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Research Article

Soil properties, growth and yield of cocoa (*Theobroma cacao* L.) trees from moribund field as affected by pruning and fertilizer application

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Abstract

An experiment was conducted to investigate the effects of fertilizer application and pruning on soil properties and performance of cocoa trees from a moribund field. The fertilizers (NPK compound inorganic fertilizer and poultry manure) and pruning intensities (none, moderate and heavy branch removal) had significant effects on soil properties and flower production, pod and bean yields of cocoa trees. The fertilizers enhanced soil fertility (increased soil pH, organic carbon, N, P, K, Ca and CEC). Heavy pruned cocoa trees produced significantly higher number of pods per tree (49.7) compared with moderate pruning (42.4) and unpruned (45.3). Cocoa pods were heavier for heavy pruned trees (1.4) compared with the unpruned (1.2) and moderate (1.01) pruning intensities. Total bean weight was high for heavy pruning (0.34 kg) followed by the unpruned trees (0.32 kg) and lowest for moderate (0.28 kg) pruning treatment. Pod weights were 2.83 and 2.74 kg for trees treated with poultry manure and NPK amended soils compared with unamended (2.38 kg). The number of beans per pod was respectively, 226.4, 211.7 and 206.4 while weight of beans per tree was 0.76, 0.70 and 0.64 kg for poultry manure, NPK and no amendment. Poultry manure treatment of heavy pruned cocoa enhanced weights of pods and beans compared with NPK while lowest values were recorded for unamended trees. Pruning enhanced cocoa tree vigour by reducing shade density and competition for assimilate from organs (root, branches, leaves) and promote light regime and health of trees. The fertilizers improved soil physical, chemical and biological properties for cocoa tree productivity. There were positive and significant impacts of rehabilitation practice involving pruning and fertilizer amendment for rejuvenation and enhanced performance (flowering, pod and bean production) of old, moribund cocoa trees.

***Keywords**:* Cacao, moribund trees, rehabilitation, soil, amendment, pod, bean, productivity

Introduction

Cocoa (*Theobroma cacao* L.), an important commodity crop, has tremendous economic value to producer countries. Cocoa is also being used in various culinary products worldwide (FAO Stat, 2020). Cocoa is cultivated for its seed (bean) for manufacturing cocoa liquor, cocoa butter and chocolates. Cocoa beans are harvested, fermented, roasted, and ground to form a paste known as cocoa mass or liquor. Chocolate has health benefits due to its high content of flavonoids that are crucial in reducing the risk of cardiovascular disease, cancer and other age-related diseases (Bertoldi *et al*., 2016).

The cocoa industry faces challenges due to decline in productivity particularly in regions with aging cocoa plantations, moribund, abandoned and poorly managed fields which associated with reduced tree health and bean quality (Opeke, 2006; Adebiyi and Okunlola; 2013; Adeogun *et al*., 2010). It is crucial to identify sustainable management practices to revitalize these gardens which should be rehabilitated and renovated in order to restore the productive capacity. Abandonment of gardens may be due to fall in cocoa prices, ageing of cocoa farmers, the invasion of pests and diseases, war and other social-political causes and difficulties in the transmission of hereditary rights over the orchard (Kinnagbe, 2015; Jagoret *et al*., 2018, Abdulai *et al*., 2020).

The rehabilitation of cocoa fields may be necessary when there is a decline in pod and bean yields; when trees become unmanageable; when replanting or replacement of old varieties results in low yields with small pods and beans; when

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fields show little or no tolerance to Witches' Broom and Black Pod diseases; and when there is a need to correct widely spaced (3 × 3 m) traditional planting systems, which promote heavy weed growth, increase labour requirements for pruning, and encourage frequent use of herbicides. By addressing these issues, farmers can rejuvenate moribund orchards and return them to optimal productivity (Schroth *et al*., 2016; O'Sullivan *et al*., 2018). Cocoa rehabilitation aims at restoring yields through "good management practices". These include pruning, replacement of traditional, susceptible cocoa genotypes by new, disease and drought-resistant, high-yielding, and fine flavour cocoa cultivars, integrated pest management practices, agro forestry, and low carbon cultivation practices (Schroth *et al*., 2016). Cocoa agronomists have recommended methods and protocols for the rehabilitation and renovation of old cocoa orchards (Rivel *et al*., 2019; Somarriba *et al*., 2021) such as improving air circulation through removal of excess branches, reducing the risk of fungal diseases like frosty pod rot, enhancing sunlight interception and distribution within canopy and field (WCF, 2018). Renovation aims at restoring productive capacity of the field to another cultivation cycle at the same site (Tost *et al*., 2022), reconstruction of old field to new orchard using improved varieties, spacing and shaded canopy that will promote health and productivity of the trees (Abdulai *et al*., 2020).

Rejuvenation of old cocoa trees in plantation may be based on the use of pruning intensities such as complete removal of tree crown by pollarding, removal of diseased branches/twigs, or reduction in tree height. Rehabilitation (Rh) and Renovation (Re) interventions focusing on pruning are based on the assessment of key variables and critical thresholds such as age of cocoa (>40 years), yields (<500 kg $ha^{-1}year^{-1}$), and planting density (<800 plants ha^{-1}). In addition, consideration is given to pest and disease status, height of the cocoa tree, and shade levels (Sharma and Singh, 2006; Rievel *et al*., 2019; Somarriba *et al*., 2021). Pruning promotes a more balanced tree structure, leading to increased yields and better fruit quality, makes it easier to access and harvest cocoa pods (FAO, 2017), and induce compensatory growth. Pruning changes the tree architecture to a more open cup shape structure for improving light interception and distribution within tree crown and reduce self-shading (Thomas and Balasimha, 1992; Persello *et al*., 2019). Although, rehabilitation and renovation (Rh/Re) are essential practices in cocoa production cycle, there are methods and protocols to assess the Rh/Re needs of a cocoa orchard, and to make decisions regarding whether to rehabilitate, renovate or not at all, as well as the extent and period to apply the practice (ICI, 2019; Adoma *et al*., 2022).

Rehabilitation and renovation (Rh/Re) practices in cocoa agro forestry systems are central to the transition towards profitable, climate-smart cocoa production. However, smallholder cocoa farmers are often reluctant to adopt technical recommendations for Rh/Re, mainly due to the financial burden involved and the perceived risks of adopting new climate-smart practices. Pruning, for instance, may require the removal of up to 26% of aboveground cocoa tree biomass (ICI, 2019), thereby reducing the negative effects of neighboring trees. These practices enhance leaf flushing and photosynthesis, which support carbohydrate production (Valle *et al*., 1990; Persello *et al*., 2019; Djuiden *et al*., 2021). Furthermore, pruning stimulates the development of more fruiting branches, promotes a strong upright tree with a well-defined canopy, reduces foliage density, improves air circulation, and lowers the risks of pests and diseases (Asare *et al*., 2015; Djuideu *et al*., 2021).

Soil fertility in smallholder cocoa fields is generally poor (Ali *et al*., 2018), and nutrient limitations largely explain low productivity (Coates *et al*., 2013). Fertilizer use can

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complement the beneficial effects of Rh/Re by mitigating soil fertility constraints. However, inadequate knowledge about fertilizer use, coupled with poor field management and the age of cocoa stands, limits its adoption. With appropriate agronomic practices, these moribund cocoa fields can be restored to productivity. Against this background, the present study was designed to assess the effects of fertilizer application and pruning on the performance of cocoa trees in a degraded field. Specifically, the study evaluated the sole and combined effects of different pruning intensities and organic and inorganic fertilizers on soil physical and chemical properties, flowering, and pod and bean yields.

Materials and Methods

The study was carried out in a moribund cocoa field at the Teaching and Research Farm, Federal University of Technology (FUTA) Akure, Ondo state (Rainforest zone of south-western Nigeria) which is located on altitude of 332 m above sea level, 7°16'N, 5°12'E. The experiment was laid out in a Randomized Complete Block Design (RCBD) in three replications. The variables are: fertilizers (unamended, NPK and poultry manure) and pruning intensities (no pruning, moderate and heavy pruning). Fertilizer NPK (15:15:15) was applied at: 0, 300 and 600 g per tree (NPK i and NPK ii respectively), and Poultry manure was applied at: 0, 4 and 8 t/ha (PM i and PM ii respectively).

Pruning treatments

The cocoa field has not undergone any known pruning intervention for an extended period. Rows consisting of twenty (20) trees were selected; fifteen (15) trees were randomly selected for pruning (five trees for heavy, moderate and no-pruning respectively) from each row. For each pruning treatment, three central trees were included in the measurements and analyzed to minimize possible border effects. Pruning treatment followed a set of guidelines aimed at working towards an open cup shape of the crowns. After removal of dead, diseased and damaged branches, criss-cross branches were removed, competition with neighboring trees were reduced by cutting back branches to the middle line between two consecutive trees and open centre canopy is maintained. This exercise enhanced light distribution within cocoa trees and the entire field. There are size differences among cocoa tree, thus, the absolute amount of pruned material varied among trees. The fresh weight of leaf and twig/branch materials removed was measured in the field itself. Pruning intensities were based on the removal of dead, diseased, and overgrown branches from the cocoa trees. On an average, the moderate and heavy pruning treatments removed 15 and 25% of above ground biomass following the methods of Kotowska *et al.,* (2015). Pruning was done during the dormant season to stimulate new growth and therefore to enhance the rejuvenation of the old cocoa trees and for pest and disease control. Data on vegetative and reproductive response to pruning were collected from November 2023 to June 2024. Flushing activities as well as counts of flowers, developing pods and wilted pods were recorded. Both open flowers and fully formed flower buds were counted. Ripened cocoa pods were harvested at three weeks interval both from stem and canopy.

Soil amendment using NPK fertilizer and poultry manure:

Two types of fertilizers were used in the study, organic and inorganic. Poultry manure was applied at 600 kg per hectare while NPK compound fertilizer was applied at 400 kg/ha, both fertilizers were applied evenly around the base of each tree. Soil samples were collected from study site at the beginning and end of the experiment. The soil samples were subjected to analysis of physical, chemical, and biological properties, e.g. Soil pH, Organic carbon, N, P, K, Mg, Ca, Na and cation exchange capacity (CEC). Cocoa tree growth (number of stems, branches, and flowers) and yield (pod weight, number of

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beans, bean weight) variables were measured. The time course of number of flowers and cherelles and healthy pods were observed and recorded. Data collected were subjected to analysis of variance (ANOVA) and significant treatment means were separated using the Least Significant Difference (LSD) test at 5% level of probability.

Results and Discussion

Soil chemical properties at commencement and termination of experiment

The cocoa soil had a mean pH of 4.7, indicating acidity, with potential consequences for soil fertility (Table 1a). Nitrogen (N), an essential nutrient for plant growth, was very low at 0.2%. Potassium (K), which is critical for cocoa growth—particularly for fruit development and disease resistance—was also relatively low at 71.5 mg/kg. Phosphorus (P), essential for root development, fruiting, and overall plant growth, was low at 13.4 mg/kg. Sodium (Na) was at a moderate level of 27.4 mg/kg, while Calcium (Ca), important for cell wall development, root growth, and nutrient uptake, was relatively low at 30.8 mg/kg.

Soil biological properties revealed low to moderate levels of beneficial bacteria, suggesting reduced soil fertility and poor soil structure. Fungal populations were also low, with implications for organic matter decomposition and nutrient cycling. Thus, at the commencement of the experiment, the cocoa soil was slightly acidic and deficient in critical nutrient elements, including organic matter.

However, by the end of the study, following amendments with NPK fertilizer and poultry manure, soil fertility improved. The pH increased slightly (Table 1b), and fertility status was enhanced, as indicated by higher values of organic carbon, N, P, K, and Ca.

Time course of flower and pod production (February to April 2024)

February, 2024: Poultry manure amendment of heavily pruned trees promoted flower and pod production (Figure 1a). This demonstrates the ability of poultry manure to release nutrients gradually, thereby improving soil fertility and enhancing cocoa tree vigor. In addition, pruning reduced shading and increased sunlight penetration within the canopy, further supporting flower and pod development.

Table 1a. Soil chemical properties before the commencement of experiment

pH	N (g/g)	P (mg/kg)	K (cmol/kg)	Ca (cmol/kg)	Na (cmol/kg)	Organic carbon (g/g)
4.81	0.52	13.53	0.4	8.23	0.54	3.19

Table 1b. Soil chemical properties at termination of experiment

	pH (water)	OC (g/g)	OM (g/g)	N (g/g)	P (mg/kg)	K (cmol/kg soil)	Na (cmol/kg soil)	Ca (cmol/kg soil)	Mg (cmol/kg soil)
NPK	5.09	3.133	5.006	0.657	14.92	0.483	0.726667	6.163	3.07
Poultry manure	5.45	3.856	6.766	0.546	13.09	0.443	0.636667	8.454	4.93
Unamended	5.16	3.431	5.674	0.513	10.46	0.551	0.703333	8.366	4.33
Mean of treatments	5.23	3.473	5.814	0.525	20.67	0.488	0.692222	7.605	4.07

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Table 1c: Soil biological population at commencement of experiment

Locations within field	Bacteria (colony forming unit: cfu)	Yeast (spore forming unit: sfu)	Fungi (spore forming unit: sfu)	Nematodes Count (100g sample)
A	8.00 X 10^7	5.20 X 10^7	5.2 X 10^2	185
	7.40 X 10^7	9.60 X 10^7	4.2 X 10^2	188
B	12.00 X 10^7	12.20 X 10^7	6.5 X 10^2	112
	14.00 X 10^7	11.20 X 10^7	6.2 X 10^2	114
C	12.40 X 10^7	5.60 X 10^7	1.0 X 10^2	520
	13.00 X 10^7	9.00 X 10^7	1.5 X 10^2	528

cfu = Colony Forming Unit; sfu = Spore Forming Unit; serial dilution factor (x 10^7 & 10^2)

Table 2a: Effect of pruning and soil amendment on yield variables of cocoa (May 2024)

Treatments		No of pods harvested	Weight of pods harvested (kg)	Mean pod weight (kg)	Total number of beans harvested	Mean number of beans/pod	Mean bean weight/pod (kg)	Total weight of beans (kg)
Unpruned	Unamended	142	8.11	412.53	915	41	109.47	0.273
	Poultry manure-i	148	9.31	435.32	963	37	117.53	0.327
	Poultry manure-ii	153	11.04	478.41	988	44	125.53	0.416
	NPK i	164	11.15	484.28	889	38	136.46	0.462
	NPK ii	188	11.63	493.41	932	40	197.34	0.542
	LSD (0.05)	17.34	1.02	15.43	27.24	6.23	7.23	0.075
Pruned (Mild)	Unamended	128	6.53	432.07	631	33	105.46	0.157
	Poultry manure-i	149	7.21	456.46	748	35	84.69	0.223
	Poultry manure-ii	175	7.74	478.34	823	38	97.19	0.312
	NPK i	142	7.63	483.74	897	33	103.87	0.322
	NPK ii	171	8.07	504.17	941	36	121.33	0.344
	LSD (0.05)	11.11	1.13	14.71	37.06	0.61	8.53	0.083
Pruned (Heavy)	Unamended	157	7.32	487.42	682	39	122.14	0.214
	Poultry manure-i	163	8.15	592.63	758	34	129.49	0.281
	Poultry manure-ii	185	9.11	501.63	816	38	138.49	0.325
	NPK i	193	9.42	524.72	857	26	145.15	0.374
	NPK ii	209	10.03	549.72	916	31	155.95	0.415
	LSD (0.05)	20.42	0.53	21.58	28.36	7.41	6.23	0.032

Legend: NPK (15:15:15) was applied at: 0, and 300 g/tree NPKi and 600 g/tree (NPK ii respectively and poultry manure was applied at: 0, and 4 t/ha (PMi) and 8 t/ha (Pmii).

Effect of application of NPK to soil under heavy and moderate pruning treatments

Although NPK fertilizer provided quick burst of nutrients, it short lived and did not sustain cocoa growth and flower production over time. In the month of March 2024, compared to non-amended soils, poultry manure and NPK amended had better flower and pod production for both heavy and moderate pruning levels and moderate pruning combined with NPK fertilizer produced higher flowers and pods.

During April 2024, more cherelles and pods were recorded in both heavy and moderate pruning when combined with soil amendments. For pruned cocoa trees, there was an improvement in the weight of the pod harvested,

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which might have been due to improved light penetration and aeration (Neither *et al*., 2018). The combination of pruning and amendments promoted plant growth (increases in flowering), further resulted in good pod filling and bean development.

On cocoa trees, flower, cherelle and pod production varied depending on the period of observation (November 2023 to April, 2024). Even though no consistent patterns were found among the treatments, the effects of the amendments (poultry manure, NPK fertilizer) and pruning were noticeable on the number of flowers and pods produced. The temporal dynamics of flower and pod production differed under pruning intensities and amendments using poultry manure, NPK fertilizer and no amendment. Following the commencement of rainfall (March-April), flowering commenced while the production of cherelles and pods increased. Wibaux *et al*., (2024) and Thomas *et al*., (2024) have observed this trend in their studies. Other reports have established that flowering and fruiting in cocoa is seasonal and driven by the soil and weather conditions (Wibaux *et al*., 2024). Earlier reports by Alvim (1984) and Adjaloo *et al*., (2012) had established that weather and soil conditions are main exogenous factors driving seasonal flowering and fruiting in cocoa trees. The observed trends in flower, cherelles and pod production can be attributed to exogenous factors (weather and soil conditions) including agronomic practice would have structured flowering and pod production patterns of cocoa.

In cocoa, rainfall and soil moisture, have been attributed as the most critical factors controlling the timing and intensity of flowering. Strong correlations between flowering phenology and annual distributions of rainfall, temperature and radiation have been reported in various climates and cocoa cultivars (Alvim, 1984, Adjaloo *et al*., 2012). The study area is characterized by wet-dry seasonal transitions.

Table 2b. Effect of pruning and soil amendment on yield variables of cocoa (June 2024)

Treatments		No of pods harvested	Weight of pods harvested (kg)	Mean pod weight (kg)	Total number of beans harvested	Mean number of beans/pod	Mean bean weight/pod (kg)	Total weight of beans (kg)
Unpruned	Unamended	157	9.14	546.25	733	49	136.14	0.336
	Poultry manure-i	161	9.53	507.54	718	52	141.63	0.411
	Poultry manure-ii	166	10.21	532.42	682	54	147.63	0.426
	NPK i	173	11.27	543.34	748	45	132.14	0.451
	NPK ii	186	11.62	578.34	815	52	142.32	0.518
	LSD (0.05)	17.72	0.77	23.23	31.28	4.13	21.04	0.04
Pruned (Mild)	Unamended	135	7.26	415.20	682	41	123.37	0.246
	Poultry manure-i	141	7.64	376.71	737	44	113.16	0.273
	Poultry manure-ii	148	8.41	395.32	781	47	118.16	0.305
	NPK i	153	8.83	407.62	828	38	123.28	0.338
	NPK ii	171	9.15	426.62	864	44	136.28	0.381
	LSD (0.05)	12.31	0.05	31.41	32.63	3.24	24.15	0.03
Pruned (Heavy)	Unamended	164	0.864	514.51	824	51	132.71	0.311
	Poultry manure-i	171	0.927	489.25	893	46	138.38	0.342
	Poultry manure-ii	182	1.073	508.43	917	48	140.38	0.372
	NPK i	191	1.114	523.42	853	41	121.41	0.386
	NPK ii	196	1.218	544.31	887	46	133.61	0.463
	LSD (0.05)	18.4	0.06	35.12	44.23	4.14	22.36	0.042

Legend: NPK (15:15:15) was applied at: 0, and 300 g/tree NPKi and 600 g/tree (NPK ii respectively and poultry manure was applied at: 0, and 4 t/ha (PMi) and 8 t/ha (Pmii).

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Table 3. Interactions of amendment and pruning on yield and yield components of cocoa

Variables	No. of pods harvested	Weight of harvested pods (kg)	Mean pod weight (kg)	Number of beans harvested/tree	Number of beans/pod	Weight of beans/pod (kg)	Total weight of beans per tree (kg)
Pruning							
No pruning	44.33	1.215	493.04	1003.3	41.67	130.48	0.321
Mild pruning	45.35	1.006	416.42	883.5	36.04	119.34	0.284
Heavy pruning	49.67	1.352	461.26	939.2	33.33	111.54	0.342
Amendment							
Control	28.33	2.376	307.3	201.43	90.7	290.54	0.644
Poultry manure	33.41	2.776	310.5	226.43	88.4	300.21	0.756
NPK fertilizer	36.67	2.733	305.0	211.92	80.2	263.02	0.696
Pruning (Pr)	*	*	*	*	*	*	*
Amendment (Am)	*	ns	ns	*	*	*	*
Rate	ns	*	*	ns	ns	*	*
Pr x Am	*	*	ns	ns	ns	*	*

During the dry season with terminal drought conditions, flowering is inhibited. At the commencement of the rains at the end of the dry season, the humid atmosphere triggers intense flowering episodes in tree crops (Agele *et al*., 2024). Thus, rainfall distribution determines flowering pattern in cocoa (Bridgemohan *et al*., 2017; Restrepo *et al*., 2017). Abiotic factors (such as temperature, photoperiod, or water stress) influence the reproductive phenology of perennial fruit species in addition to the endogenous factors such as carbon status, carbon to nitrogen ratio and hormonal balance (Govindaraj and Jansirani, 2017; Capelli *et al*., 2021). Competition between vegetative and reproductive compartments plays a key role in alternate bearing (flowering and fruit production) in trees. In particular, the annual cycles of reproductive events in cocoa are often characterized by irregular bearing, with alternating periods of heavy and low flowering and pod production. Thus, the dependence of flowering and pod production climatic factors (Intra-seasonal dynamics of rainfall or soil water content, temperature, humidity and radiations) and variations in flowering and pod production in cocoa is widely reported (Opeke, 2006; Almeida and Valle, 2007; Djuideu, *et al*., 2021). The cocoa plant, is a tropical cauliflorous fruit tree, the plant produces flowers and pods twice a year and exhibits alternate harvesting patterns over consecutive six-months in regions with bi-modal rainfall distribution (Claus *et al*., 2018; Coulibaly *et al*., 2019).

Pruning and amendment effects on cocoa pod and bean yields (May, 2024):

Table 2a. presents data collected on cocoa pod and bean yield characters during May, 2024. The pod and bean yield characters of cocoa were affected by pruning intensities and soil amendments. Pod and bean weights were high for heavy pruning that were treated with poultry manure amendment compared with NPK. The moderately pruned cocoa trees had heavier pods for NPK followed by poultry manure which was significant over the weight of pods for the non-amended trees. The number of pods per tree was significantly higher for NPK and poultry manure compared with unamended control while the average weight of pods was high for poultry manure followed by the non-amended. The total number of beans per pod was significantly higher for poultry manure over NPK (Table 2a). The average weight of beans was heavier for poultry manure and total weight of beans harvested significantly heavier for poultry manure over NPK. Under moderate pruning treatment, weight of pods was heavier for NPK followed by the unamended treatment and lowest for poultry manure. The number of beans was close between NPK and poultry manure treatments while cocoa bean weights were heaviest for NPK compared with poultry manure and no amendment. Highest number of pods per tree was obtained for amended plots and lowest for the non-amended. The average weight of pods was heavier for poultry manure and total weight of pods harvested for NPK. The average weight of bean/pod was not significantly different among amendments, but the total weight of beans harvested was significantly higher for NPK and poultry manure. The average weight of beans was high for unamended over NPK and lowest value for poultry manure. The total weight of beans harvested was significantly high for NPK closely followed by poultry manure and significantly lower for non-amended. For the no pruning treatment, the total number of pods harvested was significantly higher for NPK and lowest for non-amended plots. The weights of pods were significantly high for poultry manure compared with NPK and no amendment. The total number of seeds per pod was significantly higher for poultry manure and close for NPK and no amendment, while the mean weight of seeds were heavier for poultry manure. The total weight of beans harvested per tree was heavier for poultry manure compared with NPK while lowest value was recorded for unamended treatment. The effects of pruning and amendment on cocoa pod and bean yields for June 2024 are presented in Table 2b. Analyzing observations made in the month of June 2024 revealed that trends in cocoa pod and bean yield characters were similar to that of May, 2024. Nevertheless, the values of the variables were mostly higher compared with observations made in May, 2024.

Generally, fertilizer amendment promoted flowering and pod production in cocoa. The number of pods produced per tree was higher for NPK and closely followed by poultry manure treatment and lowest for the non-amended (Table 2a and b). The average weight of pods was not significantly different among amendments while the weight of harvested pods per tree was close for NPK and poultry manure but significantly different from the unamended. The total number of beans per tree was highest for poultry manure compared with NPK; the non-amended produced the lowest. The average weight of beans per pod was higher for unamended and lowest for NPK fertilizer treatment. The total weights of beans harvested per tree was heavier for poultry manure and though not significant over the values for NPK while it is significantly lower for non-amended treatment. Flowering, pod and bean yields of cocoa differed among pruning intensities. Heavy pruning produced significantly higher number of pods per tree compared with moderate and no pruning treatments for which values were not significantly different. The average weight of pods was high for unpruned compared with heavy and moderate pruning intensities. The heavy pruning treatment produced significantly heavier pods followed by unpruned treatment and lowest for moderate pruning. The average weight of beans was higher for unpruned followed by moderate and lowest for heavy pruning while the total weight of beans was higher for unpruned, followed by heavy pruning and lowest for moderate pruning treatment. The total bean yield/tree was heavier for heavy pruning compared with unpruned and lowest for moderate pruning treatment. The effects of the fertilizers (NPK and poultry manure) differed on pod and bean yields of cocoa (Table 3). Cocoa trees from poultry manure treated plots produced heaviest pods followed by NPK and values were lowest for the non-amended trees. The weight of beans per pod was heaviest for the non-amended treatment followed by poultry manure and lowest for NPK, The total weight of beans

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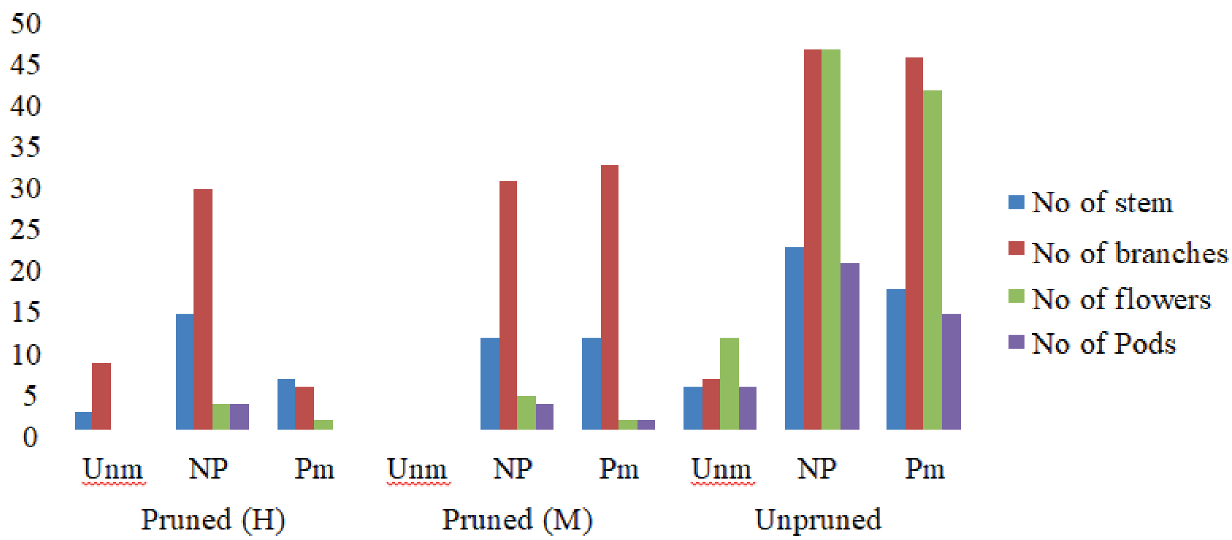

Fig. 1. **Growth variables of cocoa tree at 4 weeks after treatment**

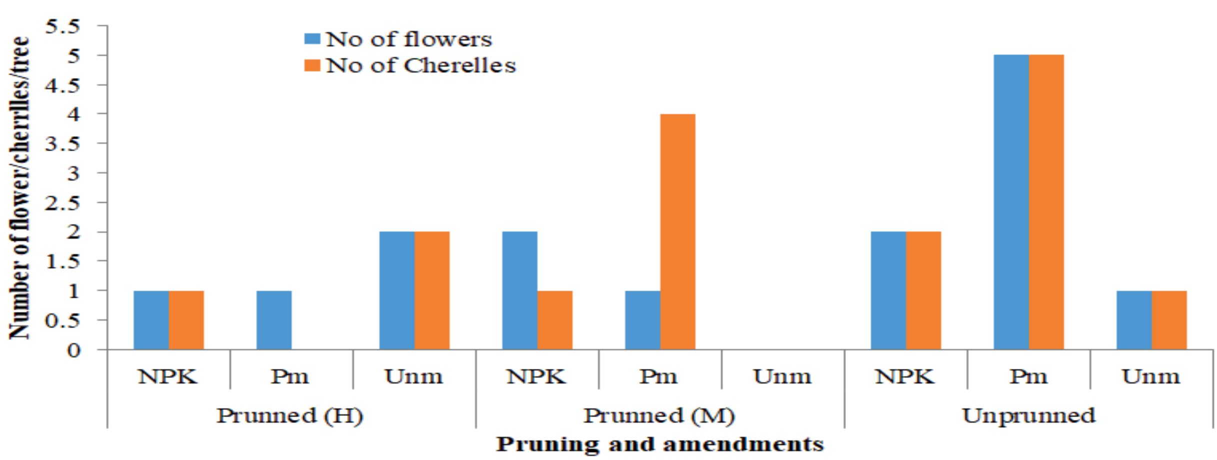

Fig 2. Effects of amendment and pruning on flower and cherelles production (December, 2023)

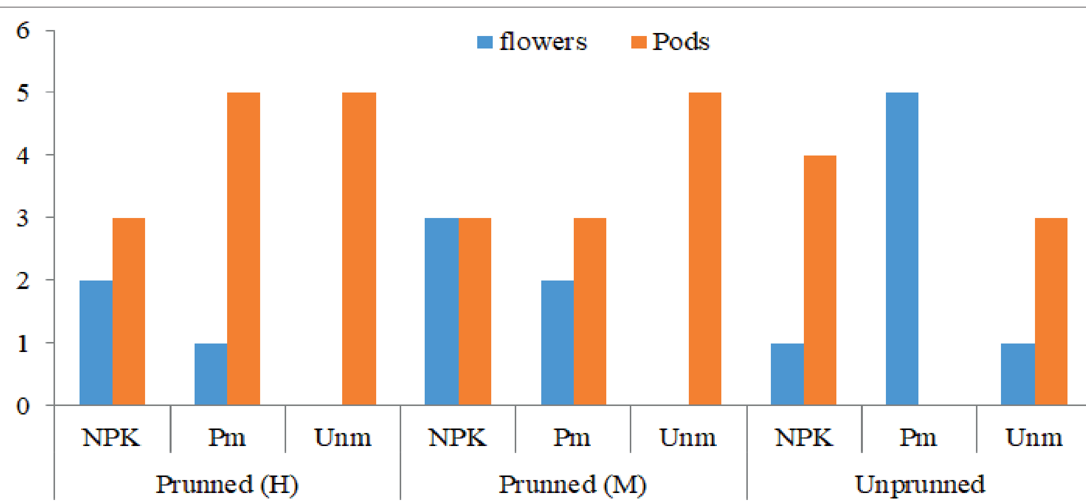

Fig. 3. Flower and cherelles production (February 2024)

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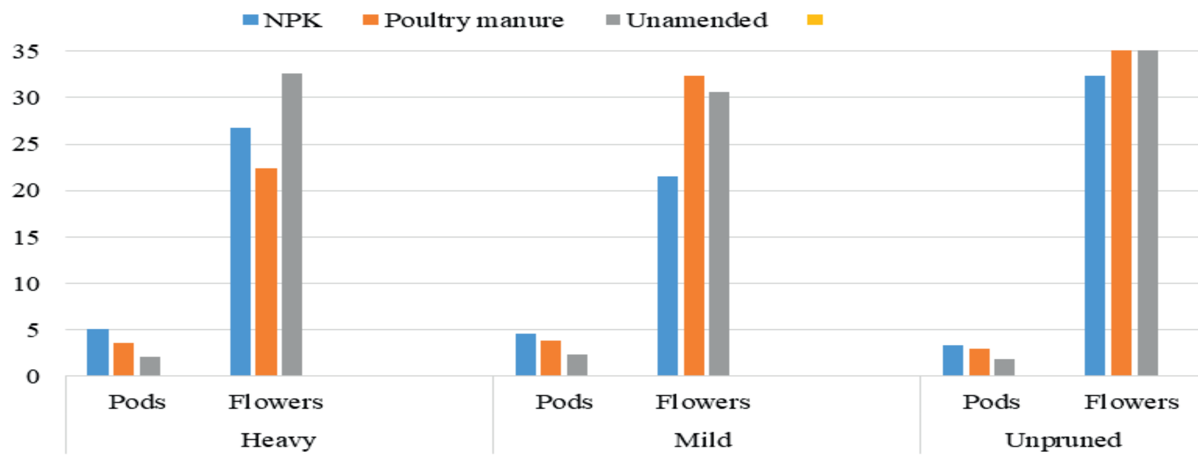

Fig. 4. Effects of pruning and amendment on the number of flowers and pods of cocoa (March l, 2024)

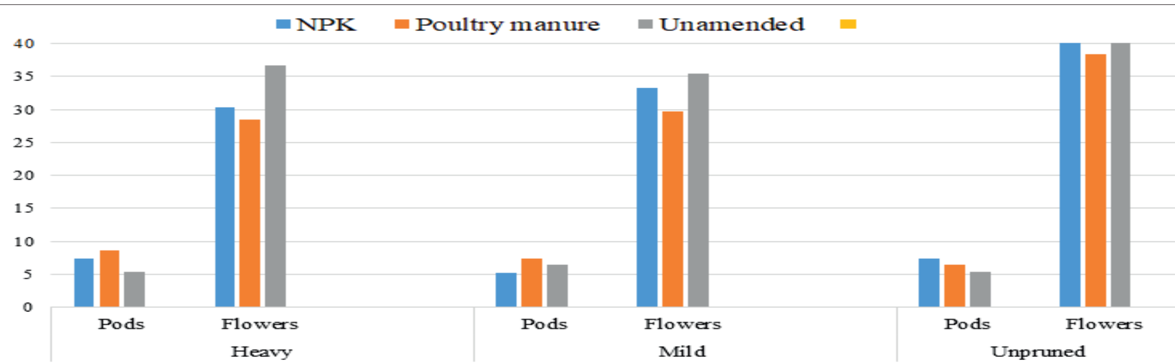

Fig. 5. Effects of pruning and amendment on the number of flowers and pods of cocoa (April 2024)

harvested per tree was heaviest for poultry manure and lowest for the no-amendment treatment (Table 3). The effects of pruning on pod and bean yields of cocoa are presented in Table 3. Larger number of pods was obtained under heavy pruning set up followed by no pruning treatment while the weight of pods were high under no pruning followed by heavy pruning treatment, total weight of beans were high under heavy pruning followed by moderate and lowest under the unpruned cocoa trees. The mean weight of beans per pod was heavier for moderate followed by heavy pruning treatment and lowest for no pruning. The total weight of beans per tree was heaviest for heavy pruning followed by no pruning and lowest for moderate pruning. The effects of pruning and amendment was significant for almost all cocoa yield variables measured, treatment effect was significant for number and weight of beans per pod and total weight of beans harvested. The interactions of pruning and amendment were significant for most variables except mean pod weight, the number and weight of beans harvested per tree (Table 3).

Application of NPK and poultry fertilizer (inorganic and organic) amendment of soil produce changes in soil properties (physical) fertility, and microbial activity (IPNI, 2020). The organic fertilizer (poultry manure) increase microbial diversity, fertility status of soil of the moribund field. Proper nutrient management is essential for maintaining soil fertility in cocoa orchards (Maguire-Naipaul *et al*., 2020). Soil fertility management in agricultural landscape is a challenge especially for tropical fruit trees in plantation (Asare *et al*., 2018; IPNI, 2020).

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Poor soil fertility, particularly inadequate levels of critical nutrients such as organic matter, N, P, K, Ca, and Mg, has been reported as an important constraint to cocoa productivity (Dossa *et al*., 2018; CRIN, 2022). These reports also confirmed the high capability of cocoa trees to rapidly deplete soil nutrient, a menace to productivity. Depleted nutrients need to be replenished via fertilizer application to supplement that due to litter decomposition. Regularly monitoring of the status of soil fertility including microbial activity is recommended to inform management decisions (ICCO, 2020). Application of NPK fertilizer and poultry manure enhanced cocoa performance however, the treatment promoted production of flowers and cherelles compared with the unamended. This observation may be attributed to enhanced nutrient availability. The pruning treatments also responded to amendment in terms of flowering, pod and bean production which is attributable to pruning-enhanced reduction in shading and promotion of light interception (incidence and transmission within cocoa canopy) and improve aeration (Shaffer and Gaye, 1989; Porpiglia and Barden, 2018). Poultry manure slowly released nutrients, promoting healthy plant growth and flower production and heavy pruning reduced shading, allowing more sunlight to reach the plant, and increased nutrient availability, promoting flower and cherelle production sustained growth and flower production over time. NPK fertilizer applied to heavy and moderate pruned trees provided quick burst of nutrients which appeared to have rapidly sustained flower and pod production. The combination of pruning and amendment resulted in enhanced lowering and improved pod filling and bean development. Following pruning, it is the formation of new laterals and leaves which have consequences on flowering and pod production. The performance improvement of amendment of pruned cocoa trees may be due to improved light penetration and aeration and improved aeration (wind effects) leading to healthier plants (Tang *et al*., 2015; Riedel *et al*., 2019). Pruning of cocoa trees is necessary for maintenance of optimum leaf area index with positive consequences on vegetative growth which may explain the differences in growth and yield between pruned and unpruned trees. The poorer performance of unpruned cocoa trees may be due to exhaustion of source (dry matter) by the large number of old less photosynthetically active leaves at the expense of other active leaves on the trees may explain the low yield for unpruned trees. Pruning promoted healthy plant architecture, while soil amendment improved soil fertility and tree vigour. In cocoa agro ecosystems, nutrient cycling and associated carbon and macro-nutrient inputs from leaf litter fall (nutrient release from litter fall) following its decomposition is widely reported (Becker *et al*., 2015; Pérez-Flores *et al*., 2018; Saj *et al*., 2021). Nutrient cycling plays important role to soil fertility maintenance for enhanced cocoa productivity, nutrient cycling from litter fall helps to sustain the fertility, physical and biological properties of cocoa soils (Fontes *et al*., 2014 Schneidewind *et al*.,2019). This is especially relevant for West Africa where soils are heavily leached of nutrients and low nutrient reserves, the exports of nutrient from cocoa harvest is rarely replaced by application of mineral fertilizers. In the West African cocoa agroforests, estimated litter fall amount to 10 t ha^{-1} yr^{-1} (Dawoe *et al*., 2010; Saj *et al*., 2021). However, the distribution over time within the year depends on climatic condition (Sari *et al*., 2022). Litter fall is generally reported to be higher in the dry than in wet season (Becker *et al*., 2015; Saj *et al*., 2021). The nutrient concentrations in litter also varied within the year, for example, Pérez-Flores *et al*., (2018) reported that magnesium concentration was higher during the rainy season, while P and Ca concentrations were higher in dry season in the litter.

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Conclusions

Pruning intensities (heavy and moderate) and fertilizers (NPK inorganic and poultry manure) promoted cocoa tree performance (enhanced flowering and subsequent pod and bean production). The heavy and moderate pruned cocoa trees produced higher number of flowers and pods, and heavy bean yields compared with the unpruned. Pruning promoted healthy plant architecture and productivity possibly due to enhanced light transmission, aeration within the canopy and health of cocoa trees. The enhanced vigour following pruning treatments may be related to the reduction of shade density and competition for assimilate by cocoa tree parts (root, branches, leaves).

Application of fertilizers improved chemical and biological properties further enhanced cocoa tree productivity. Poultry manure promoted production of flowering and cherelles especially for the moderately pruned trees while NPK amendment enhanced them under both moderate and heavy pruning. There was positive and significant impact of pruning and soil amendment on the performance (flowering, pod and bean yield variables) of the old (aged between 25 and 40 years) of poorly managed cocoa trees. The fertilizers enhanced soil nutrient status, tree health, flowering, pod and bean production possibly through the synergistic effects of pruning-induced light penetration. Thus, pruning and fertilizer application are crucial for enhancing growth and yield of old abandoned cocoa trees.

The rehabilitation of old and moribund (poorly managed) cocoa farms based on pruning regimes (heavy and moderate intensities) and soil amendments (NPK fertilizer and poultry manure) brought improvement in cocoa tree performance (flowering, pod production and bean yields). Thus, the combined use of pruning and fertilizers is recommended for enhancing productivity of cocoa especially from moribund, old and poorly managed fields.

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