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Enhancement of Soil Fertility and Musa sp. AAA (Cavendish) Yield by *Arachis repens* and *Desmodium adscendens* Cover Crops in Côte d'Ivoire: An Agroecological Approach

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ABSTRACT: This study, conducted in Akressi, Côte d'Ivoire, assesses the impact of cover crops (*Arachis repens* and *Desmodium adscendens*) on soil properties and dessert banana production (Cavendish, Grande-Naine) over two cycles. Ferralitic soils, degraded by intensive monoculture, are examined using a Fischer block design with three treatments: control (bare soil with herbicides), *A. repens,* and *D. adscendens*. Soil physical properties (bulk density: 1.90–1.94 g/cm^{3,} porosity: 25.15–27.18%, gravimetric moisture: 17.34–21.58%) remain unchanged ($p > 0.05$). After 12 months, cover crops enhance chemical properties: pH (5.80 control, 6.03 *A. repens,* 5.93 *D. adscendens*), organic carbon (1.11% control, 1.24% *A. repens,* 1.38% *D. adscendens*), organic matter (1.90% control, 2.13% *A. repens,* 2.37% *D. adscendens*), nitrogen (0.10% control, 0.11% *A. repens,* 0.12% *D. adscendens*), CEC (5.38 cmol/kg control, 7.20 cmol/kg *A. repens,* 8.61 cmol/kg *D. adscendens*), and calcium (1.56 cmol/kg control, 1.66 cmol/kg *A. repens,* 1.75 cmol/kg *D. adscendens*) increase significantly ($p < 0.05$). In the first cycle, growth (height: 245–247 cm) and yield (41.21–42.08 t/ha) are similar ($p > 0.05$). In the second cycle, control plants are taller (271.76 cm vs. 255.36 cm *A. repens*); *A. repens* delays flowering (158 vs. 135 days) and harvest (235 vs. 214 days *D. adscendens*) and reduces functional leaves (10.84 vs. 11.66 control at flowering) ($p < 0.01$). *Desmodium adscendens* increases hands (7.82 vs. 7.33 *A. repens*) and fingers (140.57 vs. 127.10 *A. repens*) ($p < 0.05$). Yields remain comparable (44.17 control, 44.36 *A. repens,* 44.50 t/ha *D. adscendens*). Cover crops, particularly *D. adscendens,* enhance soil chemical fertility without compromising yield, supporting sustainable banana production.

KEYWORDS: Cover crops, Soil fertility, Dessert banana, Agroecology, Chemical properties, Yield components.

1 INTRODUCTION

The dessert banana (*Musa* sp. AAA) is the third most important tropical fruit crop. Its production relies exclusively on the Cavendish variety group, which alone accounts for 97% of the international market [1]. As the world's leading exported fruit, the banana plays a fundamental economic and social role for both producing and exporting countries, generating significant revenue and serving as a major source of employment, particularly in rural areas [2]. Furthermore, Latin America represents approximately 80% of global dessert banana exports, while Africa accounts for only 3.4% of the total volume [3]. Côte d'Ivoire produces more than 400,000 tons of bananas annually, primarily destined for the European Union. The country's banana industry contributes about 8% of the agricultural GDP and between 2% and 3% of the overall GDP [4].

This major crop is nevertheless subject to numerous constraints, mainly associated with climate variability, pest infestations, and diseases [5], [6]. In addition to these challenges, there is a gradual decline in soil fertility, driven by the intensive monoculture of dessert bananas [7].

In this context, the integration of agroecological practices, particularly the use of cover crops in banana plantations, emerges as a promising solution for restoring soil quality and ensuring sustainable productivity. Cover crops play a crucial role in enhancing the physical, chemical, and biological properties of soils in West Africa [8]. They contribute to soil structuring by reducing bulk density and increasing porosity, which improves water infiltration and retention [9]. Furthermore, they mitigate water and wind erosion by protecting

the soil surface from the impact of rainfall, which is particularly important in tropical regions experiencing high seasonal precipitation. Chemically, the incorporation of plant biomass enriches the soil with organic matter and enhances its nutrient retention capacity [10].

This study aims to assess the impact of cover crops on the physicochemical properties of soils, as well as on the growth and yield of industrial dessert banana cultivation.

2 MATERIALS AND METHODS

STUDY SITE

The experiments were conducted in an industrial banana plantation in Akressi, located at geographic coordinates 5°37' North latitude, 3°05' West longitude, and an altitude of 87 meters. This village, situated in the South Comoé region, falls under the jurisdiction of the Aboisso department. This area is characterized by a transitional equatorial climate, with an annual average rainfall of 1,500 mm and a mean temperature of 27°C [11]. The climate follows four distinct seasons: a major dry season from December to February, a major rainy season from March to July, a minor dry season from August to September, and a minor rainy season from October to November [12]. There is a short dry season from November to March, followed by an extended rainy season. The soils are highly leached ferralitic soils due to the intense precipitation levels [13].

MATERIALS

The plant material consisted of banana vitroplants belonging to the Grande-Naine variety of the Cavendish (AAA) subgroup, as well as legumes from the Fabaceae family: *Arachis repens* and *Desmodium adscendens*.

METHODS

TRIAL MANAGEMENT

The experimental plot was established on flat land that had been left fallow for one year. The site was manually cleared, and plant debris was removed to facilitate trial setup. The suckers were planted in holes measuring 60 × 60 × 40 cm. A staggered twin-row planting system was adopted, with spacing of 2.2 m along the row and 1.7 m between staggered double rows, resulting in a planting density of 1,820 plants per hectare. Vitroplants were transferred to the field after eight weeks in the greenhouse. The study was conducted over two initial cycles of dessert banana cultivation. Cover crop cuttings were transplanted under banana plants after a three-month nursery phase.

Fertilizer application followed the technical requirements of banana cultivation. Herbicide treatments were applied only in control plots (without cover crops) at intervals determined by the level of weed growth. In contrast, manual weeding was performed as needed in plots with cover crops to prevent competition with weeds. Black leaf streak disease (cercosporiosis) was managed through mechanical removal of necrotic leaves, as well as aerial application of contact fungicides on a weekly basis and systemic fungicides every 14 days.

EXPERIMENTAL DESIGN

The experimental setup was a Fischer block design comprising three treatments, each replicated three times. The trial included elementary plots, each measuring 36 m × 10 m, with 64 planted banana trees per plot. The treatments were defined as follows:

- T0: Control or conventional practice with herbicide applications;
- T1: *Arachis repens* associated with banana plants;
- T2: *Desmodium adscendens* associated with banana plants

SOIL SAMPLING

Soil sampling was conducted prior to the establishment of cover crops and at the harvest of the first two cycles of dessert banana cultivation. To this end, soil samples were collected at depths of 0-20 cm in each elementary plot. For the evaluation of physical parameters such as bulk density, total porosity, and gravimetric moisture content, undisturbed soil samples were taken using a metal cylinder of known volume. These samples were collected along the diagonals of the plots at five points: the center and the four corners of the elementary plot.

At the same depth and following the diagonal sampling method, five disturbed soil samples intended for laboratory analyses were collected using a cylindrical soil auger [14]. These soil samples were then mixed to form a single composite sample [15].

ANALYZED PHYSICAL PARAMETERS

Bulk density was assessed using the cylinder method [16]. The collected samples were weighed before and after oven-drying at 105 °C until a constant dry mass (DM) was obtained. Bulk density, expressed in g/cm^{3,} was evaluated using the following formula:

$$Bulk\ density = Dry\ mass\ of\ soil/Soil\ volume$$

Total porosity was determined based on bulk density by applying the following formula:

$$Total\ porosity\ = (1 - Bulk\ density/Praticle\ density \times 100)$$

Gravimetric soil moisture was assessed using the gravimetry method, based on fresh samples, considering their constant dry weight after oven-drying at 105 °C [17], [18].

Analyzed Chemical Parameters Additional soil analyses focused on acidity, total nitrogen content (N), organic carbon content (OC), organic matter content (OM), available phosphorus (P-ass.), exchangeable bases (Ca^{2+}, Mg^{2+}, and K^{+}), cation exchange capacity (CEC), and trace elements (Fe, Zn, Cu).

Soil acidity was assessed by measuring pH using the electrometric “glass electrode” method in a soil/water ratio of 1: 2.5 [19]. Total nitrogen content (N) was determined using the Kjeldahl method [20]. Organic carbon content (OC) was analyzed following the method of Walkley and Black [21]. Organic matter content (OM) was calculated based on the carbon percentage (C) using the following formula [22]: OM (%) = OC (%) × 1,72. Available phosphorus content was determined using the Olsen-Dabin method [22], [23]. Exchangeable bases were quantified via ammonium acetate extraction at pH 7 [24]. CEC was also assessed by the method of Ciesielski & Sterckeman [24]. Trace elements (Fe, Zn, Cu) were analyzed by atomic emission spectrometry [25].

OBSERVED PARAMETERS IN BANANA PLANTS DURING TWO PRODUCTION CYCLES

GROWTH PARAMETERS

Plant height and pseudostem circumference were measured to monitor pseudostem growth. Banana plant height was recorded in centimeters from the collar to the "V" formed by the petioles of the last emerging leaves within the foliage cluster at the top of the plant. Pseudostem circumference was assessed at 1 meter above the ground.

PRODUCTION PARAMETERS

The total number of functional leaves was determined at flowering and harvest. Data collection involved counting fully expanded leaves, considering cigar leaf unfolding stages (00, 02, 04, 06 to 08) and leaf ranks, which were numbered from the youngest (the one located just after the cigar leaf) to the oldest. Functional leaves are those with photosynthetic activity and more than 50% green surface area [26].

Moreover, the planting-to-flowering interval (PFI) and planting-to-harvest interval (PHI) in days (d) were determined for both banana production cycles. The number of hands was recorded before and after the removal of false hands and the first true hands. Fingers were also counted, and internal lengths (cm) of the median finger from the first and last hand were measured. The grade of the median finger from the last hand was recorded in centimeters (cm), and yield (t.ha^{-1}) was determined for each cycle using the formula: (average bunch weight × planting density).

STATISTICAL DATA ANALYSIS

All data collected during the experiments were entered using Excel 2016 and analyzed with SPSS version 22. An analysis of variance (ANOVA) was performed to evaluate the effects of cover crops on soil fertility and the agro-physiological parameters of the plants. In cases of significant differences between means, the Newman-Keuls multiple comparison test at a 5% threshold was used to classify them into homogeneous groups.

3 RESULTS

EFFECTS OF COVER CROPS ON SOIL PHYSICAL PROPERTIES

BULK DENSITY, TOTAL POROSITY, AND GRAVIMETRIC MOISTURE CONTENT

The values of bulk density, total porosity, and gravimetric moisture content of the soil before cover crop establishment, as well as 6 and 12 months after their introduction into banana plantations, are presented in Table I. The analyses indicate that bulk density, porosity, and gravimetric moisture content did not undergo significant changes over the study period, regardless of the applied treatments.

Before the experiment, bulk density ranged from 1.92 to 1.94 g/cm^3 depending on the treatment, with total porosity between 25.21% and 26.09%. Gravimetric moisture content varied between 17.41% and 18.38%. The observed differences were not statistically significant ($p > 0.05$).

After six months, bulk density values remained close to initial levels, varying between 1.90 and 1.94 g/cm^3. Total porosity ranged from 25.15% to 27.18%, while gravimetric moisture content was between 17.34% and 18.38%. No significant difference was observed between treatments ($p > 0.05$).

After twelve months, bulk density remained between 1.90 and 1.92 g/cm^{3,} while total porosity varied from 25.87% to 26.97%. Gravimetric moisture content showed a slight increase compared to initial values, reaching up to 21.58% under *Arachis repens*. However, statistical tests indicated that none of these variations were significant ($p > 0.05$).

Table 1. Physical properties of soils in the experimental site before, 6, and 12 months after cover crop establishment

Crop stage	Treatments	Bulk density (g/cm³)	Total porosity (%)	Gravimetric moisture content (%)
Before CC	**Control**	1,92±0,04	26,09±1,62	17,90±2,01
	A. repens	1,94±0,06	25,21±2,49	17,41±1,07
	D. adscendens	1,92±0,09	25,97±3,65	18,38±2,18
	Probability	0,75	0,75	0,53
	Significance	NS	NS	NS
Six months after CC	**Control**	1,90±0,10	27,18±4,05	17,64±1,93
	A. repens	1,94±0,06	25,15±2,45	17,34±1,05
	D. adscendens	1,92±0,09	25,97±3,65	18,38±2,18
	Probability	0,46	0,46	0,46
	Significance	NS	NS	NS
Twelve months after CC	**Control**	1,92±0,08	25,87±3,14	20,39±1,83
	A. repens	1,90±0,10	26,97±4,15	21,58±2,09
	D. adscendens	1,91±0,04	26,37±1,70	21,49±0,92
	Probability	0,76	0,76	0,27
	Significance	NS	NS	NS

CC: Cover crops; For each column and at the same crop stage, means followed by the same letter are not significantly different at the 5% threshold (Student and Newman-Keuls test). NS: Not significant.

3.1.1 EFFECTS OF COVER CROPS ON SOIL CHEMICAL PROPERTIES

Before cover crop establishment, no significant differences were observed in the values of various soil chemical parameters across the plots (Table II). These soils were relatively homogeneous in terms of pH, cation exchange capacity (CEC), and their contents of organic carbon (OC), organic matter (OM), nitrogen (N), available phosphorus (P-ass.), calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), copper (Cu), iron (Fe), and zinc (Zn).

Similarly, six months later, soil samples collected from legume-covered plots exhibited statistically identical chemical compositions to those of the control. At this observation time, soil pH ranged between 6.56 and 6.70. Carbon content was 1.23%, 1.14%, and 1.16% in bare soil and in plots with *Arachis repens* and *Desmodium adscendens,* respectively. Organic matter content varied between 1.96% and 2.11%, while nitrogen content remained at 0.11% regardless of treatment. Regarding phosphorus levels, they fluctuated between 104.99 and 131.12 ppm.

The cation exchange capacity in the soils ranged from 8.18 to 9.78 cmol.kg^{-1}. Calcium concentrations varied from 1.66 to 1.83 cmol.kg$^{-1,}$ while magnesium content ranged between 1.22 and 1.29 cmol.kg^{-1}. Additionally, potassium levels fluctuated between 0.16 and 0.22 cmol.kg$^{-1,}$ and sodium concentrations were between 0.09 and 0.10 cmol.kg^{-1}.

Regarding trace elements, copper levels ranged between 6.09 and 7.20 ppm, while iron concentrations varied from 15.83 to 17.98 ppm. Zinc content fluctuated between 5.06 and 5.77 ppm.

However, 12 months after cover crop establishment, significant effects were observed in the presence of plant species for several evaluated chemical parameters. The pH of the bare soil (control) was lower (5.80) than that of soils covered with *Arachis repens* and *Desmodium adscendens,* which recorded values of 6.03 and 5.93, respectively.

Additionally, soils covered with cover crops, particularly *D. adscendens,* exhibited higher levels of carbon, organic matter, nitrogen, cation exchange capacity (CEC), and calcium. Conversely, the lowest concentrations of these parameters were found in the control soil.

Furthermore, in the control soil, high concentrations of potassium (0.33 cmol.kg^{-1}), sodium (0.19 cmol.kg^{-1}), and iron (12.03 ppm) were observed. However, regarding available phosphorus, copper, and zinc, cover crops did not induce any significant effects.

Table 2. Chemical characteristics of the soil in the experimental site before, 6, and 12 months after cover crop establishment

Soil Chemical Parameters	Crop stage														
	Before CC					Six months after CC					Twelve months after CC				
	Treatments			Statistical Test		Treatments			Statistical Test		Treatments			Statistical Test	
	Tém.	*A. rep.*	*D. ads.*	Prob.	Sign.	Tém.	*A. rep.*	*D. ads.*	Prob.	Sign.	Tém.	*A. rep.*	*D. ads.*	Prob.	Sign.
pH eau	6,56± 0,32	6,66± 0,20	6,50± 0,36	0,80	NS	6,70± 0,10	6,76± 0,23	6,56± 0,40	0,68	NS	5,80± 0,15b	6,03± 0,05a	5,93± 0,13a	0,00	VHS
OC (%)	0,90± 0,11	1,06± 0,16	0,99± 0,07	0,31	NS	1,23± 0,21	1,14± 0,19	1,16± 0,21	0,85	NS	1,11± 0,24b	1,24± 0,17ab	1,38± 0,05a	0,01	S
OM	1,54± 0,18	1,82± 0,27	1,54± 0,12	0,31	NS	2,11± 0,36	1,96± 0,32	1,99± 0,36	0,85	NS	1,90± 0,41b	2,13± 0,29ab	2,37± 0,08a	0,01	S
N(%)	0,08± 0,00	0,09± 0,01	0,09± 0,00	0,14	NS	0,11± 0,02	0,11± 0,01	0,11± 0,01	0,96	NS	0,10± 0,02b	0,11± 0,01ab	0,12± 0,00a	0,02	S
P-ass (ppm)	53,10± 17,17	71,07± 9,72	66,17± 8,57	0,26	NS	131,12± 58,98	104,99± 83,32	121,73± 60,43	0,89	NS	77,33± 8,50	73,33± 13,02	81,00± 24,43	0,62	NS
CEC (Cmol.kg^{-1})	8,18± 0,36	8,74± 0,96	7,46± 1,32	0,33	NS	9,78± 1,24	8,80± 1,44	8,18± 1,00	0,34	NS	5,38± 2,87b	7,20± 2,16ab	8,61± 1,66a	0,02	S
Ca (Cmol.kg^{-1})	2,26± 0,56	2,62± 0,76	2,49± 0,31	0,76	NS	1,83± 0,24	1,82± 0,39	1,66± 0,47	0,83	NS	1,56± 0,13b	1,66± 0,15ab	1,75± 0,13a	0,03	S
Mg (Cmol.kg^{-1})	2,02± 0,36	2,07± 0,36	1,92± 0,44	0,89	NS	1,28± 0,18	1,22± 0,08	1,29± 0,08	0,73	NS	1,21± 0,10	1,07± 0,09	1,10± 0,16	0,06	NS
K (Cmol.kg^{-1})	0,20± 0,05	0,26± 0,08	0,23± 0,02	0,54	NS	0,19± 0,05	0,16± 0,02	0,22± 0,04	0,36	NS	0,33± 0,08a	0,18± 0,04b	0,23± 0,03b	0,00	VHS
Na (Cmol.kg^{-1})	0,14± 0,01	0,15± 0,02	0,14± 0,03	0,88	NS	0,10± 0,01	0,09± 0,01	0,09± 0,00	0,57	NS	0,19± 0,06a	0,12± 0,02b	0,11± 0,00b	0,00	VHS
Cu (Cmol.kg^{-1})	0,47± 0,52	0,69± 0,61	0,81± 0,30	0,72	NS	7,05± 1,40	7,20± 1,55	6,09± 2,33	0,73	NS	6,34± 0,60	6,68± 0,38	6,83± 0,89	0,28	NS
Fe (Cmol.kg^{-1})	14,90± 1,66	17,25± 2,23	15,68± 0,19	0,26	NS	15,83± 2,25	16,52± 2,78	17,98± 1,94	0,55	NS	12,03± 4,67a	8,52± 2,21b	8,94± 0,55b	0,04	S
Zn (Cmol.kg^{-1})	6,33± 1,72	5,93± 1,74	5,88± 1,60	0,93	NS	5,77± 2,22	5,71± 2,28	5,06± 1,65	0,90	NS	2,64± 0,13	2,62± 0,15	2,76± 0,35	0,41	NS

OC: Organic Carbon; OM: Organic Matter; N: Nitrogen; P-ass.: Available Phosphorus; CEC: Cation Exchange Capacity; Ca: Calcium; Mg: Magnesium; K: Potassium; Na: Sodium; Cu: Copper; Fe: Iron; Zn: Zinc; CC: Cover Crops; Ctrl.: Control; A. rep.: Arachis repens; D. ads.: Desmodium adscendens; Prob.: Probability; Sig.: Significance. For each row and at the same crop stage, means followed by the same letter are not significantly different at the 5% threshold (Student and Newman-Keuls test). VHS: Very Highly Significant; NS: Not Significant; S: Significant

3.1.2 EFFECTS OF COVER CROPS ON BANANA GROWTH PARAMETERS

Pseudostem length of banana plants the analysis of variance conducted on banana plant height revealed no significant difference among treatments during the first cultivation cycle (p = 0.69). plant height ranged from 245.29 to 246.96 cm (Figure 1). However, during the second planting cycle, height variation among treatments was significant (P = 0.00). The tallest banana plants were observed in the control plots, reaching 271.76 cm. The shortest plants were recorded in plots associated with *Arachis repens,* measuring 255.36 cm.

3.1.3 PSEUDOSTEM CIRCUMFERENCE OF BANANA PLANTS

During the first planting cycle, pseudostem circumferences were not significantly affected by the applied treatments (P = 0.21). Values fluctuated between 55.28 and 57.20 cm (Figure 2). However, in the second cultivation cycle, banana plants exhibited different pseudostem circumferences depending on the treatment (P = 0.00). The largest circumferences were recorded in the control plots (66.13 cm). *Arachis repens* induced the smallest circumference in banana plants (58.27 cm). Banana plants in plots covered with *Desmodium adscendens* exhibited intermediate circumferences, with a value of 62.20 cm.

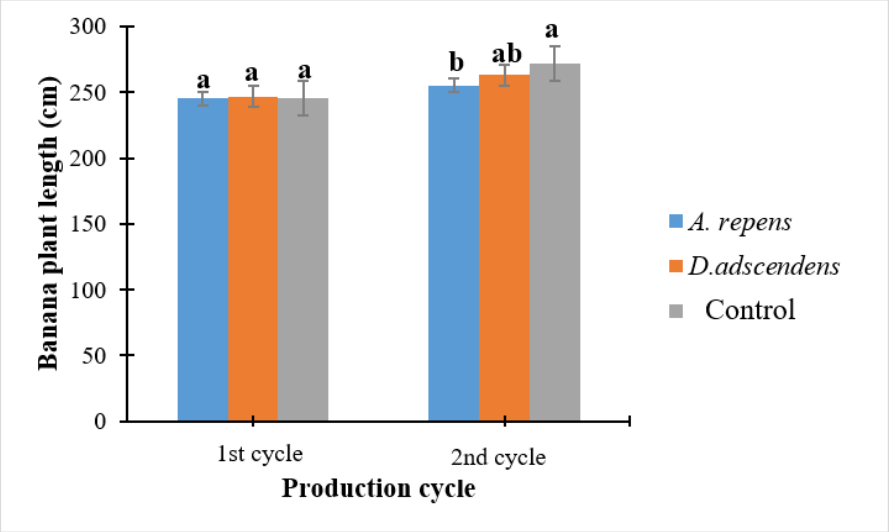

Fig. 1. Pseudostem length of banana plants as a function of treatments in the first and second production cycles

Means within the same cycle followed by the same letter on the histograms are not significantly different at the 5% threshold (Student and Newman-Keuls test).

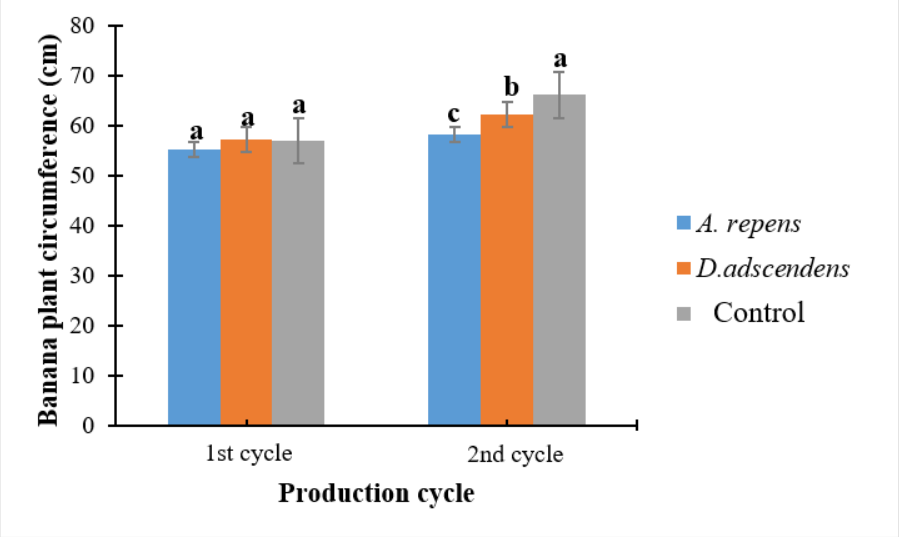

Fig. 2. Pseudostem circumference of banana plants at 1 m above ground at flowering as a function of treatments in the first and second production cycles

Means within the same cycle followed by the same letter on the histograms are not significantly different at the 5% threshold (Student and Newman-Keuls test).

3.1.4 EFFECTS OF COVER CROPS ON BANANA PRODUCTION PARAMETERS

3.2 NUMBER OF FUNCTIONAL LEAVES AT FLOWERING

The number of functional leaves observed at flowering in banana plants showed significant variation depending on the treatments applied in both the first and second cultivation cycles (P = 0.00).

At flowering during the first cycle of the experiment, the highest number of functional leaves was recorded in banana plants from plots covered with *Desmodium adscendens* (14.44 leaves/plant), followed by those in control plots (13.60 leaves/plant). *Arachis repens* resulted in the lowest number of functional leaves in banana plants, with 12.84 leaves/plant.

At flowering in the second cycle, banana plants from *D. adscendens* plots and the control soil exhibited the highest number of functional leaves (11.53 leaves/plant and 11.66 leaves/plant, respectively). In contrast, plants associated with *A. repens* had the lowest number of functional leaves, with 10.84 leaves/plant (Figure 3).

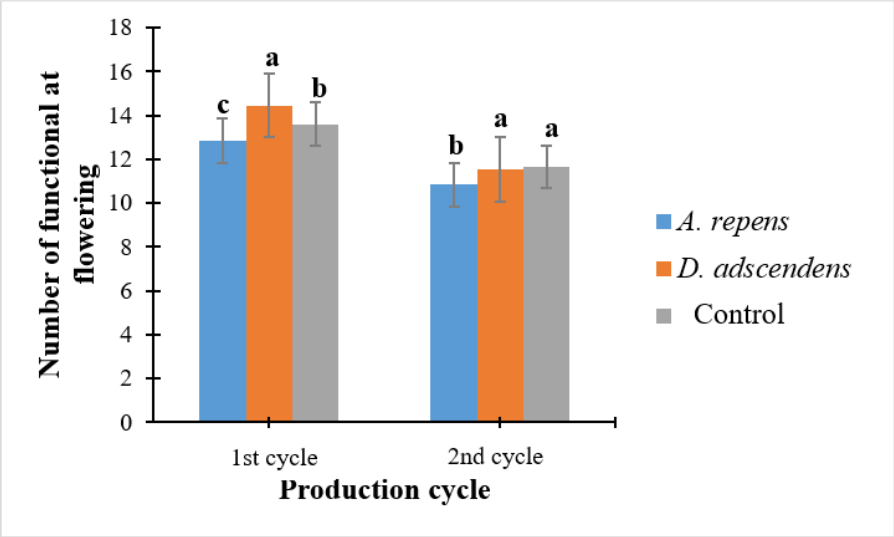

Fig. 3. Number of functional leaves in banana plants at the flowering stage according to treatments in the first and second production cycles

Means within the same cycle followed by the same letter on the histograms are not significantly different at the 5% threshold (Student and Newman-Keuls test).

3.3 NUMBER OF FUNCTIONAL LEAVES AT HARVEST

At the end of the first planting cycle (harvest), the analysis of variance conducted on the number of functional leaves revealed no significant differences among treatments. The number of functional leaves observed in banana plants, regardless of plot origin, ranged between 8.42 and 8.62 leaves per plant.

However, in the second planting cycle, a significant difference was observed among treatments. Banana plants in the control plots exhibited the highest number of functional leaves at harvest (6.26 leaves per plant). In plots with *Arachis repens,* banana plants presented the lowest number of functional leaves at harvest, with 5.4 leaves per plant (Figure 4).

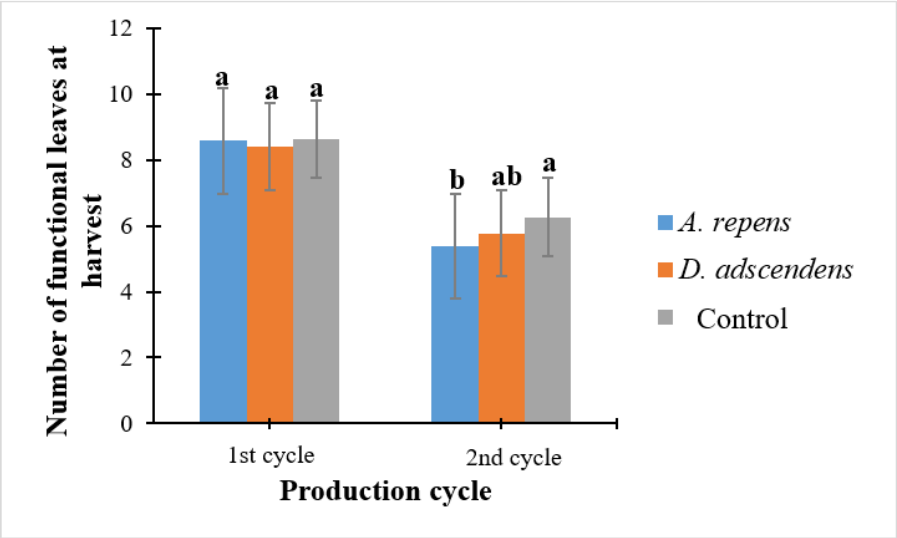

Fig. 4. ***Number of functional leaves in banana plants at harvest according to treatments in the first and second production cycles***

Means within the same cycle followed by the same letter on the histograms are not significantly different at the 5% threshold (Student and Newman-Keuls test).

3.4 PLANTING-TO-FLOWERING INTERVAL (PFI) OF BANANA PLANTS

Table III presents the planting-to-flowering intervals (PFI) for the first and second planting cycles of banana plants. During the first planting cycle, no significant difference was observed among treatments (P = 0.72). The planting-to-flowering interval (PFI1) for banana plants ranged between 163 and 165 days after planting. However, in the second planting cycle, treatments had a significant effect on the planting-to-flowering interval (PFI2) of banana plants (P = 0.00). Flowering occurred earlier in the control soil and in plots covered with *Desmodium adscendens,* at the 135th and 138th day after the first cycle's harvest, respectively. The longest flowering delay was recorded in plots with *Arachis repens,* at 158 days after the first cycle's harvest.

Table 3. ***Planting-to-flowering interval (PFI) of banana plants as a function of treatments during the two production cycles***

Treatments	PFI of banana plants (days)	
	1st cultivation cycle	2nd cultivation cycle
Control	165 ±4	135 ±5a
A. repens	163 ±4	158 ±4b
D. adscendens	165 ±4	138 ±8a
Probability	0,72	0,00
Significance	NS	VHS

For each column, means followed by the same letter are not significantly different at the 5% threshold (Student and Newman-Keuls test). NS: Not significant; VHS: Very highly significant

3.5 PLANTING-TO-HARVEST INTERVAL (PHI) OF BANANA PLANTS

The planting-to-harvest interval (PHI1) did not show any significant variation among treatments in the first cultivation cycle (Table IV). It remained at 242 days for all banana plants, regardless of treatment. However, in the second cycle, a much shorter planting-to-harvest interval (PHI2) was observed in banana plants from *Desmodium adscendens* plots and the control soil, recorded at 214 and 217 days after the first cycle's harvest, respectively. In contrast, the latest harvest occurred in plots with *Arachis repens,* at 235 days after the first cycle's harvest.

Table 4. Planting-to-harvest interval (PHI) of banana plants as a function of treatments during the two production cycles

Treatments	PHI of banana plants (days)	
	1st cultivation cycle	2nd cultivation cycle
Control	242±4	217 ±7a
A. repens	242±4	235 ±4b
D. adscendens	242±4	214 ±4a
Probability	1,00	0,00
Significance	NS	VHS

For each column, means followed by the same letter are not significantly different at the 5% threshold (Student and Newman-Keuls test). NS: Not significant; VHS: Very highly significant

3.6 YIELD COMPONENTS

The yield parameters including the number of hands before thinning per bunch (NHBT/bunch), the number of hands after thinning per bunch (NHAT/bunch), the number of fingers, the internal length of the last hand (ILLH), the internal length of the first hand (ILFH), and the fruit grade are presented in Table V as a function of treatments in the first and second cultivation cycles.

During the first production cycle, variance analyses did not reveal any significant differences among treatments for NHBT (P = 0.88), NHAT (P = 0.09), the number of fingers (P = 0.90), ILLH (P = 0.56), and ILFH (P = 0.73). Regarding NHBT, values ranged between 8.63 and 8.73 hands per bunch, while NHAT values were between 7.00 and 7.38 hands per bunch. The number of fingers per banana bunch varied between 123.90 and 126.70. ILLH ranged between 15.81 and 16.09 cm, and ILFH was at least 20 cm across all treatments.

In contrast, fruit grade showed a significant variation depending on treatments. The highest fruit grade was recorded in bananas from control plots (33.21 mm), whereas bananas from plots covered with *Arachis repens* and *Desmodium adscendens* exhibited the lowest values (32.70 mm and 32.73 mm, respectively).

During the second cultivation cycle of banana plants, significant differences were observed only for NHBT (P = 0.01), NHAT (P = 0.03), and the number of fingers (P = 0.03). The highest NHBT values were recorded in banana plants from *Desmodium adscendens* plots and the control plots (9.89 and 9.83 hands per bunch, respectively).

The highest NHAT value was noted in *D. adscendens* plots (7.82 hands per bunch), as was the highest number of fingers, reaching 140.10 fingers per bunch. Conversely, the lowest values for these three parameters were observed in *Arachis repens* plots (9.35 hands per bunch, 7.33 hands per bunch, and 127.10 fingers per bunch, respectively).

Additionally, ILLH varied between 16.28 and 16.93 cm, while ILFH ranged from 19.05 to 19.73 cm. As for fruit grade, values fluctuated between 30.78 and 32.23 mm.

3.7 YIELD

At the end of the first cultivation cycle, no significant differences were observed among treatments (Figure 5). The recorded yields were 41.88 $t.ha^{-1}$ (*Arachis repens*), 42.08 $t.ha^{-1}$ (*Desmodium adscendens*), and 41.21 $t.ha^{-1}$ (control plot).

At the end of the second cultivation cycle, yield did not vary significantly among the evaluated treatments. Values ranged from 44.17 to 44.50 $t.ha^{-1}$. *A. repens* and *D. adscendens* resulted in yields of 44.36 $t.ha^{-1}$ and 44.50 $t.ha^{-1,}$ respectively. Conversely, the yield recorded in the control treatment was 44.17 $t.ha^{-1}$ (Figure 6).

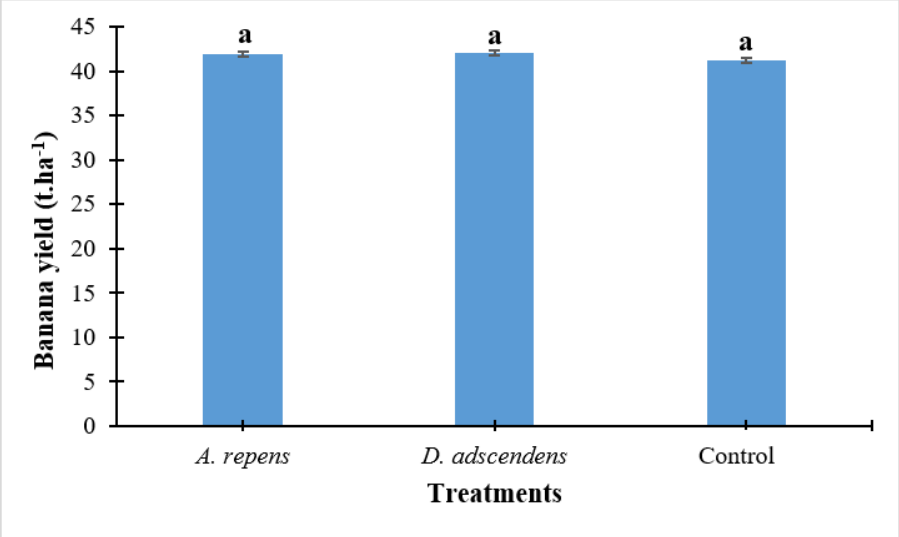

Fig. 5. Yield of banana plants according to treatments at the end of the first cultivation cycle

Means within the same cycle followed by the same letter on the histograms are not significantly different at the 5% threshold (Student and Newman-Keuls test).

Table 5. Yield components of banana plants in the first and second production cycles according to treatments

Banana cultivation cycles	Treatments	yield components in the first planting cycle					
		NHBT/ bunch	NHAT/ bunch	Number of fingers/ bunch	ILLH of the bunch	ILFH of the bunch	Fruit grade
1st cycle	Control	8,70±0,81	7,00±0,86	126,70±14,81	16,09±1,13	20,55±1,09	33,21±0,70 a
	A. repens	8,63±0,67	7,33±0,55	125,30±9,01	15,83±1,21	20,67±1,21	32,70±0,88 b
	D. adscendens	8,73±0,72	7,38±0,75	123,90±16,03	15,81±1,06	20,42±1,14	32,73±0,87 b
	Probability	0,88	0,09	0,11	0,56	0,73	0,02
	Significance	NS	NS	NS	NS	NS	S
2nd cycle	Control	9,89±0,84a	7,63±0,81ab	134,73±21,33ab	16,28±1,60	19,05±1,77	30,78±4,71 b
	A. repens	9,35±1,00b	7,33±0,97b	127,10±27,38b	16,65±1,39	19,68±2,09	32,23±1,94 a
	D. adscendens	9,89±0,84a	7,82±0,79a	140,57±21,77a	16,93±1,68	19,73±1,87	31,70±1,34 ab
	Probability	0,01	0,03	0,03	0,16	0,21	0,05
	Significance	S	S	S	NS	NS	NS

NHBT: Number of hands before thinning; NHAT: Number of hands after thinning; ILLH: Internal length of the last hand; ILFH: Internal length of the first hand. For each column and within the same cultivation cycle, means followed by the same letter are not significantly different at the 5% threshold (Student and Newman-Keuls test). NS: Not significant; S: Significant.

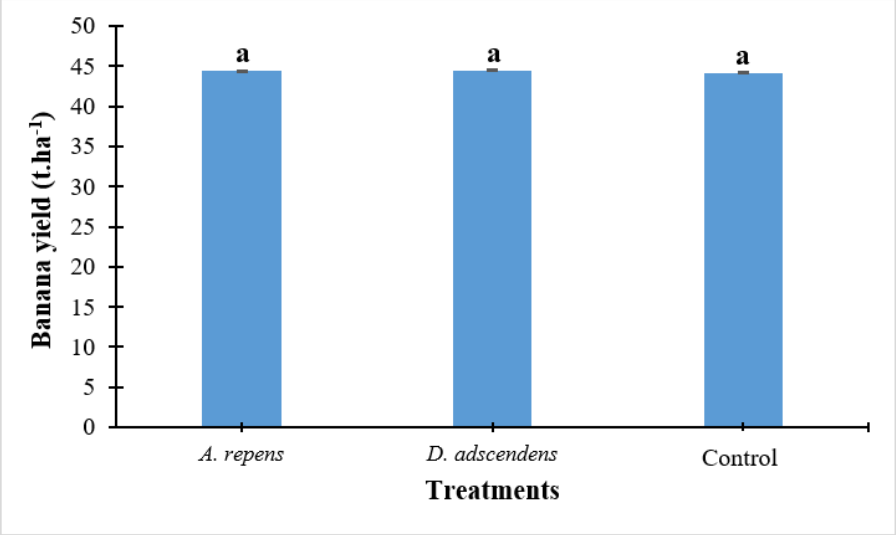

Fig. 6. Yield of banana plants according to treatments at the end of the second cultivation cycle

Means within the same cycle followed by the same letter on the histograms are not significantly different at the 5% threshold (Student and Newman-Keuls test).

4 DISCUSSION

The study of physical parameters such as bulk density, total porosity, and soil gravimetric moisture revealed that these were not influenced by leguminous cover crops. This observation could be explained by the fact that cover crops tend to exert their effects over the long term. Several studies have highlighted the potential of cover crops to improve certain physical properties [27].

However, the extent to which crops cover can modify these properties may depend on the duration of the growth period [28]. Research conducted by Mbuthia *et al* [29]. found that the long-term use of cover crops in a monoculture production system, such as cotton, leads to significant changes in soil structure.

The results on soil chemical properties reveal that cover crops significantly improved these properties 12 months after their establishment in the banana plantation. An increase in soil pH was observed in plots with cover crops compared to the control soil, indicating reduced acidity in these plots. Konaté *et al*. [30] highlight that atmospheric nitrogen fixation by legumes and the decomposition of their litter lead to an enrichment of the soil in organic matter and an increased nitrogen mineralization. During mineralization, free protons in the soil solution are complexed by humic acids, thereby increasing soil pH [31]. These processes make essential nutrients available to plants while also promoting a shift in soil pH towards neutrality. Additionally, the soil pH recorded in plots covered with *Desmodium adscendens* and *Arachis repens* is favorable for the optimal development of dessert bananas, which require a pH range between 4.0 and 8.0 [32]. A similar study conducted by Tanoh *et al*. [33] reported that legumes improved soil acidity, with soil pH increasing from 5.43 to 6.23. The results also revealed high levels of carbon and organic matter in the soil solution under the influence of cover crops. This effect is likely due to the decomposition of cover crop biomass, which has undoubtedly contributed to an increase in soil carbon content and a potential enhancement in soil organic matter levels [34].

The increase in soil organic matter content is widely considered beneficial for soil function and fertility and, in agricultural production systems, is an integral part of sustainable agriculture. Moreover, the storage of the carbon component of organic matter in agricultural soils is also regarded as a means of reducing atmospheric carbon dioxide levels and mitigating the impact of climate change [35]. Regarding nitrogen, 12 months after the establishment of cover crops, nitrogen levels increased in soils covered with legumes at both studied sites. This rise in nitrogen levels could partly be attributed to the symbiotic fixation of atmospheric nitrogen. Indeed, due to their ability to utilize atmospheric nitrogen, legumes can improve the nitrogen balance in cropping systems [36], [37].

Moreover, the increase in nitrogen content may be attributed to the recycling of leguminous residues in the soil. These residues are particularly rich in nitrogen and serve as a source of organic nitrogen, potentially enhancing nitrogen availability within the system [38]. The findings reported by Barrios *et al*. [39] indicated that peanut and cowpea residues contain higher nitrogen levels and decompose more rapidly, thereby releasing greater amounts of nitrogen into the soil solution. Furthermore, cation exchange capacity (CEC) was higher in soils under cover crops at both Aboisso and Tiassalé. This can be explained by the abundant production of litter enriched with mineral elements, which forms beneath these plants. Upon decomposition, this organic matter contributes to the formation of organo-

mineral complexes, thereby improving the mineral status of the soil. According to Beringer [40], variations in CEC based on Ca^{2+} concentrations are due to the significant role of this mineral, which accounts for 65% of exchangeable bases.

Chemical analysis revealed a lower potassium content in soils covered with vegetation compared to bare or control soils. This could be explained by plant uptake of this nutrient. Potassium is an essential nutrient for legumes, as well as for all other crops. It serves as an activator of numerous enzymes, particularly those involved in protein synthesis. Additionally, potassium plays a crucial role in maintaining the plant's water balance. In legumes, potassium is necessary for the proper development and functioning of root nodules. These plants require high levels of nutrients, including potassium, to enhance their performance in symbiotic nitrogen fixation and overall growth [41].

The sodium content was also low in soils under cover crops. This observation suggests that legumes may have the ability to restore salt-degraded soils [42]. Indeed, salt accumulation particularly Na^+ from saline irrigation water [43] and excessive use of chemical inputs [44] can lead to ionic imbalance and toxicity in plants, potentially affecting vital metabolic processes [45]. The levels of Cu, Fe, and Zn varied. The results showed that soil trace element concentrations were not affected by the different evaluated treatments, except for Fe content, which was higher in the control soil. This result is likely influenced by edaphic factors, particularly soil pH, which affects the availability of minor elements in the soil solution [46]. Indeed, iron becomes more available as soil pH decreases [47]. In this study, soils covered with legumes exhibited higher pH values than the control or bare soil. This trace element is essential for plants due to its physiological importance [48]. However, this minor element is a heavy metal and is not biodegradable. As a result, it remains persistent in soils over the long term and can become toxic to plants [49], [50].

Regarding growth parameters, such as the circumference and height of banana plants, the results highlighted an impact of the different treatments only during the second planting cycle. Indeed, the averages of these two parameters were higher in plants from the control plots. These observations could be explained by the delayed effects of cover crops on banana plants. Although these plants largely contributed to the improvement of soil chemical parameters, the implementation of this contribution may depend on various factors, such as the duration of cover crop growth, soil type, cash crop characteristics, and meteorological conditions [51].

The results revealed a variation in the number of leaves at flowering and harvest across the two banana production cycles in the experimental plots. The number of leaves was lower in banana plants associated with *Arachis repens*. These observations suggest that defoliation, generally applied to all banana plants, was more intensified in these plants, which had fewer leaves. According to Robinson [52], defoliation is an agronomic practice primarily conducted for two reasons: first, to reduce the inoculum of black streak disease (BSD) by eliminating necrotic leaves exceeding 50% damage, and second, to improve fruit quality by preventing young leaves from rubbing against the developing bunch. Several studies have evaluated the minimum number of leaves required to achieve maximum yield. Robinson *et al*. [53] found that vigorous banana plants can produce acceptable fruits with only 2 to 4 leaves during the filling period, due to a compensatory increase in CO_2 assimilation that can reach up to 35% in defoliated plants.

Regarding production parameters, the planting-to-flowering interval (PFI) and the planting-to-harvest interval (PHI) were influenced by the treatments. Flowering and harvest in banana plants associated with *Arachis repens* were delayed exclusively during the second cultivation cycle. This delay appears to be linked to variations in the number of leaves at flowering and harvest. Indeed, the growth and development of the banana bunch from inflorescence emergence to harvest depend on the physiological activity of functional leaves that remain present upon the appearance of the inflorescence at the apex of the pseudostem [54]. Thus, the lower number of functional leaves observed in the cited treatments, following defoliation conducted for banana plant maintenance, seems to have delayed the accumulation of dry matter during fruit development.

The treatments influenced certain yield components, including the number of hands before thinning per bunch (NMAVA/bunch), the number of hands after thinning per bunch (NMAPA/bunch), the number of fingers per bunch, and fruit grade. During the second planting cycle, variability in NMAVA/bunch, NMAPA/bunch, and the number of fingers per bunch was observed, with higher values recorded both in pure banana cultivation and in banana plants associated with *Desmodium adscendens*. This observation may be related to the flux of carbon and nitrogen assimilates available at the time of inflorescence emergence, as described by [55]. According to this author, maximum photosynthetic production at floral initiation influences the potential number of banana fruits. Thus, the high leaf count during the vegetative growth phase of banana plants in control plots and plots covered with *D. adscendens* likely contributed to an increase in the number of hands and fingers per bunch. Another explanation for the variability in the number of hands and fingers may be the existence of a hormonal flux, whose concentration at floral initiation determines the potential number of hands with female flowers to be formed, as indicated by Kwa and Tomekpe [56]. Moreover, during the first production cycle, banana fruit grade was influenced by the treatments. However, the values obtained in this study complied with quality standards in the banana sector. Indeed, the minimum grade for bananas intended for export and fresh consumer sales has been set at 27 mm [57]. In this study, the lowest recorded grade was 32.70 mm, observed in bananas from plots covered with *Arachis repens*.

Yield was not affected by cover crops. Thus, they did not have any adverse effect on dessert banana production, as the yield values of plants associated with legumes were statistically identical to those of pure cultivation (monoculture of dessert bananas). Similar results were reported by Olson *et al* [58].

5 CONCLUSION

The legumes used as cover crops in the trials, namely *Arachis repens* and *Desmodium adscendens,* contributed to soil fertility restoration. Based on soil chemical analysis, the study revealed that these plants not only increased soil pH and cation capacity (CEC) but also enriched the soil with nitrogen, organic matter, and calcium compared to bare soil. Overall, cover crops influenced the agromorphological parameters of dessert bananas during the second cultivation cycle. Banana plants associated with these cover crops exhibited earlier production in the second cycle. Although *A. repens* did not significantly increase the number of hands and fingers during the second cultivation cycle, the yield values obtained from bananas treated with this legume were statistically identical to those obtained with *D. adscendens* and the control treatment.

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