World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(Research Article)

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Effect of Irrigation Frequency on the Agronomic Performance, Yield and Economic Profitability of Okra (*Abelmoschus esculentus* L.) Cultivar Clemson Spineless under Edapho-Climatic Conditions of Faranah, Guinea

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World Journal of Advanced Research and Reviews, 2025, 28(03), 1895-1903

Publication history: Received on 15 November 2025; revised on 24 December 2025; accepted on 26 December 2025

Article DOI: https://doi.org/10.30574/wjarr.2025.28.3.4276

Abstract

Rational water management remains a major challenge for vegetable production in Guinea, particularly during the dry season. This study evaluated the effects of different irrigation frequencies on the growth, yield, and economic profitability of okra (Abelmoschus esculentus L.), cultivar Clemson Spineless, under the edapho-climatic conditions of Faranah. The experiment was conducted from January to April 2023 on sandy-loam soil (pH 6.0) using a randomized complete block design with four irrigation treatments: two irrigations per day (FA_0), one irrigation per day (FA_1), one irrigation every two days (FA_2), and one irrigation every three days (FA_3), each replicated four times. Growth parameters, yield components, and economic indicators were assessed. Irrigation frequency significantly affected vegetative growth and yield. The highest yields were obtained under FA_0 (10.31 t ha^{-1}) and FA_1 (10.21 t ha^{-1}). However, FA_1 recorded the highest net benefit (50,362,188 GNF) and profitability rate (97.30%). Daily irrigation therefore represents the most efficient strategy for optimizing okra productivity and profitability under dry-season conditions in Faranah.

Keywords: Irrigation frequency; Okra; Yield; Vegetative growth; Economic profitability

1. Introduction

Okra (*Abelmoschus esculentus L.*) occupies a prominent position in West African vegetable production systems due to its food, nutritional, and economic importance. Its sustained demand in both urban and rural areas makes it a strategic crop for food security and household income generation [1], [2] . However, okra productivity remains strongly constrained by water availability and recurrent dry-season water stress, even though irrigation constitutes a key lever for sustainable intensification [3]. At the regional scale, improving irrigation practices (frequency, dose and schedule) is identified as a direct determinant of yield, fruit quality and the stability of market gardening income [4].

From a physiological perspective, water deficit reduces carbon assimilation and stomatal conductance, disrupts photosynthetic efficiency, and results in decreased vegetative growth and fruiting [5], [6]. These effects are manifested on key agronomic indicators such as growth speed, plant height, number of fruits per plant, length and average weight of fruits, as well as the shape coefficient, all parameters directly linked to commercial yield and pod quality [7], [8]. In

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this context, adjusting irrigation frequency represents a simple and accessible approach to optimize soil water status, buffer water stress, and enhance water use efficiency (WUE) without increasing production costs [10].

Recent advances indicate that regulated deficit irrigation strategies can maintain or even improve yields while reducing water use [7], [8]. In okra, appropriately adjusted irrigation frequencies and application rates maximize water productivity and pod quality, particularly when irrigation is combined with complementary agronomic practices such as mulching or balanced fertilization [9]. A systematic review of deficit irrigation methods further confirms the relevance of these approaches for vegetable crops under water-limited conditions [12]. From a techno-economic perspective, irrigation-related costs including labor, water, and inputs can weigh heavily on profit margins; however, optimizing irrigation frequency tends to reduce production risk and increase the profitability of vegetable enterprises [13].

Nevertheless, crop responses to water stress and irrigation frequency vary according to genotype, phenological stage, and environmental conditions [14] [15]. Consequently, context-specific experiments remain essential to calibrate irrigation frequency that balances growth (growth rate, plant height), yield components (number of fruits per plant, average fruit length and weight, shape coefficient), and economic performance (costs, net benefits, and profitability rate). Recent studies under tropical conditions confirm that well-scheduled irrigation regimes can maintain yield levels while improving WUE and the commercial quality of pods [13] [7] [8], while dry-season margin analyses highlight the importance of rational water management to secure value addition [16]. The overall objective of this study is therefore to determine the optimal irrigation frequency for improving growth, yield, and economic profitability of okra.

2. Materials and Methods

2.1. Experimental site

The experiment was conducted at the experimental station of the Department of Agricultural Extension of ISAV-VGE, Faranah (10°02′ N, 10°44′ W). The soil is sandy-loam with pH 6.0. The climate is Sudanian-Guinean, characterized by a long dry season from November to April.

2.2. Plant material

The okra cultivar Clemson Spineless was used. This improved variety is widely cultivated in West Africa due to its adaptability and stable yield performance.

2.3. Fertilization material

Two types of fertilizers were used : poultry manure applied at a rate of 20 t ha^{-1} as a basal fertilizer, and technical urea applied at 200 kg ha^{-1} as a top-dressing fertilizer.

2.4. Methods

2.4.1. Experimental design

The experiment was conducted using a randomized complete block design (RCBD) with four treatments and four replications, resulting in a total of 16 experimental plots. The treatments corresponded to the following irrigation frequencies: FA_0, two irrigations per day (control); FA_1, one irrigation per day; FA_2, one irrigation every two days; and FA_3, one irrigation every three days.

2.4.2. Biometric parameters

Measurements included average plant height at harvest (APH, cm), recorded biweekly; average daily growth rate (ADGR, cm day^{-1}), calculated as the difference between consecutive height measurements divided by the number of days between measurements (ADGR = $\Delta H/t$); average number of branches per plant (ANB/P) average number of fruits per plant (ANF/P) [9]; and yield (YLD, t ha^{-1}), calculated according to [10] as:

$$\text{YLD (t ha}^{-1}\text{)} = [\text{fruit mass (kg)} / \text{plot area (m}^2\text{)}] \times (10{,}000 \text{ m}^2 / 1{,}000).$$

2.4.3. Economic analysis

Economic parameters were calculated following the method described by [11] using the following formulas: $VP = PU \times QP$; $B = VP - D$; $R = (B/D) \times 100$, where VP is the production value (GNF), PU is the unit price (GNF), QP is the quantity produced, B is the net benefit, D is the total production cost, and R is the profitability rate.

2.5. Statistical analysis

Data were subjected to analysis of variance (ANOVA) to evaluate treatment effects on the measured parameters. Mean comparisons were performed using Tukey's test at the 1% significance level ($p < 0.01$). Statistical analyses were carried out using SPSS software version 25, and figures were generated using GraphPad Prism version 8.

3. Résult

3.1. Effects of irrigation frequency on biometric parameters of okra

Figure 1 shows the effect of different irrigation frequencies on the average plant height (APH) of okra at harvest. The results indicate that irrigation frequency had a significant effect ($P < 0.05$) on this parameter. The control treatment FA_0 (two irrigations per day) recorded the greatest plant height (94.80 cm), followed by FA_1 (73.54 cm). In contrast, FA_2 and FA_3 resulted in the lowest mean plant heights, with values of 54.83 cm and 48.13 cm, respectively. These findings demonstrate a strong dependence of plant height on water availability, with a progressive and significant reduction as irrigation frequency decreased, highlighting the negative effect of water stress on vegetative growth of okra.

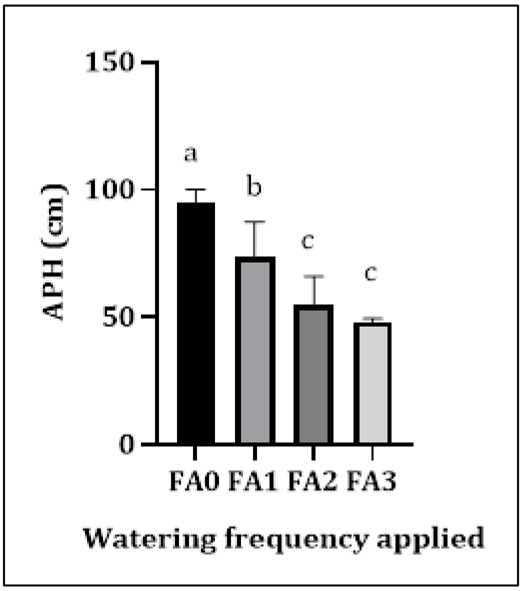

Figure 1 Effect of different irrigation frequencies on average plant height of okra at harvest.

Figure 2 illustrates the effect of irrigation frequency on the average daily growth rate of the collar (ADGR) of okra plants at harvest. Treatment FA_0 recorded the highest value (0.91 cm), which was significantly higher than those of the other treatments ($P < 0.05$). Treatments FA_1, FA_2, and FA_3 showed the lowest values, with no significant differences among them. These results suggest that any reduction in irrigation frequency, even moderate, negatively affects vegetative growth, reflecting a marked sensitivity of structural development of okra plants to water deficit.

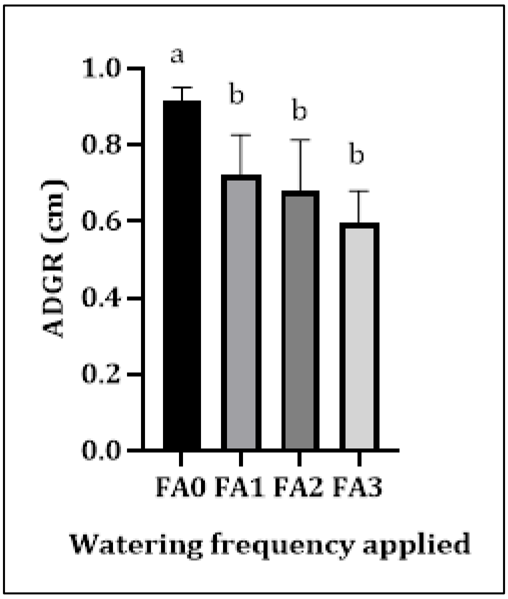

Figure 2 Effect of different irrigation frequencies on the average daily growth rate (ADGR) of okra plants at harvest.

Figure 3 presents the effects of the four irrigation frequencies on the average number of branches per plant (ANB/P) and the average number of fruits per plant (ANF/P). Irrigation frequency significantly affected both branching and fruiting ($P < 0.05$). For ANB/P, FA_0 recorded the highest value (4 branches plant^{-1}), followed by FA_1 (3.5 branches plant^{-1}), whereas FA_2 and FA_3 showed the lowest values (3 branches plant^{-1}), indicating reduced branching capacity under water stress. Regarding ANF/P, FA_0 produced the highest number of fruits per plant (14 fruits plant^{-1}), significantly higher than the other treatments, followed by FA_1 (11.5 fruits plant^{-1}). FA_2 and FA_3 recorded the lowest values, with 10.25 and 8.5 fruits plant^{-1}, respectively. These results indicate that reduced irrigation frequency directly affects flowering, fruit set, and fruit retention.

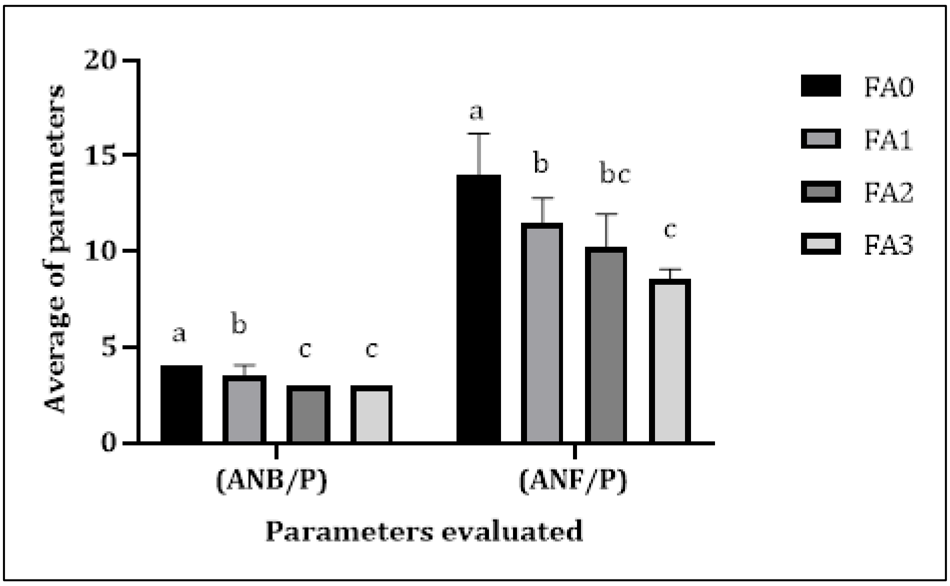

Figure 3 Effects of four irrigation frequencies on the average number of branches per plant (ANB/P) and the average number of fruits per plant (ANF/P).

Figure 4 shows the effect of irrigation frequency on okra yield. The highest yields were recorded under FA_0 (10.31 t ha^{-1}) and FA_1 (10.21 t ha^{-1}), with no significant difference between the two treatments ($P < 0.05$). In contrast, FA_3 resulted in the lowest yield (5.83 t ha^{-1}). This substantial yield reduction indicates that extending the irrigation interval beyond 48 hours induces severe water stress, strongly limiting okra production.

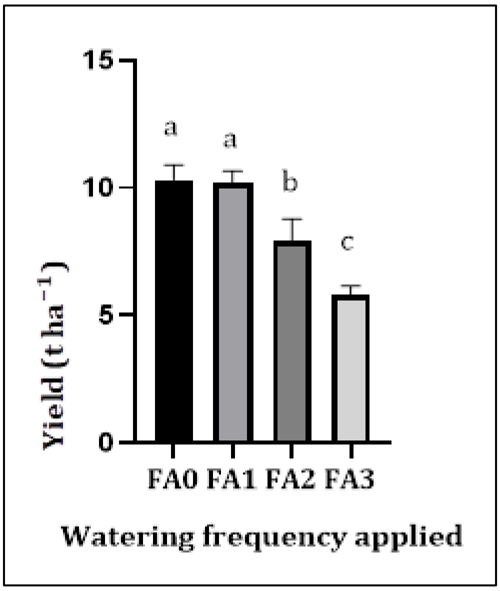

Figure 4 Effect of different irrigation frequencies on okra yield.

3.2. Correlation between biometric parameters and yield

Table 1 presents the Pearson correlation matrix between the studied biometric parameters and yield (YLD). All observed correlations were positive and significant ($P < 0.05$), indicating strong physiological coherence in okra responses to irrigation frequency. Average plant height at harvest (APH) was strongly correlated with average daily growth rate (ADGR; r = 0.969), average number of branches per plant (ANB/P; r = 0.991), and average number of fruits per plant (ANF/P; r = 0.982). Moreover, ANB/P and ANF/P were strongly correlated (r = 0.950), demonstrating that branching directly determines fruiting capacity. Yield also showed strong positive correlations with all biometric parameters, particularly ANF/P (r = 0.904) and APH (r = 0.884), indicating that okra yield mainly depends on vegetative vigor and fruit number.

Table 1 Pearson correlation matrix between biometric parameters and okra yield.

Biometric parameter	APH	ADGR	ANB/P	ANF/P	yield
APH	1	0.969	0.991	0.982	0.884
ADGR	0.969	1	0.946	0.985	0.816
ANB/P	0.991	0.946	1	0.950	0.835
ANF/P	0.982	0.985	0.950	1	0.904
Yield	0.884	0.816	0.835	0.904	1

3.3. Principal component analysis (PCA)

Figure 5 presents the biplot derived from principal component analysis (PCA) combining irrigation frequencies and biometric parameters of okra. The first two axes (F1 and F2) explained 98.58% of the total variability, indicating excellent representativeness. Axis F1 alone accounted for 94.18% of the variance and represents a global agronomic performance axis, strongly and positively correlated with all measured parameters. High irrigation frequencies (FA_0 and FA_1) were associated with optimal growth, fruiting, and yield, whereas extended irrigation frequencies (FA_2 and FA_3) were associated with poor performance, reflecting severe water stress.

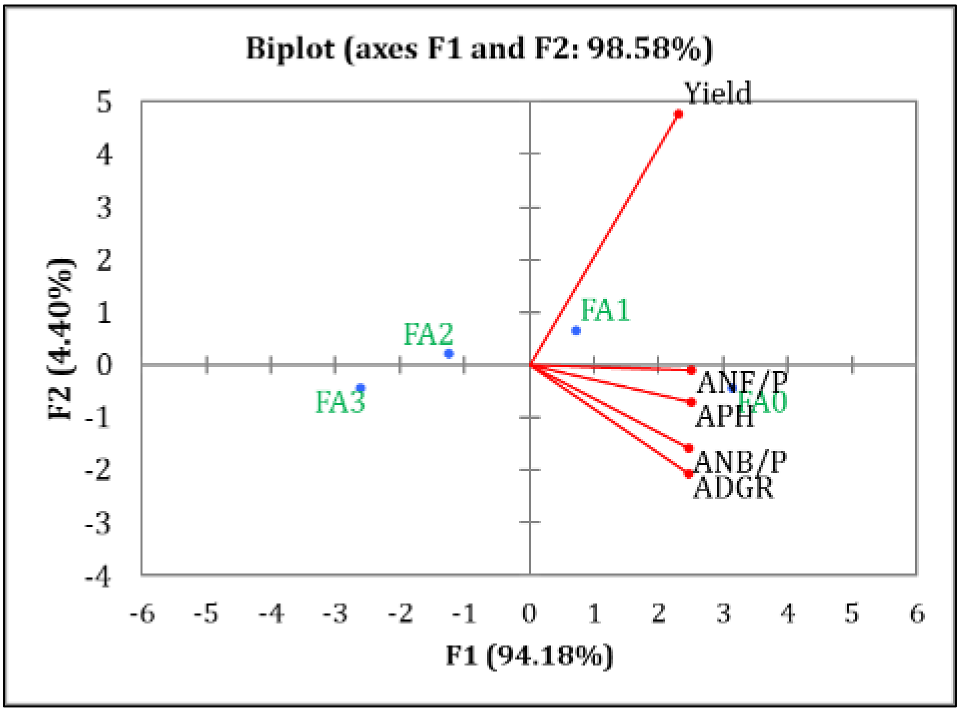

Figure 5 Principal component analysis of irrigation frequencies combined with biometric parameters of okra

3.4. Economic analysis of irrigation frequencies

Economic analysis (Table 2) showed that production costs, profitability, and value–cost ratio varied considerably among irrigation frequencies. Treatment FA_1 was the most economically profitable, with a net benefit of 50,362,188 GNF, a profitability rate of 97.3%, and a value–cost ratio of 1.97. Although FA_0 achieved the highest production, its higher costs reduced its relative profitability. Treatment FA_2 remained profitable but with intermediate performance, whereas FA_3 was the least economically advantageous, as cost reductions did not compensate for the substantial yield decline. Overall, FA_1 represents the best compromise between productivity and economic profitability.

Table 2 Economic analysis of different irrigation frequencies in okra production

Treatment	Expense (GNF)	Production (Kg)	Unit price (GNF)	Production value (GNF)	Profit (GNF)	Rate of return (%)	RVC
FA0	61 848 958	10 315	10 000	103 150 000	41 301 042	66.77	1.66
FA1	51 757 812	10 212	10 000	102 120 000	50 362 188	97.3	1.97
FA2	46 875 000	7 947	10 000	79 470 000	32 595 000	69.53	1.69
FA3	45 247 396	5 835	10 000	58 350 000	13 102 604	28,95	1.28

4. Discussion

4.1. Effect of irrigation frequency on biometric parameters

Average plant height, average daily growth rate (ADGR), and number of branches per plant decreased progressively and significantly with decreasing irrigation frequency. These results confirm that vegetative growth of okra is highly sensitive to water stress, particularly when the irrigation interval exceeds 48 hours. Similar trends were reported by [7] who demonstrated that reduced water supply limits stem elongation, cell division, and vegetative tissue expansion in okra, leading to a marked decline in vegetative growth. Strong correlations between water availability, fruit size, and yield have also been reported in recent studies on okra under different irrigation strategies[7] [8].

The reduction in ADGR observed under FA_1, FA_2, and FA_3 treatments suggests that even moderate water deficit can negatively affect plant structural vigor. Hydraulic traits such as stem or collar diameter are closely associated with water transport efficiency and assimilate translocation capacity in plants. Water deficit reduces stomatal conductance, carbon assimilation and photosynthetic efficiency, leading to impaired vegetative growth and yield [12], [18] and [13].

The results also showed a significant decrease in the number of branches and fruits per plant as irrigation intervals increased. Treatment FA_0 promoted more abundant branching and higher fruiting, whereas FA_2 and FA_3 caused marked reductions in these parameters. These observations are consistent with findings by [8] reported that water stress limits branching, disrupts flowering, and reduces fruit retention in okra, leading to significant yield losses. Similar results have been reported by [7], indicating that water deficit reduces branching and fruit set, thereby decreasing the number of fruits per plant in okra.

The pronounced reduction in fruit number per plant under FA_3 can be attributed to disturbances in physiological processes related to flowering and fruit set. Under water deficit, plant growth and productivity are substantially reduced, as limited water availability affects floral initiation and fruit filling, resulting in lower total yield. Comparable findings have been reported in studies on water stress effects, showing that prolonged irrigation intervals significantly reduce both vegetative growth and yield components in Abelmoschus esculentus L. [16], [17]. Maintaining optimal plant water status helps preserve cellular integrity, sustain turgor, optimize gas exchange, and maintain photosynthetic activity, thereby limiting growth and yield losses in vegetable crops under water stress [18].

Yield was strongly influenced by irrigation frequency, with maximum values obtained under FA_0 and FA_1. The absence of a significant difference between these two treatments indicates that okra can maintain optimal yield with daily irrigation, representing a technically and economically viable option under conditions of limited water resources. The sharp yield decline observed under FA_3 confirms that extending irrigation intervals beyond 48 hours induces severe water stress, reducing photosynthesis, assimilate translocation, and fruit filling. Similar yield reductions have been reported by [17], who observed a significant negative effect of water stress on tomato yield.

4.2. Relationships between biometric parameters and yield

The Pearson correlation matrix revealed strong positive correlations between all biometric parameters and yield, particularly between number of fruits per plant, plant height, and yield. These findings confirm that okra yield is primarily determined by vegetative vigor and fruiting capacity, both of which strongly depend on water availability. The strong correlation observed between number of branches and number of fruits highlights the key role of branching in yield determination, as it increases the number of potential flowering sites. These results are consistent with those reported by [7] [8], who identified vegetative growth, branching, and fruit number as major yield components of okra under different water regimes.

Principal component analysis confirmed the results of univariate analyses and correlations. The main axis (F1), explaining more than 94% of total variance, clearly discriminated treatments according to their overall agronomic performance. Treatments FA_0 and FA_1 were associated with high values of growth, fruiting, and yield, whereas FA_2 and FA_3 were associated with poor performance. This structure highlights irrigation frequency as the dominant factor controlling the expression of agronomic traits in okra. Similar conclusions were reported by [14], [15] using multivariate analyses in comparable agro-climatic environments.

4.3. Economic analysis and agronomic implications

Economic analysis showed that treatment FA_1 provided the best compromise between production cost and yield, with the highest net benefit and value–cost ratio. Although FA_0 achieved maximum production, the additional costs associated with frequent irrigation reduced its relative profitability. These results emphasize that irrigation optimization should aim not only at maximizing yield but also at improving economic profitability, a principle widely highlighted in recent studies on irrigated agriculture, where water economic efficiency is a central criterion for production system sustainability [7], [8].

Under the edapho-climatic conditions of Faranah, characterized by high temperatures and strong evapotranspiration, daily irrigation (FA_1) appears to be the most efficient strategy, combining agronomic performance, water saving, and economic profitability. This approach confirms that rational and well-managed irrigation, rather than excessive water application, allows sustainable optimization of dry-season vegetable production systems. Similar conclusions were reported by [19], who showed that moderate irrigation regimes maintain high yields while improving water-use efficiency and reducing costs under hot climates.

5. Conclusion

This study demonstrates that irrigation frequency significantly influences okra growth, yield, and economic profitability. High irrigation frequencies (FA_0 and FA_1) promoted vigorous vegetative growth, improved fruiting, and higher yields, whereas extended irrigation intervals (FA_2 and FA_3) induced severe water stress and significantly reduced production. Although maximum yield was obtained under FA_0, economic analysis revealed that FA_1 represents the optimal strategy, offering the best compromise between yield and profitability. Therefore, one irrigation per day appears to be a simple, accessible, and strategic lever to enhance the resilience of dry-season vegetable production systems, improve food security, and ensure farmer profitability in Guinea.

Compliance with ethical standards

Acknowledgments

The authors sincerely thank the staff of the Department of Agricultural Extension of ISAV-VGE, Faranah, for facilitating all conditions necessary for the successful implementation of this study.

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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