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Effects of Management Practices on Agronomic Parameters in Cocoa Agroecosystems at Peripheral Zone of Ebo Forest Reserve, Littoral Region, Cameroon

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Abstract

The study was carried out to assess the effect of management practices on agronomic parameters of cocoa agroecosystems in the peripheral zone of Ebo Forest Reserve. Purposive random sampling was conducted to establish experimental plots on the farms of willing farmers. Demonstration plots were established and agronomic parameters were monitored for "farmers' practice (FP) and integrated crop pest and disease management (ICPM) practice" using indicators of Cocoa agro-ecosystem analysis (AESA). The FP and ICPM treatments were replicated in ten sites. From AESA records of agronomic parameters, the "observe, learn, decide and act" (OLDA) model was implemented in the ICPM treatments only. The effects of management practices were analyzed using a two-way analysis of variance (ANOVA), and treatment means compared using Turkey's T-test at 5% probability. Results of ANOVA between the two Management practices showed that over 50% of the response variables were statistically significant. Means separated through GLM ANOVA with Tukey pairwise comparisons at $\alpha = 0.05$ showed that 14 (53.8%) out of 26 response variables monitored were statistically significant between the two management practices. Pruning, shade management, phytosanitary harvest, rational use of pesticides, farm sanitation, pod harvesting, breaking, fermentation of beans and drying were regular in the ICPM treatment and time-bound in the FP treatment. The average total production varied from 385.83 kg/ha in FP treatment to 572.8 kg/ha in the ICPM treatment, still below the average standard of 1000 kg/ha. The OLDA model applied in ICPM treatment following AESA is a relevant tool to enhance sustainability in the management of cocoa agroecosystems. Farmers should be sensitized and trained on appropriate farm management techniques and enhance access to extension services as well as make available improved and grafted planting materials to ensure appropriate productivity levels.

Keywords

Agroecosystem, Agronomic Parameters, Cocoa Management Practices

1. Introduction

The "chocolate tree" *Theobroma cacao* L. is a Malvaceae, cultivated as an economic crop in the humid tropics worldwide, with 72% of the production in West and Central Africa [1] [2] [3]. Approximately 2.5 million farmers around the world depend on cocoa for their livelihoods [4]; 85% of these farmers are smallholders, growing cocoa on less than 10 hectares of land [5] [6]. Thus, it is largely a "smallholder crop", with individual farms ranging in size from 0.5 to 7 ha [7] [8] [9]. Cocoa remains a major source of foreign exchange for exporting countries, particularly in West/Central Africa where governments are heavily investing in the continued cultivation of the crop. [4] [10] [11] [12].

Cameroon is ranked as the third-largest producer of cocoa in Africa with a production capacity of 380,000 tonnes in 2017 after Ghana with 882,175 tonnes and the Ivory Coast with a production of 2.01 million tonnes [13]. Cocoa contributed 22.4% of the country's overall export share in 2017 [14]. Cocoa accounted for USD 492 million in 2018 and was the second top export in Cameroon after crude petroleum [15]. Despite the economic importance of cacao, the yield remains low [16] [17] [18] [19]. Cocoa Practices was developed in response to the challenges faced in the cocoa sector and to provide a set of comprehensive sustainability guidelines for cocoa production [19] [20] [21] [22]. These guidelines support cocoa-growing practices that are socially responsible, economically viable, and ecologically sustainable [11] [19] [23]. Small-scale farmers often have limited or no access to technical knowledge regarding best-known agricultural practices [9] [24] [21]. [25] pointed out that, the most important factor determining the productivity of a farm is good farming practice. Others include the age of trees, the number of productive trees per land area, and yield per tree [19] [26] [27]. The gap between on-farm cocoa yields and research station yields in West and Central Africa is excessive [11] [28]. Average yields across West Africa are under 500 kg per hectare while on-station trials typically reach between 2,000 kg and 3000 kg per ha [9] [16] [28]. The average productivity for Cameroonian cocoa farms is 300 kg/ha [4]. Closing this yield gap will be fundamental to the future growth of the sector and the conservation of rapidly dwindling West African forest resources [28]. There is also a strong focus on the control of black pod disease, capsids, use of pesticides, post-harvest techniques, and social issues [19] [25] that contribute to the productivity of cocoa.

There is limited documentation of intensive field research on changes in various agronomic parameters and crop health in remote cocoa-growing communities around protected areas. In areas where cocoa cultivation is still timid with limited access to extension services such as the Ebo landscape, farmers use the calendar method of activities to manage the fields irrespective of the agroecological conditions of the farm [28] while the integrated approach seeks to observe, learn, decide and act (OLDA) on the farm-specific situations [24] [25] [29]. Most studies have focused on the farmers' perception and adaptation of different management practices in producing quality cocoa [20] [30]. Others captured the effect of farmers' behavior in adopting Good Agricultural Practices (GAP) and Good Post-Harvest Management Practices (GPHMP) [7] [8]. They found out that farmers' management practices had a significant relationship with cacao beans quality but they did not look at the contribution of the management practices on various agronomic parameters and crop health. More so, studies have investigated cocoa agroecosystems generally [22] [26] [27], and mineral nutrition of cocoa [31] but little research has been documented on cocoa agroecosystem analysis (AESA) at the peripheral zone (PZ) of a protected area (PA). Cocoa agroecosystems (AES) at the PZ of a PA could serve as a buffer zone for the PA and requires a more friendly environmental practice [30] [32] [33]. Adoption of cocoa innovations associated with protected area management will go a long way to reconcile biodiversity conservation and quality cocoa production.

The main focus of this study is to document the extent to which cocoa farm management practices affect production and structural changes in the agronomic parameters of the cocoa agro-ecosystem (AES). The intended purpose of the study is to contribute to the adaptation of the "observe, learn, decide and act" (OLDA) approach to the indicators of agroecosystem analysis (AESA) of the plots. The study seeks to investigate the relationship between farmers' management practice (FP) using the calendar method and integrated crop pest management (ICPM) practice using the OLDA model.

2. Materials and Methods

2.1. Research Design and Selection of Study Site

The study was carried out in cocoa-growing villages in the peripheral zone of the Ebo Forest Reserve, within the Ebo Landscape in the Littoral Region of Cameroon. Ebo forest is a proposed National Park that is co-managed by the Ebo Forest Research Project (EFRP) and the Cameroon Ministry of Forestry and Wildlife (MINFOF) [34].

The Ebo landscape is located between the UTM coordinates 446,622N - 503,984N and 621,032E - 672,785E. The Ebo landscape which is a timidly cocoa growing area in the Littoral Region of Cameroon was selected because it has the fundamental characteristics of a typical cocoa frontier relevant to establishing a baseline for reconciling cocoa expansion and biodiversity conservation. It is part of the Congolian Coastal Forest and covers a total surface area of 2067.78 km^2 of evergreen lowland and submontane forest with EFR constituting 1424 km^2 [35] and parallel to the line of the Cameroon Highlands. Ebo forest extends 50 km both North to South, and West to East. The forest belongs to a transition zone between the equatorial and tropical zones with a variation in rainfall patterns of prolonged periods of the dry season and short rainy season [34].

The topography of the Ebo Forest is undulating with gentle to moderate slopes of 100 - 500 m, to steep slopes of up to 1400 m asl. Much of the Northern section is relatively mountainous whereas the Southern half is considerably flatter. The mean monthly temperature ranges between 26˚C - 28˚C with monthly peaks from December-April (28.3˚C - 28.1˚C). Average annual precipitation ranges from 2496 mm to 2950 mm with the wettest months being July to October [34]. The peripheral zone of the Ebo Forest Reserve is comprised of many small villages, which until the late 1950s and early 1960s were inhabited mostly by two major ethnic groups; the people of the Banen and Bassa tribes (**Figure 1**).

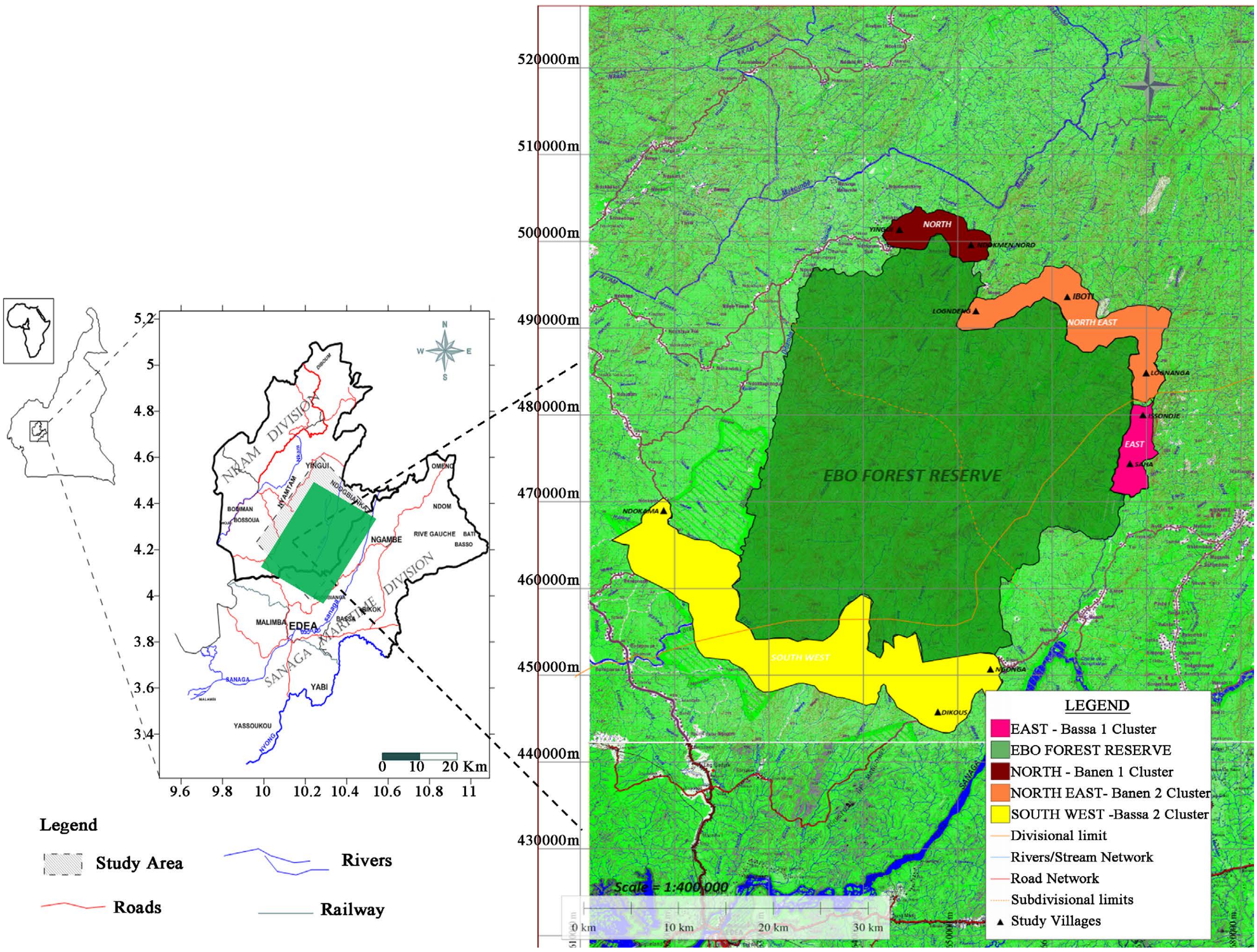


Figure 1. Location of the area showing study sites in four clusters.

2.2. Selection of Study Sites

Study sites were selected based on a multi-stage sampling technique of cocoa growing villages at varied altitudinal gradients around the coordinates (North, East, South, and West) of the reserve. In this study, peripheral villages with altitudinal and cultural affiliations around each coordinate were grouped and described as clusters [32]. A total of ten villages (**Table 1**) distributed in four clusters were selected for the study (**Figure 1**).

Table 1. List of target villages for the study.

Cluster	Altitudinal gradient	Village	Coordinates (UTM)	Municipality	Division
Southwest (Low altitudes)	≤400 m asl	Dikous	32N' 652,139 - 492,867	Edea II	Sanaga-Maritime
		Ngonga	653,380 - 450,479	Edea II	Sanaga-Maritime
		Ndokama	618,887 - 469,941	Yabassi	Nkam
North (Mid altitudes)	>400 ≤600 m asl	Yingui	643,489 - 500,304	Yingui	Nkam
		Ndogmem-Nord	650,800 - 498,921	Yingui	Nkam
East (High altitudes)	>600 <900 m asl	Isondje II	661,676 - 493,006	Massock	Sanaga-Maritime
		Saha	652,206 - 492,717	Massock	Sanaga-Maritime
North-East (Higher altitudes)	>900 m asl	Logndeng	651,848 - 492,254	Yingui	Nkam
		Iboti	661,256 - 492,844	Yingui	Nkam
		Lognanga	669,869 - 484,815	Yingui	Nkam

2.3. Experimental Design and Data Collection

Purposive random sampling was conducted to select the farm of a willing farmer for a demonstration of the effects of management practices on agronomic parameters. A cocoa field was earmarked upon a collaboration agreement (CA) with the farm owner. A demonstration plot of at least 200 trees was mapped out from the field as described by [19] [20] [21]. The plot was further divided into two subplots of 100 trees each; representing the farmers' management practice (FP) treatment and integrated crop pest and disease management practice (ICPM) treatment. The two treatments were replicated in ten sites grouped into four clusters.

The first Agroecosystem analysis (AESA) data was collected upon establishment of the plot. Subsequently, the response variables (**Table 2**) were monitored weekly for the 100 trees of each subplot.

Activities in the FP treatment were the usual approach of the farmer using the calendar cropping method while good agricultural practice using cultural operations and the Observe, Learn, Decide and Act (OLDA) model adapted from [25] was applied in the ICPM treatment only.

Based on the observations recorded during AESA data collection, the frequency of occurrence of the response variables, and analysis of the farm situation, a decision was made and actions were taken on the ICPM treatment. Following is the OLDA model (**Figure 2**) as described by [25]. In this model, there are different criteria for which a farm management decision could be taken.

Table 2. Parameters of cocoa AESA recorded and monitored.

Parameter	Options	Observations
Pods	Number of immature large pods (NILPs)	Count
	Number of healthy small pods on trunk (NHSPT)	Count
	Number of large ripe pods that can be used (NLRPU)	Count
	Number of large ripe pods attacked by black pods (NLRPBPs)	Count
	Number of unusable large pods attacked by rodents (NUnLPRs)	Count
	Number of large ripe pods attacked by insects (NLRPIs)	Count
	Number of unusable large pods attacked by black pods and removed (NUnLPBPR)	Count
	Number of unusable large pods attacked by insects and removed (NUnLPIR)	Count
Chupons	Number of chupons (water shoots/threats) on main branch (NCMBr)	Count
	Number of basal chupons (NBsCs)	Count
Leaves	Presence of new flushes (PNF); N = None	Nil
	Presence of new flushes (PNF); L = Low	≤ 25% of tree cover
	Presence of new flushes (PNF); M = Medium	> 25% ≤ 50% of tree cover
	Presence of new flushes (PNF); H = Heavy	Rating > 50% of tree cover
Crop health	Presence of creepers and mistle toes (PrCM)-N = None	Nil
	Presence of creepers and mistle toes (PrCM)-L = Low	Rating ≤ 25% of tree cover
	Presence of creepers and mistle toes (PrCM)-M = Medium	> 25% ≤ 50% of tree cover
	Presence of creepers and mistle toes (PrCM)-H = Heavy	Rating > 50% of tree cover
	Number of pods damaged by disease (NPsDD)-Bp = Blackpod	Count
	Number of pods damaged by insects (NPDI)-Cp = Capsid	Count
	Natural enemies observed (NEO)-Ra = Red ant, Pm = Praying mantis	

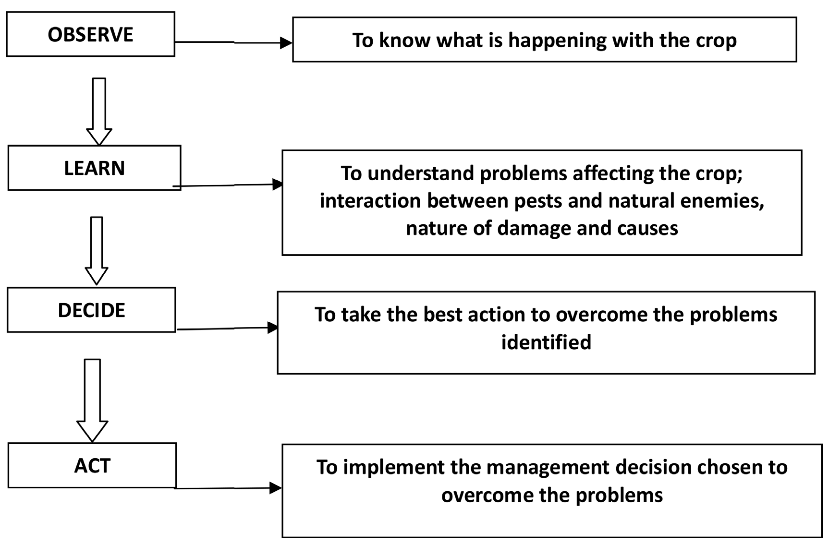


Figure 2. Framework of OLDA model (Observe-Learn-Decide-Act) (Adapted from [25]).

Some of these actions include pruning, farm sanitation, phytosanitary harvest, rational use of homologated pesticides (spot treatment or general), harvesting, breaking, fermentation, and drying. Each action requires different strategies and management prescriptions.

2.4. Crop Production

Harvesting of mature ripe cocoa pods was done regularly in the ICPM treatment following the OLDA model while in the FP treatment, it was done during low peak and high peak seasons following the calendar cropping method. After each harvest, the pods of each treatment were assembled separately, broken and the beans removed. The beans were fermented using banana leaves for 6 days before drying. During fermentation, the beans were mixed (inside-out, upside-down) every other day to ensure proper mixture and fermentation of all the beans. After fermentation, the beans were sundried for 5 days. The weight of dry cocoa beans was recorded and summed at the end of the season.

2.5. Data Analysis

The data obtained from the FP and the ICPM management practices were subjected to ANOVA to assess if it is statistically significant or not. The effects of the two management practices on variables were analyzed using a two-way analysis of variance (ANOVA) and means were compared with Turkey's test. Statistical differences concerning agronomic parameters were compared between the identified management practices and across clusters. Simple component analyses were used to show the contribution of the parameters across the axis of categorical variables.

3. Results

3.1. First AESA

Results of the first AESA showed that the farms selected varied in ages, planting distances of cocoa trees, distances of cocoa trees to other trees, and in number of shade trees per plot. All the plots were on a gentle slope and 90% had good drainage. The shade coverage was medium (*i.e.* ≥25 <50%) in 90% of the plots and 10% had heavy shade. **Figure 3** showed that 40% of the experimental plots were between 5 - 10 years and there was no plot between 30 - 40 years.

The planting distances of the ten experimental plots ranged from 3 × 3 m, 3.5 × 3.5 m, and 4 × 4 m (**Figure 4**).

3.2. Variation in Agronomic Parameters of Cocoa Agroecosystems

Table 3 shows the results of the Analysis of Variance (ANOVA) on the variation of 26 response variables recorded over 2 categorical variables of clusters and management practices on cocoa agroecosystems. Four (15%) of the response variables were statistically significant across clusters and 57.7% of the response

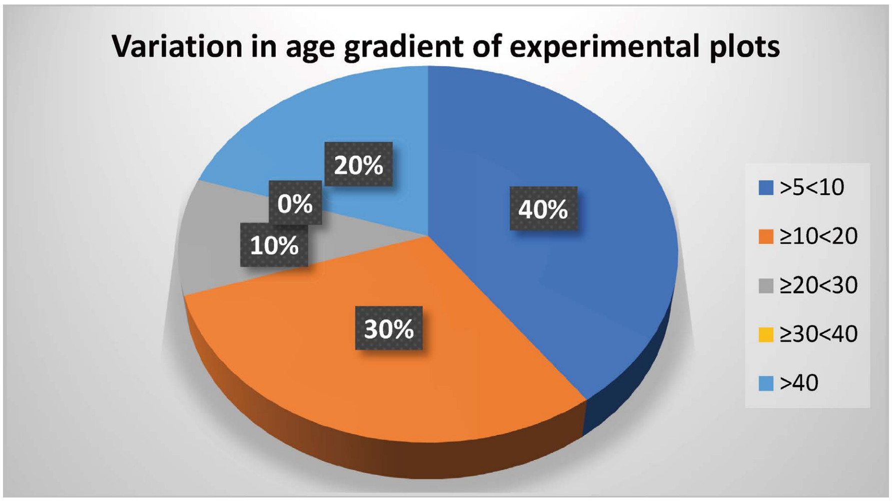


Figure 3. Variation in age gradient of experimental plots.

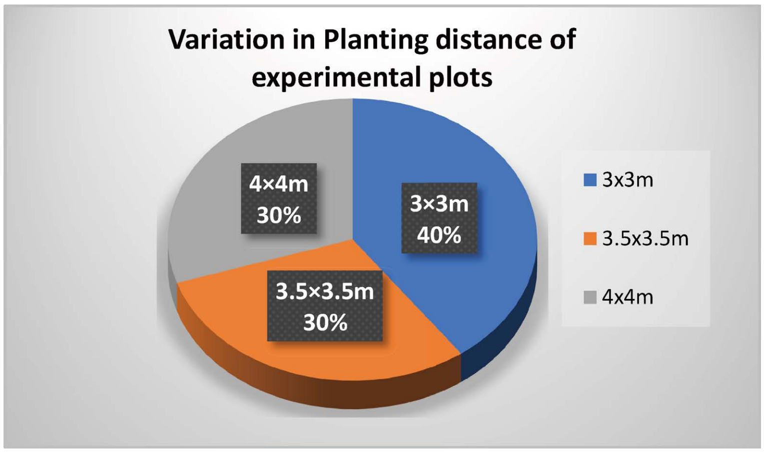


Figure 4. Variation in planting distances of experimental plots.

Table 3. Results of Analysis of Variance (ANOVA) on the variation of agronomic parameters across clusters and management practices.

Parameter	Response variable	Source of variation					
		Cluster			Management practice		
		Adjusted Mean Square	df	P-value	Adjusted Mean Square	df	P-value
Pods	NILPs	92084.4	3	0.378	8730.1	1	0.753
	NHSPT	18875	3	0.985	1817755	1	0.037
	NLRPU	62697	3	0.163	404593	1	0.002
	NLRPBPs	14911	3	0.140	61912	1	0.007
	NUnLPBPR	7877	3	0.048	120793	1	0.000
	NUnLPRs	342.673	3	0.092	5.684	1	0.846
	NLRPIs	15223	3	0.036	26271	1	0.025
	NUnLPIR	582.5	3	0.801	57141.6	1	0.000

Continued

Chupons	NCMBr	127389	3	0.113	2157867	1	0.000
	NBsCs	254076	3	0.000	647649	1	0.000
Presence of new flushes	PrNF-N	1282.5	3	0.194	195.3	1	0.619
	PrNF_L	693.4	3	0.914	35817.3	1	0.005
	PrNF_M	5890.2	3	0.372	25695.5	1	0.037
	PrNF_H	1903	3	0.485	18720	1	0.007
Presence of creepers and mistletoes	PCrMst_N	976	3	0.981	229690	1	0.001
	PCrMst_L	6669	3	0.172	127010	1	0.000
	PCrMst_M	397.1	3	0.854	21932.1	1	0.001
	PCrMst_H	488.3	3	0.612	3089.4	1	0.058
Crop health	NPsDDs_Bp	2.11168	3	0.015	7.24775	1	0.015
	NPsDDs_Ck	50.61	3	0.148	34.27	1	0.269
	NPsDDs_Rr	122.786	3	0.154	8.229	1	0.755
	NPsDIn_Cp	8.50263	3	0.237	0.36460	1	0.553
	NPsDIn_Sb	4166	3	0.000	2421	1	0.455
	NPsDIn_Ps	36.69	3	0.413	62.38	1	0.337
Natural Enemies	NEO_Ra	116846	3	0.647	2015	1	0.629
	NEO_Pm	2473	3	0.395	1263	1	0.475

Values in the Table represent P-values, the level of significance, ANOVA conducted at $\alpha = 0.05$. P-values less than 0.05 are highlighted and indicate a significant difference in the response variable for the factor concerned. NILPs = Number of immature large pods, NHSPT = Number of healthy small pods on trunk, NLRPU = Number of large ripe pods that can be used, NLRPBPs = Number of large ripe pods attacked by black pods, NUnLPBPR = Number of unusable large pods attacked by black pods and removed, NUnLPRs = Number of unusable large pods attacked by rodents, NLRPIs = Number of large ripe pods attacked by insects, NUnLPIR = Number of unusable large pods attacked by insects and removed, NCMBr = Number of chupons on main branch, NBsCs = Number of basal chupons, PrNF = Presence of new flushes (N = None, L = Low, M = Medium, H = Heavy), PCrMst = Presence of creepers and mistle toes (N = None, L = Low, M = Medium, H = Heavy), NPsDD/incidences = Number of pods damaged by diseas/incidencee (Bp = Blackpod, Ck = Canker, Rr = root rot), NPsDIn = Number of pods damaged by insects/incidence (Cp = Capsid, Sb = Stem borer, Ps = Psyelles), NEO = Natural enemies observed (Ra = Red ant, Pm = Praying mantis).

variables were statistically significant between the management practices.

Variation in agronomic parameters in cocoa agroecosystems across clusters showed statistically significant differences for number of large ripe pods attacked by insects (NLRPIs) (P = 0.036), number of pods damaged by insects due to incidence of capsid, NPsDIn-Cp (P = 0.000) and red ants observed as natural enemies, NEO-Ra (P = 0.000). The expression of the rest of the variables was not statistically significant across clusters (P > 0.05).

With respect to the management practices, there were significant variations in number of healthy small pods on tree trunk (NHSPT) (P = 0.037), number of large ripe pods that can be used, NLRPU (P = 0.002), number of large ripe pods attacked by blackpod disease, NLRPBPs (P = 0.007), number of unusable large pods attacked by blackpods and removed, NUnLPBPR (P = 0.000), number of large ripe pods attacked by insects, NLRPIs (P = 0.025), number of unusable large pods attacked by insects and removed, NUnLPIR (P = 0.000), number of chupons on main branch, NCMBr (P = 0.000), number of basal chupons, NBsCs (P = 0.000), light presence of new flushes PrNF-L (P = 0.005), medium presence of new flushes PrNF-M (P = 0.037), heavy presence of new flushes PrNF-H (P = 0.007), no presence of creepers and mistle toes, PCrMst_N (P = 0.001), low presence of creepers and mistle toes, PCrMst_L (P = 0.000), medium presence of creepers and mistle toes, PCrMst_M (P = 0.001), and number of pods damaged by disease due to incidence of blackpod, NPsDD_Bp (P = 0.015).

3.3. Variation of Agronomic Parameters between Clusters

Four out of twenty-six variables analyzed were statistically significant between the four clusters. The number of unusable large pods attacked by black pods and removed (NUnLPBPR) ranged from means of 16 ± 6.34 in the North Cluster to 88.8 ± 31.1 in the North East cluster (NEC), and this difference was statistically significant. Similarly, the number of large ripe pods attacked by insects (NLRPIs) ranged from 126 ± 22.1 in the North cluster to 207.6 ± 35.6 in the East Cluster. The East and South West clusters were not statistically significant in the observed number of large ripe pods attacked by insects (NLRPIs) (**Figure 5**).

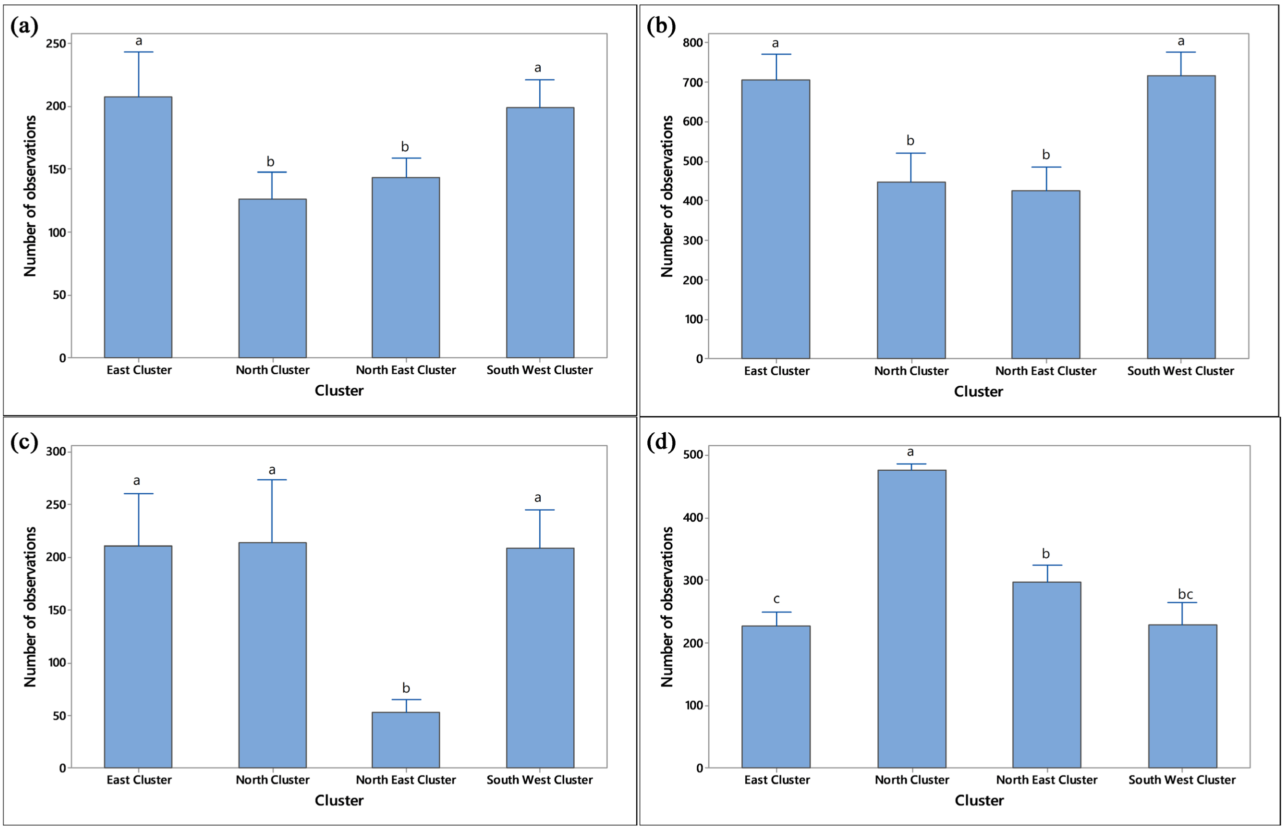


Figure 5. Variation of statistically significant response variables across four clusters in the PZ of EFR. (a) Variation in frequency of number of large ripe pods attacked by insects (NLRPIs) across clusters; (b) Variation in frequency of number of basal chupons (NBsCs) observed across clusters; (c) Variation in frequency of number of pods damaged by insects due to capsid (NPsDIn_Cp) across clusters; (d) Variation in frequency of natural enemies observed with incidences of red ants (Neo_Ra) across clusters.

Number of basal chupons (NBsCs) was statistically significant across clusters with the means higher in the East cluster (EC) and South West Cluster (SWC) and lower in North cluster (NC) and North East (NEC). The presence of new flushes (PrNF) was dominantly low and medium across clusters with a low frequency of heavy flushes. The presence of creepers and mistletoes (PrCrMst) was mainly none and low. Frequency of medium and heavycreepers and mistletoes was minimal. Incidences of damage caused by blackpod disease and capsid pest were statistically significant. Damage to crop health caused by blackpod was least in NC and predominant in EC, NEC, and SWC while damage caused by capsid was least in NEC which is at higher altitude with a significant level of natural enemies. Natural enemies with a regulating role to prey on pests were recurrent in NC and SWC. NC recorded highest incidences of red ants while SWC recorded highest incidences of praying mantis. Response variables that were statistically significant are represented in **Figure 5**.

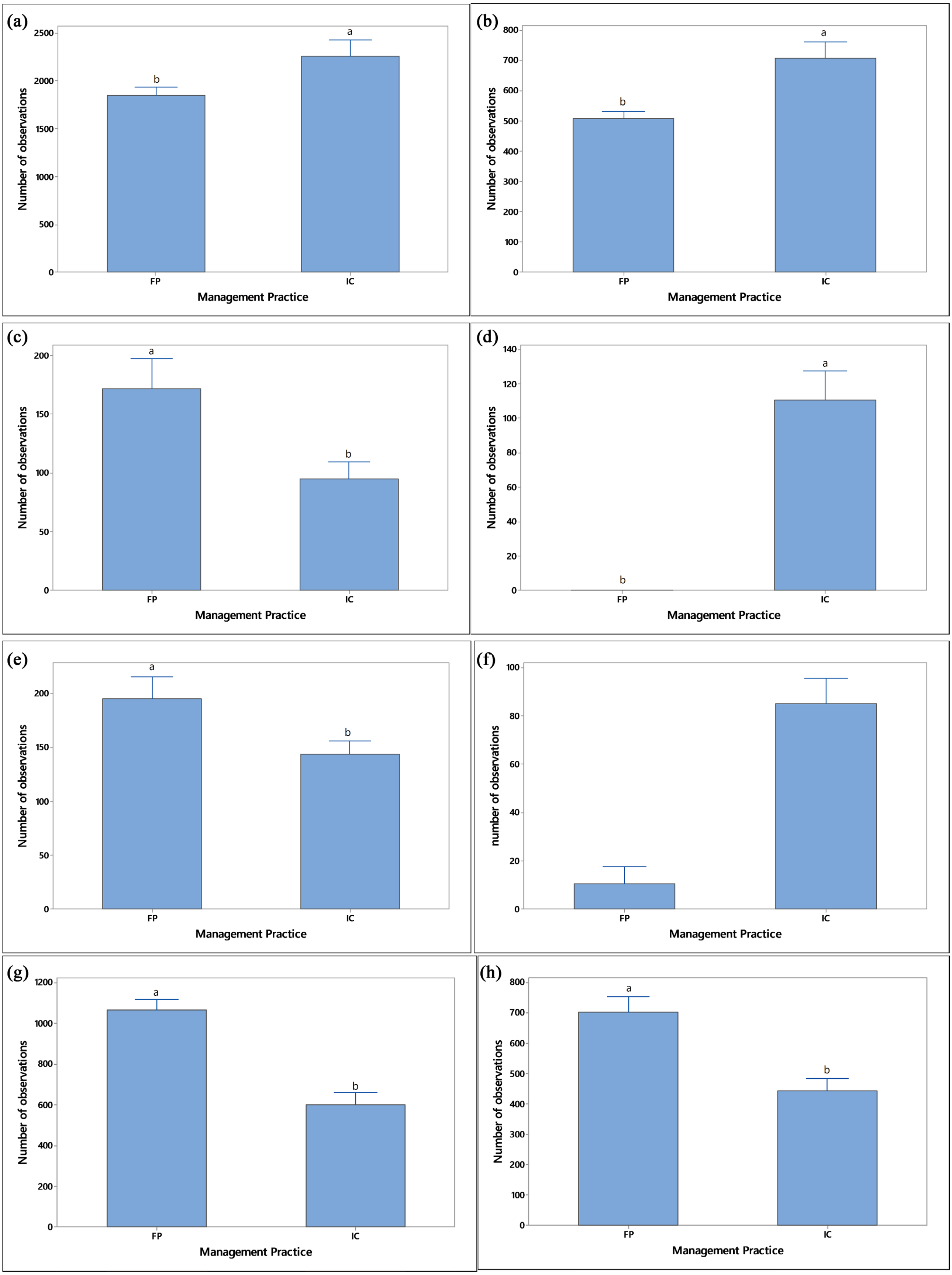
Bars represent mean occurrence (frequency) ± SE. Means separated through GLM ANOVA with Tukey pairwise comparisons at $\alpha = 0.05$. Bars with the same letter for each response variable are not significantly different. Vertical axis represents Mean Frequency of occurrence of each response variable and horizontal axis represents the clusters.

3.4. Variation of Agronomic Parameters between Management Practices

Figure 6 shows the expression of the response variable between two management practices implemented in the study sites. It showed that 53.8% of the response variables monitored were statistically significant between the two management practices. They include; number of healthy small pods on the tree trunk, number of large ripe pods that can be used, number of large ripe pods attacked by black pods, number of unusable large pods attacked by black pod disease and removed, number of large ripe pods attacked by insects, number of unusable large pods attacked by insects and removed, number of basal chupons, number of chupons on main branches, low, medium and heavy presence of new flushes, the incidence of pods damaged by blackpod disease, as well as none, low and moderate presence of creepers and mistletoes. Variation of statistically significant response variables across two management practices in the PZ of EFR are represented in **Figure 6** below.

From the bar charts, the number of healthy small pods on trunk (NHSPT) ranged from 1846.4 ± 87.2 in the FP treatment to 2260 ± 169 in the ICPM treatment. Similarly, number of large ripe pods that can be used (NLRPU) ranged from 507.3 ± 24.8 in the FP treatment to 706 ± 54.1 for the ICPM treatment. The number of chupons on the main branch (NCMBr) was higher in the FP (1063.9 ± 53.5) than in ICPM (600.3 ± 57.5). This goes to reflect the inverse observed in the NHSPT.

The number of large ripe pods attacked by black pods (NLRPBPs) and number


(a)
Number of observations
2500
2000
1500
1000
500
0
b
a
FP
IC
Management Practice
(b)
Number of observations
800
700
600
500
400
300
200
100
0
b
a
FP
IC
Management Practice
(c)
Number of observations
200
150
100
50
0
a
b
FP
IC
Management Practice
(d)
Number of observations
140
120
100
80
60
40
20
0
b
a
FP
IC
Management Practice
(e)
Number of observations
200
150
100
50
0
a
b
FP
IC
Management Practice
(f)
number of observations
100
80
60
40
20
0
FP
IC
Management Practice
(g)
Number of observations
1200
1000
800
600
400
200
0
a
b
FP
IC
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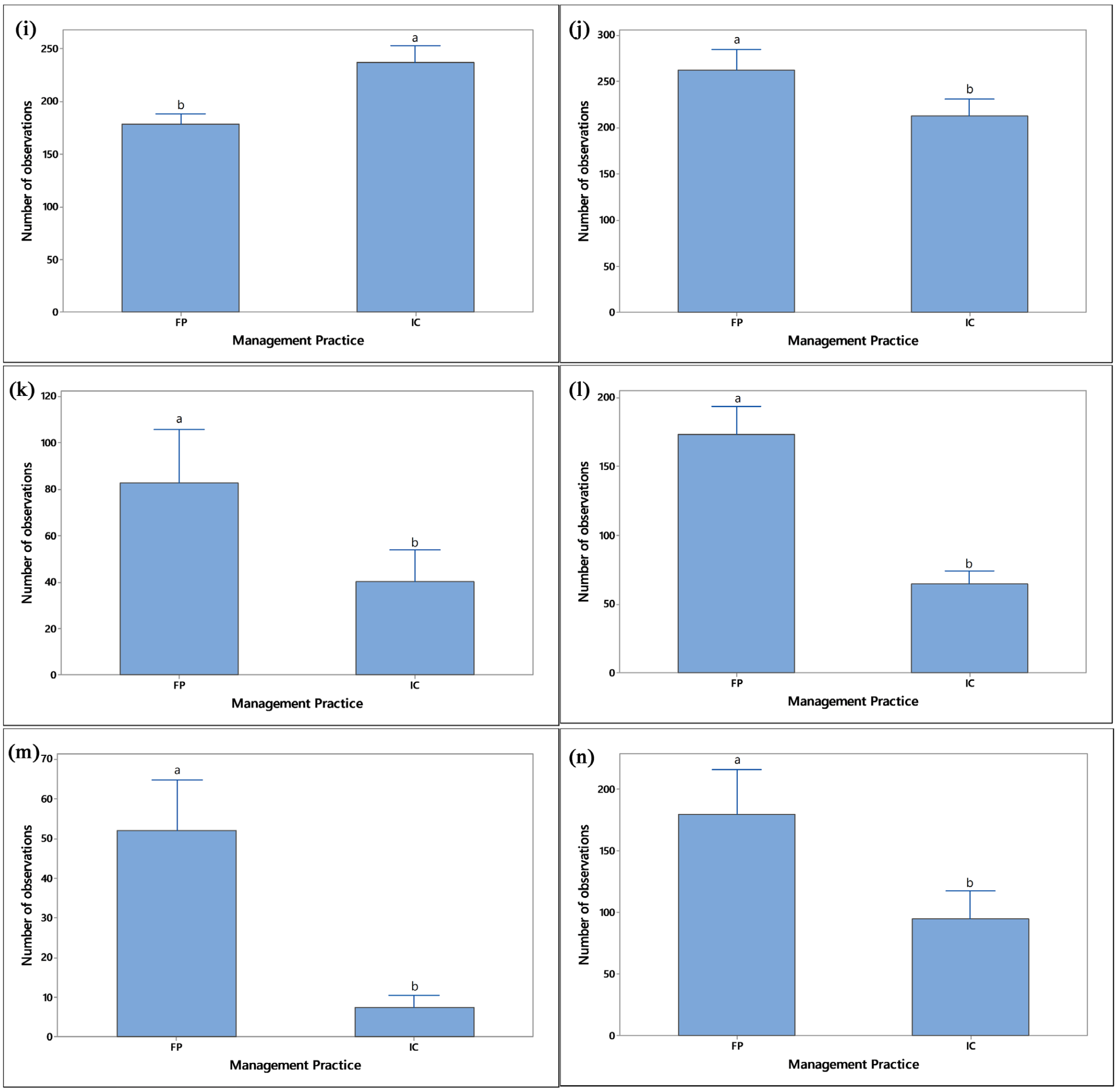

Bars represent mean occurrence(frequency) ± SE. Means separated through GLM ANOVA with Tukey pairwise comparisons at α = 0.05. Bars with the same letter for each response variable are not significantly different. The vertical axis represents Mean Frequency of occurrence of each response variable. FP = Farmer's practice, IC = Integrated crop pest and disease management.

Figure 6. Variation of statistically significant response variables across two management practices in the PZ of EFR. (a) Variation in Mean frequency of number of healthy small pods on trunk (NHSPT) between two management practices; (b) Variation in Mean frequency of number of large ripe pods that can be used (NLRPU) between two management practice; (c) Variation in Mean frequency of number of large ripe pods attacked by blackpods (NLRPBPs) across two management practices; (d) Variation in Mean frequency of number of unusable large pods attacked by blackpods and removed (NunLPBPR) across two management practices; (e) Variation in Mean frequency of number of large ripe pods attacked by insects (NLRPIs) across two management practices; (f) Variation in Mean frequency of unusable large pods attacked by insects and removed (NunLPIR) across two management practices; (g) Variation in Mean frequency of number of chupons on main branches (NCMBr) across management practices; (h) Variation in Mean frequency of number of basal chupons (NBsCs) between the two management practices; (i) Variation in Mean frequency of low presence of new flushes (PrNF_L) between two management practices; (j) Variation in Mean frequency of medium presence of new flushes (PrNF_M) between two management practices; (k) Variation in Mean frequency of heavy presence of new flushes (PrNF_H) between two management practices; (l) Variation in Mean frequency of low presence of creepers and mistletoes (PCrMst_L) between two management practices; (m) Variation in Mean frequency of moderate presence of creepers and mistletoes (PCrMst_M) between two management practices; (n) Variation in Mean frequency of number of pods damaged by disease with incidences of blackpod (NPsDDs_Bp) between the two management practices.

of large ripe pods attacked by insects (NLRPIs) were higher in the FP than in the ICPM. In addition, number of unusable large pods attacked by black pods and removed (NUnLPBPR) and number of unusable large pods attacked by insects and removed (NUnLPIR) were higher in the ICPM treatment than in the FP treatment. There were no records in the FP treatment because it was allowed for the farm owner to perform his usual approach.

In the ICPM treatment, OLDA model was incorporated in the agroecosystem analysis and preventive measures were applied to minimize pest infestation and disease infection. Should they occur and the pods could no longer be used, sanitary harvest was implemented wherein, the diseased/infested pods were harvested, counted, and dumped in a pit to prevent further spread to healthy pods. Number of unusable large pods attacked by rodents was not statistically significant in the two management practices. This shows that management practice has no effect on rodents' attacks on the crop.

Number of basal chupons (NBsCs) was higher in FP than in ICPM practice. From observations in ICPM, basal chupons were pruned during the maintenance of the cocoa trees. The no-presence of new flushes (PrNF-N) was minimal in the two MP and similar incidences were recorded. When the heavy presence of new flushes (PrNF-H) is observed, it causes the humidity of the microenvironment to increase and it is conducive for black pod disease. Incidences of no presence of creepers and mistletoes were higher in ICPM while low, medium, and heavy were higher in FP.

3.5. Association of Variables

3.5.1. Association of Variables with the Cluster

Figure 7(a) shows the association of response variables with the different clusters. There is a strong association of number of unusable pods attacked by rodents (NunLPRs), heavy presence of creepers and mistletoes (PCrMst_H), number of pods damaged by disease (NPsDDs_Ck), number of unusable large pods attacked by blackpod and removed (NUnLPBPR) in the North East Cluster with significantly high loadings.

When only statistically significant variables are considered (**Figure 7(b)**), the North East cluster is strongly associated with number of pods damaged by insects with the incidence of capsid (NPsDIn_Cp) and number of basal chupons (NBsCs). The North Cluster is strongly associated with number of large ripe pods attacked by insects (NLRPIs) while the East and South West clusters are highly similar, and closely associated with natural enemies observed with the incidence of red ants (NEO_Ra) and number of unusable large pods attacked by black pod and removed (NUnLPBPR) which have high loadings at these sites.

3.5.2. Association of Variables with Management Practice

Figure 8(a) shows the association of response variables with the different management practices. With the ICPM subplot, there is a strong association between

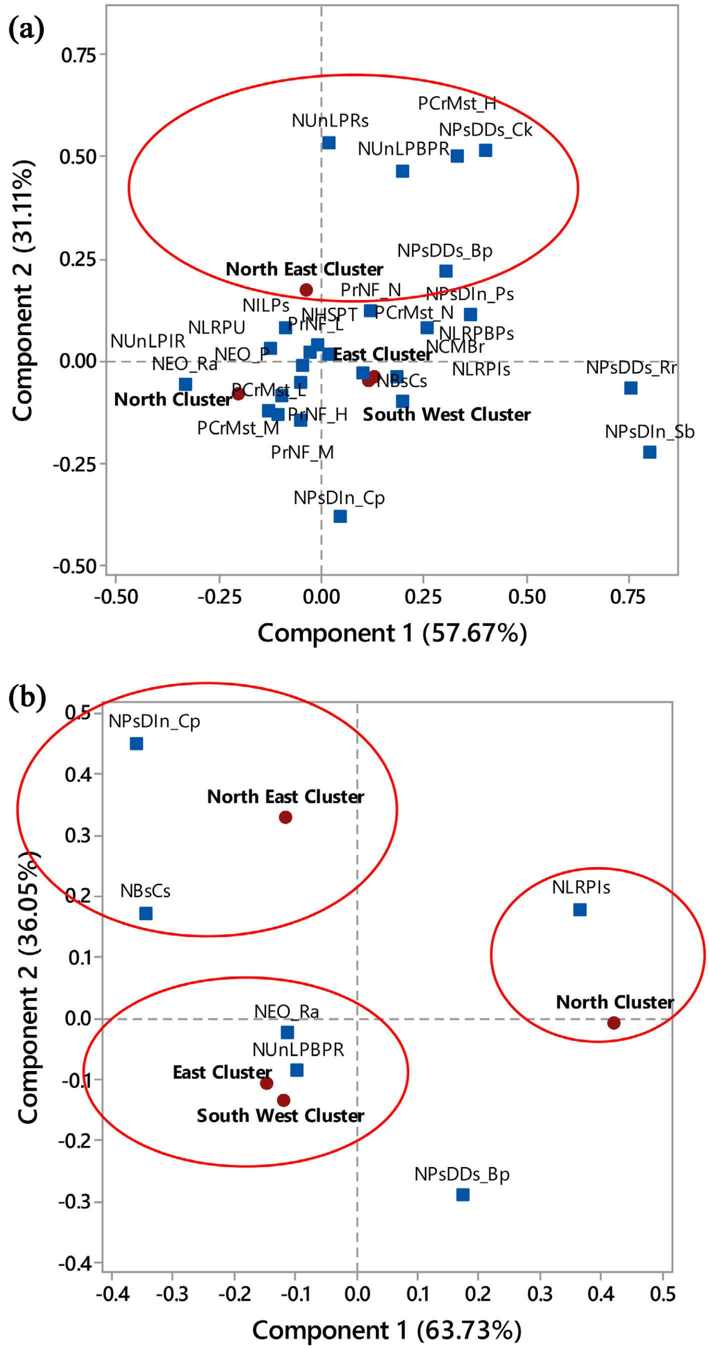

Figure 7. Simple correspondent analysis results showing association of response variables with clusters. (a) Ordination with all variables; (b) Ordination with only significantly different (differentiating variables). Variables with significantly high loadings at a particular cluster associate closely with that cluster. Variables at opposite ends of a cluster are usually negatively correlated.

number of healthy small pods on a tree trunk (NHSPT), number of large ripe pods that can be used (NLRPU), number of unusable large pods attacked by insects and removed (NunLPIR), low presence of new flushes (PrNF-L), number of pods damaged by disease with incidence of canker (NPsDDs_Ck), number of unusable large pods attacked by black pod and removed (NUnLPBPR), number of unusable large pods attacked by insects and removed (NUnLPIR). These responses have significantly high loadings in the ICPM treatment. Similarly, when only statistically significant variables are considered (Figure 8(b)), the ICPM practice is strongly associated with number of healthy small pods on tree trunk (NHSPT), number of large ripe pods that can be used (NLRPU), no presence of

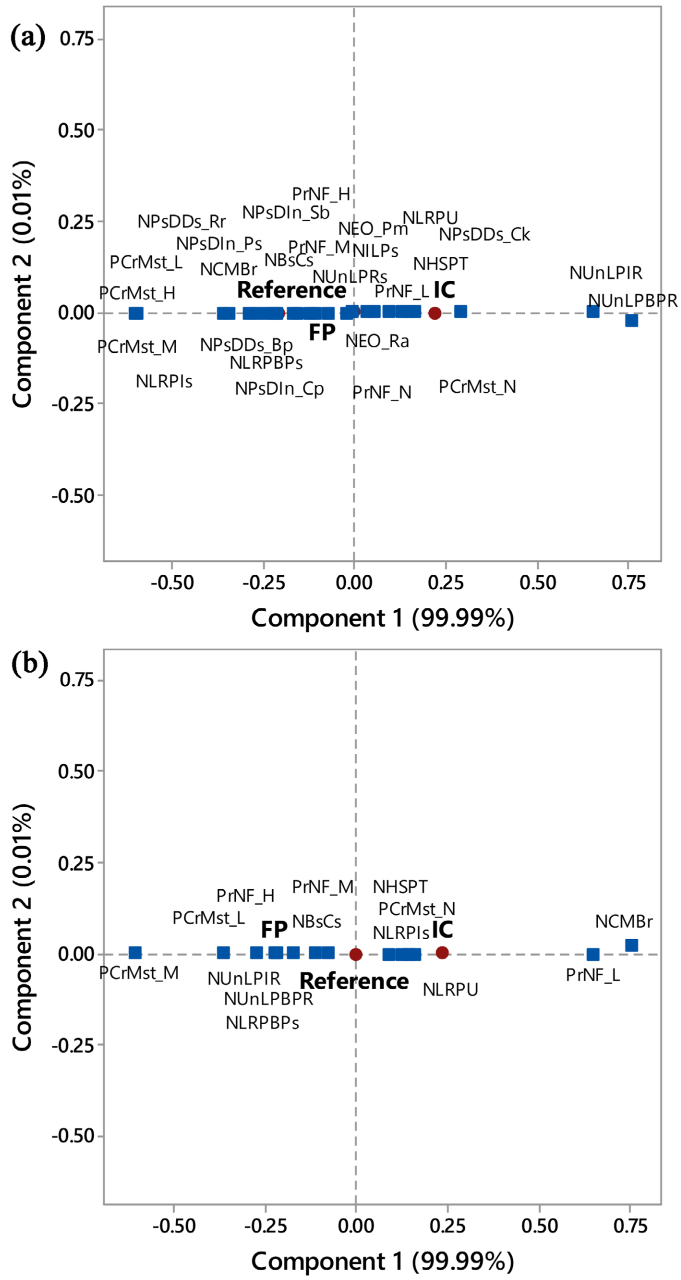

Figure 8. Simple correspondent analysis results showing association of response variables with management practices. (a) = ordination with all variables; (b) = ordination with only significantly different (differentiating variables). Variables with significantly high loadings at a particular MP associate closely with that MP. Variables at opposite ends of a MP are usually negatively correlated.

creepers and mistletoes (PrCrMst-N), number of large ripe pods attacked by insects (NLRPIs) and number of chupons on the main branch (NCMBr). The FP plot is strongly associated with number of large ripe pods attacked by blackpods (NLRPBPs), medium presence of creepers and mistletoes (PrCrMst-M), heavy presence of creepers and mistletoes (PrCrMst-H), medium presence of new flushes (PrNf-M), heavy presence of new flushes (PrNF-H) and closely associated with natural enemies observed with the incidence of red ants (NEO_Ra) and number of unusable large pods attacked by black pods and removed (NUnLPBPR) which have high loadings at these sites.

Variables at opposite ends of the axis are usually negatively correlated. No presence of new flushes (PrNF_N) and heavy presence of new flushes (PrNF_H) on the y-axis are negatively correlated while on the x-axis, number of unusable large pods attacked by blackpod and removed (NUnLPBPR) is negatively correlated with heavy presence of creepers and mistletoes (PrCrMst-H).

3.6. Variation in Crop Production

One hundred trees were monitored per plot from each study site making a total of 1000trees for each treatment (FP and ICPM) from all the ten sites. An average number of mature ripe pods harvested and weight of dry cocoa beans from the two plots were recorded. Table 4 shows that the average total production varied from 385.83 kg in FP plots to 572.8 kg in ICPM plots.

Table 4. Average production of cocoa beans in ICPM and FP plots.

CLUSTER	VILLAGE	NO. OF PODS HARVESTED		WEIGHT OF DRY BEANS (kg)	
		ICPM	FP	ICPM	FP
NORTH	Yingui	1654	1086	63.6	41.7
	Ndogmem-Nord	1879	1072	75.2	42.88
NORTHEAST	Logndeng	1405	875	50.1	31.25
	Iboti	1915	1309	76.6	52.4
	Lognanga	1542	1234	61.68	49.36
EAST	Issondje II	1032	726	36.85	25.03
	Saha	1676	1044	67.04	41.76
SOUTHWEST	Ngonga	1204	828	46.30	31.84
	Dikous	1096	806	40.59	29.85
	Ndokama	1426	1034	54.84	39.76
TOTAL		**14,829**	**10,014**	**572.8 kg**	**385.83 kg**
AVERAGE		**1482.9**	**1001.4**	**57.3**	**38.6**

4. Discussions

4.1. First AESA

From the first AESA, 40% of the experimental plots were between 5 - 10 years and there was no plot between 30 - 40 years. The farmers with young farms were willing to allow the research to be conducted in their farms so they could gather experience from the two practices and eventually make sound crop management decisions [19]. This is in harmony with findings of [1] [4] who attest that, a significant proportion of farmers in FFS indicated not having any other source of information. Though the research was not FFS *per se*, the host farmers with limited access to Agricultural extension Services could testify to gaining experience from the study. The variation in planting distances at 3 × 3 m, 3.5 × 3.5 m and 4 × 4 m showed they have limited information on cocoa production.

Agroecosystem analysis (AESA) data collection is one of the key instruments in sustainable tree crop production [1] [20] [25]. The results show that the appropriation of OLDA model in cocoa AESA could improve quality and quantity of production [36]. This is in harmony with the findings of [22] who described agricultural development as a function of agroecosystem properties enhancing productivity, stability, sustainability and equitability. Farmers monitored cocoa trees and fruits through the collection of AESA data. The farmers adopt the owner management system which [37] regarded as pessimistic in their maximin criterion. Understanding the behaviour and important properties of an agroecosystem requires knowledge of only a few key functional relationships [17] [22] [25] [37]. The length of time that a cocoa farm remains productive and financially viable is determined by the application of good maintenance practices, guided by keen observation, analysis of the situation, deciding on what to do and taking action [25], in particular pruning, farm sanitation, phytosanitary harvest, soil enrichment, and pest and disease control through preventive measures or rational use of pesticides [11] [16] [29]. Pruning was conducted for high observations of basal chupons or chupons on main branches, heavy presence of new flushes and presence of creepers and mistletoes [5] [9] [11]. Farm sanitation was carried out to clean/redress observations on poor drainage, disease/insect zoo, overgrown fields leading to high humidity [21] [25]. Phytosanitary harvest was to remove and discard pods damaged by disease or pest and cannot be used. When absolutely necessary, rational use of pesticides was conducted for observations on usable pods affected by pests and diseases. If less than 20% of the plot was affected, spot treatment was implemented on affected area while general treatment was done when over 20% of the plot was affected [25]. Soil enrichment through fertilizer application was an option when there were high observations on no or low presence of new flushes as well as high number of immature large pods [31]. It is therefore important to maintain a high standard of farm management [36] so that the cocoa tree is less susceptible to parasites, disease, and insect attacks, as well as to ensure an appropriate response to specific outbreaks when they do occur [3] [10] [38].

4.2. Variation in Agronomic Parameters across Clusters and Management Practices

Significant changes were noted between the management practices and across the clusters. The effect of insects on cocoa pods varied with altitudinal gradient and management practice. The number of pods damaged by insects (NPsDIs) was significant across clusters and of the different insect pests observed, only pods damaged by capsid (*Sahlbergella singularis* and *Distanfiella theobroma*) were statistically significant across clusters. This shows that capsid is the main pest causing destruction in cocoa agroecosystems in the study site. This is in harmony with the assertions of [36] [38] that the most important pest in cocoa agroecosystem is capsid.

The number of pods damaged by black pod disease (NPsDDs) was significantly different between management practices. This affirms the findings by many other researchers that black pod disease caused by *Phytophthora megakarya* and other *Phytophthora* sps, is the main disease affecting yields in cocoa agroecosystems [1] [2] [4]. A healthy crop is a more productive crop [9] [17] and the growth is more vigorous, yields are generally higher and the plant is better able to resist or compensate for pest/disease attacks [28] [31].

4.2.1. Variation across Clusters

The agroecological conditions of the cocoa fields varied across clusters due to demarcation following altitudinal gradients around coordinates of the Ebo Forest Reserve. Fischer *et al.*, 2008 cited in [3] argued that the feasibility of any given approach to agricultural development depends on a landscape's biophysical properties of which, topography plays a major role. The micro-climate, in turn, influences the incidence of pests and diseases. [31] and [39] asserted that several factors together determine the changes in agronomic parameters including the actual yield of cocoa. These defining factors include local temperature, carbon-dioxide (CO_2), sunlight radiation and the crop physiology and phenology [17] [31].

Four (15.4%) of the variables were statistically significant between the four clusters. The number of large ripe pods attacked by insects (NLRPIs) shows the spread of pests in the plots and it was higher in North and Southwest clusters which are located at mid and low altitudes respectively. It could be influenced by limited shade and intensity of sunlight conducive to insect zoo [31] [33] [39]. The East and North East clusters are at higher altitudes manifesting slightly similar agro-ecological situation including high humidity of the clusters and concurrently, higher incidence of blackpod.

4.2.2. Variation between Management Practices

Results of ANOVA between the two Management practices captured the management (agricultural practice, farm hygiene, crop health)) of farm and production parameters. In the ICPM subplot, appropriate pruning was conducted regularly. Pruning is the removal of unwanted branches (chupons or water threats/shoots) from a cocoa tree [11] [13] [28] [29]. It is an important operation and can affect yield for months, even years, as well as affect the shape and structure of the tree for the rest of its life [19] [25]. It is beneficial to the cocoa tree in that it improves the structure of the plant, aeration, and stimulate flowering and pod production. It minimizes the establishment of pests/disease zoos [17] [20]. Insects and diseases multiply more on un-pruned cocoa trees with dense canopies than on trees that have been opened up by pruning and display well-aired canopies [4] [27] [28]. In farmers/community practice, farmers find it difficult to do proper pruning of the cocoa trees. They prefer to leave some chupons on the main branches thinking it will produce more pods whereas it will limit the aeration of the crop [1] [4] [19]. The application of appropriate integrated crop management ensures the sustainable productivity of cocoa farms. The ICPM practice incorporating cultural operations was put in place to manage the ICPM treatments. This is in harmony with the findings of [19] who found that an integrated crop pest/disease management (ICPM) practice can never be a prescriptive, 'off the shelf package. A grower must look at all the options available to him or her and make an informed decision as to which measures to take. A routine of farm maintenance involving chupon removal, weeding, and removal/ destruction of infected plant material (pods and branches) is probably the single most important method for managing many key cocoa pests [19].

One management tool currently neglected by the farmers as observed in the FP plots is rational pesticide use. This observation is in harmony with the findings of [11] who attest that farmers use pesticides irrationally and sometimes mix insecticides and fungicides which end up destroying the fields.

In controlling cocoa diseases, all trees should receive individual attention, as a single infected plant is likely to act as a source of infection for all the other trees on the farm [4]. If left unattended, one sick tree will eventually lead to all the others also contracting the disease. The disease zoo enables farmers to understand the relationships between disease, humidity, and black pod disease development [11] [25] [28]. This understanding was applied by the research team to guide the action on phytosanitary harvesting and shade management.

The use of pesticides should be minimized as much as possible to protect the crop. More emphasis should be placed on resistant varieties and cultural and biological control of pests and diseases. In the FP subplot, there was the routine use of pesticides by farmers following the calendar method. Heavy use of chemicals can cause disease resistance, negative effects on beneficial micro-organisms, and are harmful to humans and the environment [5] [9] [12] [39].

4.3. Cocoa Harvest, Post-Harvest, On-Farm Processing, and Storage

In the ICPM treatment, pods were harvested every two weeks if there were few ripe pods, and every week during peak periods. Likewise, it is important to do a separate round of the farm every week to remove sick pods with a cocoa hook that is used only for removing diseased material [16]. It is essential that the pods do not become over-ripe as they are more likely to become infected with diseases, and the beans inside over-ripe pods will germinate. [36] stipulates that evidence to date suggests that Ochratoxin "A" (OTA) producing organisms enter the cocoa supply chain via damaged pods. OTA is a naturally occurring food-borne mycotoxin found in a wide variety of agricultural commodities [16]. To reduce Ochratoxin "A" in the cocoa supply chain, it is recommended that farmers should not wound pods with a machete. Wounded pods of any kind should not be stored for any longer than one day. Every step in the process contributes to the final quantity and quality of the cocoa produce [8] [9] [12].

Crop Production

The cocoa harvested, fermented, and dried from the FP /treatments had some broken pieces while the dried beans from ICPM treatment were not adulterated. This was probably caused by the materials used. Though the plots were in similar locations, there was significant variation in agronomic parameters monitored, and production in the two management practices. The ICPM practice is in line with the model Ordinance of the International Cocoa Standards [16] [17] which provides that cocoa of merchant quality must be: "(a) Fermented, thoroughly dry, free from smoky beans, free from abnormal or foreign odor and free from any evidence of adulteration. (b) Reasonably uniform in size, reasonably free from broken beans, fragments and pieces of shell, and be virtually free from foreign matter". Thus, this is similar to the results of [24] [40], which showed that on-farm demonstrations are vital for the adoption of sustainable agricultural practices. The results of this study showed that 80% of the farm owners were not acquainted with sustainable management practices, and could not implement adequate measures to ensure the production of quality cocoa beans [7] [8]. The cumulative production from the ICPM treatments was higher (572.8 kg) than that from FP treatment (382.83 kg) though none attained the required standard. The yields in both ICPM and FP practices were generally below the expected standard of 1000 kg giving a yield gap of 427.2 kg and 617.17 kg respectively [9]. This outcome was probably due to dominance of local varieties, availability of shade trees, age of fields with 2 plots of over 40 years, and appropriation of agrochemicals and fertilizers [9] [24].

5. Conclusion

Results of the study showed that, over 50% of the agronomic parameters monitored were statistically significant between the two management practices at $P < 0.05$. This implies, FP and ICPM management practices have a significant effect on the agronomic parameters of cocoa agroecosystems and eventually crop productivity in Ebo landscape. The regular cocoa agroecosystem analysis (AESA) enabled the research team to identify problems in the cocoa fields, analysed them and made sound crop management decisions for actions, especially for ICPM treatment. The study enabled the farmer to know why, when and how to prune, conduct farm sanitation, phytosanitary harvest, spot or general treatment of the farm, type of pesticide to use and how, harvesting and post-harvest management of the crop. The production from the ICPM treatment was higher (572.8 kg) than that from FP treatment (382.83 kg) indicating that, the appropriation of ICPM treatment will go a long way to improve production and productivity in cocoa agroecosystems. The "observe, learn, decide and act (OLDA)" model applied in ICPM treatment following AESA is a relevant tool in the appropriate management of cocoa agroecosystems. With the set baseline, subsequent studies in the area could improve the results.

6. Recommendation

Considering the high conservation value of Ebo Forest Reserve and the importance of cocoa agroecosystems as buffer to the reserve and potential source of income for farmers, it is recommended that:

- The Integrated Crop Pest Management (ICPM) practice should be appropriated to increase the quantity and quality of production in a limited land area. Farmers should seek professional advice on ICPM to control pests and diseases.
- High-yielding varieties of Cocoa should be planted in the most suitable pattern and density according to the varietal requirements to ensure high productivity and easy management of the farms.
- Appropriate management decision should be taken for the old farms, regeneration, rehabilitation or replanting.

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Conflicts of Interest

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

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