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Supporting Cotton Productivity in Côte d'Ivoire through Agronomic Interventions

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Abstract

Modern agronomic concepts such as high-density planting systems are emerging in cotton-based cropping systems. Agronomic practices specific to new cotton varieties made in specific niches, management of the vegetation cover using growth regulators (retardants and defoliants) for better quality and above all the improvement of crop health through integrated nutrient management with an emphasis on the foliar feeding pattern, can significantly increase cotton productivity and improve the socio-economic status of farmers of cotton. It is in this context that studies on cotton sowing densities, the supplementation of mineral fertilization with trace elements and the management of the resumption of vegetation of cotton plants at the end of the cycle have been carried out in a farming environment and in research stations. The results of the survey in the farmer's environment, of the trials conducted in stations and on observation posts showed a positive correlation between sowing densities and seed cotton yield. About 22% of the variations in seed cotton yield are related to sowing density. The best seed cotton yields are obtained with the high sowing densities in the north and the low densities in the south of the Ivorian cotton basin. Studies on the supplementation of base fertilizer with trace elements have shown that the combined application of 200 kg/ha of NPK + 50 kg/ha of urea + 2 kg/ha of ZnS04 increases the seed cotton yield and provides a monetary gain of 36,622 CFA francs/ha. The study on the management of vegetation resumption at the end of the cycle showed that the application of 4 l/ha of Ethephon and 62.5 ml/ha of Diuron at 100 days after emergence improves defoliation and capsule opening for better management of vegetation recovery at the end of the season. Studies have shown that seeding density is a factor in seed cotton yield. Seed cotton yields were improved by supplementing with mineral fertilizer with zinc and adding desiccants and defoliants at the end of the cycle.

Keywords

Cotton, Seeding Density, Defoliants, Vegetation Recovery

1. Introduction

After achieving a record production of 400,000 tons of seed cotton and a yield of 1400 kg/ha in 1999/2000, the sociopolitical crisis in Côte d'Ivoire led to a sharp decline in production to 145,000 tons and a decrease in yield to 732 kg/ha from 2003/2004 [1]. Since 2010/2011, thanks to the recovery efforts led by the State of Côte d'Ivoire, the stakeholders in the sector, and development partners, cotton cultivation has regained momentum [2]. However, field yields remain well below the pre-crisis level of 1.4 tons per hectare.

This situation is largely due to the misalignment of farming practices with the current context marked by climate change, with planting densities in the field generally being lower or higher than those recommended by research [3].

Moreover, the decline in soil fertility under cotton, characterized by soil acidification, the emergence of new pests and diseases, and prolonged rains at the end of the season promoting regrowth of cotton vegetation and rotting of already mature capsules, represent additional constraints explaining the low yields [3].

In light of the low seed cotton yield observed in the cotton basin, the objective of this study is to develop agronomic strategies that can ensure the sustainability of cotton production.

2. Materials and Methods

2.1. Updating Seeding Densities in Cotton Crops

2.1.1. Monitoring of Yield Trends as a Function of Sowing Densities in Farmer Areas

This activity was carried out by collecting data from farmers on a network of around 500 plots. These plots were selected in June 2023 in 50 localities, with 10 plots per locality (or cotton-growing zone). The plots were selected in proportion to the different decades or sowing periods. Agronomic data were collected on each plot, including the name of the cotton variety sown, the sowing date, the dates of cultivation operations, the sowing density (number of cotton plants/ha) and the seed cotton yield. Simple correlations between sowing density and seed cotton yield obtained by farmers were established for the major cotton companies. A one-factor Analysis of Variance (ANOVA) was also used to determine the optimum sowing densities for farmers.

2.1.2. Evaluation of the Effects of Seeding Densities on Cotton Yields at the Station and on the Observation Post

A trial was set up in Bouaké (Cotton Station) and duplicated on the Observation

Posts (PO). The experimental set-up is made of Fisher blocks with four repeats. Only one seeding rate factor was evaluated, with 19 levels (Table 1). The elementary plot is 48 m^2, 10 m long and 4.8 m wide. The distance between two blocks is 2 m.

Table 1. Cotton seeding densities compared at the station and the observation posts.

Treatments	Seeding geometry	Number of seeds/pocket	Densities (seeds/ha)
T1	1.0 × 0.40	2	50,000
T2	1.0 × 0.30	2	66,666
T3	1.0 × 0.20	2	100,000
T4	1.0 × 0.15	1	66,666
T5	1.0 × 0.10	1	100,000
T6	0.9 × 0.40	2	55,555
T7	0.9 × 0.30	2	74,074
T8	0.9 × 0.20	2	111,111
T9	0.9 × 0.20	1	55,555
T10	0.9 × 0.15	1	74,074
T11	0.9 × 0.10	1	111,111
T12	0.8 × 0.40	2	62,500
T13	0.8 × 0.30	2	83,300
T14	0.8 × 0.20	2	125,000
T15	0.8 × 0.15	1	83,333
T16	0.8 × 0.10	1	125,000
T17	0.7 × 0.25	2	114,285
T18	0.7 × 0.20	2	142,857
T19	0.7 × 0.15	1	95,238

2.1.3. Observations and Measurements of the Morphological Parameters of Cotton

These observations were made on 10 plants chosen from the three central lines, taking care to leave 2 m at each end. On the first of the three lines, three consecutive plants are chosen by the observer. He then makes a lateral move to reach the second line. On this line, the observer travels 1 linear meter and will choose four successive plants. The same lateral movement is made to reach the third line. At this level, the observer travels another 1 meter and chooses three consecutive plants. This makes it possible to have ten plants per elementary plot.

- Plant height (cm): The height of the main stem (HT) is measured from the cotyledonary nodes to the apex of the plant. Measurements are made on the 30th, 60th, 90th day after emergence (DAE) and at harvest.
- Number of nodes: Knots are counted at the 30th, 60th, 90th DAE and at harvest.
- Number of vegetative and fruiting branches: the count of vegetative and

fruiting branches is carried out at harvest. These branches are counted from those between the cotyledonary nodes and the apex of plants.

- Average number of green bolls: Of the ten plants labelled in the four central lines, green bolls are counted at the 60th, 75th, 90th and 105th DAE.
- Rate of flower bud and green capsule shedding: this operation is performed at the 60th and 90th DAE. It consists of counting the flower buds and fallen green capsules, in order to obtain an indication of the intensity of the losses suffered by the plants, according to the treatments (sowing densities). To do this, after collection, a sorting is carried out to distinguish healthy organs from those that are attacked (with a hole or insect bites). This activity is done every 3 days in the two interlines of the three central lines, leaving 2 m at each of the two edges.

2.1.4. Observations and Measurements of Entomological Parameters of Cotton

These observations are made on the main pests of cotton. On each elementary plot, the count of the different insects is carried out on 30 plants taken in groups of five consecutively on the three central lines, according to the diagonal method. Observations of the cotton entomofauna are made on a weekly basis, from the 35th to the 122nd DAE. These direct observations on plants are supplemented by health analyses of green capsules. Three to six weekly health analyses (ASCV) are carried out on 25 green capsules of the same age (greater than 2 cm in diameter) between the 80th and 115th DAE. The harvested green bolls are carefully dissected with a knife to determine which ones have internal rot and which are healthy. Eventually, the rates of healthy and rotten capsules are determined as well as the number of lepidopteran larvae encountered.

2.1.5. Observations and Measurements of Production Parameters

- Boll average weight (BAW): after the bolls have been fully opened, out of five cotton plants belonging to the lateral lines of each of the elementary plots, three bolls in position 1 of the fruiting branches (BF) are harvested. These capsules are collected from the BFs in the low, middle and terminal positions [4]. The BAW is calculated per plot by dividing the total weight of seed cotton by the number of bolls harvested.
- Seed cotton yield: the seed cotton is harvested on the three central lines of 8 m long, taking care to leave 1 m of border at the 2 ends of each line.
  - For plots with 0.7 m row spacing, the harvesting area is: 3 lines × 0.7 m × 8 m = 16.8 m^2.
  - For plots with 0.8 m row spacing, the harvesting area is: 3 lines × 0.8 m × 8 m = 19.2 m^2.
  - For plots with 0.9 m spacing, the harvesting area is: 3 lines × 0.9 m × 8 m = 21.6 m^2.
  - For plots with 1 m spacing, the harvesting area is: 3 lines × 1 m × 8 m = 24 m^2.

2.1.6. Statistical Analyses

The data collected were subjected to an analysis of variance (ANOVA) under the

R.4.0.1 software, after verification of the normality of the distribution. When a significant difference is observed ($p < 0.05$) between seeding densities (treatments) for a given parameter, multiple comparisons are made using the Duncan test at the 5% threshold.

2.2. Evaluation of the Effects of Increasing Doses of Zinc Sulphate on the Agromorphological Parameters of Cotton

2.2.1. Experimental Design

This activity is carried out through an experiment at the Cotton Station in Bouaké. The experimental set-up is made of Fisher blocks with four repeats. A single factor corresponding to the dose of zinc sulphate, with eight levels, is evaluated (Table 2). The elementary plot measures 64 m^2, 10 m long and 6.4 m wide. The elementary plots are separated by 1 m and the blocks are 2 m apart.

Table 2. Fertilizer treatments including doses of zinc sulfate evaluated.

Treatments		NPK (kg/ha)	Urea (kg/ha)	Zinc sulphate (kg/ha)
Absolute control (without manure)	T0	0	0	0
Positive control or recommended fertilization	T1	200 (15 JAL)	50 (45 JAL)	0
Recommended fertilisation (FR) + 150% $ZnSO_4$	T2	200 (15 JAL)	50 (45 JAL)	6 (15 JAL)
Recommended fertiliser (FR) + 125% $ZnSO_4$	T3	200 (15 JAL)	50 (45 JAL)	5 (15 JAL)
Recommended fertiliser (FR) + 100% $ZnSO_4$	T4	200 (15 JAL)	50 (45 JAL)	4 (15 JAL)
Recommended fertiliser (FR) + 75% $ZnSO_4$	T5	200 (15 JAL)	50 (45 JAL)	3 (15 JAL)
Recommended fertilisation (FR) + 50% $ZnSO_4$	T6	200 (15 JAL)	50 (45 JAL)	2 (15 JAL)
Recommended fertiliser (FR) + 25% $ZnSO_4$	T7	200 (15 JAL)	50 (45 JAL)	1 (15 JAL)

2.2.2. Observations and Measurements of the Morphological Parameters of Cotton

These observations are made on 10 plants chosen from the three central lines, taking care to leave 2 m at each end of each line. On the first of the three lines, three consecutive plants are chosen by the observer. He then makes a lateral move to reach the second line. On this line, the observer travels 1 linear meter and will choose four successive plants. The same lateral movement is made to reach the third line. At this level, he travels another 1 meter and chooses three consecutive plants. This will make it possible to have ten plants per elementary plot.

- **Plant height (cm):** The height of the main stem (HT) is measured from the cotyledonary nodes to the apex of the plant. Measurements are made on the 30th, 60th, 90th day after emergence (DAE) and at harvest.
- **Number of nodes:** Knots are counted at the 30th, 60th, 90th DAE and at harvest.
- **Number of vegetative and fruiting branches:** The count of vegetative and fruiting branches is carried out at harvest. These branches will be counted from those located between the cotyledonary nodes and the apex of the plants.
- **Average number of green bolls:** Of the ten plants labelled in the four central

lines, green bolls are counted at the 60th, 75th, 90th and 105th DAE.

- **Rate of fall of flower buds and green capsules (shedding):** This operation is performed from the 60th and 90th JAL. It consists of counting the flower buds and green capsules that have fallen off, in order to obtain an indication of the intensity of the temporary loss suffered by the plants, depending on the treatments (sowing densities). To do this, after collection, a sorting is carried out to distinguish healthy or attacked organs (with a hole or insect bites). This activity is done every 3 days in the two interlines of the three central lines, leaving 2 m at each of the two edges.

2.2.3. Observations and Measurements of Production Parameters

- **Boll Average weight (BAW)**: After the bolls have been fully opened, out of five cotton plants belonging to the lateral lines of each of the elementary plots, three bolls in position 1 of the fruiting branches (BF) are harvested. These capsules are collected from the BFs in the low, middle and terminal positions [4]. The PMP is calculated per plot by dividing the total weight of seed cotton by the number of bolls harvested.
- **Seed cotton yield:** The seed cotton is harvested on the four central lines of 8 m long while taking care to leave 1 m of border at the 2 ends of each line. The harvesting area is: 4 rows × 0.8 m × 8 m = 25.6 m^2.

2.2.4. Statistical Analyses

The data collected are subjected to an analysis of variance (ANOVA) under the R.4.0.1 software, after verification of the normality of the distribution. When a significant difference is observed ($p < 0.05$) for a given parameter, multiple comparisons are made using the Duncan test at the 5% threshold.

2.3. Management of Revegetation of Cotton Plants at the End of the Cycle

2.3.1. Experimental Design

This activity was conducted at the Bouaké cotton research station, through two (02) trials.

- *Test* 1: *Evaluation of the effects of diuron applied as a defoliant and/or desiccant on the agromorphological and technological parameters of cotton*

This test was conducted using a Fisher block design with four replicates. The objects compared are described in **Table 3**.

- *Test* 2: *Evaluation of the effects of ethephon applied as a defoliant and/or desiccant on the agromorphological and technological parameters of cotton*

This test was conducted using a Fisher block design with four replicates. The objects in comparison are described in **Table 4**.

2.3.2. Observations and Measurements of the Morphological Parameters of Cotton

Observations were made on 10 plants chosen from the four central lines, taking care to leave 2 m at each end of each line. On the first of the three lines, three

Table 3. Defoliant/desiccant rates and application periods in Trial 1.

Treatments	Defoliant Rates (mL/ha)	Date d'application (JAL)
T1	0	100
T2	31.3	100
T3	62.5	100
T4	125	100
T5	0	120
T6	31.3	120
T7	62.5	120
T8	125	120

Table 4. Defoliant/desiccant rates and application periods in Trial 2.

Treatments	Ethephon Doses (l/ha)	Date d'application (JAL)
T1	0	100
T2	1	100
T3	2	100
T4	4	100
T5	0	120
T6	1	120
T7	2	120
T8	4	120

consecutive plants were chosen by the observer. He then makes a lateral move to reach the second line. On this line, the observer travels 1 linear meter and chooses two successive plants. The same lateral movement is made to reach the third line. At this level, he travels another 1 meter and chooses two consecutive plants. The same lateral movement is made to reach the fourth row where three plants are chosen. This made it possible to have 10 plants per elementary plot.

- **Stands after the demarriage and at the harvest**: After the demarriage and at the harvest, the plants on the four central lines of 10 m long were counted by elementary plot.
- **Plant height (cm):** The height of the main stem (HT) was measured from the cotyledonary nodes to the apex of the plant. Measurements were taken on the 30^{th}, 60^{th}, 90^{th}, 120^{th} day after emergence (DAE) and at harvest.
- **Caulinar growth rate:** The caulinar growth rate (VC) of cotton plants, in cm/day, was determined from the curve of the evolution of plant heights [5]. It was calculated by the following formula:

$$\text{Speed}(\text{cm/j}) = \frac{H_F - H_I}{\text{Number of days between HF et HI}}$$

HI: Initial height of the cotton plant

HF: Final Pitch

- **Number of nodes:** Nodes were counted at the 60th, 90th, 120th JAL and at harvest.
- **Defoliation rate:** For each of the plots, live leaf counts were carried out on the 10 randomly selected plants. These counts were conducted prior to application and every seven days after application until the last seed cotton harvest [6]. Thus, the defoliation rate was calculated according to the equation below:

$$\text{Defoliation rate} = \frac{\text{NF2} - \text{NF1}}{\text{NF1}} \times 100$$

NF2: Final number of live leaves

NF1: Initial number of live leaves

- **Leaf desiccation rate:** For each plot, counts of live leaves (fresh leaves still green) and dried leaves were performed before and every seven days after application until the last harvest of seed cotton [6]. Thus, the desiccation rate was calculated according to the equation below.

$$\text{Desiccation rate} = \frac{\text{NS2} - \text{NS1}}{\text{NS1}} \times 100$$

NS2: Final Number of Dry Leaves

NS1: Initial Number of Dry Leaves

- **Number of vegetative and fruiting branches:** The count of vegetative and fruiting branches was carried out at harvest. These branches are counted from those between the cotyledonary nodes and the apex of plants.
- **Average number of green Boll:** Out of the ten labelled plants in the four rows green capsules were counted at the 60th, 75th, 90th and 105th JAL.
- **Rate of flower bud and green capsule shedding:** This operation was performed from the 60th and 90th JAL. It consisted of counting the flower buds and green capsules that had fallen off, in order to obtain an indication of the intensity of the temporary loss suffered by the plants, according to the treatments (sowing densities). To do this, after collection, a sorting was carried out to distinguish healthy or attacked organs (with a hole or insect bites). This activity was done every 3 days in the two interlines of the three central lines, leaving 2 m at each of the two edges.

2.3.3. Observations and Measurements of Production Parameters

- **Boll opening rate:** In each of the elementary plots, all capsules on plants were counted as well as those that were opened. Once these observations were made, the opening rate of the green capsules was determined using the following formula:

$$\text{Boll opening rate} = \frac{\text{N2}}{\text{N1}} \times 100$$

N2: number of boll opened

N1: total number of boll

- **Boll Average weight (BAW)**: After total opening of the bolls, out of five cotton plants belonging to the lateral lines of each of the elementary plots, three bolls in position 1 of the fruiting branches (BF) were harvested. These capsules were collected from the BFs in the low, middle and terminal positions [7]. The PMP was calculated per plot by dividing the total weight of seed cotton by the number of bolls harvested.
- **Sanitary analysis of green capsules (ASCV):** Three to six weekly sanitary analyses (ASCV) were carried out on 25 greens capsules of the same age (with a diameter greater than 2 cm) per elementary plot between the 80th and 115th DAE. The harvested green bolls were carefully dissected with a knife, to determine which ones had internal rot and which were healthy. Eventually, the rate of healthy and rotten capsules was determined as well as the number of lepidopteran larvae encountered.
- **Seed cotton yield:** The seed cotton was harvested from the four central lines of 8 m long while taking care to leave 1 m of border at the 2 ends of each line. The harvesting area was: 4 rows × 0.8 m × 8 m = 25.6 m^2.

2.3.4. Statistical Analyses

The data collected were subjected to an analysis of variance (ANOVA) under the R.4.0.1 software, after verification of the normality of the distribution. When a significant difference is observed ($p < 0.05$) between seeding densities (treatments) for a given parameter, multiple comparisons are made using the Duncan test at the 5% threshold.

3. Results

3.1. Monitoring of Yield Trends as a Function of Sowing Densities in Farmer Areas

- **The case of CIDT zones**

In CIDT zones, sowing density explains a significant part of the yield variations ($R^2 = 0.1884$; $r = -0.434$; $p = 0.000$) (**Figure 1**). The best yields were observed with densities between 30,000 and 40,000 plants/ha (**Figure 2**).

- **Case of COIC zones**

A weakly positive and non-significant relationship was observed between yield and seeding density in COIC ($R^2 = 0.0033$ $r = 0.058$ $p = 0.458$) (**Figure 3**). However, the highest yield was given by seeding densities ranging from 60,000 to 80,000 plants/ha (**Figure 4**).

- **Case of SECO zones**

The analyses revealed a negative and significant relationship between yield and seeding density in the SECO zone ($R^2 = 0.0513$; $r = -0.226$; $p = 0.035$) (**Figure 5**). Seeding rates between 60,000 and 90,000 plants/ha yielded the best yields (**Figure 6**).

- **Ivory Cotton zones**

A positive and significant relationship between yield and seeding density in the

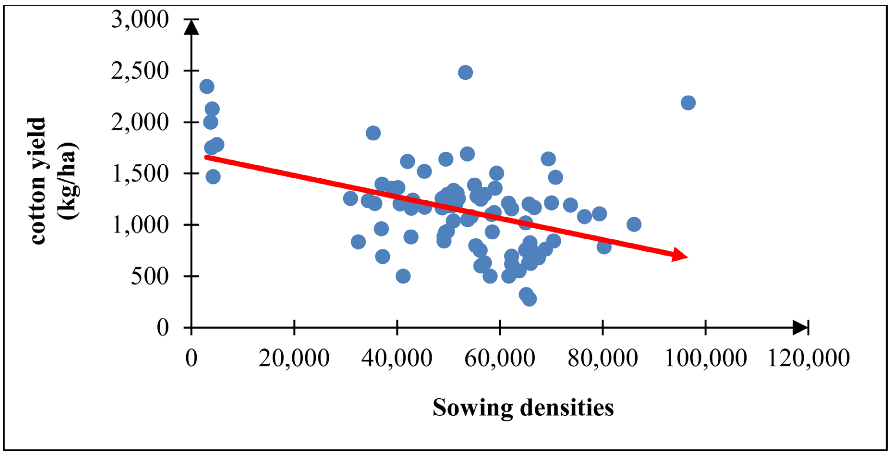

Figure 1. Relationship between yield and sowing density in CIDT zones.

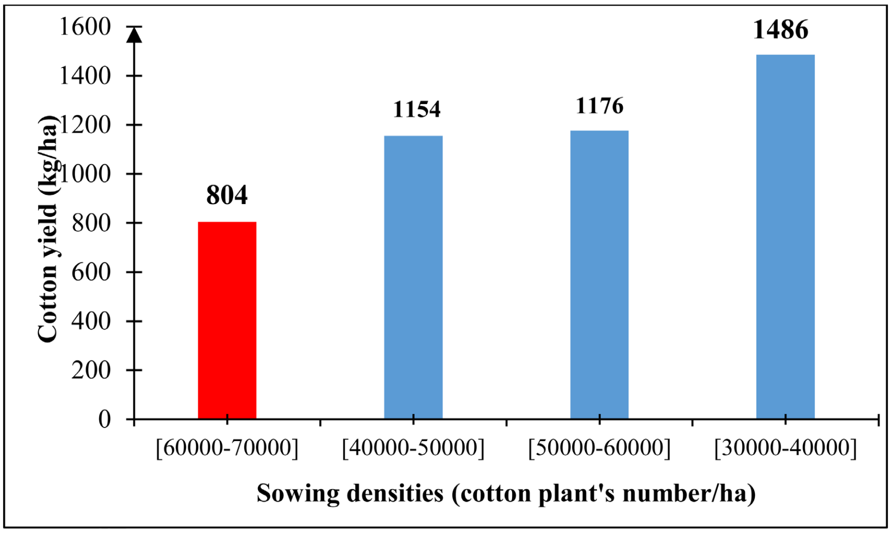

Figure 2. Yields as a function of sowing densities in CIDT zones.

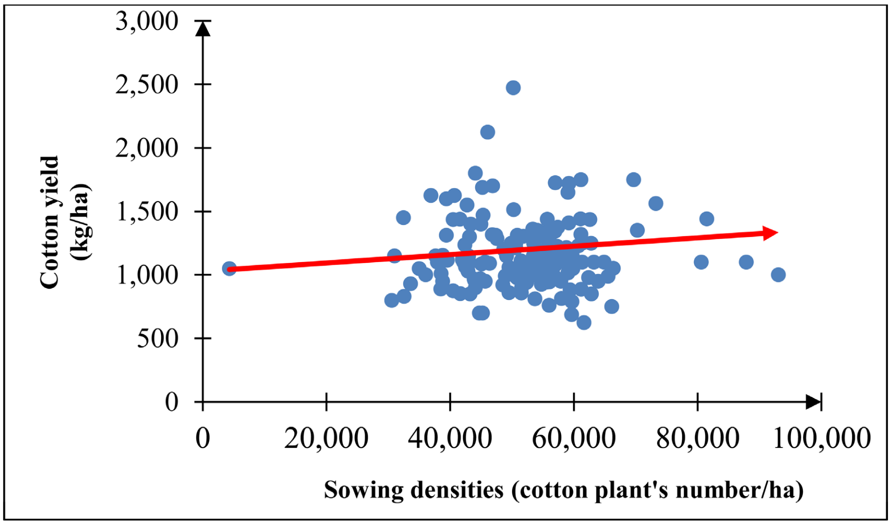

Figure 3. Relationship between yield and sowing density in COIC areas.

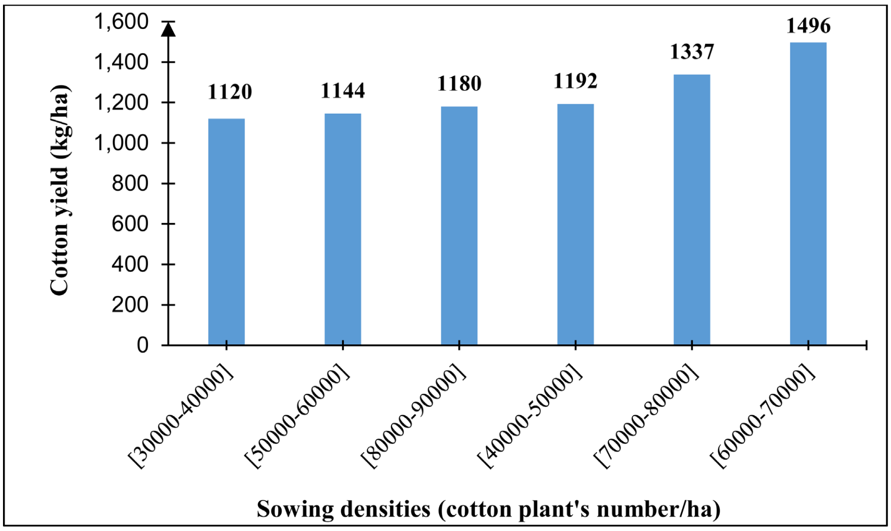

Figure 4. Yields as a function of sowing densities in COIC areas.

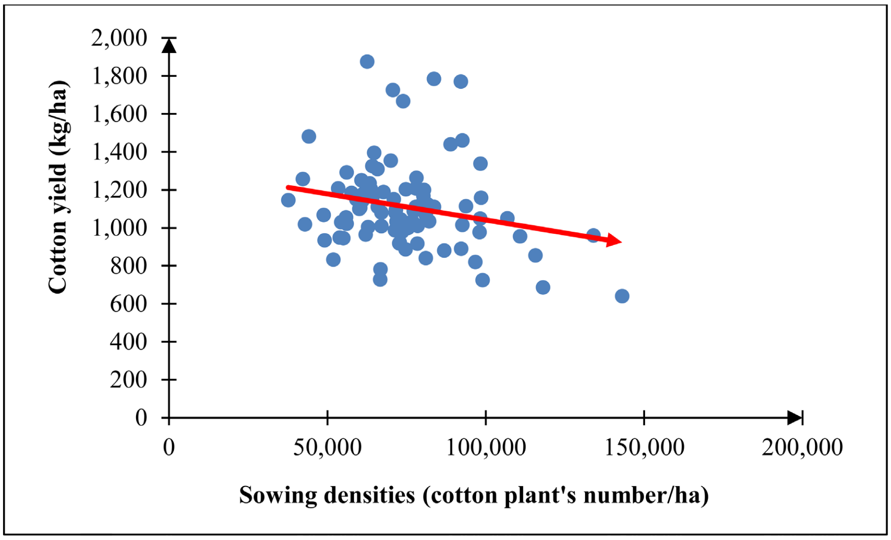

Figure 5. Relationship between yield and sowing density in the SECO zone.

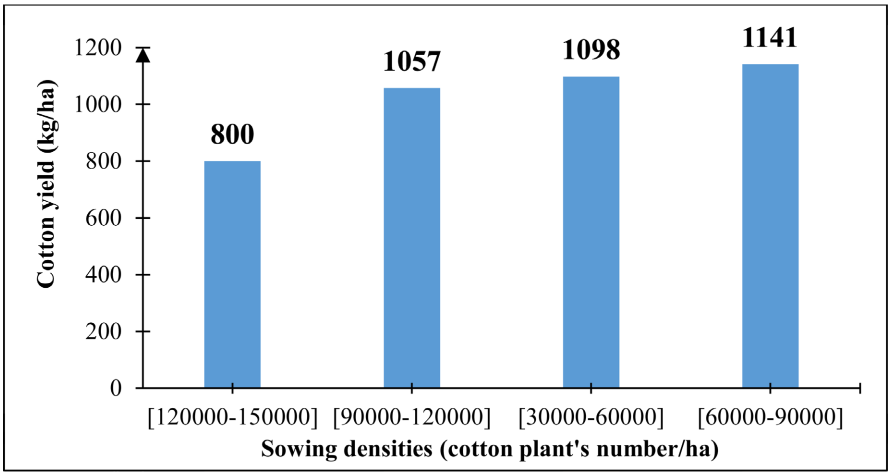

Figure 6. Yields as a function of sowing densities in the SECO zone.

Ivory Cotton zone $R^2 = 0.0874$; $r = 0.296$; $p = 0.001$ was observed (Figure 7). Increasing seeding density would lead to an increase in yield. The best yields were given by densities between 80,000 and 100,000 plants/ha (Figure 8).

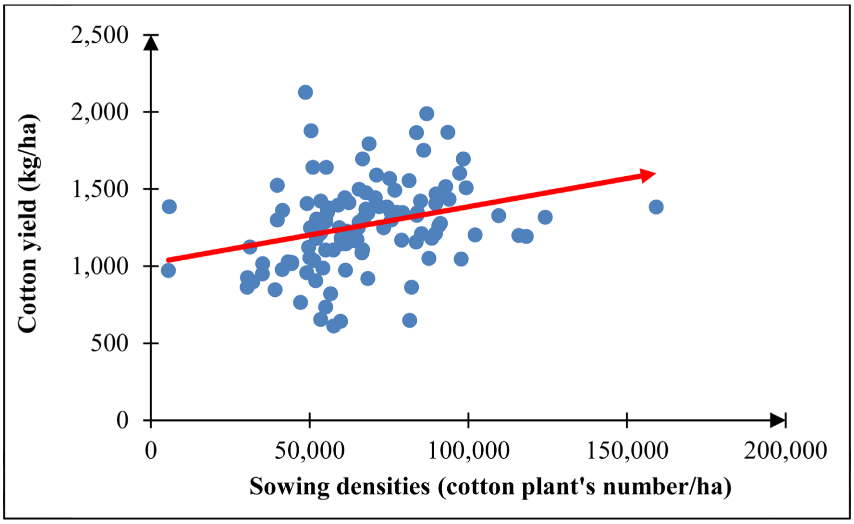

Figure 7. Relationship between yield and sowing density in the Ivory Cotton zone.

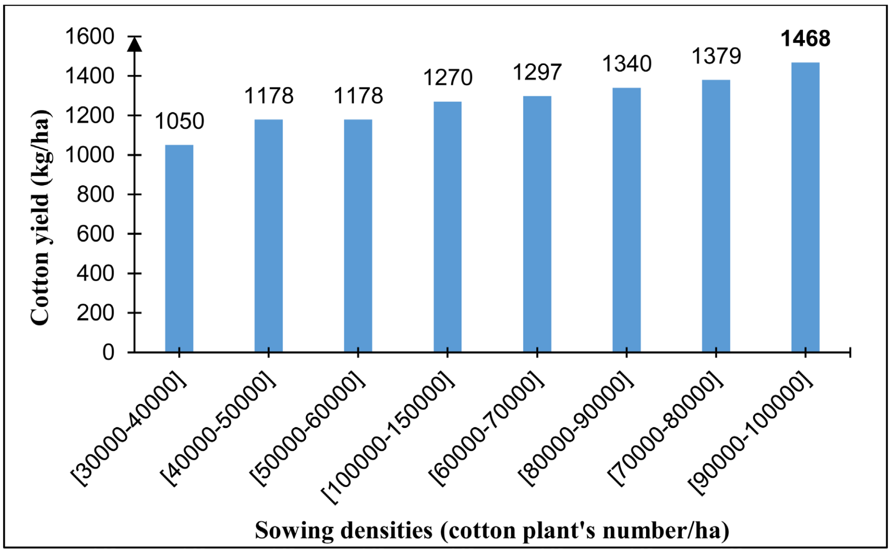

Figure 8. Yields as a function of sowing densities in the Ivory Cotton zone.

3.2. Assessing the Effects of Seeding Densities on Cotton Yields

3.2.1. Effects of Seeding Density on Growth and Production Parameters

The growth and production parameters at the different sites as a function of seeding densities are presented in Table 5.

On the Seguela PO, the best yield was obtained with the low sowing densities based on spacings of 90 to 100 cm between rows and 15 to 30 cm between pockets.

At the Nambingué PO, it was the densities based on a spacing of 90 to 100 cm between the rows and 10, 15 and 40 cm on the row at a rate of 1 or 2 plants per pocket that gave the best yields.

At the Boundiali PO, the high densities with cotton rows spaced 70 cm apart and spacings of 15 and 25 cm between the plants, unmarried to 1 or 2 plants/pocket which were better.

Finally, in Bouaké, the best yields were obtained with sowing densities based on spacings of 80 and 100 cm between rows and 10 to 20 cm between pockets, unmarried to 1 or 2 plants/pocket.

Table 5. Growth and production parameters at different sites as a function of sowing densities

Sites	Densities (geometry)	HREC	CC (nb/plt)	STD	PMC	RDT
PO Séguéla	74,074 (90 cm × 15 + 1Pl)	133	12	51,250	6.450	**2812**
	66,666 (100 cm × 30 + 2Pl)	125	15	41,812	6.425	**2760**
	66,666 (100 cm × 15 + 1Pl)	145	13	36,750	6.650	2646
PO Nambingué	55,555 (90 cm × 40 + 2Pl)	105	05	31,875	4.45	**1018**
	66,666 (100 cm × 15 + 1Pl)	106	04	40,697	6.20	854
	111,111 (90 cm × 10 + 1Pl)	94	03	53,611	5.77	821
PO Boundiali	142,857 (70 cm × 20 + 2Pl)	132	16	54,642	5.48	**1398**
	114,285 (70 cm × 25 + 2Pl)	127	15	56,071	5.56	**1339**
	83,333 (80 cm × 15 + 1Pl)	131	14	43,125	5.46	1236
Bouaké Cotton Station	83,333 (80 cm × 15 + 1Pl)	117	13	46,093	6.73	**1983**
	100,000 (100 cm × 20 + 2Pl)	104	12	39,562	6.70	1813
	125,000 (80 cm × 10 + 1Pl)	103	09	50,625	6.55	1797

H90: Height 90 JAL, CC: Capsular Load (Average Number of Capsules/Plant), STD: Stand at Harvest, PMC: Average Capsular Weight, RDT: Yield.

3.2.2. Effects of Seeding Density on Health Parameters

At the experimental station (Bouaké) and at the OP (Seguela), sowing density had no significant effect on pest attacks (Table 6).

3.3. Improvement of Cotton Productivity by the Addition of Zinc Sulphate

Effects of Zinc Sulphate doses on Growth and Production Parameters

Analyses of the campaign data (Table 7) indicate that the optimal rate would be 2 kg/ha $ZnSO_4$/ha. This dose generated a gain of about 35,100 CFA francs/ha.

3.4. Management of Revegetation of Cotton Plants at the End of the Cycle

3.4.1. Effects of Ethephon Applied as a Defoliant and/or Desiccant on Agromorphological Parameters

The different doses of ethephon reduced the growth rate and increased the defoliation rate and the capsule opening rate, respectively. The rate of 4 L/ha at

Table 6. Effects of seeding density on health parameters.

Sites		Cap.S (%)	Cap.P (%)	Cap.T (%)	BEM/30 plts	JASS/30 plts
Bouake Cotton Station	AVG.	22.80	1.71	0.35	13.5	46.4
	MIN.	2	0	0	1	1
	MAX.	25	11	4	84	182
	P	0.866	0.883	0.455	0.933	0.578
	SIG.	NS	NS	NS	NS	NS
PO Seguela	AVG.	21.45%	2.44%	0.97%	60.95	108.3
	MIN.	0%	0%	0%	28	49
	MAX.	25%	25%	7%	118	184
	P	0.684	0.777	0.216	0.612	0.757
	SIG.	NS	NS	NS	NS	NS

Cap. S: Healthy green capsule rate, Cap. P: Rate of rotten green capsules, Cap. T: Rate of green bolls with holes, BEM: Average number of whiteflies (*Bemisia Tabaci*/30 plants), JASS: Average number of jasside/30 plants.

Table 7. Parameters of growth, production and financial profitability of fertilizers supplemented with $ZnSO_4$.

Fertilizers	HREC	PMC	GDR	GAIN/LOSS	RevADD
T0	79.50	5.08	742.17	−97.37	−216,798
FR	97.23	5.75	1464.83	0.00	–
FR + 1ZN	106.24	6.04	1484.36	1.32	6000
FR + 2ZN	108.36	6.64	1582.02	7.41	35,100
FR + 3ZN	109.86	6.13	1509.67	2.97	13,500
FR + 4ZN	102.86	5.84	1471.34	0.44	2100
FR + 5ZN	110.16	5.71	1451.81	−0.90	−3900
FR + 6ZN	108.73	5.28	1393.22	−5.14	−21,600

HREC: Harvest height, SML: Average capsular weight, RDT: Yield RevADD: Additional income.

100 days after emergence appears to be optimal for its effects on both growth (Table 8) and production (Table 9) parameters.

3.4.2. Effects of Diuron Applied as a Defoliant and/or Desiccant on Agromorphological Parameters

The different doses did not significantly alter the growth rate. However, they increased the defoliation rate and the opening rate of the capsules. The rate of 62.5 ml/ha applied at 100 days after emergence appears to be optimal for its effects on both development (Table 10) and production (Table 11) parameters.

Table 8. Growth parameters by ethephon rates and application dates.

Defoliants	VCC (cm/d)	TxDef (%)	TxOC (%)
T0	0.65	-	-
1 l/ha × 100 JAL	0.06	57	85
2 l/ha × 100 JAL	0.04	50	**90**
4 l/ha × 100 JAL	0.02	54	**90**
1 l/ha × 120 JAL	0.09	**64**	70
2 l/ha × 120 JAL	0.06	54	71
4 l/ha × 120 JAL	0.03	**65**	83

VCC: Growth Rate, TxDef: Defoliation Rate, TxOC: Green Capsule Open Rate.

Table 9. Production parameters according to the doses and dates of application of ethephon doses.

Defoliants	PRCT (%)	RDT (kg/ha)	GAIN (%)
T0	32.05	1021	-
1 l/ha × 100 JAL	78.26	1670	39
2 l/ha × 100 JAL	80.95	1738	41
4 l/ha × 100 JAL	82.26	2021	50
1 l/ha × 120 JAL	40.22	1426	28
2 l/ha × 120 JAL	38.18	1602	36
4 l/ha × 120 JAL	45.22	1563	35

PRCT: Early production, RTD: Seed cotton yield.

Table 10. Growth parameters by diuron dose and application dates.

Defoliants	VCC (cm/d)	TxDef (%)	TxOC (%)
T0	0.38	-	-
31.3 ml/ha × 100 JAL	0.34	51.48	40.00
62.5 ml/ha × 100 JAL	0.31	52.66	58.89
125 ml/ha × 100 JAL	0.32	60.84	56.39
31.3 ml/ha × 120 JAL	0.35	59.00	51.24
62.5 ml/ha × 120 JAL	0.37	43.76	34.52
125 ml/ha × 120 JAL	0.36	56.52	27.92

VCC: Growth Rate, TxDef: Defoliation Rate, TxOC: Green Capsule Open Rate.

4. Discussion

The survey in a farmer environment and the results of experiments in a controlled environment (PO and station) have shown a variation in the best densities depending on the production areas. Thus, in the southern part of the cotton basin,

Table 11. Production parameters according to the rates and dates of application of doses of diuron + Thidiazuron.

Defoliants	PRCT (%)	GDR (kg/ha)	GAIN (%)
T0	59.57	1904	-
31.3 ml/ha × 100 JAL	61.16	2211	13.91
62.5 ml/ha × 100 JAL	**67.40**	**2330**	**18.06**
125 ml/ha × 100 JAL	64.50	2275	16.31
31.3 ml/ha × 120 JAL	59.73	2062	07.67
62.5 ml/ha × 120 JAL	56.94	2197	13.33
125 ml/ha × 120 JAL	60.46	2148	11.36

PRCT: Early production, RTD: Seed cotton yield.

it is the low densities that give the best yields. This could be explained by an area where the soils are still much fertile [8] with significant rainfall (> sometimes to 1200 mm) [9]. In this production area of the cotton basin, cotton plants have a great growth and these low densities allow a good realization of sowing and fertilization operations, given the short distance between pockets.

However, in the northern part of the cotton basin, high densities seem to be better. This high density can be explained by a less productive environment [8], [9] and so producers use these high densities in order to cover the soil and create a micro-climate conducive to the development of cotton plants. The results of the survey and experiments showed an influence of sowing densities on yields. These results confirm the work of [10].

The results of the study on the supplementation of the bottom fertilizer (200 kg/ha of mineral fertilizer with an alcohol content of 15-15-15+6S+1B) with zinc sulphate in cotton production indicated that the dose of 2 kg/ha of $ZnSO_4$/ha resulted in the best yield. This dose generated a gain of about 35,100 CFA francs/ha. This positive effect of zinc input could be explained by the deterioration in the level of fertility (in major, secondary and trace elements) of the soils of the cotton basin. These soils are cultivated continuously without any significant input of organic matter or return of crop residues. These results are consistent with those of [11]-[13] on coffee and cotton. They showed that the contribution of zinc in fertilization played an important role in fruit set and retention, as well as in fruit yield and plant quality. These results are consistent with those of [14] who also observed that foliar application of zinc improved cotton growth parameters and yield under stressed conditions.

The study on the management of vegetation resumption at the end of the cycle showed that the application of 4 l/ha of Ethephon and 62.5 ml/ha of Diuron at 100 days after emergence improves defoliation and capsule opening for better management of vegetation recovery at the end of the season. The results of our work are contrary to those of [15] who showed that aggressive defoliation treatment decreased defoliation and increased desiccation, but did not influence yield or cotton fiber quality. This difference in the results could be explained by the type of molecule used as a defoliant.

5. Conclusions

The survey in a farmer environment and the results of experiments in a controlled environment have highlighted a variation in good densities depending on the production areas. Thus, low densities are adapted to the southern part, while in the northern part, high densities seem to be better.

Analysis of data from the 2023-2024 campaign indicated that the optimal dose of zinc sulphate would be 2 kg/ha $ZnSO_4$/ha. This dose generated a gain of about 35,100 CFA francs/ha.

Concerning the management of cotton revegetation at the end of the cycle, the dose of 4 l/ha of ethephon applied 100 days after emergence seems to be optimal, for its effects on both growth and production parameters. The dose of 62.5 ml/ha of diuron applied at 100 days after emergence appears to be optimal, for its effects on both development and production parameters.

Conflicts of Interest

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

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