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Effect of *Vigna radiata* (Mung Bean) Cropping Systems Intercropped with Rice in a Smallholder Farming Environment in Tshilenge, Kasaï-Oriental: Integrated Assessment of Agronomic, Ecological and Phytosanitary Performance

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Abstract: Smallholder agriculture in developing countries, such as sub-Saharan Africa, represents about 80 to 90% of agricultural holdings, with an average area ranging from 0.5 to 2 hectares per household, and employs 60-70% of the active population, thus constituting the main source of employment. The present study aims to determine whether rice-*Vigna radiata* intercropping constitutes a sustainable and profitable alternative for family farmers. To this end, a field experiment was conducted in Tshilenge, specifically in the village of Bena-Ntanda (-6.130199, 23.432759 and 621m), using a Fisher complete randomized block design. In pure stands, mung beans (yellow and green cultivars) and rice (Nerica 4 variety) were sown at spacings of 0.20 m x 0.20 m with two seeds (mung bean) and four grains (rice) per hole, respectively. In intercropping, rice was sown one month before mung beans at spacings of 0.40 m x 0.20 m (4 grains per hole), while for *Vigna radiata* (yellow and green) spacings were 0.30 m x 0.20 m (2 seeds per hole). The rice-*Vigna radiata* cropping system represents a sustainable and profitable alternative for family farmers in smallholder farming environments. It has promoted increased vegetative growth in both mung bean and rice. Although a slight reduction in yield (13%) was observed for the two crops, the attack incidence was significantly lower in intercropping compared to pure stands. Thus, rice-*Vigna radiata* intercropping constitutes a simple, affordable (low-cost) agricultural practice that enables income diversification and enhances the resilience of production systems to climate change.

Keywords: *Rice-Vigna radiata Cropping System, Agronomic Performances, Ecological Performances, Phytosanitary Performances, Tshilenge, Kasaï-Oriental, D.R. Congo.*

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I. INTRODUCTION

In sub-Saharan Africa, smallholder agriculture represents about 80 to 90% of agricultural holdings, with an average area ranging from 0.5 to 2 hectares per household, and employs 60-70% of the active population, thus constituting the main source of employment in rural areas (Kanfany *et al.*, 2025; Diatta *et al.*, 2019; Muyayabantu *et al.*, 2013; Coulibaly *et al.*, 2012; Mathu *et al.*, 2012).

The study seeks to determine whether rice-*Vigna radiata* intercropping constitutes a sustainable and profitable

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alternative for family farmers, who face: soil degradation and low use of chemical inputs, pest insect pressure responsible for losses of 20 to 50%, and economic constraints related to the high cost of fertilizers and pesticides (Mohoric, 2025; Said, 2021; Niyibizi, 2020; Mesmin, 2018; Onzo *et al.,* 2016; Jahn *et al.,* 2004).

A central question breaks down into several specific questions: does intercropping: (1) improve land and time use (land saving, duration of occupation)? (2) naturally reduce the incidence of insect pests? (3) is it economically profitable for smallholder households? (4) does it promote functional diversity and ecological resilience against biotic (pests) and abiotic (poor soils) stresses?

In summary, this is an agronomic experiment aimed at demonstrating that rice-*Vigna radiata* intercropping is a promising agroecological strategy for improving productivity, sustainability and food security in smallholder environments.

Indeed, rice requires about 80 to 120 kg of nitrogen per hectare, depending on varieties and growing conditions. This requirement is divided into three crucial stages of plant growth and development: tillering, appearance of secondary shoots, 20-30 days after sowing, absorbs about 25 to 30% of total nitrogen (Fageria, 2007; Dobermann & Fairhurst, 2000). At the stem elongation stage, rapid vegetative growth phase before panicle emergence, 40-60 days after sowing, the plant requires about 35 to 40% of nitrogen. Thus, the assimilated nitrogen promotes the formation of reproductive organs and biomass accumulation (Fageria, 2007; Dobermann & Fairhurst, 2000).

Finally, during flowering and grain filling, 60-80 days after sowing, the nitrogen absorbed (30 to 35%) supports photosynthesis and the transfer of assimilates to the grains. Therefore, a nitrogen deficit at this stage reduces grain weight and yield (Fageria, 2007; Dobermann & Fairhurst, 2000).

Vigna radiata fixes about 50-80 kg N/ha through symbiosis (Kanfany *et al.,* 2025; Eshetu, 2023; Asnake, 2019; Diatta *et al.,* 2019; Kouassi *et al.,* 2019; Hossain *et al.,* 2017; Mathu *et al.,* 2012). Sown one month after rice, the fixed nitrogen becomes progressively available and coincides with the stem elongation stage of rice, a critical phase (40-60 DAS), which allows the associated system to partially compensate for the need for mineral nitrogen fertilizers (Kimou *et al.,* 2023; Beatriz, 2019; Guinet *et al.,* 2019; ECHO, 2017; Corre-Hellou, 2013; Fontaine *et al.,* 2013). It is in this logic that the field experiment was conducted in Tshilenge, specifically in the village of Bena-Ntanda, using a Fisher complete randomized block design.

II. MATERIALS AND METHODS

➢ *Environment*

- *Location of the Experimental Site*

The trial was set up in the province of Kasaï-Oriental, specifically in the territory of Tshilenge, in the village of Bena-ntanda, georeferenced: -6.130199, 23.432759 and 621m.

The territory of Tshilenge is one of the five territories that make up the province of Kasaï-Oriental, located 23 km southeast of Mbujimayi, with an estimated area of 2021 km² (Omasombo, 2014). Four watercourses serve as natural boundary limits: the Lubilanji River (North) in the territory of Katanda (province of Kasaï-Oriental), the Kalelu River (South) in the territory of Luilu (province of Lomami), to the East in the territory of Ngandajika, and the Mbujimayi River (West) in the territories of Miabi, Kamiji and Lupatapata (Omasombo, 2014).

The soils of this region are mostly derived from the alteration of the ancient geological substratum (sands and sandstones of Kasaï). Towards the plateaus, ferrasols (oxisols) and sandy soils are more widespread. While in the lowlands and river valleys (Lubilanji and Kalelu), hydromorphic soils dominate (Omasombo, 2014; Muyayabantu, 2017).

The climate is Aw_3 type according to the Köppen classification, characterized by a rainy season lasting 8-9 months subdivided agronomically into two seasons: season A from September to December and season B from January to April, and a dry season lasting 3-4 months. The average temperature is around 25°C (Omasombo, 2014).

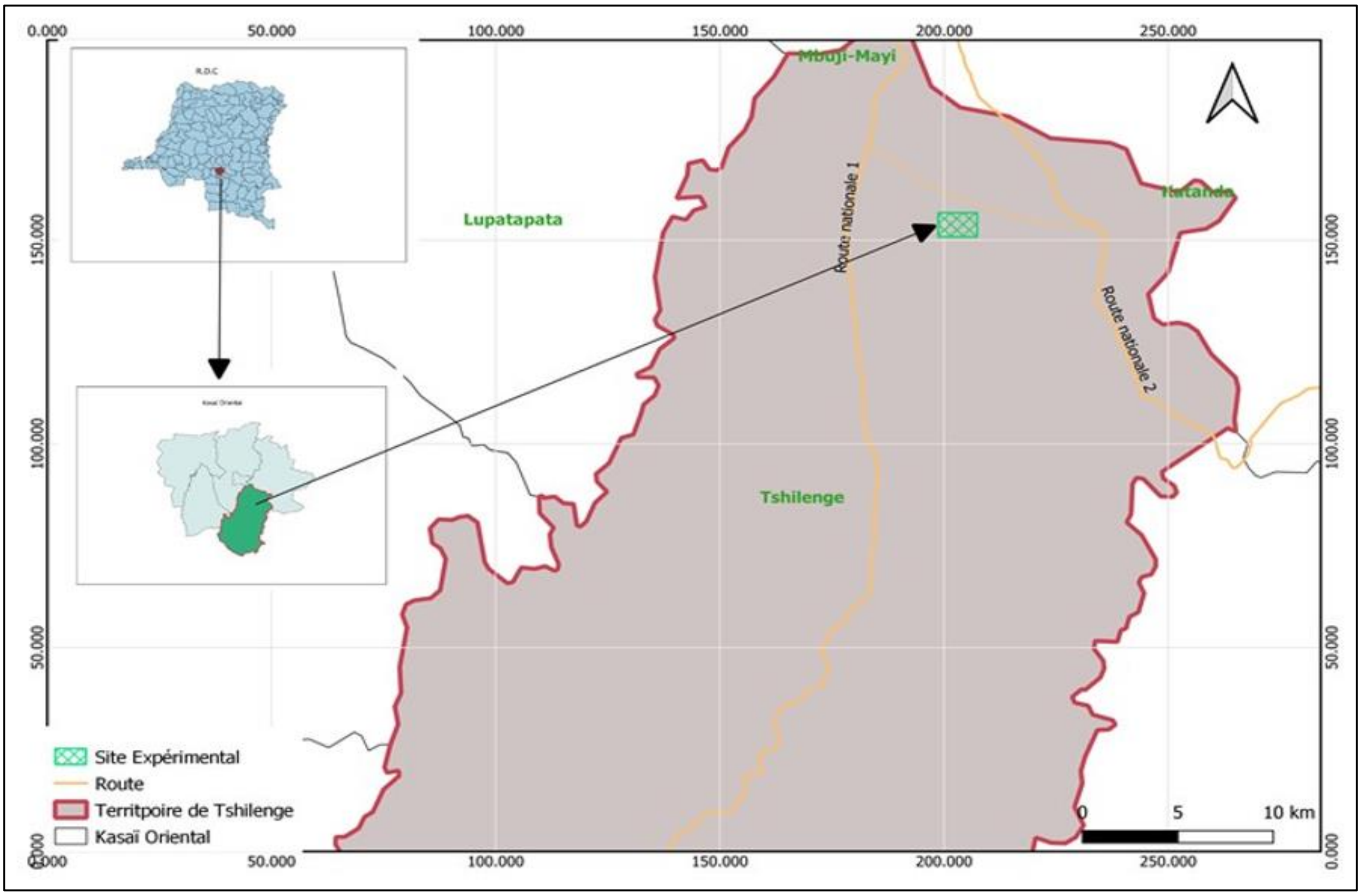

Fig 1 Location Map of the Experimental Site (Tshilenge, Bena-Ntanda, Kasaï-Oriental, D.R. Congo).

- *Materials*

For the establishment of the trial, we used yellow and green mung beans (*Vigna radiata*) and Nerica 4 (Rice). At the time of trial establishment, a decameter, rope and stakes were used for land delimitation and plot preparation. For the various measurements and weighings, we used a caliper, a decameter (metal), and a precision balance, brand $KERN_{PNJ}$.

- *Method*

- *Experimental Design*

The trial was set up in a Fisher complete randomized block design. In pure stands, mung beans (yellow and green cultivars) and rice (Nerica 4 variety) were sown at spacings of 0.20 m x 0.20 m with two seeds (mung bean) and four grains (rice) per hole. In intercropping, rice was sown one month before mung beans at spacings of 0.40 m x 0.20 m (4 grains per hole), while for *Vigna radiata* (yellow and green) spacings were 0.30 m x 0.20 m (2 seeds per hole). The distance between blocks was 1.5 m, while between plots it was 1 m. In total, the trial had 15 plots of 6 m² for a total area of 195.5 m² (17 m x 11.5 m), i.e., 1.96 ares.

The performance of the rice-*Vigna radiata* cropping system on growth and production was evaluated at 45 and 60 days after sowing (DAS), respectively. For rice cultivation, at 60 DAS and production at 100 DAS. Maintenance consisted of manual weeding using a hoe; for this purpose, three weedings at 14-day intervals were carried out.

Planche 1 Experimental Design Implemented in the Field in a Rural Environment (Tshilenge-Bena-Ntanda).

- *Growth and Production of Mung Bean and Rice in the Rice-Vigna radiata Cropping System*

Leaf area (cm²) was calculated using the formula proposed by Hamid & Agata (1989).

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$$L_A = \text{L x W x k} \qquad \{1\}$$

Where:

L: length (cm), W: width (cm) of leaflets, and k: correction factor which varies according to the crop. For *Vigna radiata*, it is 0.70 (Hamid & Agata, 1989).

Plot production (g/m²) and 100-seed weight (g) were weighed using a precision balance. While yield (kg/ha) was obtained by extrapolating plot production using the following formula:

$$Yield(kg.ha^{-1}) = \frac{Plot\ production\ (g)\ x\ 10000\ m^2}{Plot\ area\ m^2} \qquad \{2\}$$

For nodulation, 10% of plants were uprooted with a clod of soil to a depth of 25 cm using a spade, then soaked in a bucket of water for 10 minutes to carefully remove the soil without damaging the roots. After soaking, the plants were placed in the open air to dry. After drying, nodules were counted on the plant, and the whole plant was also weighed. Then the plant was cut into two parts (aboveground biomass and roots + nodules) which were weighed separately. Finally, the nodules on the roots were removed and subsequently weig hed.

Planche 2 V. Radiata Plant Showing Roots and Nodules for Nodulation Index Assessment.

Concerning the nodulation index (%), it was calculated using the mathematical formula proposed by Herridge (1988) cited by Yogesh et al. (2024); Tadewos et al. (2022); Kouame et al. (2020); Asnake & Fassil (2019); Kouassi et al. (2019).

$$Nodulation_{\ Index} = \frac{Number\ of\ nodules\ x\ Average\ nodule\ weight\ (g)}{\text{Plant weight(roots + aboveground biomass)}(g)}\ x\ 100 \qquad \{3\}$$

The higher the nodulation index, the better the nodulation, consequently, the better the symbiotic nitrogen fixation (Yogesh *et al.,* 2024; Tadewos *et al.,* 2022; Kouame *et al.,* 2020; Asnake & Fassil, 2019; Kouassi et *al.,* 2019).

Table 1 Interpretation of nodulation index (%)

Nodulation value (%)	Nodulation Level	Interpretation
[0 – 3 [	Low	Insufficient nodulation, limited nitrogen fixation.
[3 – 5 [	Moderate	Correct nodulation, suboptimal contribution.
[5 – 7 [	Good	Effective nodulation, balance between aboveground and belowground biomass, efficient nitrogen fixation.
[> 7 [	Very High	Intense nodulation, strong contribution of nodules to total biomass, maximum nitrogen fixation.

Yogesh et al. (2024) ; Tadewos et al. (2022) ; Kouassi et al. (2019).

Concerning the harvest index (HI) (%) for both mung bean and rice, it was calculated using the formula developed by Donald (1962), cited by Bahlouli (2009), Poorter & Nagel (2000), Samir et al. (1997): the ratio between grain weight (kg/ha) and total plant weight (aboveground biomass (leaves, stems, pods, grains) plus belowground biomass (roots)) (kg/ha).

$$HI(\%) = \frac{\text{Grain weight (kg/ha)}}{\text{Grain weight + Plant weight (biomass + roots)}(kg/ha)} x100 \qquad \{4\}$$

Table 2 Interpretation of Harvest Index (%)

HI value (%)	Harvest Index Level	Interpretation
[0 – 30 [	Low	Abundant vegetative biomass, low grain production. Stressed plant.
[30 – 50 [	Medium	Balance between vegetative growth and reproduction, average plant adaptation.
[> 50 [	High	The plant devotes more than half of its production to grain formation, good plant adaptation.

Bahlouli (2009) ; Poorter & Nagel (2000); Samir et al. (1997)

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For the phytosanitary status, the infestation level was calculated according to the formula proposed by Niyibizi (2020), Mesmin (2018), Onzo et al. (2016) :

$$I(\%) = \frac{\text{Number of attacked (infested)}}{\text{Total Number of plant}} x100 \qquad \{5\}$$

Table 3 Interpretation of Infestation Incidence (%)

Incidence %	Infestation Level	Interpretation
[0 – 10 [	Low	Little damage and Low loss (< 5%)
[10 – 25 [	Moderate	Medium damage and Moderate loss (5-15%)
[25 – 50 [	High	Significant damage and High loss (15-35%)
[> 50 [	Very High	Severe infestation and Severe loss (> 35%, even up to 100%)

Mesmin (2018), Onzo et al. (2016), Abreu et al. (2014)

- *Statistical Data Analysis*

The results of this analysis present a correlation circle with two axes. The first axis explains more than half of the information (principal component) and the second axis, perpendicular, explains a variance of 10-15% of the biological phenomenon.

From these two axes, three angles are formed: acute angle (< 90°: positive correlation), for rice indicates crop performance (production), while for mung beans, active growth. Obtuse angle (> 90°: negative correlation) opposition between pest attack incidence and rice yield, *Vigna radiata* performance and rice aggressiveness, and harvest index and growth. Finally, right angle (∟90°: independent variables), indicates independence between panicle length and pest incidence, and between grain number and weight.

III. RESULTS AND DISCUSSION

- *Results*

Table 4 on the evolution of meteorological parameters (September 2025 – February 2026) provides useful information to link the mung bean cycle (about 60 days) and that of rice (about 100 days) to climatic conditions and sowing dates. This Table shows that temperature (23.9 - 24.7 °C) remained relatively stable, meaning that both crops evolved within a favorable range without marked thermal stress. While relative humidity varied between 82% and 89%, this range is characteristic of humid tropical climates, demonstrating that both crops evolved in a favorable environment for their development, and on the other hand, this humidity can also favor biological processes responsible for the emergence of pests and diseases.

Rainfall showed two peaks, high in September (81.7 mm) and November (83.7 mm), favorable for crop establishment and vegetative growth. Very low in January (2.5 mm), indicating severe water stress. Indeed, rice sown in September benefited from abundant rainfall for its establishment. Mung bean sown one month later (October) also benefited from still high humidity; however, both crops experienced water stress in January, especially mung bean which would be at the critical stage of pod formation and filling.

Table 4. Evolution of Meteorological Data During our Field Trial (September 2025 – February 2026)

Mois	**Température (°C)**	**Humidité (%)**	**Pluviométrie (mm)**
September	24,7	82,1	81,7
October	24,6	85,0	30,3
November	24,2	89,7	83,7
December	24,3	88,9	14,5
January	24,2	89,5	2,5
February	23,9	89,4	25,9

Source: Meteorological Station in Bena-Ntanda (Tshilenge)

- *Performance of Mung Bean and Rice in a Rice-Vigna radiata Cropping System*

- ✓ *Mung Bean (V. radiata)*

The figure opposite presents the general behavior of the two varieties of *Vigna radiata* (yellow and green) in the cropping system (monoculture and intercropping). Indeed, the two mung bean cultivars in intercropping are characterized by stem height, collar diameter, leaf area, leaf width and length, nodule diameter on the right of axis 1 (78.33% of explained variance: correlated variables). While in monocultures (on the left), these two cultivars are characterized by yield components (plot production, 100-seed weight) and their vulnerability to insect pest attacks (axis 2: 10.97% of explained variance). Therefore, individuals located on the right (axis 1) are characterized by strong aboveground growth and symbiotic activity (large nodules), and those on the left (axis 2) have better conversion into yield and vulnerability to insect attacks. Biologically, this reflects a growth strategy oriented towards resource capture (light, nutrients) and efficient allocation to seeds.

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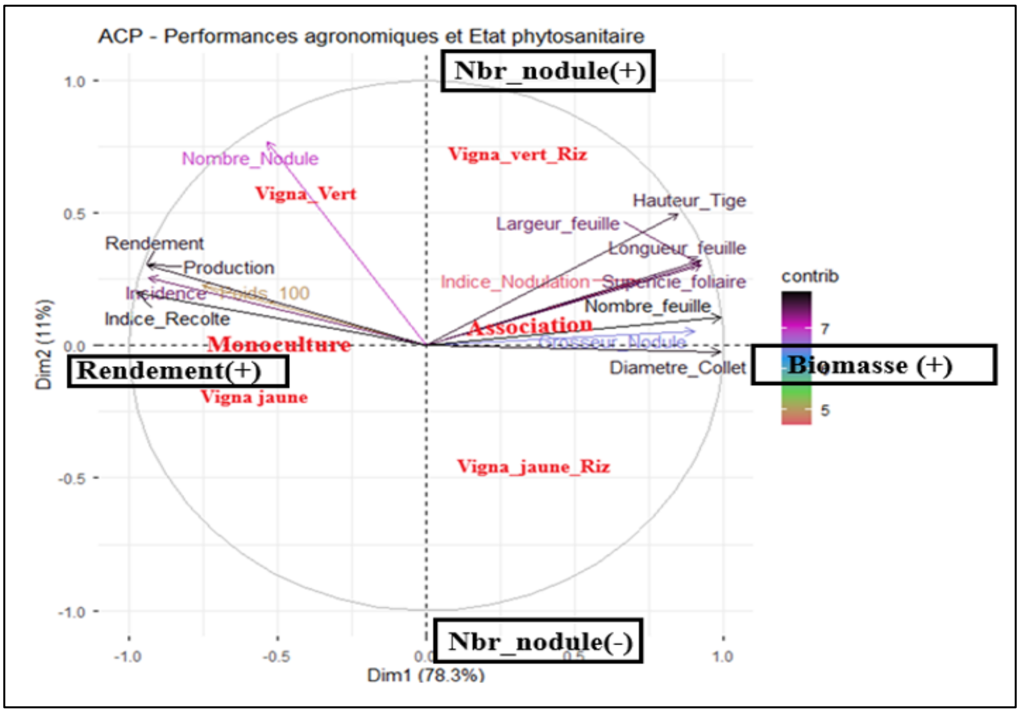

Fig 2 Effect of the Rice-*Vigna radiata* Cropping System on the Performance and Phytosanitary Status of Mung Bean.

✓ *Rice (Oryza Sativa)*

The behavior of rice cultivation in the cropping system, as illustrated by the figure opposite, reveals that in monoculture, plants on the right have long panicles bearing an abundant number of grains, high production, high yield and vulnerability to insect pest attacks (axis 1: 81.74%). While in intercropping (on the left), plants developed an abundant number of tillers, long with a large collar diameter (axis 2: 11.43%).

Therefore, axis 1 presents rice plants characterized by average vegetative growth (fewer tillers, smaller collar diameter and lower height) but maintains high productivity although more attacked (monocultures). While axis 2 (on the left) highlights the beneficial effect of intercropping with *Vigna radiata* on growth, production and especially the phytosanitary status of the field (low attack incidence). Biologically, these two axes group rice plants by their physiological profile (growth + symbiosis) in intercropping while in monoculture by their agronomic profile (yield + vulnerability).

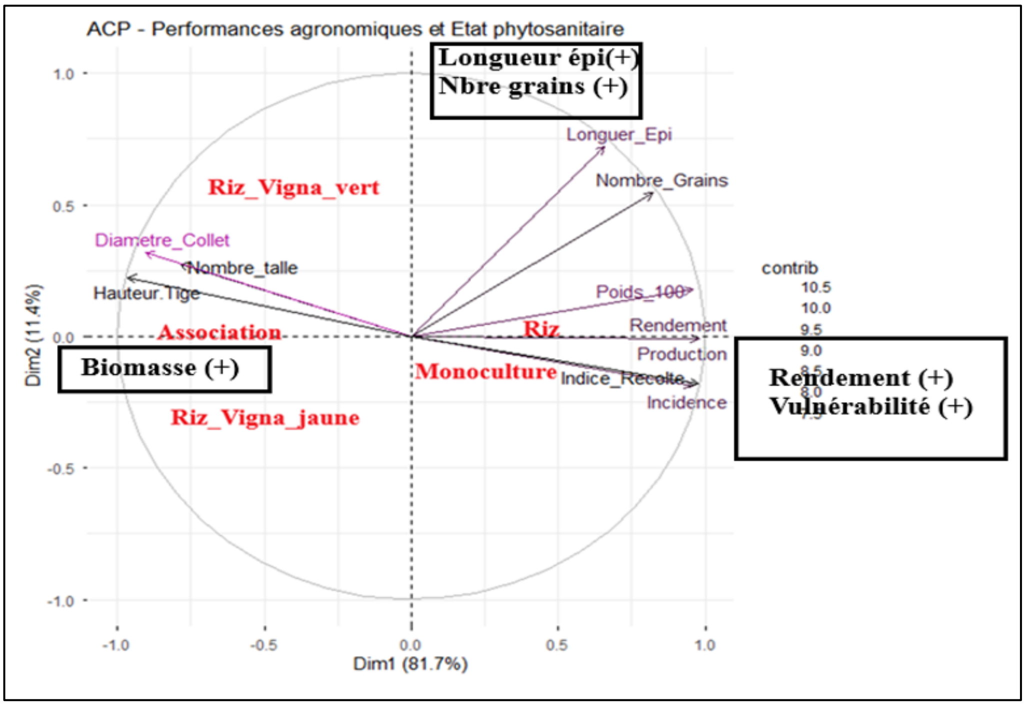

Fig 3 Effect of the Rice-*Vigna radiata* Cropping System on the Performance and Phytosanitary Status of Rice.

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- *Discussion*

- *Growth and Development of Rice and Mung Bean in a Rice-Vigna radiata Cropping System*

The growth of mung bean in the rice-*Vigna radiata* cropping system is more marked in intercropping than in pure stands. According to AL-Sabagh et al. (2024), Du et al. (2018), Fan et al. (2018), Egli & Bruening (2005), Lyu et al. (2005), when legumes are grown in intercropping, the reduction in light is detected by phytochromes which trigger intense production of growth phytohormones including auxin and gibberellin, which stimulate cell elongation (rapid stem and leaf growth) and allow them to escape shading and access light in order not to disrupt their photosynthetic activities (Du *et al.*, 2018; Fan *et al.*, 2018; Ballaré, 2014; Egli & Bruening, 2005; Lyu *et al.*, 2005).

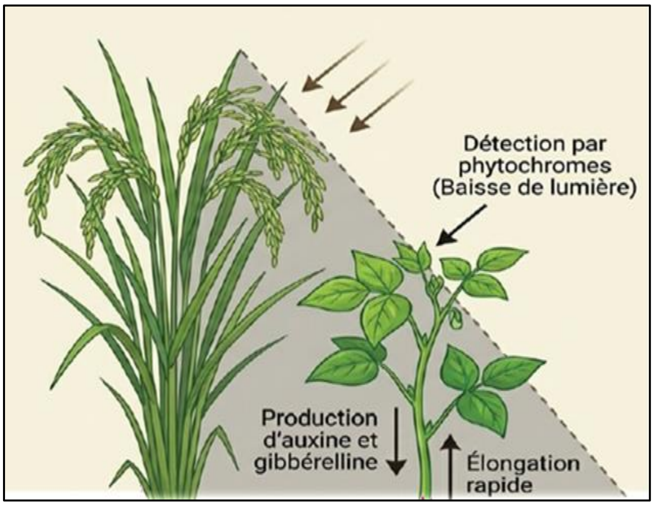

Fig 4 Adaptation Mechanism to Light Competition: Shade Avoidance Syndrome

Thanks to this mechanism developed by legumes known as Shade Avoidance Syndrome ("SAS"), mung bean would have detected this photonic stress (light stress) by the presence of rice; thus the activated mechanism triggered rapid growth in intercropped plots compared to pure stands (AL-Sabagh *et al.*, 2024; Yogesh *et al.*, 2024; Tadewos *et al.*, 2022; Wangiyana *et al.*, 2022; Ballaré, 2014).

Concerning nodulation in the rice-*Vigna radiata* cropping system, it was found that the number of nodules was not different in monoculture as in intercropping. While nodules were larger in intercropped plots compared to pure stands. Indeed, the results of studies conducted by Yogesh et al. (2024), Raboin et al. (2023), Tadewos et al. (2022), Kouame et al. (2020), Muhammad et al. (2020), Kouassi et al. (2019), Diatta et al. (2019) and Asnake & Fassil (2019) report that in intercropping, legumes cease to produce new nodules which remain constant and thus reallocate this metabolic energy to symbiotic fixation and assimilation of atmospheric nitrogen, which would justify that they are larger in intercropping than in pure stands.

Regarding the harvest index, a decrease in this index was observed in intercropping compared to pure stands. This situation could be explained by the fact that in intercropping, mung bean activates the shade avoidance syndrome mechanism, which translates photonic competition due to the presence of rice into a survival mechanism; thus, a significant portion of assimilated photosynthates would be reallocated to the development of vegetative organs (high vegetative growth and nodule enlargement due to high energy activity) at the expense of reproductive efficiency (seed production) (Tadewos *et al.*, 2022; Kouame *et al.*, 2020; Kouassi *et al.*, 2019; Fan *et al.*, 2018; Franklin, 2008; Valladares & Niinemets, 2008; Egli & Bruening, 2005; Lyu *et al.*, 2005).

Concerning plot production (g/m²) and yield (kg/ha) of mung bean, a decrease in production and yield was observed in intercropped stands. Indeed, this recorded decrease would be attributed both to the reduction in density in intercropped plots and especially to competition for resources (water, light, mineral elements) resulting from the coexistence of these two crops, which would have forced mung bean to adapt to this environment (Fan *et al.*, 2018; Franklin, 2008; Valladares & Niinemets, 2008; Egli & Bruening, 2005; Lyu *et al.*, 2005).

The harvest index which decreases from 40.77 - 41.83% (respectively for green and yellow mung bean in pure stands) to 33 - 33.63% (intercropping, respectively for green and yellow mung bean cultivars) confirms this imbalance (Kanfany *et al.*, 2025; Yogesh *et al.*, 2024; Raboin *et al.*, 2023).

On the other hand, for rice cultivation in the rice-*Vigna radiata* cropping system, the results of this work demonstrate that the growth of this crop is better in intercropped plots compared to pure stands. Indeed, the improvement in growth in intercropped plots would be the positive consequence of the presence of mung bean in this system, which would have facilitated rice cultivation by transferring a quantity of fixed atmospheric nitrogen, which significantly increased the number of tillers and vegetative growth (Mohoric, 2025; Cheyrou, 2024; Raboin *et al.*, 2023; Wangiyana *et al.*, 2022; Pogni, 2021; Guinet *et al.*, 2019; Beatriz, 2019; Fontaine *et al.*, 2013; Muyayabantu *et al.*, 2013; Hinsinger, 2012).

Concerning the harvest index for rice cultivation, it is higher in monoculture than in intercropping. In intercropping, although rice would have benefited from nitrogen transferred by mung bean, a situation that favors biomass production, competition (water and other resources) resulting from the coexistence of these two plant species, especially during grain filling, would reduce grain weight (Wangiyana *et al.*, 2022).

Regarding plot production (g/m²) and yield (kg/ha) for rice cultivation, they decrease in intercropping compared to monoculture. Indeed, this decrease in intercropped stands would be due on the one hand to the reduction in sowing density in intercropped plots and on the other hand, to competition resulting from coexistence, which would have favored more vegetative growth at the expense of grain filling (Poorter & Nagel, 2000; Bahlouli, 2009). Thus, the harvest index which drops from 45.83% (pure stand) to 35.48% (intercropping) confirms this imbalance.

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- *Phytosanitary Status of Mung Bean and Rice in a Rice-Vigna radiata Cropping System*

Concerning the attack incidence (%), the results of this study demonstrate that it is higher in pure stands than in intercropping. Indeed, in intercropped plots, the coexistence of two plant species creates an ecological synergy with complementary effects (barrier effect, olfactory confusion, dilution effect, and habitat for beneficials) (Mohoric, 2025; Said, 2021; Mesmin, 2018; Corre-Hellou *et al.*, 2013; Fontaine *et al.*, 2013). Thus, the presence of mung bean in the same plot with rice would constitute an obstacle to the movement of rice insect pests (*Leptocorisa oratorius*). Similarly, the presence of rice would act as a vertical barrier hindering the access of *Leptoglossus phyllopus* to mung bean pods located in the lower stratum (Mohoric, 2025; Said, 2021; Niyibizi, 2020; Diatta *et al.*, 2019; Mesmin, 2018; Onzo *et al.*, 2016; Pelzer *et al.*, 2014; Corre-Hellou *et al.*, 2013; Fontaine *et al.*, 2013; Jahn *et al.*, 2004).

It also results from intercropped plots that a mixture of volatile compound emissions, notably E-β-farnesene ($C_{15}H_{24}$), geranyl acetate ($C_{12}H_{20}O_2$) emitted by cereals and linalool ($C_{10}H_{18}O$), (Z)-3-hexenyl acetate ($C_8H_{14}O_2$) by legumes, generates an olfactory noise that would disrupt the ability of insect pests to locate their specific host plants (Pickett & Khan, 2016; Bruce *et al.*, 2005).

In addition, in intercropped plots, the reciprocal reduction in density of these two crops (rice and mung bean) would reduce the concentration of host plants, consequently decreasing the probability of their encounter by insect pests, thus making the barrier effect and olfactory confusion even more impactful (Said, 2021; Niyibizi, 2020; Mesmin, 2018; Pickett & Khan, 2016; Bruce *et al.*, 2005; Jahn *et al.*, 2004).

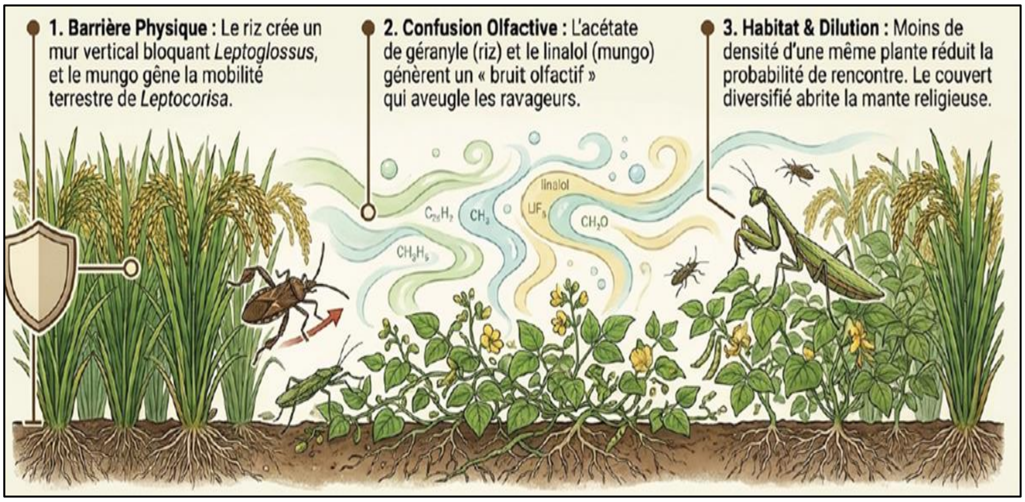

Fig 5 Eco-Service of the Rice-*Vigna radiata* Cropping System in Integrated Crop Protection

IV. CONCLUSION

The present study focused on: Effects of *Vigna radiata* cropping systems intercropped with rice in a smallholder farming environment in Tshilenge, Kasaï-Oriental: integrated assessment of agronomic, ecological, economic and phytosanitary performance. This study aimed to determine whether rice-*Vigna radiata* intercropping constitutes a sustainable and profitable alternative for family farmers.

To this end, a trial was set up in Tshilenge, specifically in the village of Bena-Ntanda, using a Fisher complete randomized block design.

After experimentation, the results for mung bean showed an increase in growth in intercropping of about 20% in stem height, leaf length and width, 40% in collar diameter and number of leaves, and 44% in leaf area. A decrease of 13% in production and 20% in harvest index was observed. In parallel, symbiotic nitrogen fixation was maintained (stable nodulation index, larger nodules). A low attack incidence in intercropping of about 16% was recorded compared to 25% in monocultures.

For rice, in intercropping, there was an increase of 20% in stem height, 40% in collar diameter and number of tillers. However, panicle length and grain number remained stable, while 100-grain weight decreased by about 10% and harvest index by 20%. In intercropping, the attack incidence is about 17% compared to 28% in pure stands.

These results indicate that in the intercropping system, the attack incidence is low for both *Vigna radiata* and rice. This positive impact of the intercropping system on pest management is the synergistic result of the ecological mechanisms involved, which limited the movement (barrier effects) and inhibited the localization (olfactory confusion through emission of volatile compounds) of insect pests to their specific hosts.

Thus, these results confirm that the rice-*Vigna radiata* intercropping system is a sustainable and profitable alternative for family farmers in smallholder environments because it allows crop protection without pesticide use, but promotes the synergy of ecological mechanisms that limited the movement (barrier effects) and inhibited the localization (olfactory confusion through emission of volatile compounds) of insect pests to their specific hosts, on the one hand, and on the other hand, reduces the use of nitrogen fertilizers. Therefore, rice-*Vigna radiata* intercropping is a simple agricultural practice, affordable (low cost), allowing income diversification and resilience of production systems in the face of climate change.

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