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Mucuna pruriens, *Crotalaria juncea*, and chickpea (*Cicer arietinum*) have the potential for improving productivity of banana-based systems in Eastern Democratic Republic of Congo

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Abstract

Intercropping banana and shorter annual crops in small holder systems is inevitable despite shade being a limitation. Current production is also limited to the wet seasons. Strategies to exploit the spaces under banana shade and drier seasons are crucial for optimal production of these systems. We determined the performance of two legume cover crops, *Mucuna pruriens* and *Crotalaria juncea*, and chickpea (*Cicer arietinum*), a grain legume, under different banana shade levels and over the wet and dry seasons in eastern Democratic Republic of Congo. Banana and legume monocrops served as controls. Shade reduced weed biomass and legume root nodulation, biomass, and grain yields. Chickpea root nodulation had a lower sensitivity to shade (3–9% reduction) compared with mucuna (30–60%) and crotalaria (31–71%). Legume biomass yield declines varied from 37–83%, 56–93%, and 80–98% for mucuna, crotalaria, and chickpea, respectively. Higher nodulation occurred in the rainy compared with the dry season. Biomass yield declines, albeit low occurred in the dry season for mucuna (15%) and crotalaria (30%). In contrast, chickpea biomass and grain yields increased by 394% and 4487%, respectively, in the dry season. A higher banana vegetative growth occurred in the intercropped plots. Land equivalent ratios of 1.15–1.34 under dense shading for mucuna and crotalaria and 1.10–1.62 for chickpea occurred irrespective of the seasons. These findings suggest that these cover crops and chickpea could be exploited to enhance biomass (for fodder, mulch, or manure) and grain yields under banana shade and over the drier seasons.

KEYWORDS
cover crop, dry season, intercrop, land equivalence ratio, legume, root nodulation

1 | INTRODUCTION

Intercropping of bananas with annual and perennial crops is common and inevitable in East and Central Africa due to the small farm sizes and the need to meet multiple household needs (Gambart et al., 2020; Ntamwira et al., 2021; Ocimati, 2019; Ocimati et al., 2018; Sivirihauma et al., 2017). Farms are continuously and intensively cultivated in this region hastening land degradation and yield reduction

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(Blomme et al., 2020; Niroula & Thapa, 2005; UBOS, 2010). External inputs such as manure and inorganic fertilizers are hardly used in the region. For example, in Uganda in 2013, only 2.8% of the land under key crops received fertilizers at a rate of 30 kg/ha of fertilizer, with banana accounting for 25% of this land area (Sunday & Ocen, 2015).

The use of legumes can be an alternative for recovering and improving the soils, since legumes use their roots and vegetation to protect the soil and fix atmospheric nitrogen, hence improving the soil fertility status of fields. The biomass generated from the legume crop can also be incorporated into the soil as green manure or compost or used as mulch, thus improving soil quality. Preliminary evaluations of a wider range of annual crops under banana in Eastern Democratic Republic of Congo (DR Congo) showed *Mucuna pruriens*, *Crotalaria juncea*, and chickpea (*Cicer arietinum*) to have a high potential for improving the performance of banana systems (Blomme et al., 2020).

Mucuna pruriens is a tropical legume widely used as a forage, fallow, soil cover, and green manure crop due to its rapid growth rate. The plant fixes nitrogen, thus fertilizing the soil (Aklamavo & Mensah, 1997; Munganga et al., 2018). A total dry biomass production ranging from 7 to 11 tons ha^{-1} has been reported for mucuna (Obert, 2003). Mucuna prefers hot and humid climates with annual rainfall of 1000–2500 mm but will grow with annual rainfall as low as 400 mm, possibly due to its deep root system. In Blomme et al. (2020), the crop exhibited reasonable growth in long dry season and under shaded conditions.

Crotalaria sp. has been rated highly due to its ability to improve soil fertility, adapt to low light conditions, grow rapidly, and suppress weeds (Daniel et al., 2020). Its deep root system, high biomass production, and ability to fix atmospheric nitrogen through its association with bacteria and mycorrhizal fungi improve the chemical, physical, and biological attributes of the soil (Gitti et al., 2012; Wang et al., 2002). It has been reported to fix up to 305 kg N ha^{-1} (Perin et al., 2004; Wang et al., 2002). Crotalaria is thus a good nitrogen source for other crops within intercrops (Chieza et al., 2017; Daniel et al., 2020; Nogueira & Correia, 2016). It is also drought-resistant and grows on almost all soil types (Blomme et al., 2016, 2020; Chiu, 2004). In more a recent study, Blomme et al. (2020) observed crotalaria to perform well under banana shade, suggesting that it could be used to improve the resilience of banana cropping systems. However, Blomme et al. (2020) only assessed the performance of *Crotalaria* sp. during one growing season, that is, over the short rainy season (Feb to May) with about 544 mm of rainfall.

Blomme et al. (2020) reported that chickpea offers a high potential for improving land use and food security. Chickpea grains contain a high protein and starch content and are therefore very important in human nutrition (Jukanti et al., 2013). This crop has a high potential to significantly contribute to sustainable agriculture, because its N_2-fixation reduces requirements for N fertilizer inputs, and it also contributes to cropping system diversification when, for example, used in rotation (Biabani, 2011). This legume has also shown to have a great potential for withstanding drier conditions (Blomme et al., 2020).

The current study built upon Blomme et al. (2020) by exploring the growth, yield, and agronomic advantage of incorporating these legumes under banana in two contrasting (wet and dry) seasons. The study also evaluated effects of soil characteristics and environmental factors on crop growth and nodule formation during the two contrasting seasons. This information could potentially influence farmers' decisions to adopt or not to adopt these legume crops.

2 | MATERIALS AND METHODS

2.1 | Study area

This study was conducted through field experiments established in 2020 at the INERA-Mulungu research station (02°20.042′S, 028°47.311′E; 1707 masl), South Kivu province, Democratic Republic of Congo (DR Congo). This region receives an annual precipitation of 1656 ± 235 mm (2015–2018) and has two cropping (rainy) seasons separated by two dry seasons. The main dry season from May till September receives ≤150 mm of monthly rainfall while the shorter dry season (January–February) receives a mean monthly rainfall of about 150 mm and further separates the two annual cropping seasons. The first annual cropping cycle (season A) runs from September to end of December or start of January, while the second cropping cycle (season B) starts in mid-February/early March and ends in May. Cumulative rainfall and accompanying cloud cover is slightly higher in season A (749.3 mm) as compared with season B (561.7 mm) (Figure 1). Soils at INERA-Mulungu are volcanic-derived Andosol and reasonably fertile (Kempers & Zweers, 1986).

2.2 | Experimental design

The trials were conducted during two contrasting seasons, the main dry season (from early May till the end of September 2020) and first annual cropping season (October 2020 till end of February 2021). The experiment assessed the response of three novel legume crops, mucuna (forage and cover crop), crotalaria (forage and cover crop), and chickpea (food crop), under different shade levels provided by mature banana plants (12-year-old field) over the two contrasting

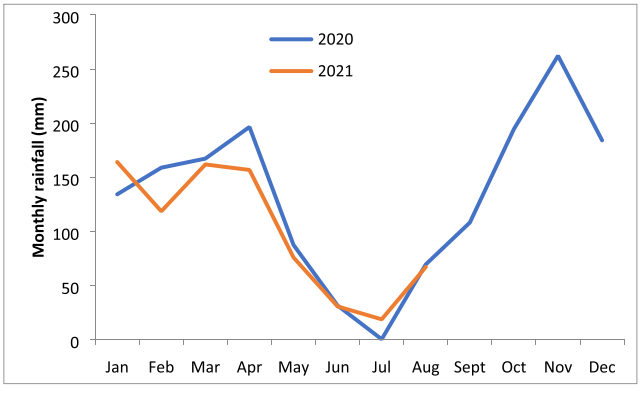


FIGURE 1 Annual rainfall at the study site in south Kivu (DR Congo)

seasons. The cooking banana cultivar "Barhabesha" (genome AAA-EAH), at two plant spacing levels, namely, 2 × 2 m and 4 × 4 m, was used. Banana (for both 2 × 2 m and 4 × 4 m spacing) and legume monocrop fields served as control plots.

The experimental design used for the study was a split plot design with the banana fields of different planting densities (i.e., 2 × 2 m banana-legume intercrop, 2 × 2 m banana monocrop, 4 × 4 m banana-legume intercrop, and 4 × 4 m banana monocrop fields) and legume monocrop serving as the main plots and the legume treatments as the subplots. Main plots measured 16 × 16 m and were subdivided into nine subplots measuring 4 × 4 m, with a 1 m gap separating the subplots. The legume crops were randomly allocated within the 2 × 2 m and 4 × 4 m banana-legume intercrop and the legume monocrop fields, in three replications. There were in total 18 legume-banana intercrop subplots, nine legume monocrop subplots, and 18 banana monocrop subplots (nine each for the 2 × 2 m and 4 × 4 m plots). The plant spacing for the three legume crops was 25 × 50 cm, respectively, within and between lines, with two legume seeds planted per planting hole. The same experimental design was used during both seasons, with the same legume species planted in the same plot during the two contrasting seasons. It was hoped that this cross-season/continued legume cultivation would more clearly demonstrate legume species effects on soil fertility and banana growth.

Minimal tillage was carried out before legume planting, while hand weeding was done at 1 and 2 months after planting in the legume inter- and mono-cropped fields. Hand weeding was carried out at monthly intervals in the banana mono-cropped fields. The biomass of each sub-plot obtained during the first annual crop harvest was maintained as mulch cover.

2.3 | Light intensity measurements

An ACCUPAR photometer probe (Model LP-80, Decagon Devices, Pullman, WA, USA; Decagon Devices, 2004) was used to measure the photosynthetically active radiation (PAR, μmol/m^2/s) received by the legume plants under the leaf canopy of the different banana planting densities and above the legume monocrops. In the intercropped plots, PAR values were assessed at 50 cm from a banana plant and at the center of each legume subplot, at a height of 30 cm above the legume intercrop. In the mono-cropped plots, PAR was measured at center of the subplot and 30 cm above the legumes.

2.4 | Soil characterization

Composite soil samples were collected before the first annual crop planting and at harvest of the second planting season for each legume × banana treatment plot and were subsequently bulked across replications. Soil samples were taken with a soil auger from the upper 30 cm soil layer. The soil samples were analyzed for soil pH, OM, N, P, K, Ca, and Mg at the IITA-Kalambo soil lab in eastern DR Congo. The soil pH was measured from a 1:2.5 soil:water extract. Carbon was determined by the Walkley-Black method, which involves the oxidation of organic matter by a mixture of potassium dichromate and sulfuric acid. The organic matter content was determined using the van Bemmelen conversion factor 1.724 (SOM = %OC × 1.724). Total nitrogen was determined using a sulfuric (1 L)/selenium (3.5 g) digestion mixture, digested at 300°C and later quantified calorimetrically at 655 nm using the spectrophotometer. Phosphorus was measured by digestion mixture of selenium powder and lithium sulphate, hydrogen peroxide (30% solution), and concentrated sulfuric acid. The exchangeable cations (K, Ca, and Mg) and available phosphorus were extracted using the Mehlich 3 extraction method at a pH of 2.5 and thereafter determined using an atomic absorption spectrophotometer (Mehlich, 1984).

In addition, soil samples were also collected at depths of 0–5 cm, 10–15 cm, and 15–20 cm using a 100 cm^3 (5 cm in diameter and 5 cm high) inox bulk density sampling ring cylinder to determine soil moisture. Six soil moisture samples (two samples per depth range) were collected from the center of each subplot at the flowering stage of the legume crop in both cropping seasons (i.e., in August 2020 and January 2021). Fresh weight of each soil sample was measured in the field and samples were subsequently dried in an oven at 90°C for 72 h. Soil moisture was calculated using the following formula: percentage moisture = (((fresh weight − dry weight)/dry weight) × 100). No profound differences in soil moisture were observed at the different soil depths; therefore, soil moisture content of each subplot was computed as an average of all six samples.

Soil temperature was also recorded with a thermometer (Hotbred thermometer, −5/65°C and °F), around noon and at 5 cm soil depth, for each subplot at the flowering stage of the legume crops. Six temperature measurements were taken at the center of each subplot. Measurements for legume plots were taken mid-way between the legume rows (i.e., 25 cm from legume rows).

2.5 | Weed biomass measurements

To determine the effect of the legume crops on weed suppression, weed biomass was determined at legume harvesting in both the monocrop and intercrop treatments in a net plot of 1 × 1 m located at the center of subplots. The harvested weed biomass was dried in the open air for 72 h and subsequently in an oven at 90°C for 48 h to obtain its dry weight.

2.6 | Yield and growth assessments

The aboveground biomass (fresh and dry biomass weight) of the three legume crops (*Mucuna pruriens*, *Crotalaria juncea*, and *Cicer arietinum*) in both the intercrop and monocrop subplots was assessed at pod formation in a 1 × 1 m net plot located in the center of a subplot. The dry weight of the biomass was determined as described for the weed biomass above. In addition, the number of root nodules on five flowering legume plants per legume species and subplot was

determined at pod filling stage (i.e., in August for dry season and January for the wet season). For the chickpea, the remaining plants in the subplots were harvested for grain yield assessment. The remaining biomass from the three legume crops were retained in the fields as mulch for the subsequent season.

For the banana crop, changes in growth parameters (height and pseudostem circumference) were assessed for the mother plant and selected suckers from the time the legumes were introduced in a plot to legume harvest. A total of 81 and 25 banana mats for the 2 × 2 m and 4 × 4 m spacing plots, respectively, were assessed in both the intercrop and the banana monocrop plots. Data were collected on plant circumference at soil level and plant height for all mother plants and the two retained suckers per mat at legume harvest in the May–September season and at both planting and legume harvest in the September–February season (as a basis for determining changes in plant growth). For the flowered banana plants, data were also collected on the number of hands in the bunch and the total number of fingers on the second lowest hand. In addition, pseudostem girth at soil level (Gbase) and 1 m height (G1m) was also recorded. These data were used to estimate bunch weight and yield of the flowered plants. Bunch weights were estimated using the following allometric equation (Wairegi et al., 2009):

$$\mathrm{Ln}\,(\mathrm{Bwt}) = \mathrm{k} + \mathrm{c}\,\mathrm{ln}\,(\mathrm{hands}) + \mathrm{d}\,\mathrm{ln}\,(\mathrm{Fingers}) + f\,\mathrm{ln}\,(\mathrm{vol_{stem}}) \quad (1)$$

where k is the intercept, c and d are parameter coefficients, f is the coefficient of $\mathrm{vol_{stem}}$ (volume of the stem between the base and 1 m height), $\mathrm{Vol_{stem}} = 100/12\pi\ [\mathrm{G^2base} + \mathrm{G^2 1m} + (\mathrm{Gbase} \times \mathrm{G1m})]$, and $\mathrm{k} = -8.908$; $\mathrm{c} = 0.561$, $\mathrm{d} = 0.482$, and $f = 0.925$.

The land use efficiency of the different banana-legume intercrops was determined using the land equivalent ratio (LER). LER is the amount of mono-cultured land needed to produce the same yield as the specified intercrops (Willey, 1985). To compute LER, bunch, grain, and biomass yields were respectively used for banana, chickpea, and the two cover crops (mucuna and crotalaria). For each crop, the relative yield (RY) was calculated to determine the partial LER for that crop and then the partial LERs were summed to give the total LER for the intercrop (Mazaheri et al., 2006) as shown below.

$$\mathrm{LER} = \mathrm{RY_1} + \mathrm{RY_2}$$

where $\mathrm{RY_1}$ is the $\mathrm{I_1/M_1}$, $\mathrm{RY_2}$ is the $\mathrm{I_2/M_2}$, $\mathrm{I_1}$ is the yield of crop 1 grown as intercrop, $\mathrm{M_1}$ is the yield of crop 1 grown as monocrop, $\mathrm{I_2}$ is the yield of crop 2 grown as intercrop, $\mathrm{M_2}$ is the yield of crop 2 grown as monocrop, $\mathrm{RY_1}$ is the partial LER of crop 1 or ratio of yield of crop 1, and $\mathrm{RY_2}$ is the partial LER of crop 2 or ratio of yield of crop 2.

2.7 | Data analysis

An analysis of variance was conducted to determine the effects of the different treatments (planting densities, seasons, and legume types) on the different measured parameters using the R Statistical software version 4.0.2 (2020-06-22) (R Core Team, 2020). The Tukey test at 5% probability level was used for mean separation. A simple linear regression model computed with R Statistical software was used to determine the relationship between parameters. Crop biomass and/grain yield served as the dependent variables while different parameters including PAR at 30 cm from a mat, PAR in the middle point between four banana mats, weed biomass, number of root nodules, and soil chemical and physical attributes served as independent variables in the model. The effect of the legumes on banana growth was determined independently for the mother plants and suckers as the change in growth (plant height and girth at soil level and 1 m height) from the time of legume planting to harvest.

3 | RESULTS

3.1 | Light intensity

The amount of PAR intercepted above the legume intercrops increased with declining banana plant density (i.e., increasing banana plant spacings) in both the dry and wet seasons (Table 1). In comparison with the sole legume cropped plots, PAR was significantly reduced in the 2 × 2 m (i.e., by 65–68%) and 4 × 4 m (30–47% reduction) banana fields. PAR also varied significantly ($p < 0.05$) between the seasons. PAR values were lower (i.e., 1026–1118 μmol/m^2/s) in the dry season (May–Sept 2020) than for the wet Sept 2020–Feb 2021 season (1242–1433 μmol/m^2/s) (Table 1). The period July to September, although a dry period, is characterized by a persistent stratocumulus type cloud cover.

3.2 | Impact of the legume cover crops and chickpea on soil physical and chemical attributes

Soil moisture was lower under the banana monocrops compared with the banana-legume intercrops and the legume monocrops (Table 2). Soil moisture content was consistently higher (38.8 to 66.8%) in the 4 × 4 m spaced banana fields and the legume monocrops (38.6 to 69.8)%) than in the 2 × 2 m spaced banana plots (37.3 to 60.2) (Table 2). However, no significant ($p > 0.05$) differences in soil moisture generally occurred between treatments for a crop or intercrop treatment within a season. Soil moisture as expected was higher in the wet season (47.3 to 69.8%) compared with the dry season (31.6 to 45%; Table 2).

Soil temperature was generally higher under the sole banana crops (22.9–25.7°C) compared with the intercrops (20.6–23.9°C) or legume monocrops (20.7–23.8°C) (Table 2). Generally, soil temperature did not differ profoundly ($p > 0.05$) between the plant densities for a specific intercrop (Table 2).

Soil pH varied between 6.29 and 6.59 at the onset of the experiments and declined to between 6.26 and 6.50 at close of the experiments (Table S1). pH declines were consistently observed under the banana monocrop. In the intercropped plots, except for the 2 × 2 banana-chickpea intercrop, soil pH was observed to increase under the legume intercrops (Table S1). SOC, Soil N, SOM, P, and K irrespective

TABLE 1 Photosynthetically active radiation values measured 50 cm from a banana mat and at the center of a plot, according to planting season, banana cropping system, and intercropping type

		Photosynthetically active radiation (μmol m^{-2} s^{-1})							
		Mucuna		Crotalaria		Chickpea		Banana	
Season	Cropping system	At center of plot	50 cm from banana mat	At center of plot	50 cm from banana mat	At center of plot	50 cm from banana mat	At center of plot	50 cm from banana mat
May–Sept 2020	2 × 2 m	643c (243)	608c (301)	590c (28)	781 cd (90)	682c (88)	619c (122)	654a (168)	639b (137)
	4 × 4 m	1278b (214)	1006b (302)	1245b (213)	912ba (131)	1276b (33)	797bc (109)	1231a (281)	639b (136)
	Monocrop	1556ab (35)	1661a (54)	1547ab (21)	1661a (54)	1553ab (61)	1661a (54)	-	-
Sept. 2020–Feb 2021	2 × 2 m	769c (234)	674bc (364)	602c (343)	459d (163)	496c (382)	553c (79)	857a (19)	655b (95)
	4 × 4 m	1766a (39)	1580a (360)	1540ab (369)	1220b (309)	1872a (265)	1169b (256)	1484a (619)	11143a (234)
	Monocrop	1948a (123)	2046a (48)	2121a (20)	2046a (48)	2030a (159)	2046a (48)		
	Fpr (F)	0.192 (1.9)	0.023 (4.0)	0.160 (2.18)	0.006 (8.46)	0.022 (5.7)	0.029 (5.1)	0.269 (1.5)	0.061 (5.3)

Note: Values in brackets are the standard deviations. Means in a column followed by the same letter are not significantly different from each other according to Tukey's HSD test ($p \leq 0.05$).

TABLE 2 Soil moisture (%) and temperature (°C) values according to planting season, banana plant spacing, and intercrop type

		Soil moisture (%)				Soil temperature (°C)			
Season	Cropping system	Mucuna	Crotalaria	Chickpea	Banana monocrop	Mucuna	Crotalaria	Chickpea	Banana monocrop
May–Sept 2020	2 × 2 m	41.6b (0.9)	37.3b (5.1)	39.6c (3.2)	31.6c (0.9)	22.4a (2.0)	20.6c (0.5)	23.3a (0.6)	25.0a (1.1)
	4 × 4 m	44.1b (0.9)	38.8b (1.5)	45.0c (2.4)	35.0c (2.2)	20.6a (0.7)	23.9a (0.5)	23.2a (0.3)	25.7a (0.5)
	Monocrop	44.2b (1.4)	38.6b (2.7)	44.0c (1.9)		21.2a (0.6)	20.7c (1.0)	23.4a (0.4)	
Sept 2020–Feb 2021	2 × 2 m	54.1a (2.3)	60.2a (3.5)	56.7b (6.9)	47.3b (3.6)	22.4a (0.2)	22.4ab (0.2)	22.9a (0.5)	22.9b (0.3)
	4 × 4 m	58.8a (3.7)	63.7a (3.6)	66.8ab (5.6)	57.3a (2.0)	21.8a (0.2)	21.0bc (0.8)	23.1a (0.7)	24.4ab (0.6)
	Monocrop	57.9a (4.0)	64.9a (6.2)	69.8a (1.9)		21.9a (2.2)	21.2bc (0.0)	23.8a (0.3)	
	Fpr (F)	0.7325 (0.32)	0.778 (0.26)	0.2295 (1.7)	0.0536 (5.4)	0.506 (0.7)	0.001(22.97)	0.348 (1.2)	0.398 (0.8)

Note: Values in brackets are the standard deviations. Means in a column followed by the same letter are not significantly different from each other according to Tukey's HSD test ($p \leq 0.05$).

of the treatments, respectively, varied from 5.22%–5.64%, 0.21%–0.26%, 9.10%–9.44%, 190 mg/kg–226 mg/kg, and 1.18–3.09 me/100 g at onset of the experiment (Table S1). At close of trial, SOC, N, SOM, P, and K values, respectively, varied between 5.03% and 5.57%, 0.26% and 0.34%, 8.68% and 9.60%, 180.6 mg/kg and 221.2 mg/kg, and 2.02 me/100 g and 2.89 me/100 g (Table S1). The observed changes in soil chemical attributes at termination of the trials were not profound and/or consistent between the banana-legume intercrop treatments. This could be attributed to the short time duration of the experiment, which was inadequate for determining the impact of the intercrop treatments on the soil chemical attributes.

3.3 | Weed biomass yield

Weed biomass yields were highest under the banana monocrops (18.0–36.7 t/ha) followed by the chickpea treatments (5–23.3 t/ha) and least under the mucuna monocrop and intercrop treatments (0–3.9 t/ha). For the banana monocrop and chickpea intercropping treatments, weed biomass generally increased with increasing banana plant spacing whereas it declined with increasing banana plant density for the mucuna and crotalaria intercropping treatments. The banana monocrop and mucuna treatments relative to the crotalaria and chickpea treatments had no significant differences ($p > 0.05$) in weed biomass yields (Table 3).

Within seasons, weed biomass yields did not differ significantly between the mucuna and crotalaria treatments (Table 3). In contrast, weed biomass in chickpea plots significantly ($p = 0.004$) increased with declining banana plant density from the 2 × 2 m spaced plots to the monocrops (Table 3). In general, weed biomass yields were higher in the wet September season than the dry May season in the banana monocrop and mucuna plots (Table 3). In contrast, weed biomass in the crotalaria and chickpea fields was higher in the dry seasons (Table 3).

3.4 | Banana growth parameters

Banana-legume intercropping improved banana growth parameters measured 10 months after legume planting (end of February 2021). Compared with the mono-cropped banana plants, the legume crop

TABLE 3 Weed biomass yield (dry weight; t/ha) according to treatment, cropping arrangement, and planting season

Season/month of planting	Treatment	Banana monocrop	Mucuna	Crotalaria	Chickpea
Dry/May 2020	2 × 2 m	18.0b (2.0)	0.8b (0.3)	6.3a (3.2)	9.3b (1.2)
	4 × 4 m	20.0b (0.0)	0.0b (0.0)	5.7a (1.2)	20.0a (0.0)
	Monocrop	-	0.0b (0.0)	0.0b (0.0)	23.3a (5.8)
Wet/sept. 2020	2 × 2 m	31.7a (2.9)	3.9a (0.8)	4.3ab (1.2)	5.0b (0.0)
	4 × 4 m	36.7a (2.9)	2.5a (0.5)	2.0ab (1.0)	5.0b (0.0)
	Monocrop	-	2.7a (0.6)	2.7ab (2.5)	20.0a (0.0)
	Fpr (F)	0.291 (1.3)	0.708 (0.4)	0.025 (5.24)	0.004 (10.1)

Note: In brackets are the standard deviations. Means in a column followed by the same letter are not significantly different from each other according to Tukey's HSD test ($p \leq 0.05$).

TABLE 4 The change in plant height and pseudostem circumference at soil level (PC) of banana mother plant and attached suckers as influenced by legume intercrops

			Plant height (cm)			PC (cm)		
Banana spacing	Cropping practice	Legumes	Mother plant	Sucker 1	Sucker 2	Mother plant	Sucker 1	Sucker 2
2 × 2 m	Intercrop	Chickpea	34.7ab	37.0abc	14.8a	5.3a	5.9ab	2.0b
		Crotalaria	49.9a	20.5c	38.2a	6.7a	8.0ab	8.3b
		Mucuna	50.1a	30.2c	20.1a	7.2a	6.9ab	2.5b
		Mean	**44.9**	**29.2**	**24.4**	**6.4**	**6.9**	**4.3**
	Monocrop	Banana	30.2 ab	23.1c	9.0a	2.8a	0.4b	3.9b
4 × 4 m	Intercrop	Chickpea	46.9ab	56.2a	46.3a	6.3a	12.2a	35.0a
		Crotalaria	50.7a	34.6bc	13.3a	5.4a	7.2ab	NA
		Mucuna	53.2a	55.3ab	43.8a	4.2a	16.2a	16.7ab
		Mean	**50.3**	**48.7**	**34.5**	**5.3**	**11.9**	**25.9**
	Monocrop	Banana	1.2b	23.2c	19.7a	4.6a	9.5ab	3.3b
		Fpr (F)	0.602	0.573	0.594	0.551	0.604	0.076

Note: Means in a column followed by the same letter are not significantly different from each other according to Tukey's HSD test ($p \leq 0.05$).

plots generally recorded an improvement in banana plant height and girth for both the mother plants and suckers (Table 4). However, no significant differences were observed across the treatments (possibly due to the high variability within treatments). For example, the average change in mother plant height in the 2 × 2 m and 4 × 4 m treatments were, respectively, 45 cm and 50 cm in the intercrops compared, respectively, with 30 cm and 1 cm in the control banana monocrops (Table 4).

3.5 | The performance of legume cover crops and chickpea under varying banana plant densities

Higher mucuna, crotalaria, and chickpea biomass yields were obtained in the monocrop treatments and under the lower banana planting density with a wider (i.e., 4 × 4 m) banana plant spacing in both cropping seasons compared with the 2 × 2 m spaced banana fields (Table 5). Biomass yield declines varying between 37 and 83%; 56–93% and 80–98% were observed for mucuna, crotalaria, and chickpea, respectively, in the 2 × 2 m plots compared with the 4 × 4 m and monocrop fields. There was no significant difference in biomass yield between the mucuna monocrop and the mucuna under the 4 × 4 m banana crop for both the May and September planting season. Similar observations occurred for the crotalaria and chickpea crop in the September–February season. However, there was a significantly higher yield of the crotalaria and chickpea crops in the monocrop compared with yields under the 4 × 4 m in the dry May to September season (Table 5).

Seasonal effects on biomass yield were also observed. The highest yields for mucuna and crotalaria were obtained in September 2020–February 2021 season (i.e., 28.5 t/ha and 83.9 t/ha for mucuna and crotalaria, respectively) compared with 24.3 t/ha and 58.4 t/ha for mucuna and crotalaria, respectively, in the May–September 2020 season. In contrast, the biomass yield of chickpea was lower in the wet season (September–February; 2.3 t/ha) compared with dry season (May–September; 11.2 t/ha).

The average number of nodules per plant increased with increasing PAR in both planting seasons across the three legume crops. On average, 5 to 37 nodules per plant were observed in the 2 × 2 m plots compared with 7 to 71 in 4 × 4 m plots and 9 to 108 in the

TABLE 5 The aboveground biomass yield (dry weight) and number of root nodules of mucuna, crotalaria, and chickpea and chickpea grain yield under different banana-legume intercrop treatments and two contrasting seasons

Season	Cropping systems	Biomass (t/ha)			Number of root nodules			Chickpea grain yield (kg/ha)
		Mucuna	Crotalaria	Chickpea	Mucuna	Crotalaria	Chickpea	
May–Sept 2020	2 × 2 m	15.3cd (4.0)	22.0bc (1.7)	0.3d (0.6)	4.5d (0.3)	5.7d (1.0)	28.6c (0.8)	84.7c (21.4)
	4 × 4 m	24.3bc (5.1)	50.0b (10.1)	9.0b (1.7)	6.9cd (0.4)	11.1d (3.2)	31.1c (1.0)	308.3b (98.4)
	Monocrop	33.3ab (5.8)	103.3a (5.8)	24.3a (5.1)	8.8c (0.5)	12.2d (2.6)	30.9c (0.3)	1850a (454)
Sept 2020–Feb 2021	2 × 2 m	6.8d (5.5)	8.3c (2.9)	0.8cd (0.3)	9.3c (0.9)	29.0c (10.9)	36.5b (2.4)	1.0d (1.6)
	4 × 4 m	41.0a (1.7)	113.3a (11.6)	2.0cd (0.0)	17.4b (2.7)	72.1b (1.9)	38.3ab (2.2)	37.8cd (7.9)
	Monocrop	37.7a (4.0)	130.0a (26.5)	4.0bc (1.7)	25.9a (4.3)	107.8a (8.5)	40.8a (1.0)	48.9cd (16.2)
	Fpr (F)	0.003 (10.4)	0.001 (13.3)	0.001 (32.9)	0.004 (9.8)	0.001 (51.0)	0.325 (1.3)	0.001 (43.9)

Note: Experiments were conducted at INERA, eastern DR Congo. In brackets are the standard deviations. Means followed by the same letter within a column are not significantly different at 5% Turkey test.

monocrops (Table 5). Seasonal effects on root nodulation were also observed. The number of nodules per plant were higher (9–108 nodules) in the wet season compared with 5–31 nodules in the dry season (Table 5).

Significant interactions also occurred between the seasons and the legume species. For example, crotalaria registered a higher root nodulation (29–108 nodules per plant) in the wet season (Table 5) compared with 9 to 26 for mucuna and 37 to 41 for chickpea. In contrast, chickpea had the highest number of root nodules (29–31) in the dry season compared with 6 to 12 nodules for crotalaria and 5 to 9 root nodules for mucuna. Mucuna had the lowest number of nodules of the three legumes in both the dry and wet season.

The chickpea grain yield followed a similar trend as that for the chickpea biomass yield. A significantly higher ($p = 0.001$) chickpea grain yield was recorded in the dry season (mean of 747.7 kg/ha) than for the wet season (mean 29.2 kg/ha) (Table 5).

The linear regression model of chickpea biomass yield against a range of factors selected soil moisture, PAR close to banana mat, soil temperature, soil organic carbon, and soil pH as the significant explanatory variables (Table 6). These variables were negatively associated with chickpea biomass and explained 83% (adjusted $R^2 = 0.83$, $p = 3.75e{-}05$) of the variation in chickpea biomass in the trials. For chickpea grain yield, the model selected biomass yield, number of root nodules, weed biomass, soil temperature, SOC, and pH as the main explanatory variables. These variables explained 96% of the variation in chickpea grain yield (adjusted $R^2 = 0.96$, $p = 6.61e{-}08$). Grain yield increased with increasing biomass, soil temperature, whereas it declined with increasing root nodulation, weed biomass, SOC and soil pH. Root nodulation in chickpea was explained by soil moisture and SOC ($R^2 = 0.91$; $p = 6.92e{-}09$. Nodulation was observed to significantly increase with soil moisture content and to decline with SOC (Table 6).

Concerning mucuna, biomass yield was explained by PAR at center of plot, PAR close to banana mat, soil moisture, number of root nodules, weed biomass, and soil pH (Table 6). These variables explained 88% of the variation in mucuna biomass yield (i.e., adjusted $R^2 = 0.88$, $p = 0.0001$). Biomass yield increased with increasing PAR at center of plot, soil moisture, and number of root nodules, whereas it was negatively associated with PAR measured close to banana mat, weed biomass, and soil pH. Root nodulation in mucuna was significantly ($R^2 = 0.77$; $p = 0.0001$) and positively influenced by mucuna and weed biomass and the amount of PAR close to the banana mat.

Crotalaria biomass yield was affected by weed biomass, number of root nodules, soil temperature, soil pH, and SOC (Table 6). These variables explained 96% of the variation in crotalaria biomass yield (adjusted $R^2 = 0.96$, $p = 1.2e{-}08$). Increased soil temperature resulted in low biomass yield whereas crotalaria yield increased with root nodulation, soil pH, and SOC. Root nodulation in crotalaria was significantly ($R^2 = 0.91$; $p = 1.227e{-}05$) explained by crotalaria and weed biomass, PAR close to the banana mat: soil moisture, temperature, pH, and organic carbon (Table 6). Root nodulation increased with crotalaria biomass yield, PAR close to the mat, soil moisture, and soil temperature. In contrast, it declined with weed biomass, soil pH, and SOC.

3.6 | The land equivalent ratio (LER)

An agronomic yield advantage, measured in terms of LER (i.e., LER > 1), was observed for all the banana-legume intercrop treatments, irrespective of the banana spacing/shade intensity (Figure 2). LER varied between 1.10 in the 2 × 2 m banana-chickpea intercrop and 1.95 in the 4 × 4 m banana-mucuna intercrop. Note that dry biomass yield was used for the LER calculations for mucuna and crotalaria, while grain yield was used for chickpea. LER values for the mucuna-banana intercrop was higher than that for the crotalaria-banana intercrop for both the 2 × 2 m and 4 × 4 m spacings. These results suggest that the mucuna-banana intercrops were more efficient than the crotalaria-banana intercrop.

The mean LER values were higher in the 4 × 4 m spacing arrangement than for the 2 × 2 m spacing (Figure 2). Thus, intercropping of legumes within the 4 × 4 m spaced banana crop had a higher agronomic advantage over the sole banana crop and the intercrops within the 2 × 2 m spaced banana crop. The cost–benefit analysis or

TABLE 6 Model outcomes of regressions of legume yield parameters (biomass and grain yield) and root nodulation as dependent variables with different explanatory variables

Crop	Parameters	Estimate	Std. error	*t* value	Pr(>|t|)
Chickpea biomass	(intercept)	2580.0	482.9	5.342	0.0002***
	Soil moisture	−0.588	0.241	−2.440	0.0312*
	PAR around mat	−0.0167	0.006	−2.906	0.0132*
	Soil temperature	−5.486	2.039	−2.690	0.0197*
	SOC	−62.460	14.69	−4.251	0.0011**
	Soil pH	−324.600	60.52	−5.363	0.0002***
Chickpea grain yield	(intercept)	19,864.928	14,590.265	1.362	0.2006
	Biomass yield	83.239	8.191	10.162	6.3e−07***
	No. of nodules	−27.933	12.842	−2.175	0.0520
	Weed biomass	−33.565	9.264	−3.623	0.0040**
	Soil temperature	122.107	83.159	1.468	0.1700
	SOC	−930.964	390.209	−2.386	0.0361*
	Soil pH	−2576.699	1818.317	−1.417	0.1842
Chickpea root nodulation	(intercept)	20.591	11.776	1.748	0.1010
	Soil moisture (%)	0.900	0.070	12.941	1.5e−09***
	SOC	−3.146	2.214	−1.421	0.1760
Mucuna biomass	(intercept)	963.100	492.100	1.957	0.0820
	PAR at center of plot	0.016	0.005	3.344	0.0086**
	PAR close to banana mat	−0.016	0.007	−2.280	0.0486*
	Soil moisture	2.675	0.815	3.282	0.0095**
	No. of nodules	0.495	0.344	1.438	0.1843
	Weed biomass	−5.307	1.502	−3.533	0.0064**
	Soil pH	−162.200	79.430	−2.042	0.0716
Mucuna root nodulation	(intercept)	−7.532	3.100	−2.430	0.032*
	Mucuna biomass	0.432	0.075	5.761	9.0e−05***
	Weed biomass	2.230	0.703	3.170	0.008**
	PAR close to banana mat	0.004	0.002	2.196	0.049*
Crotalaria biomass	(intercept)	−9617.000	984.300	−9.771	4.60e−07***
	Weed biomass	5.214	1.598	3.262	0.0068**
	No. of nodules	0.452	0.072	6.289	4.01e−05***
	Soil temperature	−17.750	2.965e	−5.988	6.33e−05***
	Soil pH	1465.00	135.400	10.819	1.52e−07***
	SOC	137.700	42.320	3.254	0.0069**
Crotalaria root nodulation	(intercept)	1.3e+04	0.004	3.410	0.007**
	Crotalaria biomass	0.784	0.246	3.183	0.010**
	Weed biomass	−5.567	2.643	−2.106	0.060
	PAR close to banana mat	0.060	0.017	3.445	0.006**
	Soil moisture	2.455	0.690	3.560	0.005**
	Soil temperature	20.630	5.444	3.789	0.004**
	Soil pH	−1837.000	520.900	−3.526	0.005**
	SOC	−287.800	104.000	−2.767	0.020*

Note: Values not followed by an asterisk (*) are statistically not significantly different at $p \leq 0.05$.
*Significantly different at 0.05.
**Significantly different at 0.01.
***Significantly different at 0.001.

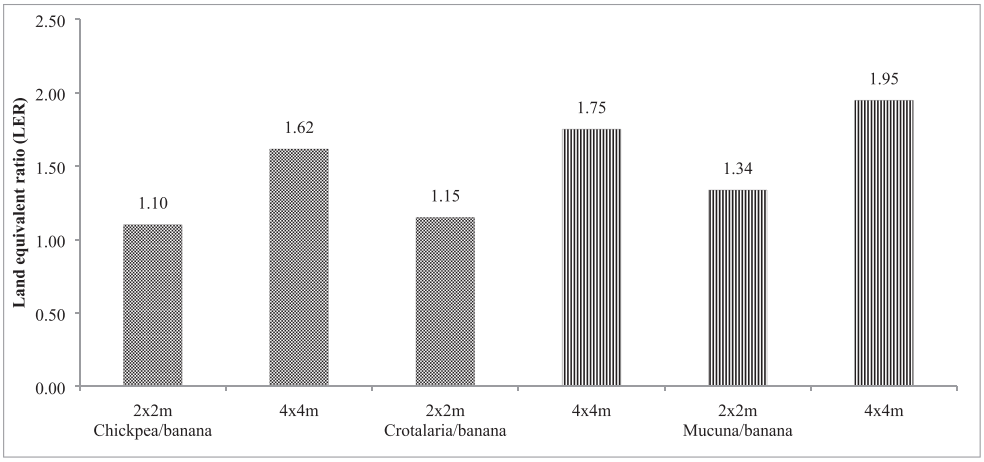


FIGURE 2 Land equivalent ratio (LER) according to banana planting density and banana-legume treatment

financial advantage of the intercrop options was however not determined as these legume crops are novel and currently not cultivated on farms in the region.

4 | DISCUSSION

4.1 | Impact of the legume cover crops and chickpea on soil moisture and temperature

The increase in soil moisture from 2 × 2 m to 4 × 4 m to the legume monocrop plot observed across seasons (cf. Table 2) can be attributed to (i) the higher water uptake by the banana crop in highly dense plots relative to the other treatments and (ii) the higher vigor and associated better ground coverage by the legume crops in the less dense banana plots and legume monocrop fields. The cover crops potentially improved water infiltration and limited soil evapotranspiration. These results are consistent with the findings of Mulinge et al. (2017).

Cover crops may influence soil temperature by absorbing solar radiation or by changing the heat capacity of the soil through changes in soil moisture content. In the current study, reductions in soil temperature in intercropped plots compared with the banana monocrop plots may be explained in part by greater soil moisture content in those plots (cf. Table 2). Moist soil has higher heat capacity than dry soil (Haramoto & Brainard, 2012).

4.2 | Weed biomass yield

Weed suppression is a core service provided by cover crops. Weed biomass was higher in the banana monocrop relative to the banana-legume intercrops and increased with spacing, possibly due to more light reaching the ground and lower interspecies competition for resources such as light, water, and nutrients. Among the legume intercrops, the lower weed suppression by the chickpea crop (0–86% reduction in weed biomass) could be attributed to its lesser robustness and ground canopy cover that offered less competition for light and other resources. This is consistent with the observed positive correlation between weed biomass yield and the amount of PAR ($R^2 = 0.5$ and $p = 0.05$; cf. Table 6) in the chickpea treatments. In contrast, mucuna and crotalaria were extremely suppressive to weeds (65–100% weed biomass yield reduction; cf. Table 6) due to their high biomass yields and ability to cover much of the soil surface. Weed biomass yields in these cover crop fields, in contrast to chickpea, declined with increasing PAR (i.e., reducing banana plant density) due to the positive effect of PAR on cover crop vigor and biomass yields. Reductions in weed biomass of up to 90% have also been reported under *Leucaena leucocephala* alley cropping with maize at varying plant spacing distances, when compared to a crop-only controls (Jama et al., 1991; Mureithi et al., 1994). The cooler soil temperatures under the cover crops could have also retarded early growth of weeds (Dabney et al., 2001).

Higher weed biomass was observed in the dense banana-mucuna and banana-crotalaria intercropped plots because the high shade had reduced the vigor of the cover crops, especially close to the banana mats and allowing for the more shade-tolerant weed species to grow. These findings suggest that mucuna and crotalaria have a high potential for managing weeds in partially shaded banana systems and open fallows.

4.3 | Legume effects on banana growth parameters

Despite the short duration of the trial and non-significant differences ($p > 0.05$), a consistently higher vegetative growth (i.e., pseudostems and plant height) was observed in banana plants intercropped with the legume crops, suggesting that the three legumes helped improve the vigor of the banana crop. This can be attributed to better soil moisture conservation, improved N supply, and improvements in other soil physical and chemical properties. Previous studies have shown contrasting effects of intercrops on the banana crop. Faster banana and plantain growth and production has been reported when soils under banana were covered by intercrops such as taro (*Colocasia* sp.) (Armecin et al., 2005; Tutu et al., 2019; Sombo et al., 2020). Soil cover protects the superficial root system of banana against extreme

variations in soil temperature (Sanginga & Woomer, 2009), facilitates water infiltration, prevents erosion, and limits evaporation (Edson et al., 2021; Wang et al., 2019). Permanent soil cover and water availability in the soil promote banana root elongation and uptake of mineral elements (Blomme, 2000; Das et al., 2019). The legumes also return organic matter to the soil during growth, thereby improving or maintaining soil structure (Djigal et al., 2012; James & Topper, 2010). In addition, some cover crops control banana pests; for example, crotalaria contributes to control of banana nematodes (Djigal et al., 2012; Wang et al., 2002). These results contrast the findings of Ocimati et al. (2019) who show reductions, though nonsignificantly ($p > 0.05$), in growth parameters for banana plants intercropped with soybean, bush, and climbing beans. It should, however, be noted that some of the banana plants in Ocimati et al. (2019) had been pruned to four or seven leaves, potentially limiting the banana crop from benefitting from the services provided by the legume cover crops.

4.4 | Light intensity and season effects on yield of mucuna, crotalaria, and chickpea

Mucuna and crotalaria yield reductions were lower (5 to 30%) under the sparsely spaced banana fields relative to 69 to 87% in the denser 2 × 2 m spaced fields suggesting that they have a good potential for improving farm performance under sparsely spaced banana fields (cf. Table 5). These findings are consistent with the findings of Blomme et al. (2020). In contrast to mucuna and crotalaria, high reductions in chickpea biomass and grains yields of 63–99% and 83–95%, respectively, across the sparsely spaced and dense banana fields, suggest shade to be a major constraint to chickpea production. Li et al. (2010) similarly reported shade to be a major constraint to chickpea production.

Despite the lower biomass yields in the heavily shaded mucuna and crotalaria intercropped plots and the poor performance of chickpea under shade, the LER of 1.15–1.34 under dense shading for mucuna and crotalaria; and 1.10–1.62 for chickpea across the shading treatments suggests that the three legumes can improve the agronomic efficiency of banana fields. Nevertheless, an assessment of the economic efficiency of these legume-banana interactions is crucial for guiding further decisions for their integration (Ocimati et al., 2019). Farmers' decision to incorporate these legumes, especially the cover crops that do not directly contribute to household nutrition, could also be influenced by the competition with/desire to plant other annual crops on the available and often limited land area (Ocimati et al., 2019, 2021).

Biomass yield declines, albeit low occurred in the dry season for mucuna (15%) and crotalaria (30%), suggesting that these crops tolerated the deficits in soil moisture. Mucuna and crotalaria could thus be introduced on farms in the dry season (when fields are often covered with weeds) to supplement forage, cover the soil surface and improve soil fertility through N-fixation or acting as green manure/mulch in the subsequent season. In contrast, chickpea biomass and grain yield increments of 394% and 4487%, respectively, in the dry season show that chickpea performs better under drier conditions. This crop is reported to be drought-tolerant and thus useful for protecting soils against degradation in drier conditions (Blomme et al., 2020; Varshney et al., 2014). Chickpea is currently not cultivated in the study region either as a sole crop or intercrop. Given the observed advantage of chickpea in the dry season, it could be promoted as demonstrated in this study in the inter-season dry period. This will enable farmers to expand their cropping seasons to three instead of the current two, improving household food-security and incomes.

4.5 | Root nodulation

Leguminous crops are often used as a nutrient management strategy to reduce nitrogen fertilizer needs. The symbiotic association between leguminous crops and N fixing rhizobia has however been reported to be vulnerable to multiple abiotic and biotic stresses including water/drought stress, nutrition, and light availability (Hultman, 2018; Kasper et al., 2019; Ntamwira et al., 2021; Schubert, 1995). In the current study, root nodulation of the three legume crops (i.e., mucuna, crotalaria, and chickpea) declined with increasing banana canopy cover (i.e., declining PAR) and varied with seasons. Light energy is crucial for photosynthesis which plays an important role in nodulation and nitrogen fixation. Adequate energy supply through photosynthesis is reported to be crucial for efficient nodulation, nitrogen fixation, and N conversion to organic N compounds (Liu et al., 2018; Schultze & Kondorosi, 1998; Surridge, 2021).

Chickpea root nodulation showed a lower sensitivity to shade compared with mucuna and crotalaria. For example, reductions in nodules of 60%, 71%, and 9% in the dense plots and 30%, 31%, and 3% in the less dense plots were observed for mucuna, crotalaria, and chickpea, respectively. This is also supported by the fact that significant regressions ($p < 0.05$) were observed between increasing mucuna and crotalaria root nodulations with increasing PAR close to the banana mat and increasing biomass yield (that was generally correlated with PAR).

Seasonal variations in root nodulation can be attributed to variations in soil moisture level and associated plant vigor, with consistently higher root nodulation observed in the rainy season compared to the dry season. This is also supported by the significantly high ($p < 0.01$) and positive regressions between chickpea and crotalaria root nodulation with soil moisture. Similar observations have been reported for bush and climbing bean plants in the study region (Ntamwira et al., 2014, 2017, 2021; Ocimati et al., 2019). Moisture has been reported as a major factor in successful root nodulation, with more moisture required for N fixation than plant growth (Deak et al., 2019; Kasper et al., 2019; Kirda et al., 1989). Water is also needed for exporting N products from the nodules to other plant parts and any reduction in nodule water supply leads to build up of N products in the nodule thus inhibiting further N fixation (Serraj et al., 1999; Walsh, 1995). More still, severe moisture stress inhibits nodule initiation and causing nodule shedding in some legume species (Deak et al., 2019; Kasper et al., 2019; Kirda et al., 1989).

Sensitivity of root nodulation in mucuna and crotalaria to additional abiotic and biotic factors was also observed. Root nodulation in mucuna and crotalaria increased with weed biomass. This could be attributed to intra-species competition within the rhizosphere. Legumes intercropped with cereals; for example, wheat has been reported to respond by increasing root nodulation, nitrogen fixation, and production of exudates of allelopathic compounds to compensate for the limiting nutrients and enhance their competitiveness (Leoni et al., 2021; Zhao et al., 2020). Crotalaria root nodulation also increased with soil temperature, whereas it declined with increasing soil pH and SOC. Soil temperature influences root hair colonization, type of rhizobia, nodule structure, and nodule functioning (Hungria & Franco, 1993; Räsänen & Lindström, 1999; Roughley, 1970; Roughley & Dart, 1970). Critical temperatures for N fixation are reported to vary from one legume species to another. Temperatures between 35 and 40°C are reported to be critical for soybean (*Glycine max*), peanut (*Arachis hypogea*), and cowpea (*Vigna unguiculata*) (Michiels et al., 1994) whereas 25 and 30°C for the common beans (*Phaseolus* spp.) (Hungria & Franco, 1993; Piha & Munnus, 1987). High soil temperatures above the optimal strongly inhibit bacterial infection, nodule formation, and N2 fixation (Hungria & Franco, 1993; Kishinevsky et al., 1992; Piha & Munnus, 1987). For crotalaria, temperatures between 10°C and 40°C have been reported to support root nodulation (Maheshwari et al., 2021). The soil temperatures in the current study varied between 20°C and 24°C. The observed strong association between nodulation in crotalaria and soil temperature thus suggests that the current soil temperature could still be below the optimal for nodulation in crotalaria.

The strong negative association of crotalaria root nodulation with soil pH suggests that it is very sensitive to lower pH conditions, given pH conditions at the site (6.2 and 6.5) were within limits reported to be suitable for crotalaria (i.e., 5.5 to 9). Similarly, other legume crops that fix N symbiotically are reported to require neutral to slightly acidic soils (Bordeleau & Prevost, 1994; Brockwell et al., 1991). Soil acidity limits survival and persistence of rhizobia in soils, reducing root nodulation (Brockwell et al., 1991; Ibekwe et al., 1997).

The decline in crotalaria root nodulation with increase in soil SOC could be attributed to a high rate of SOC/SOM mineralization to produce N. SOC levels in the soil were high and varied between 5.2 and 5.8%. Waterer and Vessey (1993) reported the increase in SOM levels in legume-based systems to result in a higher mineralization of N from the SOM leading to lower nodulation and nitrogen fixation. In *Trifolium ripens*, most of the symbiotic rhizobium were detected between 2.03% and 3.80% SOC (Swanepoel et al., 2011). Swanepoel et al. (2011) also observed the efficiency of N fixation to proportionally decline with an increase in SOC, though the total amount of N in the soil increased with increasing SOC.

5 | CONCLUSION

The results of this study show that the integration of mucuna, crotalaria, and chickpea in banana systems can increase field-level biomass yields, soil moisture retention and banana growth parameters. The cover crops mucuna and crotalaria also reduced weed biomass and could thus be used as a strategy for weed management, especially where farmers grow bananas as monocrops. The good performance of these cover crops in the dry season could also be exploited for production of additional biomass for fodder, mulch, or manure under both small and large farm settings. The chickpea crop performed better when planted using residual soil moisture at the onset of dry season and could thus enable farmers to use their lands gainfully in the dry season periods. Land is most often left bare or covered with weeds during the dry season months. The performance of the legume crops was however constrained under the 2 × 2 m spaced banana plants, suggesting that higher benefits from the legumes will only be realized in the more sparsely spaced fields. Root nodulation, which is crucial for the nitrogen fixing function of the legume crops, was severely constrained in the heavily shaded 2 × 2 m plots. Thus, overall, benefits from the legume crops will be lower under heavy shading.

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CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as or result in a potential conflict of interest.

DATA AVAILABILITY STATEMENT

Data will be made available upon request.

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