonstrated strong control of downy mildew (*Phytophthora infestans*) relative to CP, with no significant difference observed between CS and AFS by 76 DAS. The consistent suppression of disease severity and incidence in AFS may reflect the combined effects of improved microclimatic regulation under *Gliricidia* hedgerows, enhanced soil microbial diversity, and potential antagonistic interactions that reduce pathogen buildup. This supports previous findings on the ecological services provided by agroforestry systems in managing plant diseases [15] [16].

Interestingly, when evaluating insect pests, particularly leaf-eating caterpillars and whiteflies, the agroforestry system consistently outperformed both CS and CP. While chemical control suppressed pest incidence early, its effectiveness diminished over time, and pest populations eventually reached levels comparable to or exceeding those observed in CP. In contrast, AFS maintained significantly lower pest incidence and severity across most observation periods. This may be due to enhanced natural enemy activity and habitat diversification promoted by the agroforestry design, which is known to favor predator and parasitoid populations [17] [18].

From an economic perspective, CS yielded the highest absolute profit (8,586,640 FCFA/ha) due to its superior yields, but this was achieved at the highest production cost (2,113,600 FCFA/ha). The AFS system achieved a slightly lower absolute profit (5,501,575 FCFA/ha), but its total production cost was substantially lower (1,624,750 FCFA/ha), resulting in a competitive profitability ratio (324.61% vs 369.32% for CS). Furthermore, the Value-Cost Ratio (VCR) for AFS (4.24) was close to that of CS (4.69), confirming that agroforestry remains highly profitable despite reduced yield potential. These results are consistent with broader evidence suggesting that low-input, diversified agroecological systems can achieve comparable economic viability to high-input systems while offering improved resilience and environmental sustainability [19] [20].

Overall, these findings highlight the potential of agroforestry systems as a viable, resource-efficient alternative for potato production in smallholder farming contexts. While chemical fertilizers offer superior short-term yield maximization, agroforestry provides multiple co-benefits that include sustained productivity, improved pest and disease regulation, reduced input dependency, and strong economic returns. In the face of rising input costs, environmental degradation, and climate variability, integrated agroforestry approaches may thus serve as a more resilient and sustainable pathway for future potato production intensification in resource-constrained environments.

## 5. Conclusions

This study demonstrated the agronomic, phytosanitary, and economic performance of three potato production systems under the conditions of Menoua Division, West Cameroon. The conventional system with chemical inputs consistently produced the highest yields and profits due to rapid nutrient availability and effective chemical disease suppression. However, these benefits were offset by high production costs and limited effectiveness in controlling certain insect pests, such as leaf-eating caterpillars and whiteflies.

In contrast, the agroforestry system integrating *Gliricidia sepium* provided a highly promising alternative, delivering moderate but economically competitive yields with substantially lower production costs. The agroforestry system also offered superior suppression of insect pests and nearly equivalent control of downy mildew relative to chemical interventions, likely due to its enhanced ecological stability, microclimatic regulation, and natural enemy promotion.

Economically, while conventional farming maximized absolute profit, the agroforestry system demonstrated high profitability ratios and strong value-cost efficiency, making it a more sustainable and accessible option for resource-limited smallholder farmers.

Overall, the findings underscore the value of agroforestry as a viable pathway to intensify potato production while minimizing dependence on chemical inputs, improving ecological resilience, and maintaining profitability. Promotion of agroforestry-based potato production may therefore contribute significantly to more

sustainable, climate-resilient, and environmentally sound agricultural development in Cameroon and other similar agro-ecological zones.

This study was conducted over a single cropping season at one location, which may limit the generalizability of the findings. Ongoing work is being planned to validate these results over multiple seasons and sites, particularly across different agro-ecological zones in Cameroon, to capture inter-annual climatic variability and site-specific responses.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

## References

- [1] Food and Agriculture Organization of the United Nations (2021) FAOSTAT Statistical Database. <https://www.fao.org/faostat/>
- [2] Devaux, A., Kromann, P. and Ortiz, O. (2014) Potatoes for Sustainable Global Food Security. *Potato Research*, **57**, 185-199. <https://doi.org/10.1007/s11540-014-9265-1>
- [3] Njualem, D.K., Yinda, G.S.A. and Tata, S.N. (2008) Potato Production in Cameroon: Opportunities and Constraints. *African Crop Science Journal*, **16**, 305-309.
- [4] Ngome, A.F., Becker, M., Mtei, K. and Mussgnug, F. (2013) Management Options for Improving Soil Fertility and Maize Yield in Humid Forest and Moist Savanna Zones of Sub-Saharan Africa. *Soil & Tillage Research*, **126**, 134-141. <https://doi.org/10.1016/j.still.2012.09.011>
- [5] Mbow, C., Smith, P., Skole, D., Duguma, L. and Bustamante, M. (2014) Achieving Mitigation and Adaptation to Climate Change through Sustainable Agroforestry Practices in Africa. *Current Opinion in Environmental Sustainability*, **6**, 8-14. <https://doi.org/10.1016/j.cosust.2013.09.002>
- [6] Jose, S. (2009) Agroforestry for Ecosystem Services and Environmental Benefits: An Overview. *Agroforestry Systems*, **76**, 1-10. <https://doi.org/10.1007/s10457-009-9229-7>
- [7] Tilman, D., Cassman, K.G., Matson, P.A., Naylor, R. and Polasky, S. (2002) Agricultural Sustainability and Intensive Production Practices. *Nature*, **418**, 671-677. <https://doi.org/10.1038/nature01014>
- [8] Tening, A.S., Njukeng, J.N. and Tabi, F.O. (2013) Characterization of Some Andosols Developed from Volcanic Rocks in the Western Highlands of Cameroon. *African Journal of Environmental Science and Technology*, **7**, 640-648. <https://doi.org/10.5897/AJEST2013.1504>
- [9] Yerima, B.P.K. and Van Ranst, E. (2005) Soil Classification in Cameroon. Ghent University Library.
- [10] International Potato Center (CIP) (2007) Field Screening Protocol for Major Potato Diseases and Pests. CIP.
- [11] Sileshi, G., Mafongoya, P.L., Akinnifesi, F.K. and Ajayi, O.C. (2014) Agroforestry: A Solution to Reduce Hunger and Poverty under Climate Change. *Agroforestry Systems*, **86**, 279-297. <https://doi.org/10.1007/s10457-011-9385-7>
- [12] Kader, M.A., Senge, M., Mojid, M.A. and Ito, K. (2017) Recent Advances in Mulching Materials and Methods for Modifying Soil Environment. *Soil and Tillage Research*, **168**, 155-166. <https://doi.org/10.1016/j.still.2017.01.001>

- [13] Zamil, M.F., Rahman, M.M. and Alam, M.J. (2013) Integrated Nutrient Management for Sustainable Potato Production. *Bangladesh Journal of Agricultural Research*, **38**, 647-656. <https://doi.org/10.3329/bjar.v38i4.18402>
- [14] Ayoola, O.T. and Adeniyani, O.N. (2006) Influence of Poultry Manure and NPK Fertilizer on Yield and Yield Components of Crops under Different Cropping Systems in South West Nigeria. *African Journal of Biotechnology*, **5**, 1386-1392.
- [15] Schroth, G., Sinclair, F.L. and McNeely, J.A. (2000) Biodiversity in Agroforestry Systems. In: Schroth, G. and Sinclair, F.L., Eds., *Agroforestry and Biodiversity Conservation in Tropical Landscapes*, Island Press, 1-12.
- [16] Pumariño, L., Sileshi, G.W., Gripenberg, S., Kaartinen, R., Barrios, E., Muchane, M.N., *et al.* (2015) Effects of Agroforestry on Pest, Disease and Weed Control: A Meta-Analysis. *Basic and Applied Ecology*, **16**, 573-582. <https://doi.org/10.1016/j.baae.2015.08.006>
- [17] Gurr, G.M., Wratten, S.D. and Luna, J.M. (2003) Multi-Function Agricultural Biodiversity: Pest Management and Other Benefits. *Basic and Applied Ecology*, **4**, 107-116. <https://doi.org/10.1078/1439-1791-00122>
- [18] Tscharrntke, T., Klein, A.M., Kruess, A., Steffan-Dewenter, I. and Thies, C. (2005) Landscape Perspectives on Agricultural Intensification and Biodiversity—Ecosystem Service Management. *Ecology Letters*, **8**, 857-874. <https://doi.org/10.1111/j.1461-0248.2005.00782.x>
- [19] Snapp, S.S., Blackie, M.J., Gilbert, R.A., Bezner-Kerr, R. and Kanyama-Phiri, G.Y. (2010) Biodiversity Can Support a Greener Revolution in Africa. *Proceedings of the National Academy of Sciences*, **107**, 20840-20845. <https://doi.org/10.1073/pnas.1007199107>
- [20] Tiftonell, P., Muriuki, A., Klapwijk, C.J., Shepherd, K.D., Coe, R. and Vanlauwe, B. (2011) Soil Heterogeneity and Soil Fertility Gradients in Smallholder Farms of the East African Highlands. *Soil Science Society of America Journal*, **74**, 1610-1622. <https://doi.org/10.2136/sssaj2010.0250>