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Complementary Irrigation Effect on Seed Cotton Yield in North Côte d'Ivoire

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Abstract

The study was set to assess a complementary irrigation effect on seed cotton yields in the Northern Côte d'Ivoire where the cotton is the main cash crop. Firstly, the soil samples were collected from the surface down to 30 cm depth and analyzed. The soil was sandy and silty. So, 65 kg of 46%urea and 285 kg of NPKSB15-15-15-6-1 were applied for its correction. Secondly, in a complete randomized blocks, four tests were conducted, within those were T0 (no complementary irrigation and no crop protection products and fertilizers), T1 (no complementary irrigation, with crop protection products and fertilizers, the cotton cultivation ongoing practice in the Northern Cote d'Ivoire, therefore the reference), T2 (complementary irrigation, along with crop protection products and fertilizers), T3 (only complementary irrigation, without any crop protection products and fertilizers). Thirdly, the tests were replicated in 3 blocks. As a result, from T1 to T2, the plants heights, the plants density at harvest period, bolls number per plant and seed cotton yields were respectively 88.58±1.78 vs 96.08±1.78 cm (+8.47%) at day 73; 53,934±1,260.78 vs 67,593±1,260.78 plants per ha (+25.32%); 23.11±0.81 vs 26.39±0.81 bolls per plant (+14.19%) and 1,616.26±67.86 vs 2,657.77±67.86 kg/ha (+64.44%). Conversely, the complementary irrigation led to higher pest damages on bolls, because 13±2.2% of T2 bolls were attacked, while just 4.6±2.2% of T1 bolls were damaged by insects' pest. Looking for solutions linked to climate change effects, a complementary irrigation in cotton farms in the Northern Côte d'Ivoire could be profitable to the cotton growers. Nonetheless, the farmers should pay a great attention to the pest management.

Keywords: climate change, complementary irrigation, Cote d'Ivoire, pest, seed cotton yield

1. Introduction

From 1970 to 2005, the rainfalls have drastically decreased in Côte d'Ivoire Northern regions (Brou et al., 2005). Indeed, before 1970, all northern regions were watered with more than 1000 mm a year. Sadly, due to climate change, Boundiali and Bouna regions' rainfalls have respectively decreased from 1600-1800 mm to 1200-1400 mm and from 1000-1200 mm to 800-1000 mm (Brou et al., 2005). Since the rain regime is unimodal in these regions with a single peak in August (Goula et al., 2010; Kouadio et al., 2011), rainfalls reduction jeopardizes crops' yields. Furthermore, Pastori et al. (2019) stated that climate change effects are perceptible on crops' yields due to increased extreme weather events frequency and intensity. As observed by Pastori et al. (2019), developing countries' populations rely mainly on agricultural products to meet their daily needs. So, taking a careful look at cash crops in West Africa, cotton production is an important income activity (Martin et al., 2005). In countries like Côte d'Ivoire, Burkina Faso, Tchad and Mali, seed cotton sales remain the main income source (FAO, 2018). For example, cotton cultivated lands were 2,313,422 ha in 2016, and 343,414 ha of them belonged to Côte d'Ivoire (PRPICA, 2017).

Unfortunately, far from seed cotton yields in Australia, China, Brazil and USA whose were respectively 5,500; 4,500; 3,800 and 2,700 kg/ha, in 2015; since 2000, seed cotton yields stagnated at 1,000 kg/ha in West African countries (FAO, 2018). Worst, PR-PICA (2017) reported an average yield below 1,000 kg/ha, similarly to Pakistan where the yield is about 713 kg/ha (Lakho et al., 2016). Nevertheless, In Cote d'Ivoire, these yields were lower than vulgarized cotton varieties potentials, whose were between 1,826 and 1,984 kg per ha (CNRA, 2006). In fact, these poor cotton productions were the result of integrated effects such as seeds quality, high temperature, drought, field plant density and insects' attacks (Tariq et al., 2017). According to Yang et al. (2014), a correlation was found between crop yields and cotton plants' density, while other factors were in optimal levels. Precisely, cotton yield increased with nitrogen fertilizer to a maximum and then decreased, so an appropriate quantity should be used (FAO, 2018).

Consistently, plants' yields remain closely linked to certain micro-environmental factors such as temperature, light transmittance and relative humidity (Yang et al., 2014; Assouman et al., 2016; Tariq et al., 2017). So, according to Pettigrew (2010), early planting appears to need irrigation to achieve its best yields. Thus, dryland cotton producers should not adopt an early planting production strategy (Pettigrew, 2010). When yields' improvements depend on irrigation, producers rely on water mobilization and its control (Pettigrew, 2010; Assouman et al., 2016). Worrying about water need is justified, because its scarcity over the crop cycle could be a serious matter (Luo et al., 2015; Assouman et al., 2016; Pastori et al., 2019). That's why, water stress must be minimized (Bednarz et al., 2000; 2005). Because no literature document gives an overview on complementary irrigation in Northern Cote d'Ivoire, this study assumed that complementary irrigation could allow a significant increase in seed cotton yield. In details, the objectives were the follow-up of (1) the plants' density, (2) the bolls' number per plant, and (3) pests' attacks on bolls. Finally, the aggregate effects of these components on (4) seed cotton yields was evaluated.

2. Materials and Methods

2.1 Experimental Site and Irrigation Equipment

The experiment took place at Nidieou village in northern Cote d'Ivoire, located between 9°57′ and 9°59′ latitude North and 6°35′ and 6°37′ longitude West. In the aim to perform the complementary irrigation program, a 7 m deep and 1 m diameter borehole was dug nearby the plot. Then, a 1000 liters' tank located at 135 m far away from the borehole was installed at 2 m height from the ground. Following, using a solar pump, water was pumped from the well to fill the 1000 liters' reservoir. Finally, the complementary irrigation was performed with a 6 sprinklers ramp and the nozzle flow was set at 1 cubic meter per hour, under 2 bars pressure. Thus, it allowed 16.7 mm flow rate per hour. During the water stress periods, the experimental plots were watered twice a day, between 6 and 7 AM and after 5 PM, lasting for 7 min (Petersen & Gulik, 2009). In a strict program, the irrigation was done the day after reaching rainfall limit of 3 mm and/or after 3 days without rain (2). In fact, the daily evapotranspiration was 4 mm per day (Petersen & Gulik, 2009) (1). The 2017-year rainfall records on experimental place helped to define the growing season from June to October 2018. So, the sowing took place from 28 to 30 May 2018, because 80% of the useful rainy season generally covered the period from 25 May to 3 November (Goula et al., 2010; Kouadio et al., 2011).

$$ET_c = K_c \times ET_o \quad (1)$$

where, ETC = Crop evapotranspiration, inch or mm; KC = Crop coefficient; ETO = Reference evapotranspiration for a grass reference, mm.

Each day, the ground remaining water was determined by removing the crop daily evapotranspiration and adding the effective precipitation or irrigation (Petersen & Gulik, 2009).

$$MSWDR = Previous\_Day\_MSWDR \times (ET_c \times PPT_e) \quad (2)$$

where, MSWDR = Remaining available water for plant growth, inch or mm; Previous day MSWD = Previous days maximum soul water deficit, inch or mm; PPTe = Daily effective precipitation, in or mm = (PPT – 5) × 0.75.

Two rain gauges at 3 kilometers apart, one in village and the other one on the experimental plot, allowed daily surveys. The weather radar site downloaded on a Samsung android mobile phone helped to read the daily temperature, relative humidity, wind speed and atmospheric pressure. These data were used to estimate cotton plant daily water requirements (Petersen & Gulik, 2009; Milly & Dunne, 2016).

2.2 Seed and Fertilizer

Regarding the inputs, seed variety Y616C, received from an established cotton company in Cote d'Ivoire, were used for the crop year 2018-2019, lot number 209. In addition, mineral fertilizer used was NPKSB 15-15-15-6-1. Furthermore, some insecticides' treatments were carried out with authorized products by the Ministry of Agriculture through its plant protection department. The table 1 displays the herbicides and insecticides applied. Following PRPICA (2017) recommendations. Finally, the insecticide treatments were performed every 10 days from day 35 to day 115 after germination.

Table 1. Herbicides and insecticides active components, and their doses per ha

Type	Active component and its content	Dose (L/ha)
Total herbicide	Glyphosate 360 g/L	3
Selective herbicide	Propaquizafop 100 g/L	0.8
Insecticide week 1	Emamectin 48 g/L + Acetamiprid 64 g/L	0.25
Insecticide week 2	Cypermethrin 36 g/L + Profenophos 300 g/L	0.5
Insecticide against boll warm 2nd generation	Indoxacarbe 240 g/L + Novaluron 80 g/L	0.2
Insecticide week 3	Acetamiprid 16 g/L + cypermethrin 72 g/L	0.5
Growth regulator	Mepiquat chloride 50 g/L	1

2.3 Experimental Design

The experimental design was based on 12 elementary plots of 300 m² (20 m × 15 m) each, in a randomized complete block design with 4 treatments and 3 replicates (Table 2) (Lakho et al., 2016).

Table 2. Experimental design display

Block 1	**Block 3**	**Block 2**
$T1_1$	$T0_3$	$T0_2$
$T0_1$	$T1_3$	$T1_2$
$T3_1$	$T3_3$	$T2_2$
$T2_1$	$T2_3$	$T3_2$

Note. T_0: No crop protection products and fertilizers, no irrigation; T_1: Crop protection products and fertilizers, no irrigation; T_2: Crop protection products and fertilizers, with irrigation; T_3: No crop protection products and fertilizers, with irrigation.

2.4 Soil Analysis and Fertilizer Corrections

The soil analysis helped to identify plant's nutrient requirements by knowing the soil type, pH and the various mineral components. Five samples were collected in May 2017 following the diagonal on one ha plot, at 30 cm deep. The samples were analyzed at the soil laboratory of National Polytechnic Institute F. H. B. The analysis results showed three basic parameters which were soil type, macronutrients and micronutrients components (Table 3a). According to Kouadio et al. (2018) conclusions, we may conclude that the plots were established on a sandy-silty soil. Indeed, there was a sand predominance for 74.35% (Table 3a). Therefore, due to this high sand content, this soil has a low retention capacity in exchangeable bases (Kouadio et al., 2018). Accordingly, regarding cotton growing conditions and recommendations (CNRA, 2006; Kouadio et al., 2018), cotton plant needs have been evaluated for fertilizers application (Tables 3b and 3c). Following, the quantities used per ha in T1 and T2 experimental plots were 280 kg for NPKSB-15.15.15.6.1 and 65 kg for urea-46% (Table 3c).

2.5 Sampling Method

In each plot, there were 25 lines separated by 80 cm; and on a single row 2 plants were separated by 30 cm; thus, a density of 83,333 plants per ha. The data were collected on 30 plants taken on 5 consecutive plants per row, using the sequential "diagonal" method (Michel et al., 2000; Nibouche et al., 2003) on each elementary plot. The surveys performed concerned vegetative growth, parasitic presence from day 30 after emergence, planting density and bolls production. Initially, the attacked bolls were counted by sampling 4 on 3 planting lines along the diagonal. After, the seed cotton production was estimated from 3 sub-plots of 4 planting lines over 3 meters diagonally per elementary plot, and then reported to yield per hectare (Nibouche et al., 2003). Importantly, officers from Cotton Company's management service, trained for this purpose, participated in parasitic observations and plants' density counting.

2.6 Statistical Analysis

The data were collected in triple and the statistical analyses were performed with XLSTAT, 2014 version, at 95% level of confidence. The least square means were separated according to Duncan's multiple range tests.

Table 3. Soil analysis results, chemicals' balances and fertilizers' application

(a) Analysis results

Items	Values	Items	Values
Clay (%)	12	pH KCl	4.7
Fine silt (%)	7	Mg^{2+} (Cmol+/kg)	0.253
Coarse silt (%)	6.65	K^+ (Cmol+/kg)	0.074
Coarse sand (%)	52	Density	1.4
Fine sand (%)	22.35	Na^+ (Cmol+/kg)	0.09
Nitrogen (%)	0.03	CEC (Cmol+/kg)	3.5
Carbon (%)	0.34	Fe (ppm)	76
Assimilable phosphorus (ppm)	164	Mn (ppm)	89
Total phosphorus (ppm)	700	Cu(ppm)	0
Water pH	5.6	Zn(ppm)	0

(b) Soil chemical balances

Ratio	Value	Comments on results	Average level value (Kouadio et al., 2018)
C/N	11.33	Normal mineralization	9 < C/N < 12
Mg/K	3.42	Lower limit	3 < Mg/K < 25
Ca/Mg	2.65	Lower than minimal level	3 < Ca/Mg < 5
K/CEC (%)	2.11	Lower limit	K/CEC ≥ 2 %

(c) Fertilizer applications per hectare

Nutrients	Dry matter export	Needs identification		Urea-46% (65 kg) + NPKSB-15.15.15 .6.1 (280 kg)
	50 kg urea, 200 kg NPK	Parameters	Correction Factors	
N	53	Sandy-silty soil	1.3	71.9
P_2O_5	30	Acid pH: 5.6	1.3	42
K_2O	30	Sandy-silty soil	1.4	42

3. Results and Discussion

3.1 Rainfalls From May to October 2017

The monthly average rainfalls on the experiment site were different from those of the entire zone. Generally, the rainfalls have been poor. For example, the rainfalls in the village fluctuated between the poorest 29.5 mm in October and the highest 369.25 mm in August. Similarly, on the experimental site, 29 mm in October (poorest) and 375.5 mm (highest) were recorded (Table 4). During this important vegetative period for cotton plant, rainfall totals were 996.7 mm in the village and 1,033.5 mm at the experimental site. Importantly, when Koné et al. (2017) collected the rainfalls data from 1993 to 2015, in cotton production zones, they reported a decrease from 330 to 280 mm (-15.15%) at Napié, and from 390 to 360 mm (-7.69%) at Tengrela. While, Koné et al. (2017) reported rainfalls between 326 and 396 mm in June and July on 2015, none of these performances has been observed on 2017. Thus, we may conclude that cotton production areas are becoming more and more dry, since the outputs were 168.7 in June and 143.85 mm in July in the village, and 172 mm in June and 153.2 mm in July on the experiment site. In reference to 320 mm (Koné et al., 2017), the rainfall decreases were about 149.65 mm [320 – (168.7 + 172)/2] in June and 171.47 mm [320 – (143.85 + 153.2)/2] in July. Nevertheless, August is still the rainiest month (Goula et al., 2010; Kouadio et al., 2011).

During the experiment, 7 water stress periods were identified. Facing this relative drought, complementary irrigations were necessary to overcome rainfalls shortage for cotton plant needs. Indeed, a severe water stress at a younger age can compromise a plant performance. For example, with irrigation reduction, *Acrocomia aculeata* seedlings' heights and stem diameters were reduced (Hernández et al., 2018). The 996 mm rainfall recorded was sufficient for cotton growth cycle. Konan et al. (2015) announced 700 mm for the water requirement, while Dekoula et al. (2018) mentioned 500 mm, depending on climatic zones and conditions. For a good vegetative development, the soil structure, its nutrients composition and the rainfalls frequency are all together important (Konan et al., 2015; Dekoula et al., 2018).

Table 4. Rainfalls, supplemental irrigations and ETP from May to October 2017

Observations	Periods						
	May	June	July	Aug.	Sep.	Oct.	Totals
Zone rainfall (mm)	65.35	168.7	143.85	369.25	220	29.5	996.7
Experiment zone rain (mm)	67.8	172	153.2	375.5	236	29	1,033.5
Supplemental irrigations (mm)	4	7	14	0	0	0	25.0
ET_C (mm)	166	136.1	134.4	133.8	133.2	155.6	859.1
Rainy day count	5	11	11	17	8	2	54.0
Number of irrigations days	1	2	4	0	0	0	7.0

The limiting factor was the soil water reserve between two rains. Based on daily evapotranspiration, supplemental irrigations were computed and applied for 4, 7 and 14 mm in May, June and July, respectively. Supplemental irrigations had significantly affected the plants growth. Indeed, future climate scenarios simulations showed that the best cotton productions were obtained with supplemental water irrigation (Luo et al., 2015).

3.2 Vegetative Growth

The plant heights (Table 5) significantly depended on treatments at day 73. The outputs were 96.08±1.78; 88.58±1.78; 63.28±1.78 and 45.19±1.78 cm for T2, T1, T3 and T0, respectively. Thus, cotton plant average heights in T2 (96.08±1.78 cm) was significantly higher than other treatments ($p < 0.05$). In comparison to the ongoing cotton cultivation practices which consist in applying crop protection products and fertilizers, without any irrigation (T1: 88.58±1.78 cm), an improvement has been achieved with the complementary irrigations. In effect, the additional 7.5±1.78 cm gain, thus an additional growth of 8.5%, at T2 results (96.08±1.78 cm) have been obtained with crop protection products and fertilizers' application along with supplemental irrigations. That 8.5% height improvement from T1 to T2 was significant ($p = 0.0029$). Moreover, the need for plant protection treatments could not be overshadowed by complementary irrigation. Indeed, plots T2 got a higher average than T3 (63.28±1.78 cm). Consistently, the 32.8±1.78 cm gap from T3 to T2, which represented an additional growth of 51.83% was highly significant ($p < 0.0001$). Similarly, non-irrigated and untreated plots with crop protection products and fertilizers (T0) delivered highly poor averages (45.19±1.78 cm), 18.09±1.78 cm height reduction, thus 28.58% less than T3 ($p < 0.0001$). In the same way, this positive complementary irrigation impact on *Acrocomia aculeata* seedlings was reported by Hernández et al. (2018). Cotton production requires a good rainfall distribution during the critical phases. According to Yang et al. (2014), growth, water use characteristics and yields vary with precipitations regime.

Table 5. Plant heights at day73

Tests	LS mean±SE	Interactions	LS mean±SE
T2	$96.08±1.78^{a}$	B3*T2	$99.80±3.08^{a}$
T1	$88.58±1.78^{b}$	B1*T2	$98.33±3.08^{ab}$
T3	$63.28±1.78^{c}$	B1*T1	$96.60±3.08^{ab}$
T0	$45.19±1.78^{d}$	B1*T3	$95.10±3.08^{ab}$
Blocks	LS mean±SE	B2*T2	$90.10±3.08^{b}$
B1	$83.80±1.54^{a}$	B3*T1	$89.37±3.08^{b}$
B3	$69.28±1.54^{b}$	B2*T1	$79.77±3.08^{c}$
B2	$66.77±1.54^{b}$	B2*T3	$49.83±3.08^{d}$
		B2*T0	$47.37±3.08^{d}$
		B1*T0	$45.17±3.08^{d}$
		B3*T3	$44.90±3.08^{d}$
		B3*T0	$43.03±3.08^{d}$

Note. Means within a column, in tests, blocks or interactions, followed by different letters are statistically different at $p < 0.05$ by Duncan's multiple range tests, LS: least squares, SE: Standard error.

A fertility gradient has been observed at the blocks' level for the plant heights. Indeed, the 14.52±1.54 cm additional growth for block1 (83.80±1.54 cm) against block3 (69.28±1.54 cm) represented a 20.96% height improvement, and that gap was highly significant ($p < 0.0001$). In contrast, block2 with 66.77±1.54 cm has similar achievements than block3 (p = 0.2498). Despite this block gradient, the overall results were consistent because each test was represented in each block.

3.3 Plant Density at Harvesting Season

During the sowing season, all plots had the same planting density of 83 333 plants per hectare. From an experimental plot to another, due to the combined effect of occasional drought stress and pest attacks, each single microenvironment changed from one to another. The table 5 shows the plant densities at the harvesting season. These outputs for T0, T1, T2 and T3 were respectively 20,139±1,260.78; 53,934.56±1,260.78; 67,593±1,260.78 and 34,895.56±1,260.78 plants per hectare. Admittedly, there were great variations between treatments (Table 6). In fact, T2 plots (67,593±1,260.78) which received a complementary irrigation had 25.32% higher plant density than the control areas T1 (53,934.56±1,260.78) ($p < 0.0001$). Also, that 6.7±1.3 plants per m^2 was the closest to the 6 plants per m^2 moderate density which leaded to the best yield (Khan et al., 2019). In contrast to Yang et al. (2014) conclusion, 3 plants per m^2 may lead to a poor soil coverage and a high competitivity between weeds and cotton plants for available soil water.

Additionally, the plots under irrigation without crop protection products and fertilizers T3 (34,895.56±1,260.78) had 73.3% higher plant density than the controls T0 (20,139±1,260.78) ($p < 0.0001$). Accordingly, irrigation avoid water shortage stress (Hernández et al., 2018). Hence, complementary irrigation allowed a better seed germination and improved plants viability for 73.3% by reducing water stress (Bednarz, 2005; Hernández et al., 2018). Again, T1 results were 54.6% higher than those of T3 ($p < 0.0001$), thus emphasizing on the crop protection products and fertilizers importance in cotton cultivation.

Table 6. Plant density per ha at harvest period

Tests	LS mean±SE	Interactions	LS mean±SE
T0	20,139.00±1,260.78^{d}	T0*B1	19,719.67±2,183.73^{g}
T1	53,934.56±1,260.78^{b}	T0*B2	18,798.00±2,183.73^{g}
T2	67,593.00±1,260.78^{a}	T0*B3	21,899.33±2,183.73^{fg}
T3	34,895.56±1,260.78^{c}	T1*B1	58,378.00±2,183.73^{bc}
Blocks	LS mean±SE	T1*B2	50,591.67±2,183.73^{d}
B1	44,100.00±1,091.86^{b}	T1*B3	52,834.00±2,183.73^{cd}
B2	46,429.00±1,091. 86^{a}	T2*B1	62,024.33±2,183.73^{b}
B3	41,892.58±1,091. 86^{b}	T2*B2	75,738.33±2,183.73^{a}
		T2*B3	65,016.33±2,183.73^{b}
		T3*B1	36,278.00±2,183.73^{e}
		T3*B2	40,588.00±2,183.73^{e}
		T3*B3	27,820.67±2,183.73^{f}

Note. Means within a column, in tests, blocks or interactions, followed by different letters are statistically different at $p < 0.05$ by Duncan's multiple range tests, LS: least squares, SE: Standard error.

The block results shown significant different averages. For example, B2 averaged 5.28% and 10.83% higher than B1 and B3 respectively (p = 0.0190). Recalling back plants' heights, B2 highest plants' density (46,429.00±1,091. 86) led to the poorest plants' heights (66.77±1.54 cm) (Table 5). Likewise, Khan et al. (2019) observed that cotton plants' density had a significant impact on plants' heights. Because the plants' density, the humidity and the temperature create a unique microenvironment, Khan et al. (2019) obtained better result of 6 plant per m^2, while the low density (3 plants per m^2) and the dense density (9 plants per m^2) gave unsatisfactory results. Early, Yang et al. (2014) concluded that 3 plants per m^2 may be the best density when the farm is covered area as a greenhouse.

3.4 Bolls Number per Plant

The bolls count per plant were 26.39±0.81; 23.11±0.81; 3.97±0.81 and 3.41±0.81 for T2, T1, T0 and T3, respectively (Table 7). So, the results varied tremendously. Like the growth, T2 outputs average was significantly higher than other treatments (p = 0.0040). In comparison to T1 (23.11±0.81), the bolls count per plant has been increased by 3.28±0.81 to reach T2 (26.39±0.81) and that 14.19% improvement was significant (p = 0.0040). Again, the plant protection products and fertilizers' applications importance were justified. After all, T2 had higher bolls count per plant than T3 (3.41±0.81) which was irrigated without further treatments. Of great concern, from T3 to T2, the 22.98±0.81 supplementary bolls represented a 673.9% increase, and the gap was highly significant ($p < 0.0001$). Finally, the non-irrigated and untreated plots T0 (3.97±0.81) and T3 got similar results ($p = 0.6258$).

The bolls count was positively correlated to the plants' density, like Zhi et al. (2016) concluded. At harvest, T2 and T1 had a density of 67,593.00±1,260.78 and 53,934.56±1,260.78 plants per ha, respectively. Subsequently, the boll counts per plant were 26.39±0.81 and 23.11±0.81, respectively for T2 and T1. In fact, when the soil is not directly exposed to the sun light, the humidity lasts longer along with a less competition between weeds and cotton plants for the available ground water.

Table 7. Bolls number per plant at day73

Tests	LS mean±SE	Interactions	LS mean±SE
T0	3.97±0.81^{c}	T2*B1	29.73±1.40^{a}
T1	23.11±0.81^{b}	T1*B1	26.20±1.40^{ab}
T2	26.39±0.81^{a}	T2*B2	25.67±1.40^{ab}
T3	3.41±0.81^{c}	T2*B3	23.77±1.40^{bc}
Blocks	LS mean±SE	T1*B3	22.43±1.40^{bc}
B1	15.49±0.70^{a}	T1*B2	20.70±1.40^{c}
B3	14.00±0.70^{ab}	T0*B3	6.37±1.40^{d}
B2	13.17±0.70^{b}	T3*B2	3.77±1.40^{d}
		T3*B3	3.43±1.40^{d}
		T3*B1	3.03±1.40^{d}
		T0*B1	3.00±1.40^{d}
		T0*B2	2.53±1.40^{d}

Note. Means within a column, in tests, blocks or interactions, followed by different letters are statistically different at $p < 0.05$ by Duncan's multiple range tests, LS mean: Least squares mean, SE: Standard error.

Nonetheless, the density cannot be increased over some limits, because the yield per boll decreases with an increasing cotton plants' density (Zhi et al., 2016). Afterward, the taller the cotton plants, more nodes there are, so more branches there are on the mainstem, therefore more bolls are produced (Bednarz et al., 2000). On day 73, T2 delivered the highest plants compare to T1 for 96.08±1.78 and 88.58±1.78 cm, respectively. An 8.5% height improvement at day 73, allowed 14.19% amelioration on bolls' count per plant at harvest. Even though, a low plant density leads to a high leaves' photosynthesis assimilation, the optimum density was higher than 3, but lower than 22 plants per m^2 on field (Bednarz et al., 2005). When the seed quality is no longer a matter, the seed cotton yields depend on good plants' densities, soil, ambient temperature, pest pressure and the rainfalls conditions (FAO, 2018).

3.5 Pest Damages on Cotton Bolls

Other than the water stress, seed cotton yields are seriously affected by pests' attacks on cotton plants' stems, leaves, bolls, and roots. The insects' pest counts for an important part (FAO, 2018). Bolls' pest damages percentage per plant varied with the tests (Table 8). The results were 4.6±2.2; 13.0±2.2; 27.8±2.2 and 33.3±2.2 for T1, T2, T3 and T0, respectively. From T1 to T2, the bolls' damage percentage increased by 182.61%, so showing a highly low pest impact on bolls in plots T1 compare to T2 ($p < 0.001$). Similarly, Koné et al. (2017) noted that permanent humidity allowed the development of *Jacobiella facialis* insects during the vegetative period. Moreover, *Helicoverpa armigera* bollworm can cause serious yields losses (Martin et al., 2005). Worst, these insects tend to develop a resistance for some insecticides (Tabashnik et al., 2002; Martin et al., 2005; Koné et al., 2017).

Without any agro pharmaceutical product application, T3 and T0 bolls were severely attacked by the pest insects, leading to 27.8±2.2 and 33.3±2.2% damages, respectively. The supplementary irrigation does increase bolls' damages percentage per plant. Because the bolls produce the seed cotton, in the aim to fight against bolls' insect pest such as *Helicoverpa armigera*, *Pectinophora gossypiella*, *Cryptophlebia leucotreta* and *Earias vitelli*, the world leading cotton producers, Australia, Brazil and China (Michel et al., 2000; FAO, 2018), are using the transgenic *Bacillus thuringiensis* cotton (Tabashnik et al., 2002; Yang et al., 2014; Luo et al., 2015).

Table 8. Damaged bolls' percentage per plant

Tests	LS mean±SE (%)	Interactions	LS mean±SE (%)
T1	4.6±2.2^{a}	T1*B3	2.8±3.6^{a}
T2	13.0±2.2^{b}	T1*B1	5.6±3.6^{a}
T3	27.8±2.2^{c}	T1*B2	5.6±3.6^{a}
T0	33.3±2.2^{c}	T2*B2	8.3±3.6^{a}
Blocks	LS mean±SE (%)	T2*B3	13.9±3.6^{a}
B1	18.8±1.9^{a}	T2*B1	16.7±3.6^{a}
B3	18.8±1.9^{a}	T3*B1	22.2±3.6^{ab}
B2	21.5±1.9^{a}	T0*B3	27.8±3.6^{ab}
Mean	19.7±1.9	T0*B1	30.6±3.6^{ab}
		T3*B2	30.6±3.6^{ab}
		T3*B3	30.6±3.6^{b}
		T1*B3	41.7±3.6^{c}

Note. Means within a column, in tests, blocks or interactions, followed by different letters are statistically different at $p < 0.05$ by Duncan's multiple range tests, LS mean: Least squares mean, SE: Standard error.

3.6 Seed Cotton Yield

Seed cotton yields exhibited a significant difference between tests (Table 9). The innovative approach T2 yield average (2,657.77±67.86 kg/ha) was 64.44% higher than T1 one (1,616.26±67.86 kg/ha). This 1,041.51 kg/ha yield increase from T1 to T2 was highly significant (p < 0.0001). Avoiding the water stress through a complementary irrigation contributed to a great improvement. Indeed, Bednarz et al. (2000) asserted that water stress avoidance and pest control allow a good seed cotton yield. Again, T1 yield average was 613.5% higher than T3's (226.51±67.86 kg/ha), because the pest control is a key point in cotton production (Tabashnik et al., 2002; Zhi et al., 2016; FAO, 2018). There was no significant difference between T3 and T0 (p = 0.6372). Definitely, these seed cotton yields confirmed that a complementary irrigation combined with crop protection products and fertilizers' treatment contributed to a significant improvement of seed cotton yield (Bednarz et al., 2005; Zhi et al., 2016). In the same way, with transgenic cotton plants, a complementary irrigation provided a very important benefit (Lakho et al., 2016; FAO, 2018).

Results at the blocks level showed that the average of yields differed significantly. Blocks 1 and 2 showed similar averages. In addition, blocks 1 and 2 averages were 25.45% higher than block 3, with respective probabilities (p = 0.0068) and (p = 0.0180).

Table 9. Seed cotton yield (kg/ha)

Tests	LS mean±SE (%)	Interactions	LS mean±SE (%)
T0	180.67±67.86^{c}	T0*B1	206.00±117.53^{e}
T1	1,616.26±67.86^{b}	T0*B2	184.00±117.53^{e}
T2	2,657.77±67.86^{a}	T0*B3	152.00±117.53^{e}
T3	226.51±67.86^{c}	T1*B1	1,990.77±117.53^{c}
Block	LS mean±SE (%)	T1*B2	1,574.33±117.53^{d}
B1	1,252.32±58.76^{a}	T1*B3	1,283.67±117.53^{d}
B2	1,252.33±58.76^{a}	T2*B1	2,546.30±117.53^{b}
B3	1,006.25±58.76^{b}	T2*B2	3,023.33±117.53^{a}
		T2*B3	2,403.67±117.53^{b}
		T3*B1	266.20±117.53^{e}
		T3*B2	227.67±117.53^{e}
		T3*B3	185.67±117.53^{e}

Note. Means within a column, in tests, blocks or interactions, followed by different letters are statistically different at $p < 0.05$ by Duncan's multiple range tests, LS mean: Least squares mean, SE: Standard error.

By avoiding water stress with a complementary irrigation during cotton production in the Northern Côte d'Ivoire, while applying fertilizers and a good pest management program, farmers can produce more than 2.5 metric tons of seed cotton per ha. While, CNRA (2006) promoted the cotton varieties whose yields were between 1,826 and 1,984 kg per ha, due rainfalls' uncertainties and shortages, the experimental plots delivered 1,616.26±67.86 kg per ha based on the current cultivation practices, thus a loss of 209.74 (-11.48%) and 367.74 kg (-18.53%) per ha, respectively. A complementary irrigation could help to get closer to the 2.7 metric tons per ha cotton yields in US (FAO, 2018). Even if, this objective is still far from 3.8 metric tons and more per ha observed in Australia, Brazil and China (FAO, 2018), it should be kept in mind that these countries are using a transgenic Bacillus thuringiensis cotton variety (Tabashnik et al., 2002; Yang et al., 2014; Luo et al., 2015).

4. Conclusion

The complementary irrigation helped to avoid the water stress period and leaded to a significant yields' improvement. It contributed to reduce the plants mortality, thus preserved their density through all the vegetative period. Overall the seed cotton yields had been significantly improved by enhancing it from 1,616.26±67.86 to 2,657.77±67.86 kg/ha. So, regarding the adaptation to climate change effects, cotton growers in North Côte d'Ivoire should consider a complementary irrigation system because it allowed 64.44% seed cotton yield increase. But the complementary irrigation induced a high insects' attacks up to 8.4%. Thus, cotton growers should apply appropriate pesticides in addition to optimal fertilizers' doses.

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