

# Characterisation of Cotton-Based Cropping Systems in Côte d'Ivoire: Which Cropping Practices Should Be Improved to Increase Production by Ivorian Cotton Growers?

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## Abstract

**Background:** Characterisation of cotton-based cropping systems is essential for understanding and improving cotton production in Côte d'Ivoire. The aim of this study was to determine the effects of cropping practices on seed cotton yields. A survey of a network of 600 growers in all the cotton-growing areas was carried out to gather information on the type of soil preparation (manual, harnessed and motorised), the sowing decade, the previous crop, the cotton variety, the sowing density, the date of fertilizer application (NPK and urea), the number of weeding operations, the number of insecticide treatments and, finally, the seedcotton yield. **Results:** The results showed that during the last cotton season (2023-2024), the sowing decades, crop precedents and a number of insecticide treatments had a highly significant effect on yield. Sowing in the first, second and third decade of June (1 to 10 June, 11 to 20 June and 21 to 30 June respectively). In addition, the best yields were obtained by growers who applied NPKSB base fertilizer and cover fertilizer (urea) within the sowing period at 10 days before sowing (0 - 10 days before sowing) and 45 - 60 days before sowing, respectively. In addition, better yields of close to 2 tons per hectare (1725 kg/ha) were observed among growers who applied a dozen insecticide treatments (eleven more than the six recommended by the research and development services). **Conclusion:** Further analysis will be carried out, taking into account parameters such as plot size, fertilizer doses (NPK and urea), climatic parameters (rainfall and temperature), agro-ecological zones and the physico-chemical parameters of the growers' soils. With this in mind, the Ivorian cotton companies

will be able to provide farmers with a decision-making tool to help them monitor cultivation operations and improve farm performance.

### Keywords

Cotton, Sowing Decade, Basal Fertilizer, Cover Fertilizer, Plant Protection, Yield

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## 1. Introduction

Cotton belongs to the Malvaceae family, in which the genus *Gossypium* comprises some fifty species. It is a perennial shrub, but is grown annually in all subhumid and semi-arid zones [1].

In Côte d'Ivoire, the development of cotonculture dates back to the early 1900s [2]. It remains the driving force behind the economy of the Savannah zone, thanks to the cash income it generates. In the north, the crop has become a major contributor, accounting for 1.7% of national GDP and 7% of exports [3]. Before the military-political crisis of September 2002, cotton growing employed around 200,000 farmers. In recent years, the total area under cotton has risen to 392,131 ha. It employs more than 150,000 growers and feeds nearly 3.5 million people [4].

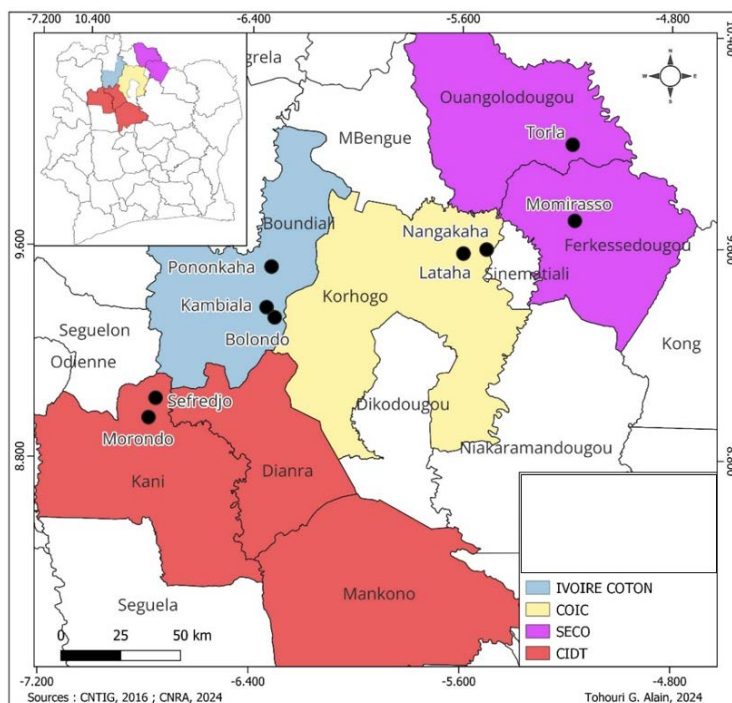
Although cotton growing has enabled Côte d'Ivoire to make undeniable socio-economic progress, cotton yields remain below expectations despite the efforts of research and support services. Several factors contribute to this situation, including the acidity of the soil under cotton. In fact, the fertilisation plan disseminated to farmers indicates the use of base fertilizers, *i.e.*, the formula 15 N-15 P-15 K-6S+1B and urea containing 46% nitrogen at 15 JAL and 40 JAL respectively. This fertilisation plan, which does not include the use of organic matter, encourages soil acidification, leading to a steady fall in cotton yields [5]. In addition, the change in the parasite facies with the appearance of a new pest, notably *Amrasca biguttula biguttula* [6], never before seen in the cotton basin, has reduced cotton yields to 500 kg/ha. It should be noted that the plant protection programme calls for six treatments starting 45 days after cotton emergence.

Today, the following research questions need to be asked: are the cultivation practices observed by the growers still relevant in Côte d'Ivoire? Shouldn't certain cultivation practices in the technical itinerary be improved to guarantee good cotton productivity? In order to provide some answers to these questions about the effectiveness of existing cultivation practices, this study was based exclusively on gathering information from growers supervised by technical agents from the main cotton companies on the dates of cultivation operations following the current technical itinerary. The overall aim of the study was to improve cotton productivity in Côte d'Ivoire by assessing the effects of cropping practices on seed cotton yields. Specifically, the aim was to assess the level of adoption of cultivation practices by cotton growers and to determine the relationship between cultivation practices and seed cotton yield.

## 2. Materials and Methods

### 2.1. Experimental Site

The study was conducted among cotton growers supervised by each cotton company in Côte d'Ivoire (**Figure 1**). It should be noted that Côte d'Ivoire has a zoning system that divides the cotton basin into exclusive activity zones (ZEA) around the existing ginning factories. For this study, the four largest cotton companies were chosen, namely Ivoire Coton, the Ivorian Cotton Company (COIC), the Olam Cotton Company (SECO) and the Ivorian Textile Company (CIDT).



**Figure 1.** Geographical location of cotton companies hosting farmers surveyed during the 2023 - 2024 season.

### 2.2. Experimental Design

In each of the four (04) large cotton companies, 10 localities were chosen and, in each locality, 15 cotton growers were surveyed. In all, 600 producers were surveyed. These surveys consisted of collecting information on the dates of all cultivation operations linked to cotton production.

### 2.3. Data Collected from Cotton Growers

The information collected from the 600 growers concerned the variety of cotton grown, the sowing density, the sowing date or sowing decades, the plant emergence date, the reseeding and removal date, the removal date, the maintenance method (tractor, manual or motorised), the previous crop, the adjacent crop, the date of application of the base fertilizer (NPKSB), the date of application of the cover fertilizer (urea), the delay before application of the base and cover fertilizers,

the number of weedings, the date of the 1st weeding after emergence of the cotton plants, the number of insecticide treatments, the date of insecticide treatments and the total yield (kg/ha).

## 2.4. Statistical Analysis

All the data collected underwent three types of statistical analysis. The first type of statistical analysis was descriptive. The second involved simple and multiple regression analyses. Finally, the last type of analysis was inferential.

The descriptive analyses were used to highlight the relative frequencies or proportions of producers observing a given cropping practice. In addition, simple or multiple regressions were used to identify the nature and strength of the relationship between cropping practices and the seed cotton yield obtained by farmers. Multiple component analyses were also used to better illustrate the relationships between cropping practices and seed cotton yield. Before this, PCA was used to detect discriminating cropping practices in the cotton production calendar for the 2023-2024 cotton season.

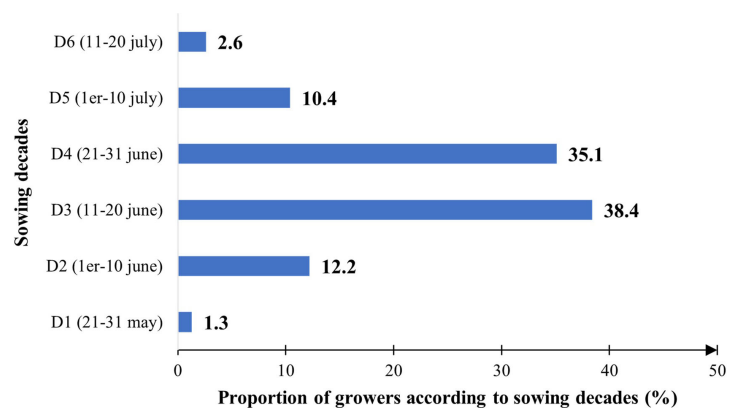
In addition to simple and multiple regressions, inferential analysis was carried out, in particular ANOVA 1, to study the effects of the discriminant cropping practices identified by the PCA on seed cotton yield. For this last statistical analysis, the conditions were checked, namely the normality of the data distribution and the equality of the variances of the modalities of the factors compared, and in the event of a significant difference, the smallest significant difference (SSD) test was used to identify the homogeneous groups. R software version 4.4.1 was used for all analyses.

## 3. Results

### 3.1. Description of the Proportions of Producers According to the Cultivation Practices Adopted

#### Sowing period

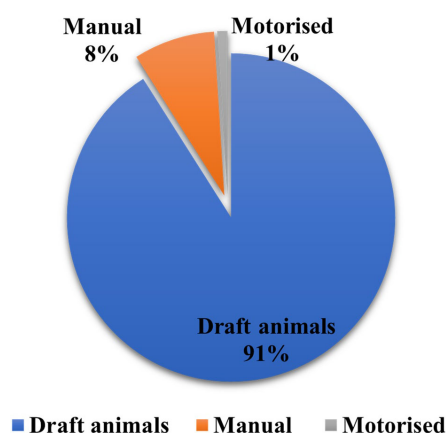
**Figure 2** shows that the vast majority of sowing took place in the 3rd decade (11 - 20 June) and the 4th decade (21 - 31 June). Late sowing in D5 and D6 was also carried out (13%).



**Figure 2.** Distribution of sowing decades.

### 3.2. Crop Maintenance Methods

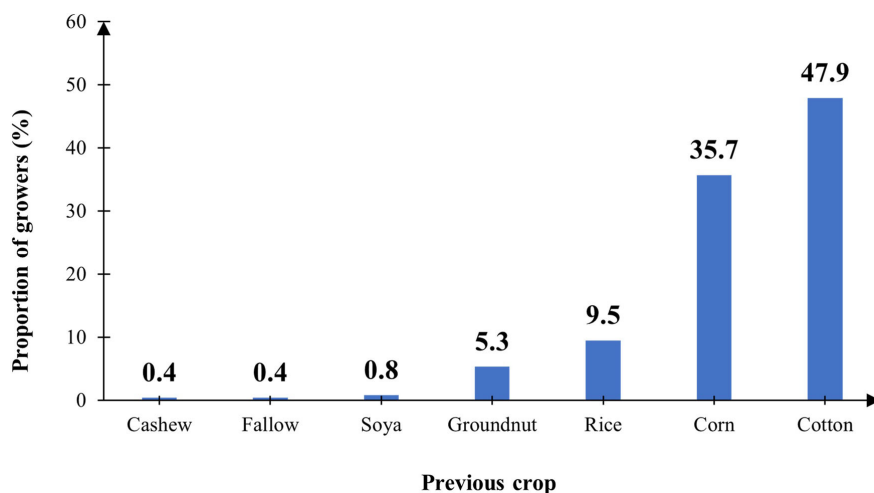
**Figure 3** shows that the majority of growers use ploughing (91%). A small proportion of growers use manual cultivation (8%) and motorised cultivation (1%).



**Figure 3.** Proportion of growers according to cultivation methods in cotton-growing areas.

### 3.3. Proportion of Previous Crops

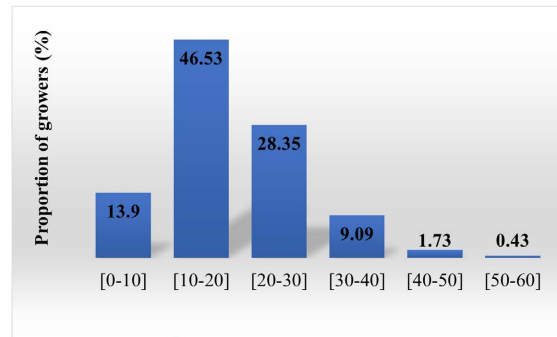
Nearly the majority of farmers (47.90%) grow cotton on cotton (**Figure 4**). A sizeable proportion (35.70%) of growers use a cereal-cotton crop rotation (45.20%). A small proportion of legumes (soya and groundnuts) are used as preceding crops (5.70%).



**Figure 4.** Proportion of growers according to previous crop.

### 3.4. Time Period for Applying Base Fertilizer (NPKSB)

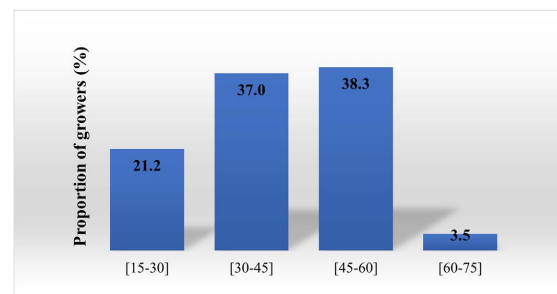
Some growers (14%) applied bottom dressing early, between 0 and 10 days after cotton emergence. The vast majority (46.53%) applied bottom dressing between 10 and 20 days after emergence. In addition, 28.35% of growers applied bottom dressing between 20 and 30 days after emergence. More than 10% of growers applied it between 30 and 60 days (**Figure 5**).



**Figure 5.** Proportion of growers according to the time period for applying base fertilizer.

### 3.5. Time Period for Applying Urea

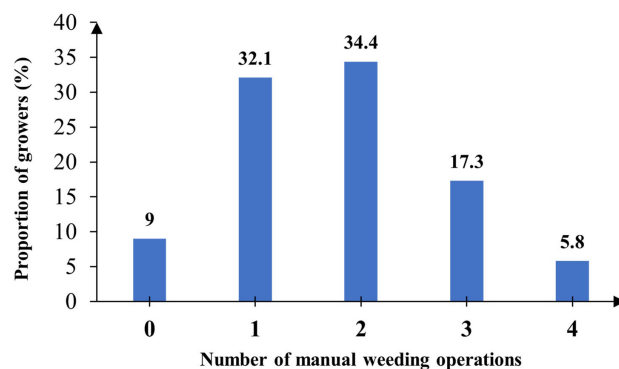
With regard to the time taken to apply urea, 21.20% of farmers applied it early, *i.e.* between 15 and 30 days before harvest. Large proportion of growers, 37.0% and 38.30% respectively, applied urea between the 30th and 45th and 45th and 60th. In addition, 3.5% of growers applied urea between 60 and 75 days (**Figure 6**).



**Figure 6.** Proportion of growers according to time of application of cover fertilizer (urea).

### 3.6. Number of Manual Weeding Operations

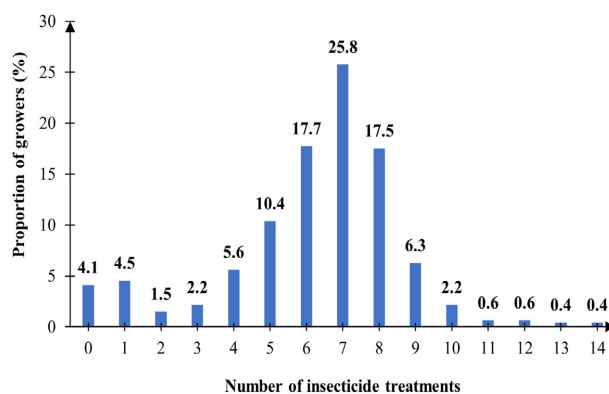
The number of manual weeding operations carried out by producers ranged from 0 to 4 during the 2023-2024 cotton season (**Figure 7**). A significant proportion (9%) did not weed. The vast majority of producers weed their cotton fields only once (32.1%), twice (34.4%) or three times (17.3%). Some producers weed four times (5.8%).



**Figure 7.** Proportion of producers according to the number of manual weeding operations.

### 3.7. Number of Insecticide Treatments

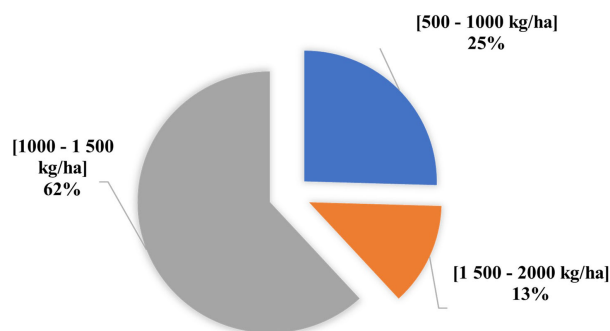
The number of insecticide treatments ranged from 0 to 14 during the 2023-2024 cotton season (**Figure 8**). More than 50% of growers carried out more than six insecticide treatments. In addition, 25% of growers applied more than seven insecticide treatments. However, 2% of growers had extensive protection with more than 10 insecticide treatments.



**Figure 8.** Proportion of growers by number of insecticide treatments.

### 3.8. Seedcotton Yields

According to **Figure 9**, the majority of growers (62%) have a yield of between 1 000 and 1500 kg/ha. And 25% of growers have a yield of between 500 and 1,000 kg/ha. In addition, 13% of growers have a yield of between 1500 and 2000 kg/ha.



**Figure 9.** Proportion of growers by seedcotton yield.

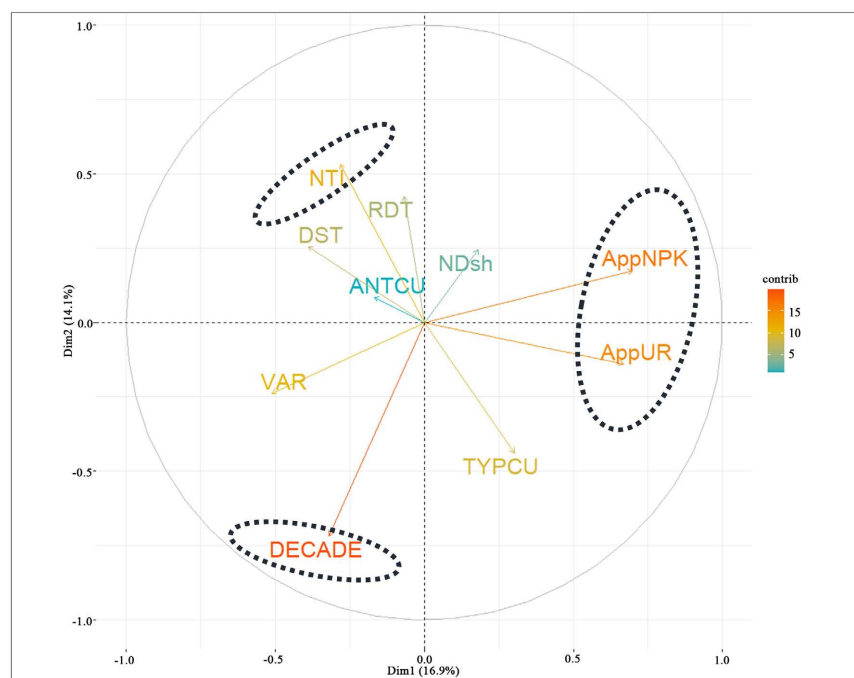
### 3.9. Discriminant Cropping Practices and Effects on Seedcotton Yield in the 2023 - 2024 Season

The multivariate analysis carried out with all the data collected on the proportions of producers following the adoption of cultivation practices revealed two dimensions (Dim 1 and Dim 2) with eigenvalues of 16.90% and 14.10% respectively (**Figure 10**). When considering the first dimension (Dim 1), variables such as AppNPK and AppUR, which respectively designate the time taken by farmers to apply base fertilizer (NPKSB) and urea, made a very good contribution to the construction of this first factorial axis, with a value of more than 15%. On this first

dimension (Dim 1), these two variables (AppNPK and AppUR) can be considered as the most discriminating among farmers, reflecting the great variability in input application times from one farmer to another.

However, on the second factorial axis or dimension (Dim 2), it is the variables NTI (number of insecticide treatments) and DECADE (sowing decade) that show a very good projection, especially as they contribute most to the formation of this second dimension. We can also affirm, according to the analyses presented by the correlation circle, that the two variables mentioned (NTI and DECADE) separate the producers as well as possible.

Furthermore, given its very good projection on factorial axis 2 (Dim 2), the “DECADE” variable contributes strongly to the discrimination of cotton growers. To summarise, it should be noted that variables such as the time taken to apply base and top dressing fertilizers (AppNPK and AppUR respectively), the number of insecticide treatments (NTI) and the sowing decade (DECADE) are the most discriminating.



NTI represent the Number of insecticide treatments, AppNPK represent NPK application time, AppUR represent urea application time, DECADE represent sowing decade, Var represents the variety grown..., TYPCU represents the crop maintenance method, ANTCU represents the crop history, NDsh represents the number of manual weeding operations, DST represents the sowing density and RDT represents the seed cotton yield.

**Figure 10.** Discriminating cropping practices in the 2023-2024 cotton season.

If we wish to highlight the relationship between the most discriminating parameters and the seed cotton yield (RDT) obtained by the farmers, we find that, on the first dimension (Dim 1), the time taken to apply fertilizers (AppNPK and AppUR) had a significantly negative relationship with the seed cotton yield (respectively  $r = -0.142$ ,  $p = 0.002$ ;  $r = -0.210$ ,  $p = 0.000$ ) (Figure 10 and Table 1). This would mean

that the longer the farmer takes to apply fertilizer, the lower the seed cotton yield. Staying on the same factorial axis, it is useful to know, through this PCA, that the number of insecticide treatments (NTI) established a significantly positive relationship with seed cotton yield ( $r = 0.232$ ,  $p = 0.000$ ). In other words, growers who had recourse to more phytosanitary treatments had almost better seed cotton yields.

On the second factorial axis (Dim 2), the variable (DECADE) reflecting sowing decades or periods established a strongly negative relationship with seedcotton yield ( $r = -0.707$ ,  $p = 0.008$ ). In other words, late sowing contributed to low seed cotton yields.

**Table 1.** Relationship between cropping practices and cotton yield.

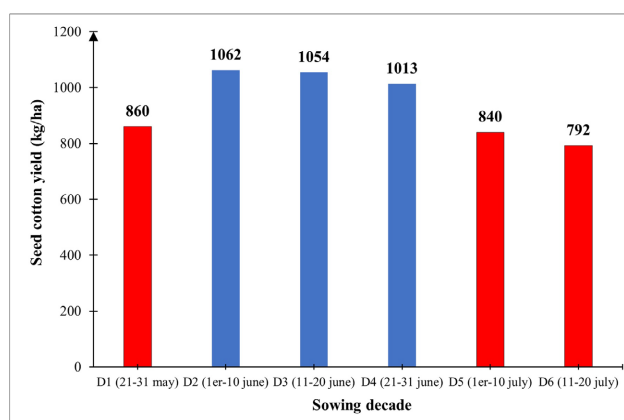
		DECADE	TYPUCU	ANTCU	VAR	DST	AppNPK	AppUR	NDsh	NTI
RDT	r	-0.707**	0.027	-0.039	-0.005	-0.040	-0.142**	-0.210**	0.056	0.232**
	p	0.008	0.558	0.399	0.911	0.5	0.002	0.000	0.231	0.000

r represents the Pearson correlation coefficient, p represents the probability, NTI represents the number of insecticide treatments, AppNPK represents the NPK application delay, AppUR represents the urea application delay, DECADE represents the sowing decade, TYPUCU represents the maintenance mode, ANTCI represents the previous crop, VAR represents the cotton variety, DST represents the sowing density, NDsh represents the number of weeding treatments.

### 3.10. Determination of Optimal Cultivation Practices for Cotton Productivity in the 2023 - 2024 Cotton Season

#### 3.10.1. Sowing Decades

Analyses of variance, of the ANOVA 1 type, revealed very significant effects of sowing decades on seed cotton yield ( $P = 0.000$ ). In fact, sowing from 1 to 10 June (D2), 11 - 20 June (D3) and 21 - 30 June (D4) resulted in yields of over 1 tonne/ha. Cotton from the first ten days of sowing, *i.e.* from 20 to 31 May, had the lowest yields, *i.e.* 860 kg/ha, 840 kg/ha and 792 kg/ha (Figure 11), together with those from the last sowing periods, *i.e.* from 1 to 10 July and 11 to 20 July (D5 and D6) respectively (Figure 11).

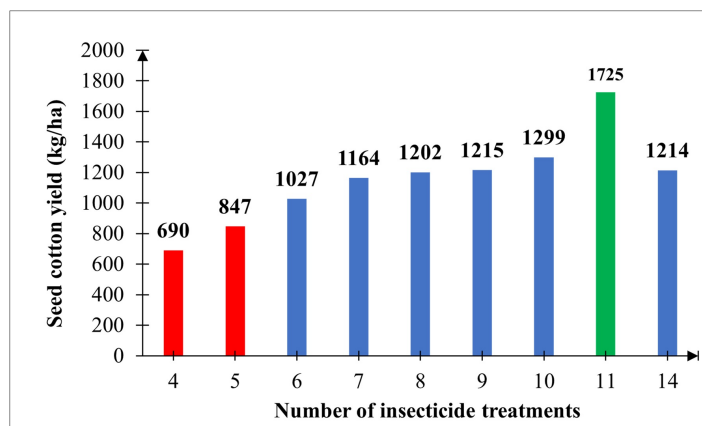


Histograms of the same color are not significantly different at the 5% level.

**Figure 11.** Seed cotton yield as a function of sowing decade.

### 3.10.2. Number of Insecticide Treatments

A highly significant effect of the number of insecticide treatments was observed on seed cotton yield ( $P = 0.000$ ). In fact, the more insecticide treatments producers increased, the higher their seed cotton yield (Figure 12). At 11 insecticides treatments, the highest yield of 1725 kg/ha was observed. However, the lowest yields were obtained by growers who applied four to five insecticide treatments (690 kg/ha and 847 kg/ha).

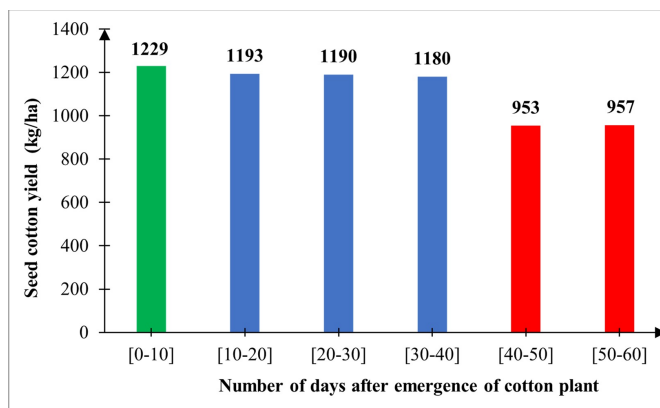


Histograms of the same color are not significantly different at the 5% level.

Figure 12. Seed cotton yield as a function of the number of insecticide treatments.

### 3.10.3. Timing of Fertilizer Application (NPKSB)

Applications of bottom-dressing fertilizer (NPKSB) between zero (at sowing) and 10 days after emergence of the cotton plants gave the highest yield of 1,229 kg/ha (Figure 13). This yield fell progressively as the delay increased. Yields were lowest for cotton plants that received bottom dressing very late, *i.e.* 40 to 50 days after emergence and 50 to 60 days after emergence (953 kg/ha and 957 kg/ha respectively). The ANOVA carried out showed a highly significant effect of the delay in applying the bottom dressing (NPKSB) on cotton productivity ( $P = 0.000$ ).

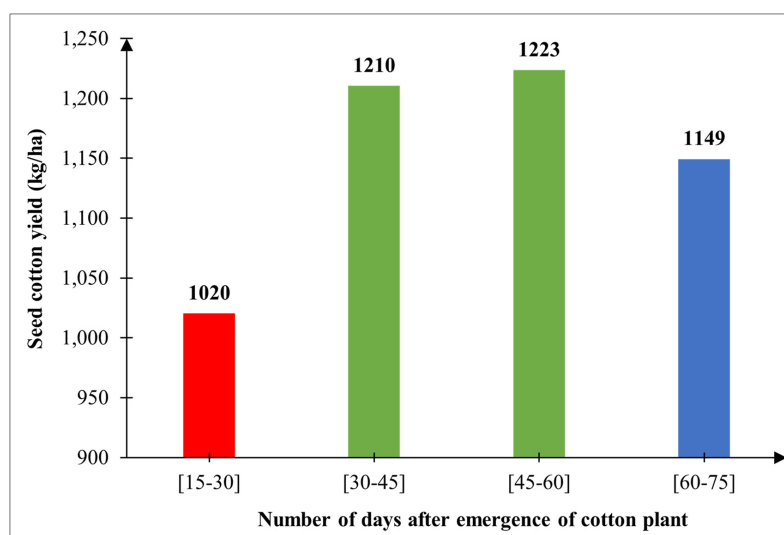


Histograms of the same color are not significantly different at the 5% level.

Figure 13. Seed cotton yield as a function of the time taken to apply the base fertilizer (NPKSB).

### 3.10.4. Timing of Application of Cover Dressing (Urea)

The effects of the time taken by growers to apply cover dressing or urea were assessed on their seed cotton yields using ANOVA 1 (Figure 14). Following this statistical analysis, a highly significant effect of the different urea application delay methods was observed ( $P = 0.000$ ) on seedcotton yield. In fact, the 30 to 45 days and 45 to 60 days delays produced the highest yields (1,210 and 1,223 kg/ha respectively). Yields were lower for early (between 15 and 30 days) and late (60 and 75 days) applications, at 1,020 and 1,149 kg/ha respectively.



Histograms of the same color are not significantly different at the 5% level.

**Figure 14.** Seed cotton yield as a function of time taken to apply cover fertilizer. (urea)

## 4. Discussion

The results showed that sowing was carried out by the vast majority of growers between 1 and 10 June and 21 and 30 June. This result was due to the onset of rains in the production zones. Nevertheless, sowing was carried out in the first decade of July. In reality, these growers were faced with an abrupt end to the rains in June and a later resumption, forcing them to sow later. According to research carried out by IDESSA (Savannah Institute) in Côte d'Ivoire, the optimum sowing dates in the northern areas of the cotton basin are from 25 May to 25 June [7]. However, the work of [8] has highlighted new cropping calendars that prohibit sowing cotton in May in order to minimise the risk of failure. For the authors mentioned above, the new sowing dates would be from 1 to 10 June (D2), 11 to 20 June (D3), 21 to 30 June and 1 to 10 July. These research results are very well confirmed by the present survey work, since the best seed cotton yields were obtained by growers who sowed the cotton in the June decades. However, thought should now be given to modelling cotton sowing periods in view of the effects of climate change, which are reflected in the irregularity of rainfall from one cotton season to the next.

With regard to phytosanitary protection of the cotton plant, surveys have

shown that growers who applied a high number of insecticide treatments obtained better seed cotton yields. In fact, during the 2022-2023 cotton season, the Ivorian and sub-regional cotton industry was hit by an attack by a new species of Jasside (*Amrasca biguttula biguttula*), which led to a 50% drop in the plant's productivity (500 kg/ha). As a result, for the following season (2023-2024), growers who were anxious to achieve a good yield used many more insecticide treatments, given the past situation and the presence of this new pest, increasing the number of insecticide treatments to twice that recommended by the research and development services, which set the number at six. However, it would be wise to strike a balance between the use of insecticides and the associated risks to the sustainability of the cotton sector.

The survey also showed that growers who applied bottom dressing (NPKSB) between sowing (0 days after seedling emergence) and 10 days after planting obtained high yields of seed cotton. Bottom dressing, as its name suggests, is a fertilizer applied to the soil which releases nutrients gradually and slowly into the soil, ensuring a constant supply throughout the cotton plant's development from seedling onwards. So, applying it at sowing or a few days after sowing would allow the young cotton plants to benefit from essential nutrients right from the start of their growth cycle, promoting healthy, vigorous growth from the outset. This would enable the crop to develop a robust root system and maximise their yield potential. This was not the case for growers who obtained low yields due to the late application of this Fertilizer. In addition, some growers who applied cover or maintenance Fertilizer (urea) early (between 15 and 30 days before harvest) obtained the lowest seed cotton yields. For several decades, research and development services have been popularising the use of this fertilizer at a rate of 50 kg/ha between 40 and 45 days old. At this age, the cotton plants, which are generally in the flowering and early fruiting phase and therefore have high nitrogen requirements, will find their needs met by this cover fertilizer [9]. This clearly explains the better yields observed in growers who applied urea either between 30 and 45 days before harvest or between 45 and 60 days before harvest. On the other hand, the results of the survey showed that some growers applied the cover dressing early to the cotton plants and obtained the lowest yields. In fact, the low yields are thought to be due to the fact that the cotton plants are very young when the Fertilizer is applied, and are therefore unable to withstand the excess nitrogen in the soil, as their need for this nutrient is low to moderate at this age. This would encourage a nutritional imbalance that would disrupt the availability of other nutrients. In addition, this early application of urea could increase the water demand of the cotton plants and cause water stress. Given that cotton growing in Côte d'Ivoire is entirely rain-fed, and that the cotton basin in the northern regions is heavily dependent on the vagaries of rainfall, it is clear that this early application of urea could increase the plant's demand for water and cause water stress. However, some growers have gone beyond the normal urea application period and applied the fertilizer late, resulting in low yields. This situation could be explained by the lack of nitrogen

during the crucial phase (flowering-fruiting).

## 5. Conclusion

In the 2023 - 2024 cotton season in Côte d'Ivoire, the sowing decade, NPK application delay, urea application delay and number of insecticide treatments were the factors that most affected cotton productivity. On the other hand, better seed cotton yields were observed among growers who sowed in sowing decades D2 (1 - 10 June), D3 (11 - 20 June) and D4 (21 - 30 June). In addition, the best yields were obtained by growers who applied NPKSB base fertilizer and cover fertilizer (urea) within the sowing period at 10 days before sowing (0-10 days before sowing) and 45 - 60 days before sowing, respectively. In addition, better yields of close to 2 tons per hectare (1725 kg/ha) were observed among growers who applied a dozen insecticide treatments (eleven more than the six recommended by the research and development services). Further analysis will be carried out, taking into account parameters such as plot size, fertilizer doses (NPK and urea), climatic parameters (rainfall and temperature), agro-ecological zones and the physico-chemical parameters of the growers' soils. With this in mind, the Ivorian cotton companies will be able to provide farmers with a decision-making tool to help them monitor cultivation operations and improve farm performance.

## Abbreviations

CNRA: National Centre for Agronomic Research, IDESSA: Savannah Institute, NTI: Number of insecticide treatments; r: Pearson correlation coefficient, p: Probability; AppNPK: NPK application delay; AppUR: Urea application delay; DEC-ADE: Sowing decade; TYPCU: Maintenance mode; ANTCI: Previous crop; VAR: Cotton variety; DST: Sowing density; NDsh: Number of weeding treatments.

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## Author Contributions

Koffi Christophe KOBENAN processed the data from the surveys and wrote the manuscript, Emmanuel Kouadio N'GORAN, Kouakou MALANNO, Kouakou Julien BROU, Kouakou Etienne TEHIA, Nogbou Ferdinand AMANGOUA, Diane Esther GNAPI, Kouadio Kra Norbert BINI read and corrected the manuscript.

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## Availability of Data and Materials

All relevant data are within this article.

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## Conflicts of Interest

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

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