Determining the Maximum Rate of Potassium Fertilizer on Oil Palm (*Elaeis guineensis Jacq*.) in Production in Southeastern Côte d'Ivoire

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Authors' contributions

This work was carried out in collaboration among all authors. Author KK designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors KKFJM and KB managed the analyses of the study. Author KB managed the literature searches and the correction of the latest version. All authors read and approved the final manuscript.

Original Research Article

ABSTRACT

In the southeastern of Côte d'Ivoire, ferralsols are characterized by poverty in exchangeable bases, especially potassium, which appears to be the predominant mineral element for oil palm cultivation. In this study, we used improved palm cultivars treated with different rates of potassium fertilizer to determin the effect on oil palms. The experiments were conducted on the CNRA station in La Mé and PALMCI in Ehania (Côte d'Ivoire), following a system block system design comprising of five treatments and four repetitions. Treatments included 5 rates of potassium fertilizer (T1, T2, T3, T4, T5) corresponding to 1; 1.5; 2; 2.5; 3 kg of KCl/tree/year. This study indicates that the different rates of KCl applied, had influence on   all of the experimental parameters, namely: yields (TR) and its components (NR; PR and PMR). Yields on the Ehania plantation were significantly higher than those on La Mé. Yield ranged from 18.8 Tons/ha/year (T1) to 22.1 Tons/ha/year (T3) in La Mé, and

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from 21.2 to 25.6 tons/ha/year in Ehania. The theoretical maximum rates were 2.4 kg of KCl/tree/year in La Mé, compared to 1.9 kg/tree/year on the Ehania plantation. Therefore, these rates will be used in the future extension of potassium fertilizer, in the cultivation of oil palm, in the southeastern of Côte d'Ivoire.

1. INTRODUCTION

Agriculture is an important economic sector and remains the leading area of activity in many African countries, notably in Côte d'Ivoire. Today, estimated at 831 million, Africa's population is expected to reach 3.8 billion by 2100. These demographic changes are imposed on profound environmental changes due to climate change, in a region where extensive agriculture is dominant and will negatively impact agricultural production [1,2,3]. In this context of food insecurity risks, it is essential to improve the means of monitoring agricultural production to address challenges of developments and reduce populations' vulnerability. Each year, a significant increase in global food production is necessary to offset an increasingly severe climate context [4]. This increase in production can be achieved either by improving yields or by increasing the area Designated for agricultural production. However, in the current context of deforestation and urbanization, few regions of the world can significantly increase the area devoted to agriculture [5]. The need to improve crop yields and productivity on existing agricultural land becomes a key and obvious objective. Only the improvement of farming techniques, including fertilization and the selection of more productive varieties, open up prospects in this direction.

Precise use of fertilizers is one of the most efficient ways to increase agricultural production in sub-Saharan Africa. Sustainability seems to be based mainly on fertilization and analytical soil fertility management techniques. In Côte d'Ivoire, the oil palm orchards cover an area larger than 350,000 hectares. The domestic annual production is 1,800,000 tons of regimes that produce 400,000 tons of crude palm oil, 55% of which is exported. Palm and palm oils bring more than 500 billion CFA francs a year and generate 10% of national revenues [6]. Côte d'Ivoire aims to double its production, starting in 2020, either by improving the yields of existing plantations or increasing the area of land devolved to this speculation.

Oil palm cultivation has been developed in the southern Ivorian forest, on soils with total natural fertility, and under appropriate rainfall conditions. Despite this relative natural fertility of forest clearing soils, the studies of De [7,8] and [9] have shown that soils in southern Côte d'Ivoire, dominated by ferralsols, developed on tertiary sediments, have specific physical-chemical characteristics. These soils are acidic and have low cation exchange capacity. These soild are particularly low in potassium. This is due to the kaolinite's low retention power, the clay fraction's main constituent. As a result, potassium deficiency is the one mainly observed on these soil types in the first generation. Thus, in soils in tropical climates, lack of potassium is the major factor limiting yields in bunches. Numerous studies show significant productivity gains, even with moderate potassium fertilizer applications in oil palm-based farming systems in Côte d'Ivoire [9-13].

Therefore, a high oil yield goal cannot be achieved without an adequate supply of potassium through use of potassium fertilizers. The optimal use of potassium fertilizers would be one of the most efficient ways to increase oil palm production in Côte d'Ivoire. However, fertilizer formulations used in Ivorian palm groves have evolved very little overtime to better adapt to new agro-pedo-climatic conditions. Mineral fertilizer applications are helping ti satisfy needs of new plant material being used. In Côte d'Ivoire, the 1 kg rate of KCl/tree/year, previously recommended by extension services, has become relatively lower because it no longer considers the current level of soil degradation and the higher nutritional needs of new plant material. Generally, this new plant material uses high doses of potassium fertilizer, so this component can account for more than 60% and 30%, respectively, maintenance and production costs for the crop [14]. Any misjudgment can significantly affect the profitability of the transaction. Therefore, it is necessary to develop an adequate rate of potassium fertilizer for better productivity of the oil palm to maintain the competitiveness of the said crop. With this in mind, this study was carried out with the general objective to study the behavior of the oil palm exposed to different rates of potassium fertilizer.

Thus the hypotheses made concern (i) the determination of the effects of potassium fertilizer on the production of oil palm and (ii) to target the optimal dose in the context of south-eastern Côte d'Ivoire.

2. MATERIALS AND METHODS

2.1 Study Areas

The studies were conducted in the field in two different locations in southeastern of Côte d'Ivoire. These are the towns of Ehania and La Mé.

The experiments were carried out on two plots in both localities. The tests were set up on a single type of operation. These are the industrial plantations of Ehania and La Mé, belonging, respectively, to an Ivorian oil palm agro-industry and a research center. The la Mé plantation belongs to the National Center for Agricultural Research (CNRA) and Ehania to PAMCI.

The town of Ehania is located in southeastern Côte d'Ivoire, about 40 km from Aboisso. Its geographical coordinates are 05-28' north latitude and 03-12' west longitude. La Mé is located in the southeast, 24 km from Abidjan and 30 km back from Guinea. Its geographical coordinates are 05-26' north latitude and 03-50' west longitude.

The South-East climate is of a humid subtropical type, with marked seasons and the Attiéen type with coastal facies. Soils, derived from the tertiary sands, are ferralsols and heavily desaturated, deep, sandy on the surface, and without coarse elements. The clay of the kaolinite type has a low cation exchange capacity. These pedoclimatic conditions are adapted to the cultivation of oil palm.

2.2 Plant Material

The plant material consists of hybrids (*Tenera*) of oil palm, obtained by a cross between *Dura* (female) and *Pisifera* (male). The *Dura* type is characterized by fruits with a thin pulp and a thick shell, while the *Pisifera* type is characterized by a high abortion rate of the fruit and a fragile shell. This *Tenera* hybrid of the C1001F category, characterized by high yield and resistance to Fusariose, results from the second cycle of reciprocal recurrent selection (SRR).

2.3 Mineral Fertilizer

The fertilization of oil palms was provided by the simple fertilizer represented by potassium chloride (KCl), at 60% K_2O, in the form of pellets.

2.4 Methods

2.4.1 Experimental device

The statistical device adopted is in Fisher blocks randomized with five treatments and four repetitions. The treatments that have been applied are T1: 1 kg of KCl/tree/year corresponds to the popularized control, T2: 1.5 kg of KCl/tree/year, T3: 2 kg of KCl/tree/year, T4: 2.5 kg of KCl/tree/year and T5: 3 kg of KCl/tree/year. These five treatments were applied annually between 2011 and 2014. An entire parcel consists of 20 (4 x 5) elemental micro-plots, each comprising 49 trees spread over seven lines of 7 trees. Of the 49 trees, 25 trees are useful, on which measurements have been carried out and the remaining 24 are bordering. The entire parcel consists of 980 trees that correspond to 6.85 hectares on the theoretical basis of 143 feet per hectare. The mad-fertilizer application was done at the end of the rainy season (mid-July) in the 2 meter radius around each tree.

2.4.2 Measured parameters

Yield components were determined from individual harvests. These include bunches number per tree (NR/tree) and the weight of bunches per tree (PR/tree), from which the average weight of bunches per tree (PMR/tree) and the tonnage of bunches or yields (TR/ha/year) were calculated. Bunches number per tree was determined by counting all bunches harvested on each good tree. The weight of bunches was obtained by weighing all bunches harvested per tree.

The average weight was calculated from the following equation:

$$PMR = PR / NR, \text{ where}$$

PMR: Average weight of bunches per tree (kg)
PR: Bunches weight per tree (kg)
NR: Bunches number per tree.

Yield or TR/ha/year was determined from the following equation:

$$TR/ha/an = NR * PMR * D, \text{ where}$$

TR/ha/year: Tonnage of bunches per hectare per year (tons),
NR: Bunches number per tree per year,
PMR: Average weight of bunches (kg) per tree,
D: Planting density that is 143 trees/ha.

2.5 Statistical Analysis

The results were statistically analyzed using GenStat Release version 10.1 software. The graphics were made using Microsoft Office Excel software, version 2007 (Microsft Software, 2007). The Newman-keuls test ranked averages using variance analysis (ANOVA) at the 1% and 5% threshold. The variable averages were separated at the probability threshold $P < 0.05$ (significant) or $P < 0.01$ (highly significant).

3. RESULTS

3.1 Effects of Potassium Fertilizer on Yield and its Components per Planting Studied

The components of the overall yield consist of number of bunches per tree per year (NR/tree/year), the weight of bunches per tree per year (PR/tree/year), the average weight of bunches per tree (PMR/tree/year). The yield of oil palm is represented by the tonnage of bunches per hectare per year (TR/ha/year). The effects of different doses of fertilizer on these variables have been studied in both localities (La Mé and Ehania) and on one type of plantation (industrial planting).

The variance analysis of the effects of different doses of KCl, locality, and their effects on performance components was studied (Table 1). The analysis results reveal that different doses of KCl, localities, and their interactions have a highly significant influence (for $p < 0.05$ to $p < 0.001$) on performance components. Therefore, the variability of the yield components was due, both to the doses of potassium fertilizer and to the study communities.

3.2 Industrial Plantation of La Mé

The results in the number of bunches (NR/ha/year), bunches weight (PR/ha/year), and average weights of bunches (PMR/ha/year) over the three campaigns were obtained (Table 2). Analysis of the variance reveals no difference between NR/ha/year averages obtained with the different doses of potassium fertilizer applied during the three campaigns. During the first campaign, NR/ha/year ranged from 2145 to 2288 bunches, depending on the different treatments. This number ranged from 2431 (T1 and T2) to 2574 (T3, T4 and T5) bunches/ha/year during the second campaign. The average harvested of bunches ranged from 2145 (T1) to 2431 bunches (T3)/ha/year in the last campaign. The NR/ha/year increasing during the first two campaigns began to decline during the third campaign.

As for PMR/ha/year, the variance analysis reveals that there is no difference ($p > 0.05$) during the first campaign (2011-2012) between the averages of the different treatments. During this campaign, the PMR ranged from 6.6 to 6.9 kg (Table 2), depending on the doses applied. However, in the second (2012-2013) and third (2013-2014) campaigns, variance analysis reveals that there are differences ($p < 0.05$) between the average values obtained with the different rates of KCl applied. The Classification according to the Newman-Keuls test, resulted in three distinct groups during these two campaigns. This is the rate of treatment 1, which produced the lowest effect on the average weight of bunches, different from those of the rates of the T2 and T3 treatments, forming the second group, being also different from the third group, formed by the rates of T4 and T5 treatments. During the second campaign, these averages ranged from 8.4 kg (T1) to 9.7 kg (T5). During the third campaign, the PMR fluctuated between 9.6 kg (T1) and 11.1 kg (T4 and T5). Comparison of PMR averages reveals that the rates of T3, T4, and T5 treatments resulted in a similar increase in weight greater than those of the T1 and T2 treatments.

Table 1. Table after analysis of two-factor variance on production characteristics

Sources of variation	df	Values of F		
		NR	PR	PMR
Treatments	4	1.90	8.58***	16.3***
Localities	1	30.6***	544.8***	3956***
Treatments*Localities	4	2.81**	11.02***	19.6***

NR: Bunches number; PR: Weight of bunches; PMR: Average weight of bunches; df: the degree of freedom
*: < 0.05; **: < 0.01; ***: < 0.001

The combined tonnage of plans or yields (TR/ha/year) for the three campaigns ranged from 18.8 Tons/ha/year (T1) to 22.1 Tons/ha/year (T3). Analysis of variance revealed that there are differences ($p < 0.05$) between averages obtained with the different doses of KCl applied (Table 3). The classification according to the Newman-Keuls test resulted in two distinct groups. The first group is formed by the first two treatments (1 and 2) whose effects differed from those of the other three treatments (3, 4, and 5). This variance analysis showed that bunches yield was significantly increased by applying different doses of potassium fertilizer. For the average NR/ha/year (Table 3) of the three campaigns, averages ranged from 2,288 bunches (T1) to 2,431 bunches (T3). Analysis of the variance reveals that there is no difference between the averages of the different doses applied. This analysis showed that the applications of different doses do not significantly influence bunches production. However, the potassium fertilizer brought in improved PMR. Analysis of variance revealed differences between the three campaigns' cumulative averages obtained with the different treatments applied. These averages ranged from 8.2 kg (T1) to 9.1 kg (T3 and T4), depending on the doses.

3.3 Ehania Industrial Plantation

Comparing the effects of different doses of potassium fertilizer on NR/ha/year, PMR/ha/year, and PR/ha/year was studied for all three campaigns (Table 4). NR/ha/year averages ranged from 2,288 bunches (T1, T2, T3, and T5) to 2,431 bunches (T4) during the first campaign,

from 2,574 bunches (T1, T2, and T5) to 2,717 bunches (T3 and T4) during the second campaign and 2,288 plans (T1) to 2,574 bunches (T5) during the third campaign. Analysis of variance revealed no difference between the averages obtained with the doses applied during these three campaigns. The application of the different doses had no influence on bunches' production during these three observation campaigns.

For the PMR (Table 4), it ranged from 7.3 kg (T2) to 7.6 kg (T4 and T5) during the 2011-2012 campaign. 9.4 kg (T1) to 11.5 kg (T5) during the 2012-2013 season and from 10.4 kg (T1) to 12.8 kg (T5). Analysis of variance revealed no difference between PMR averages obtained with the different treatments during the first campaign. However, during the second and third campaigns, differences were observed between PMR averages for different doses applied. The effects, the highest on PMR improvement, were recorded with T2, T3, T4, and T5 treatments.

For TR/ha/year (Table 5), averages ranged from 21.2 (T1) to 25.6 Tons/ha/year (T4), depending on the doses. Analysis of variance reveals that there is a difference between the averages obtained with the doses. Yields, the highest, were obtained with the T2, T3, T4, and T5 treatments whose effects constituted the second homogeneous group, while the dose of T1 treatment formed the first group according to the Newman-Keuls test. The potassium fertilizer applied improved yield during these three campaigns.

Table 2. Effects of different doses of KCl on yield and its components in La Mé industrial planting during the three campaigns

Treatments	Campaigns								
	2011 - 2012			2012 - 2013			2013 - 2014		
	NR	TR	PMR	NR	TR	PMR	NR	TR	PMR
T1	2288 a	15,1 a	6,6 a	2431 a	20,4 a	8,4 a	2145 a	20,6 a	9,6 a
T2	2145 a	14,2 a	6,6 a	2431 a	21,6 a	8,9 a	2288 a	22,4 a	9,8 a
T3	2288 a	15,3 a	6,7 a	2574 a	22,9 ab	8,9 a	2431 a	26,0 b	10,7 b
T4	2288 a	15,3 a	6,7 a	2574 a	24,4 b	9,5 b	2288 a	25,6 b	11,1 b
T5	2288 a	15,7 a	6,9 a	2574 a	24,9 b	9,7 b	2288 a	25,4 b	11,1 b
CV	8,4	14,2	10,0	11,1	13,4	9,4	15,1	9,5	9,6
P	0,176	0,314	0,751	0,353	0,033	0,025	0,272	0,045	0,002

The averages followed by the same letter in the same column are not statistically different at the threshold of 0.05 by the Newman and Keuls test
TR: Bunches tonnage (Tons/ha/year); NR: Bunches number per hectare per year based on 143 trees per hectare; PMR: Average weight of bunches (kg)
T1 : 1 ; T2 : 1,5 ; T3 : 2 ; T4 : 2,5 ; T5 : 3 (KCl doses in kg/tree/year

Table 3. Effects of different doses of KCl on the average yield of the three campaigns and its components in la Mé industrial planting

Treatments	Yield and its components		
	NR/ha/an	TR (Tons/ha/an)	PMR (kg)
T1	2288 a	18,8 a	8,2 a
T2	2289 a	19,3 a	8,4 a
T3	2431 a	22,1 b	9,1 b
T4	2383 a	21,4 b	9,1 b
T5	2382 a	21,3 b	9,0 b
CV	6,4	6,7	8,7
P	0,793	0,023	0,015

The averages followed by the same letter in the same column are not statistically different at the threshold of 0.05 by the Newman and Keuls test
TR: Bunches tonnage (Tons/ha/year); NR/ha/year: bunches number per hectare per year based on 143 trees per hectare; PMR: Average weight of bunches (kg)
T1: 1; T2: 1.5; T3: 2; T4: 2.5; T5: 3 (KCl doses in kg/tree/year

Table 4. Effects of different doses of KCl on yield and components during the three campaigns on industrial planting in Ehania

Treatments	Campaigns								
	2011 - 2012			2012 - 2013			2013 - 2014		
	NR	TR	PMR	NR	TR	PMR	NR	TR	PMR
T1	2288 a	17,1 a	7,5 a	2574 a	24,2 a	9,4a	2288 a	23,8 a	10,4 a
T2	2288 a	16,7 a	7,3 a	2574 a	27,5 b	10,7 b	2431 a	27,9 b	11,5 b
T3	2288 a	17,1 a	7,5 a	2717 a	29,6 c	10,9b	2574 a	28,2 b	11,8 bc
T4	2431 a	18,4 a	7,6 a	2717 a	29,8 c	11,0 c	2431 a	28,0 b	12,5 c
T5	2288 a	17,4 a	7,6 a	2574 a	29,6 c	11,5c	2431 a	27,4 b	12,8 c
CV	9,1	12,9	2,7	11,3	9,2	2,9	12,3	10,8	3,2
P	0,784	0,200	0,444	0,159	0,021	0,001	0,088	0,043	0,001

The averages followed by the same letter in the same column are not statistically different at the 5% meaning threshold by the Newman and Keuls test
TR: Bunches tonnage (Tons/ha/year); NR: bunches number per ha per year based on 143 trees per hectare; PMR: Average weight of bunches (kg)
T1: 1; T2: 1.5; T3: 2; T4: 2.5; T5: 3 (KCl doses in kg/tree/year)

Table 5. Effects of different doses of KCl on the average yield of the three campaigns and its components in the industrial plantation of Ehania

Treatments	Yield and its components		
	NR/ha/an	TR (tons/ha/an)	PMR (kg)
T1	2336 a	21,2 a	9,1 a
T2	2383 a	24,8 b	10,4 b
T3	2415 a	25,6 b	10,6 b
T4	2420 a	25,2 b	10,5 b
T5	2352 a	24,7 b	10,5 b
CV	7,5	8,7	2,4
P	0,131	0,015	< 0,001

The averages followed by the same letter in the same column are not statistically different at the 5% meaning threshold by the Newman and Keuls test
TR: bunches tonnage (T/ha/year); NR/ha/year: Bunches number per hectare per year based on 143 trees per hectare; PMR: Average weight of bunches (kg)
T1: 1; T2: 1.5; T3: 2; T4: 2.5; T5: 3 (KCl doses in kg/tree/year)

As for PMR, variance analysis reveals a difference between the averages obtained with the different doses (Table 5). These averages ranged from 9.1 (T1) to 10.6 kg (T3), depending on the treatments applied. From the above, it appears that the intakes of the different doses of KCl improved the PMR on the Ehania plantation.

3.4 Comparative Effects of Potassium Fertilizer on Yield at the Two Plantations Studied

Changes in yields, obtained by using new doses of potassium fertilizer compared to production recorded with the standard 1 kg dose of KCl/tree/year, were locality-specific (Fig. 1). These productivity changes correspond to yields due to increased fertilizer doses applied. This figure's analysis resulted in positive values, regardless of the dose used and the test plot. The 2 kg KCl/tree/year dose achieved the highest yield surplus, exceeding 3.5 Tons/ha/year on the two plantations studied.

Comparison of the averages obtained with the four treatments on the two plantations showed clear superiority of the yields produced by the different doses on the Ehania plantation compared to that of La Mé. These yields ranged from 25.6 (T3) to 21.2 Tons/ha/year (T1) on the Ehania plantation. In La Mé ranged from 18.8 (T1) to 22.1 Tons/ha/year (T3). The effects of

different doses of KCl were higher on the Ehania plantation than that of La Mé.

3.5 Theoretical Maximum Rates of Potassium Fertilizer on the Two Plantings of the Study

A comparison of four models (Table 6) linking yields with different rates allowed the choice of models with the best determination coefficients (R^2), and the lowest residues are best suited to each situation. With a higher R2 and low residue, the quadratic model is suitable for planting La Mé, while the cubic model has been chosen for that of Ehania. These models were selected in the study to establish the relationship between applied doses and the resulting yields.

Analysis of the cubic regression results of bunches yields, at the Ehania plantation and quadratic regression, for La Mé revealed that parables allow a better estimate of yields, taking into account the different doses of KCl. The results (Table 7) showed that the maximum theoretical doses were 2.4 and 1.9 kg of KCl/tree/year, respectively, on the La Mé and Ehania plantations, producing theoretical maximum yields in diets. Specifically, these doses yielded theoretical maximum yields in diets of 21.9 Tons/ha/year on La Mé and 25.6 Tons/ha/year on the Ehania plantation.
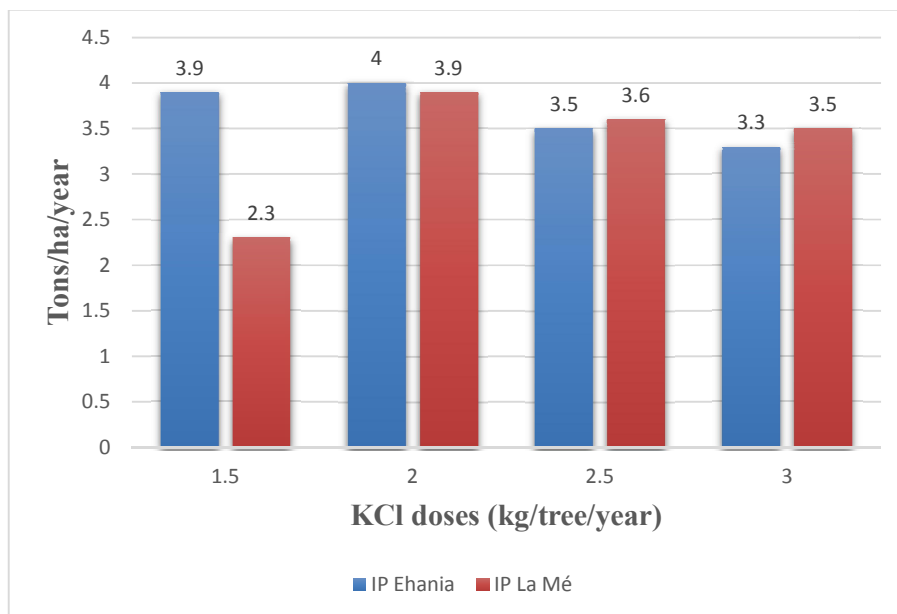

Fig. 1. Comparison of yield variation due to different doses of KCl versus dose of treatment 1 (1 kg/tree/year) on all study plantations

The curves of the Y(x) functions, also known as response curves, resulting from the different models are shown on the plantations of La Mé (Fig. 2) and Ehania (Fig. 3). The response rate on each plot corresponds to the increase in yield after adding 0.5 kg of KCl/tree/year additional potassium fertilizer.

The curves of the evolution of production values due to fertilizer gradually increase with the increase in fertilizer doses, reach their maximum with the maximum theoretical doses, and decrease as the intakes become higher and higher. Thus, these maximum doses resulted in maximum theoretical yields on all the study plots (Table 7).

4. DISCUSSION

In our trials, there was an improvement of more than 27% in bunches' yield, with an intake of 2 kg of KCl/tree/year (T3) compared to the standard dose of 1 kg of KCl/tree/year (T1), on the La Mé plantation. On Ehania, the yield increase was over 30%, with an intake of 1.5 kg of KCl/tree/year, compared to the standard dose (T1). These results show a good response of oil palm to potassium-based fertilization on Ferralsols in the localities of La Mé and Ehania, compared to responses obtained by [15] on peat soils in Malaysia. Indeed, on these peat soils, more than 25% improvement was obtained for K_2O intakes, six times higher than the doses applied in our trials. This difference in efficiency can be explained, on the one hand, by the fact that a natural richness of potassium characterizes peat soils, and on the other hand,

by the fact that the desaturated ferralsols of West Africa have the advantage of reacting very clearly and very quickly to the slightest strain by potassium fertilizers.

The different doses of KCl applied gradually improved the tonnage of oil palm bunches (TR) through a consequent increase in bunches' average weight (PMR). This efficiency of potassium nutrition on the yield of oil palm confirms previous results obtained in Cameroon by [16], in Côte d'Ivoire, by Ballo et al. [17,18,13], in Southeast Asia, by Jamaluddin and Zulkifli [19,15] and in Oceania,[20]. Potassium, by its specific action of activating the transport of assimilates from leaves to storage organs, can induce a good yield through an increase in PMR [13].

The positive effect of potassium on TR and PMR is consistent with previous work [21,11,22-25]. This trend is related to this element's active roles in reproductive metabolism and its decisive action in water stress resistance processes [26]. The increase in PMR is related to a large number of fruits on the bunch [13]. This effect of improving PMR through fertilizer intake only became significant after two campaigns. These results are consistent with those of [27], which showed that the yield in kilograms of bunches differs only from at least 20 months after applying potassium fertilizer. The increase in yields after the intake of potassium fertilizer observed during the second and third campaigns is explained by the fact that potassium manure occurs during the

Table 6. Comparison of four models to establish the relationship between diet yields and different doses of KCl applied to each parcel

Models	Gaussian	Logistic	Quadratic	Cubic
La Mé plantation				
Sum of tailings squares	16,05	17,50	2,00	12,45
Determination coefficients R^2	0,83	0,81	**0,85**	0,68
Ehania plantation				
Sum of tailings squares	5,2	22,7	69,8	13,2
Determination coefficients R^2	0,91	0,90	0,88	**0,99**

Table 7. Potassium fertilizer production functions on diet yields on each plot of the study

Localities	Production functions	R^2	KCl doses (kg/tree/year) Max	Yield (T/ha/year) Max
La Mé	$Y = 12{,}64 + 0{,}054X - 7{,}9\ 10^{-5}X^2$	0,85	2,4	21,9
Ehania	$Y = 0{,}6 + 0{,}225X - 6{,}5\ 10^{-4}X^2 + 6{,}16\ 10^{-7}X^3$	0,99	1,9	25,5

R^2: Determination coefficient; Max KCl doses: Maximum dose of KCl (Kg/tree/year); Max yield: Maximum yield (Tons/ha/year)
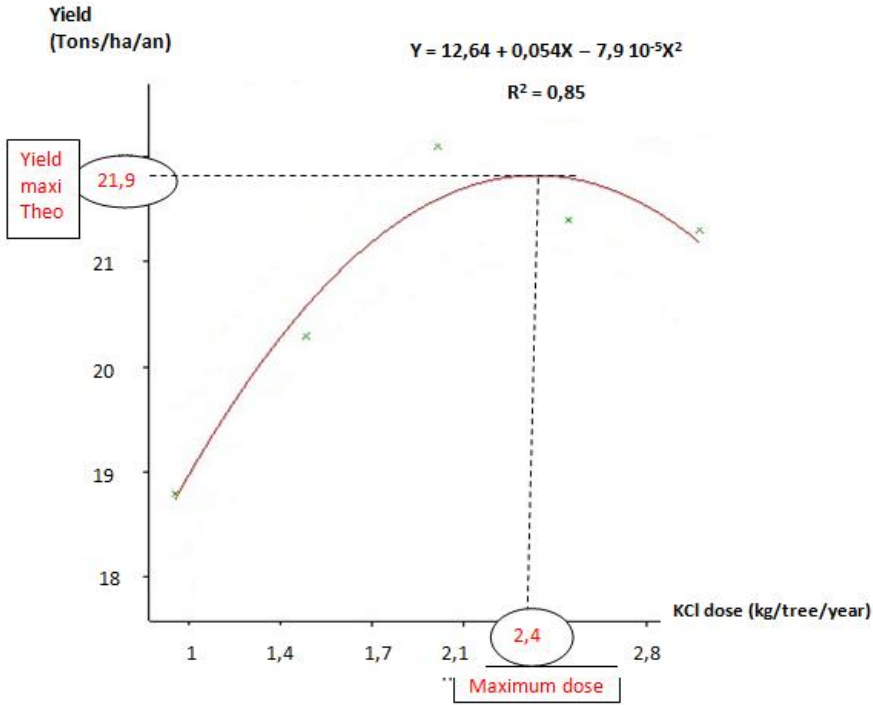
Yield
(Tons/ha/an)

$$Y = 12{,}64 + 0{,}054X - 7{,}9\ 10^{-5}X^2$$

$$R^2 = 0{,}85$$

Fig. 2. Relationship between bunches yield and different doses of KCl applied in La Mé industrial planting

Yield
(Tons/ha/year

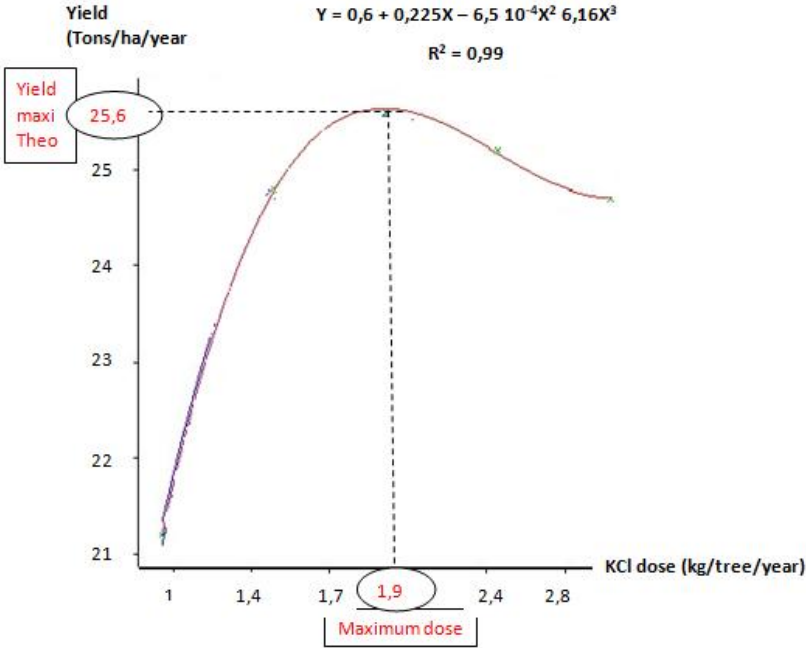$$Y = 0{,}6 + 0{,}225X - 6{,}5\ 10^{-4}X^2\ 6{,}16X^3$$

$$R^2 = 0{,}99$$

Fig. 3. Relationship between bunches yield and different doses of KCl applied in industrial plantations in Ehania

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inflorescence's active growth phase, which lasts 20 to 23 months before the diet is harvested [28]. Fertilization must compensate for exports and increase the potassium content of the soil to such a level that the absorption capacity is sufficient to cover the tree's needs.

According to [29], the potassium absorbed by the plant depends on the cultivated species, the potassium available in the soil, and environmental conditions. The amounts absorbed by the plant evolve in conjunction with the amount of fertilizer provided, peak with the maximum dose, ensure the best yield, and decrease when the fertilizer becomes toxic [30]. The new oil palm plant material, which is being popularized in Ivorian growing areas, is characterized by high yield, but these potentialities' expression is accompanied by a strong export of mineral elements [31]. The doses of T2, T3, T4, and T5 (1.5; 2; 2.5 and 3 kg KCl/tree/year) treatments make the oil palm available, all of which cover exports. Under these conditions, high-dose treatments strike a good balance between exports and the plant's mineral content nutrition, which leads to the best yields.

Besides, our results show that the effects of different doses of KCl, in improving yield components are also related to the locality in which the plantation is located. Yields on the Ehania plantation were significantly higher than those in La Mé. The production of a crop is strongly influenced by the soil's physical-chemical quality and the local climate.

Rainfall is the main climatic parameter for the cultivation of oil palm. The optimal annual need is 1800 mm of well-distributed rainfall [32,33]. For [34], water stress is, apart from any other edaphic factor, responsible for the low productivity of crops.

The rainfall recorded in the locality of Ehania and the resulting water deficit (DH) is, respectively, significantly higher and lower than those of La Mé. These two factors are mainly responsible for the highest production recorded on the Ehania plot, compared to La Mé. For [35], DH is the factor of yield, as a 100 mm change in the annual deficit, in the deficit range of 0 to 500 mm, causes a change in yield of 2.1 Tons/ha/year 10% of potential production at zero DH. This rainfall requirement, which is more satisfactory in the locality of Ehania, is less satisfactory in the La Mé area from year to year. Thus, the production of less watered La Mé bunches rarely exceeds 22 Tons/ha/year, while in Ehania, it

frequently reaches 25 Tons/ha/year, with adequate mineral fertilization.

The study results showed that in Ehania, the maximum dose was 1.9 kg of KCl/tree/year, while it was 2.5 kg of KCl/tree/year on the La Mé plantation. This lower maximum dose obtained at Ehania is explained by the higher rainfall recorded in this region, significantly higher than La Mé.

5. CONCLUSION

This study indicates that the different rates of KCl applied, had an influence on all of the experimental parameters, namely: yields (TR) and its components (NR; PR and PMR). The different treatments applied improved PR, PMR, and TR; however, their effects on NR were not significant. Yields on the Ehania plantation were significantly higher than those on La Mé. Yield ranged from 18.8 Tons/ha/year (T1) to 22.1 Tons/ha/year (T3) in La Mé, and from 21.2 to 25.6 tons/ha/year in Ehania. The theoretical maximum doses were 2.4 kg of KCl/tree/year in La Mé, compared to 1.9 kg/tree/year on the Ehania plantation. Therefore, these doses will be used in the future extension of potassium fertilizer, in the cultivation of oil palm, in the south-east of Côte d'Ivoire. In total, the soils under oil palm cultivation are currently characterized by relative poverty of mineral elements, in particular, potassium, which must necessarily be corrected with a reasoned intake of potassium manure, that potassium fertilizer improves the yield of the oil palm, and, above all, the long-popularized dose no longer allows to obtain the maximum net benefit on the harvest of bunches.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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