JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2023, 24(6), 75–85
https://doi.org/10.12911/22998993/162587
ISSN 2299–8993, License CC-BY 4.0

Received: 2023.03.14
Accepted: 2023.04.17
Published: 2023.05.01

Productivity of Cotton in Association with Food Crops in Soil without Nutritional Assistances

Silvia Lorena Montero-Cedeño[1*], Ernesto Gonzalo Cañarte-Bermúdez[2], Jose Bernardo Navarrete-Cedeño[2]

[1] Escuela Superior Politécnica Agropecuaria de Manabí, MFL, Calceta, Ecuador
[2] Instituto Nacional de Investigaciones Agropecuarias, Portoviejo, Ecuador
* Corresponding author's e-mail: smontero@espam.edu.ec

ABSTRACT
Intercropped systems have agro-ecological and socioeconomic advantages over monocultures. Cotton is used in systems associated with food crops as an option to increase sustainability in family farming. The objective of this research was to evaluate the productivity of cotton in association with food crops, without using any nutritional assistance in the soil. This study was conducted on the rainy season of 2020 in Manabí-Ecuador. Six treatments were performed: four treatments related with the association of cotton with peanut, cowpea bean, field corn, and sweet corn; and two treatments with cotton monoculture (with and without soil fertilization). Agronomic, productive, and phytosanitary variables were evaluated in 60 m^2 experimental plots. A randomized complete block design with four replications was used. The results determined that cotton yield in the association with peanut was significantly equal to the monoculture with and without fertilization. In the intercropped food crops, there was a reduction in production in relation to the monocultures. However, it was the peanut in association with cotton with the lowest reduction, in addition to presenting the best Land Equivalence Ratio (1.71) and the best Marginal Rate of Return (120.56%), which suggests that this association is a viable alternative and easy to adopt by the small cotton producer.

Keywords: competence, *gossypium*, land equivalent ratio, productivity.

INTRODUCTION

In Ecuador, cotton production had a great impact on agriculture between the 70s and 90s. However, economic and climatic events led to the near disappearance of cotton in this country (Food and Agriculture Organization of the United Nations [FAO], 2018b), where the productivity reduced from 36000 ha in 1974 to less than 1000 ha in 2018 (FAO, 2018a). Consequently, the production nowadays is too small to supply the national demand of 20000 tons of cotton fiber (INIAP, 2018). Currently, Ecuadorian cotton growers are family farmers and all cultivation practices are carried out manually, requiring a large amount of physical work (FAO, 2018c). As consequence, the production cost in the rainy season is 1425 USD ha^{-1} (INIAP, 2018), which is considered a high cost for small cotton growers. Several factors have caused the reduction of the cultivated area in Ecuador; for example, low sales prices, high production costs, as well as the slow growth of the crop in its initial phase. Besides, the length of the growth cycle last between 150 and 160 days, at 600 mm of rain precipitation, 28 °C, 650 hours of light at 160 meters at above sea level. Other difficulties are soil degradation which remains without cover for a large part of the year, the exploitation time, and the high rate of water erosion, which make the cotton system unsustainable (INIAP, 2018; 2019).

Under such environmental difficulties, it is necessary to foster new production alternatives for small cotton production in Ecuador, allowing the sustainability of the crop. One of these options is the use of intercropped systems, an association of cotton with food crops with a shorter cycle and higher planting density. By intercropped systems, there would be a decrease in production costs by minimizing weed control work. Besides, having an economic income (Aguirre, 2017) between the planting and harvesting is also an alternative for cotton small production.These systems aim not only to improve the producer's diet and income but also to reduce the concern of having production losses (Araújo et al., 2006; Agegnehu et al., 2006; Ebel et al., 2013) which are caused by external environmental factors and phytosanitary problems. Intercropped systems are widely used in other crops such as castor bean (*Ricinus communis* L.) (Pinto, 2011; Furtado et al., 2014), which is one of the crops that most favors soil and water loss, due to the low protection that this system offers against erosive factors (Rasche Alvarez et al., 2015). Intercropping is a common agricultural practice for small farmers with limited area available for production, mainly in tropical and subtropical areas (Pinto, 2011), where the decomposition processes of organic matter is accelerated, being a good alternative to maintain greater stability of soil dead cover, thus reducing soil erosion (Rasche Alvarez et al., 2015).

One of the principles for crop association is the complementarity of crops. In this system, the use of crops from different botanical families is recommended (Teixeira & Mota, 2005; Teixeira et al., 2012; Furtado et al., 2014). Therefore, crop associations can become an easy-to-apply technology for family farmers because the objective is to maximize available resources such as usable area, labor, and inputs (Agegnehu et al., 2006). However, one of the great challenges is to determine the most convenient associations (Rezende et al., 2005). Several studies demonstrate the effectiveness of crops such as corn (*Zea mays* L.), beans (*Phaseolus vulgaris* L.), cowpea (*Vigna unguiculata* L.), sorghum (*Sorghum bicolor* L.), peanut (*Arachis hypogaea* L.), sesame (*Sesamum indicum* L.), in association with other crops (Rasche Alvarez et al., 2015). In this sense, cotton is suitable for production in systems associated with food crops (corn, beans, peanuts, beans, wheat, among others), as an option to reduce environmental impacts, phytosanitary problems, an increase of beneficial fauna, decrease of economic losses (Gómez-Rodríguez & Zavaleta, 2001; Ebel et al., 2013), a help to increase land-use efficiency (Abd El-Hady and El-Khatib, 2002; Ebel et al., 2017), and even total yield (Li et al., 2009), making the cotton crop sustainable.

The aim of this research was to evaluate the agronomic, productive, and economic response of cotton to its association with several food crops (peanut, cowpea, field corn, and sweet corn), in soil without fertilization assistance. The outlook of this research is to offer a sustainable technology for small cotton farmers, which allows growing the crop without inorganic fertilization.

MATERIALS AND METHODS

Location

This research was conducted during the rainy season of 2020, in the experimental area of the "Escuela Superior PolitécnicaAgropecuaria de Manabí (ESPAM-MFL)", located in El Limón, Calceta parish, Bolívar canton, province of Manabí (00°49'27.9" S; 80°10'47. 2" W and 15 m a.s.l.); with the following environmental conditions (851.57 mm; 26.4 °C; 81% RH and 1 604 hours of sunshine), flat topography and clay- loamy soil.

Description and management of the experiment

The growing response of cotton variety Coker (2019 sowing season) was studied at intercropping conditions, using the following plants:peanut (*Arachis hypogaea* L.); cowpea (*Vigna unguiculata* L.); field-corn (*Zea mays* L.), and sweetcorn (*Z. mays* L.). Six treatments were tested:

- cotton with peanut (0.5 × 0.2 m = 10 rows);
- cotton with cowpea (0.5 × 0.2 m = 10 rows);
- cotton with field corn (0.1 × 0.2 m = 4 rows);
- cotton with sweetcorn (0.1 × 0.2 m = 4 rows);
- monoculture cotton without fertilization and
- monoculture cotton with fertilization (control).

Plots of 60 m^2 (10 × 6 m) with three double rows of cotton were used. Besides, the plots were planted with association crops between the double rows. The soil was prepared with a tractor. The sowing was performed manually, at two different times. Cotton was planted, using the spacing according to the treatments: for intercropping (peanut, cowpea bean, field corn, and sweet corn), three double rows of cotton (1 × 0.3 m) were used, each double row separated by three meters, while the two cotton monoculture plots (with and without fertilization) were planted in continuous rows (1 × 0.3 m). For weed control, a pre-emergent herbicide (pendimethalin 4 L ha^{-1}) and a post-emergent contact herbicide (paraquat 4 L ha^{-1}) were applied immediately after sowing; 20 days after sowing (das), the selective herbicide (haloxyfop-methyl 0.6 L ha^{-1}), was applied in post-emergence, plus two hand weeding during crop development. For arthropods control in the initial stages of the crop, cypermethrin at sowing and thiamethoxam (1 mL L^{-1} water) in drench at 15 days were applied.

Considering the nature of this study soil nutritional assistance was not applied in the treatments, except for the cotton plot with fertilization (check control), which had applications of urea + YaraMila®, using 205 kg ha^{-1}at 15 and 45 DAS. Sweetcorn and cowpea were harvested at 75 DAS both peanuts and field corn was harvested at 120 DAS. Finally, cotton was harvested only once at 150 DAS.

Data collection

For the evaluations, five randomized cotton plants were marked in each, those plants were used to record the following variables: Agronomic, germination percentage at 14 das; plant height at 27 and 110 das; stem diameter, number of branches/plant, and internode length (cm) at 110 and 131 das. Production: number of cotton bolls/plant (110 das); days to boll opening; weight (g) of 10 bolls (131 das); cotton yield (kg ha^{-1}) and boll weight (g) at 150 das. Phytosanitary: percentage of plants damaged by soil insects (*Agrotis* sp. and *Spodoptera* sp. at 14 das). For other arthropods, evaluation at 30 das was made by absolute sampling per plant, recording the number of arthropod specimens (pest and beneficial) in stem, leaves, flowers, and fruits in the five marked plants. Finally, we determined the percentage of diseased bolls per plot (110 das).

In the associated crops (peanut, cowpea bean, field corn, and sweet corn), evaluations of productive variables at the time of harvest were made, recording the weight of peanut with shell (kg ha^{-1}), the number of clusters ha^{-1} of cowpea bean (20 pods/ cluster); yield of field corn (kg ha^{-1}) and the number of bushels ha^{-1} (150 ears/ bushel) of sweet corn.

For the comparison of associated crop systems versus cotton monoculture, it was used the total Land Equivalent Ratio (LER), defined by Willey (1979) and cited by Teixeira y Mota (2005), using this formula (1):

$$LER = Px/Mx + Py/Uy \tag{1}$$

where: Px –yield of crop x in polyculture;
Mx –yield of$x$in monoculture;
Py –yield of crop y in polyculture;
Uy –yield of crop$y$in polyculture.

Treatments were assigned to plots following a randomized complete block design (RCBD) with six treatments and four replicates. Before submitting the data to the analysis of variance, the assumption of normality was tested using the Shapiro-Wilk test and homogeneity of variances by Bartlett's test. When the effects of the treatments were significant (≤0.05), mean comparisons were performed using Tukey's test at 5%. The Agricolae package of R Studio statistical software version 3.6 was used for the data analysis. Besides, economic analysis of the treatments was performed using CIMMYT methodology, with the calculation of the net benefit, variable costs, marginal rate of return and partial budget, (CIMMYT, 1998).

RESULTS AND DISCUSSION

No statistical differences were found in the germination percentage of the seed of Coker variety in cotton systems associated with four food crops. However, an average germination percentage of 78% was observed, above the results found by (*CAÑARTE 2020.Pdf*, n.d.), who reported a germination average of 58%.

To plant height (m), there were statistical differences (P=0.001) at 110 das, with the greatest plant height reached by the monoculture cotton without fertilization, which differed from the rest. While cotton with fertilization reached the lowest plant height. It should be considered that during this study the growth regulator mepiquat chloride was not used, which caused an uncontrolled growth of the cotton plants, which made harvesting difficult. This was verified by (*CAÑARTE 2020.Pdf*, n.d.), where they tested this same material with a growth regulator, achieving a maximum height of 1.25 m, much lower than our results, which obtained an average plant height of 2.15 m (Table 1). When the plant height of cotton associated with the monoculture was compared, it was determined that there was no response of cotton to the association with food crops. These results are contradictory to those cited by (*BELTRAO 1986.Pdf*, n.d.)), who claim that the association of cotton with cowpea caused a decrease in plant height in the order of 16 to 25%. This suggests that in associations with oilseeds such as peanuts, a symbiotic relationship is established with nitrogen-fixing bacteria, which is of great importance since this helps to replenish the N necessary for plant development (Araújo et al., 2006). At 110 das, according to Tukey´s test, cotton plants in monoculture plots without fertilization were significantly taller than those in monoculture plots with fertilization.

When cotton stem diameter (mm) was analyzed, ANOVA established significant statistical differences (P=0.005) between treatments.According to Tukey's multiple comparison procedure (≤0.05), it was in the association with peanut, that the cotton plants presented a greater stem diameter, very different from the association with field corn that had the smaller stem diameter. When comparing the stem diameter response of associated cotton with monoculture, there was no difference in diameter between associated and monoculture cotton plants, achieving an average diameter of 20.51 mm. (Table 1). These results are contradictory to those found by (Cañarte-Bermúdez, 2019) who state that the association of cotton with cowpea reduced the stem diameter of cotton, while in our research the cotton-cowpea association was the one that excelled increasing the diameter.

Regarding the number of branches/plant, ANOVA found significant statistical differences (P=0.005), with a higher number of branches in the association with sweet corn, significantly different according to Tukey (≤0.05) from the association with cowpea bean, which had the lowest number of branches/plant. Comparison between associated cotton and monoculture did not show differences in the number of cotton branches, with an average of 24.31 branches/plant (Table 1), which is related to the excessive cotton growth without the application of a growth regulator.

In the variable internode length (cm), ANOVA reported significant statistical differences (P=0.005) between treatments. Comparing the means with Tukey (≤0.05), it can be seen that the highest average value of internode length was obtained in the association with field corn, very different from the cotton monoculture with fertilization that presented the lowest average internode length, which is coherent with the lowest plant height observed in this treatment. The mean values of associated cotton were compared with monoculture cotton (with and without fertilization), statistical differences ($P<0.05$) were observed, being the cotton with fertilization the treatment with lower average of internode length (Table 1). The high values of internode length found in this experiment are a consequence of the non-use of the growth regulator, which caused the lengthening of the internodes (INIAP, 2018, 2019).

Analyzing the number of cotton bolls/plant, the ANOVA showed statistical differences between treatments (P=0.001) at 110 days,

Table 1. Average values of agronomic variables recorded in cotton associated with various food crops. 2020

Treatments	Plant height (m)		Stem diameter (mm)	Number of branch/plant	Internode length (cm)
	27 das	110 das	110 das	110 das	131 das
Cotton + peanut	0.24	2.10 abc	22.20 a	24.65 ab	5.74 ab
Cotton + cowpea	0.22	2.02 bc	21.50 ab	23.10 b	5.69 ab
Cotton + field corn	0,21	2.20 abc	18.70 b	23.40 ab	6.68 a
Cotton + sweet corn	0.22	2.26 ab	21.65 ab	25.65 a	5.55 ab
Cotton without fertilization	0.22	2.30 a	19.40 ab	25.25 ab	6.07 ab
Cotton with fertilization	0.22	2.02 c	19.60 ab	23.80 ab	4.40 b
Mean	0.22	2.15	20.51	24.31	5.69
P	*Ns*	0.001	0.005	0.005	0.005
CV (%)	9.26	4.96	7.09	4.30	13.65
Comparisons					
Cotton in association	0.22	2.14 ab	21.01	24.20	5.91a
Cotton without fertilization	0.22	2.30 a	19.40	25.25	6.07a
Cotton with fertilization	0.22	2.02 b	19.60	23.80	4.40b
P	*Ns*	0.001	*Ns*	*Ns*	0.001

Note: means with a common letter are not significantly different (p > 0.05), das – days after sowing.

obtaining the highest average value in the association of cotton with peanut, differing significantly from the others according to the Tukey mean comparison test (≤0.05). While, it was in the association with cowpea bean, where the lowest average value of cotton bolls/plant was found. There were no significant differences ($P>0.05$) in bolls yield between the associated cotton compared to the monoculture (with and without fertilization) cotton (Table 2).

The variable days before to cotton boll opening also showed significant statistical differences ($P=0.001$) in the treatments under study. According to Tukey (≤0.05), precocity was obtained in boll's opening when we associated cotton with field corn; they differed significantly from the plot of monoculture cotton with fertilization, which registered the longest time in days before to the opening of the cotton boll, this is true also for the group comparisons between cotton associated versus cotton monoculture with fertilization (Table 2). When the weight (g) of 10 cotton bolls at 131 das was analyzed, no statistical differences were found among the treatments evaluated. The same was true for comparisons between associated plots and monoculture (Table 2).

For the weight (g) of 10 whole cotton seeds (with linter), the ANOVA established significant statistical differences ($P=0.005$), highlighting the association cotton with sweetcorn, presenting the highest seed weight, compared to the association cotton with peanut, which registered the lowest weight. When the comparison of cotton associated with monoculture was analyzed, no differences were found, however, the average values of seeds weight in this experiment (7.6 g), were well above the satisfactory, which according to Farias et al. (1999), is for cotton 6.0 g/boll (Table 2).

There was a response of raw cotton yield (kg ha^{-1}) to the treatments under study. The ANOVA found significant statistical differences ($P<0.05$). Tukey´s mean comparison test (≤0.05), determined that the cotton system associated with peanut cultivation was significantly equal to the monoculture system without and with nitrogen fertilization, this intercropped system had the highest cotton yield in branch (Figure 1). These results contradict those reported by(Araújo et al., 2006), who cited a reduction in raw cotton yield in association with peanut, which could be due to the close spacing used between the cotton and peanut sowing line.

In our study, the cotton-peanut association met the principles for crop association, such as crop complementarity, in addition, to incorporate plant species from different botanical families (Agegnehu et al., 2006). Another interesting aspect of the cotton-peanut association was that it allowed a higher density of plants per area since 10 rows of peanuts were planted between the double rows of cotton, as opposed to the four rows of sweet and field corn. Therefore, the association of crops, in addition to the benefits in production and diversification, allows the small

Table 2. Average values of productive variables recorded in cotton associated with various food crops. 2020

Treatments	Number of bolls/plant	Days to bolls opening	Weight of 10 bolls (g)	Weight of 10 whole cottonseeds (g)
	110 das	das	131 das	150 das
Cotton + peanut	22.35 a	119.75 ab	360	70 b
Cotton + cowpea	11.85 c	119.75 ab	330	78 ab
Cotton + field corn	15.25 bc	110.00 b	340	73 ab
Cotton + sweet corn	19.25 ab	119.75 ab	350	85 a
Cotton without fertilization	16.55 abc	119.75 ab	340	75 ab
Cotton with fertilization	18.00 abc	126.50 a	310	75 ab
Mean	17.21	119.25	340	76
P	0.001	0.001	*Ns*	0.005
CV (%)	17.67	4.04	7.26	7.61
Comparisons				
Cotton in association	17.18	117.31b	345	76
Cotton without fertilization	16.55	119.75ab	336	75
Cotton with fertilization	18.00	126.50a	315	75
P	*Ns*	*0.005*	*Ns*	*Ns*

Note: means with a common letter are not significantly different ($p > 0.05$), das – days after sowing.

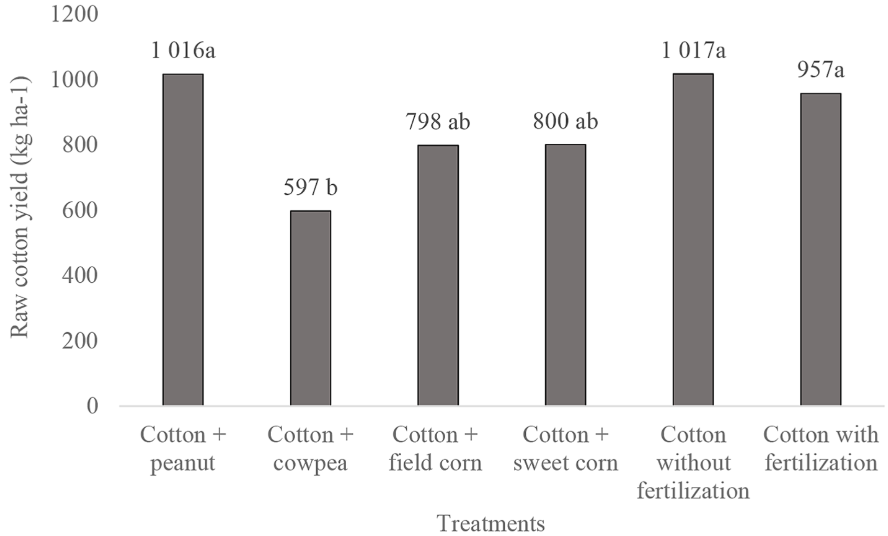

Figure 1. Average seed cotton yield values recorded in cotton intercropped systems with various food crops (2020); means with a common letter are not significantly different (p>0.05)

farmer to obtain indirect benefits such as better soil utilization, greater moisture, reduction of soil losses because of water erosion, greater coverage, nutrients recycling,due to the increase in the production of organic material, acceleration of the decomposition processes of organic compounds, increase in the activity of soil microorganisms and better weed control, which allows obtaining lower production costs of the main crop (Araújo et al., 2006; Pinto, 2011; Rasche et al., 2015). All this would help to reduce the problems of soil cover and water erosion caused by cotton monoculture. On the other hand, the association of cotton with cowpea beans presented a disadvantage, as it significantly registered the lowest yield of seed cotton, significantly which represents a 41% reduction in production compared to the cotton with peanut system (Figure 1). These results are supported by those found by Beltrao et al (1986), who tested several cowpea varieties in association with cotton, and determined a significant reduction in seed cotton yield, especially with those cowpea materials of indeterminate growth. This happened in our research, observing that the cowpea plants, close to the cotton sowing line, became climbers, overwhelming the cotton, causing a competition that involves several aspects of the ecological substrate, such as water, light, CO_2, mineral nutrients.

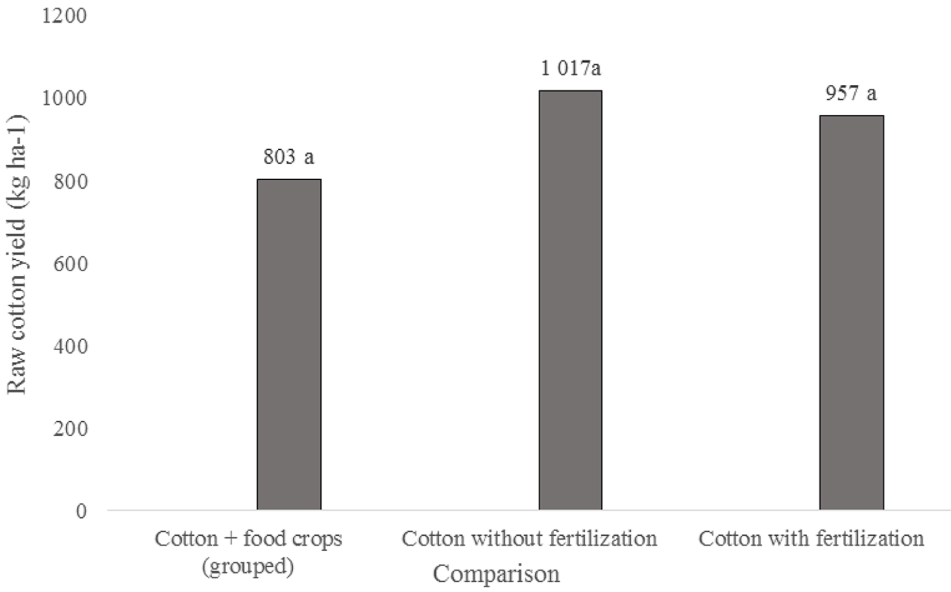

Figure 2. Comparison of average values of raw cotton yields intercropped with several food crops (grouped) and cotton monoculture without and with soil fertilization (2020); means with a common letter are not significantly different (p>0.05)

No differences in yield kg ha^{-1} were detected when comparing plots associated with food crops versus monoculture plots (with and without nitrogen fertilization) (Figure 2).

Regarding the incidence of arthropods, no significant statistical differences (P>0.05) were established in the percentage of plants damaged by the action of insects of the genera *Agrotis* and *Spodoptera* at 14 das, among the treatments under study. These results confirm the protective action of the seed treatment and the early application of insecticide in drench, which reduces the damage of these insect pests cited as important pests in the seedling stage of cotton (ICAR, 2010). These results are consistent with those reported by Sotelo-Proaño et al. (2022), who also argue that damage from these ground insects is controlled with seed treatment and early pesticide application.

Under the conditions of this research, we found the presence of a diversity of arthropod-pests with the following species standing out for their higher populations: whitefly *Bemisia tabaci* (Hemiptera: Aleyrodidae), thrips *Frankliniella* spp. (Thysanoptera: Thripidae), rootworms *Diabrotica* spp. (Coleoptera: Chrysomelidae), aphid *Aphis gossypii* (Hemiptera: Aphididae), leafhoppers *Sibovia* spp. (Hemiptera: Cicadellidae) and the leafminer*Lyriomyza* sp. (Diptera: Agromyzidae), however, no significant statistical differences (P>0.05) between treatments were reported for these species (Figure 3). These results are discordant with those presented by Ramalho and Gonzaga (1990), who argue that crop association affects insect populations through physical and biological factors. Similarly, Awaad & El-Naggar (2018), indicated that intercropped system (cotton and wheat) helps to reduce the presence of certain pests such as mole cricket *Gryllo talpa*, aphids *A. gossypii*, black cutworm *Agrotisipsilon*, and thrips *Thrips tabaci*, by reducing the amount of water used to irrigate these crops.

In addition, we observed the occurrence of a diversity of natural enemies associated with the arthropod pests living in the cotton plants, among them important predators such as spiders, ladybug *Cycloneda sanguinea* (Coleoptera: Coccinellidae) and the green fly *Condylostylus* sp. (Diptera: Dolichopodidae). These results are similar to those found by Ahmad *et al*. (2020), who mention that in cotton it is common to find a diversity of biological regulators. However, it is worth mentioning that there were no statistical differences among treatments in the presence of these predators (Figure 4). However, Ramalho and Gonzaga (1990), found that in the corn-peanut association, there was a substantial reduction of the corn borer (*Ostrinia* sp.), due to the presence of predatory spiders.

The presence of rotten cotton bolls due to the fungi *Lasiodiplodia* sp., *Fusarium* spp. and *Colletrotrichum*spp. was reported, diseases that have already been seen in cotton, grown in similar environments (INIAP, 2018; 2019; Cañarte et al., 2020). From the analysis performed on the

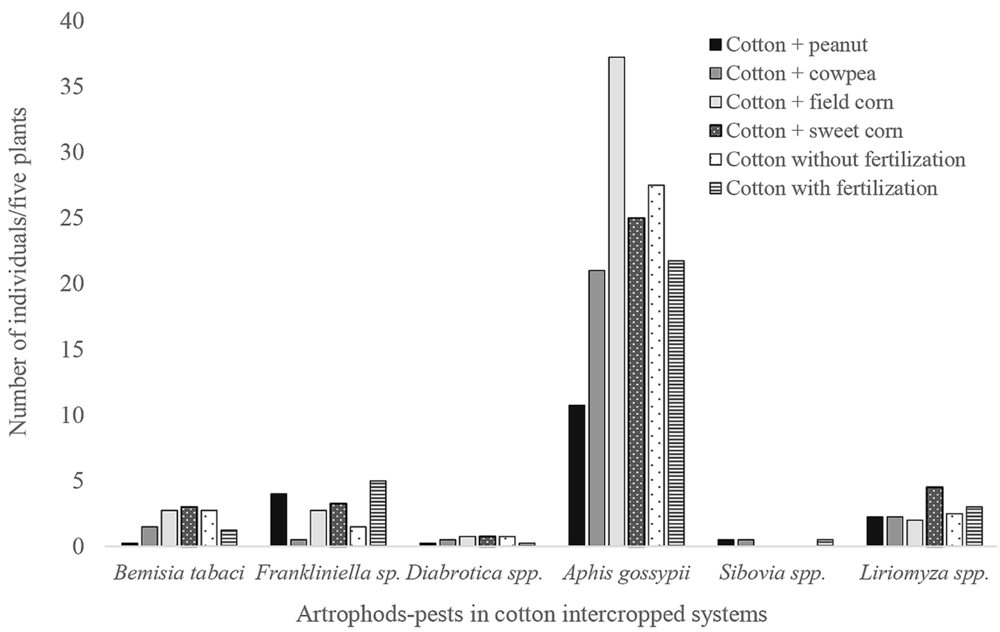

Figure 3. Cumulative values (five plants) of arthropod-pest populations present in the cotton crop associated with food crops and monoculture without and with fertilization (2020)

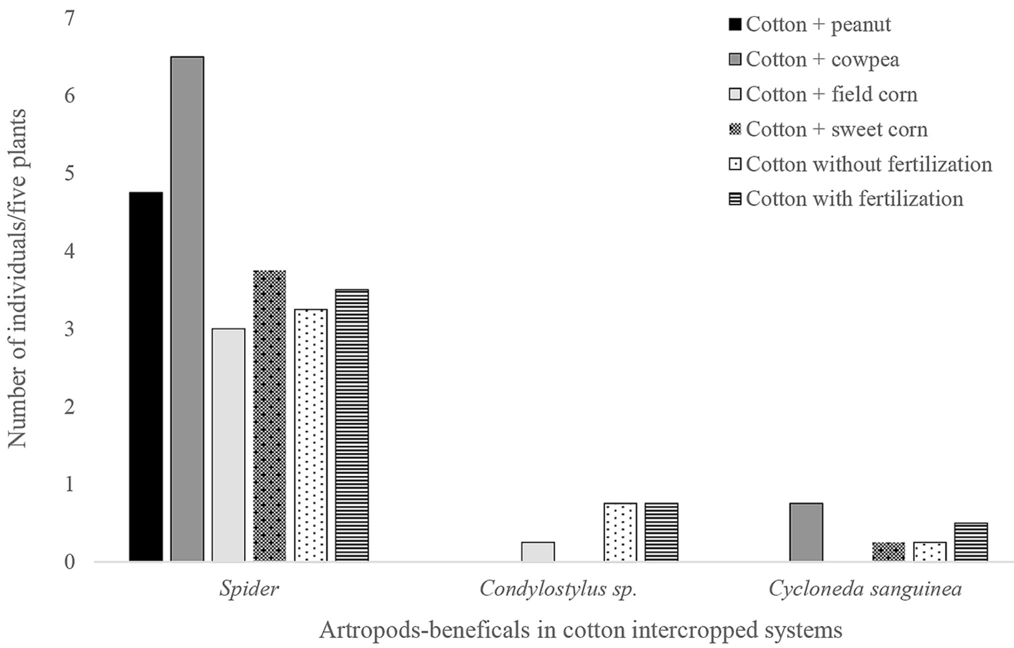

Figure 4. Cumulative values (five plants) of arthropod-beneficial populations present in the cotton crop associated with food crops and monoculture without and with fertilization (2020)

variable percentage of diseased bolls, registered at 110 das, it is clear that there was no influence of the associated systems on this variable, reporting a maximum of 7.94%.

A substantial reduction in the yield of peanut, cowpea, field corn and sweetcorn was observed when associated with cotton (Table 3). This is also reported in other associations such as castorbean-common bean and castor bean-cotton, where the crops in association had lower yields compared to their monoculture production, but different from the castor bean-corn association, where in addition to not significantly decreasing its yield in the intercropping system, it allowed almost the same

Table 3. Average yield of food crops (peanut, cowpea, field corn and sweetcorn) in association with cotton and Land Equivalent Rate (LER), 2020

Treatments (intercropped)	Experimental yield (food crop)	Referencial yield (food crop-monoculture)	Land equivalent ratio (LER)
Cotton + peanut	1647 kg ha^{-1} (shell peanut)	2365 kg ha^{-1} (shell peanut)	1.71 a
Cotton + cowpea	11925 clusters ha^{-1} (20 pods/cluster)	28800 cluster ha^{-1} (20 pods/cluster)	0.99 b
Cotton + field corn	1859 kg ha^{-1}	5382 kg ha^{-1}	1.14 b
Cotton + sweet corn	123 bushel ha^{-1} (150 ears/bushel)	235 bushel ha^{-1} (150 ears/bushel)	1.32 ab
Average			1.29
P			0.001
CV (%)			15.8

Note: means with a common letter are not significantly different (p > 0.05).

Table 4. Marginal analysis of no-dominated treatments in the cotton production system in association with various food crops, 2020

Treatments	NB (USD./ha)	VC (USD./ha)	MINB (USD./ha)	MIVC (USD./ha)	MRR (%)	MARR
Cotton + peanut	1 824.14	366	258.86	214.8	120.56	50%
Cotton + cowpea	1 565.28	151.2				

Note: NB –net benefit, VC –variable costs, MINB –marginal increase in net benefit, MIVC – marginal increase in variable costs, MRR –marginal rate of return, MARR –minimum acceptable rate of return.

amount of corn to be produced as would be obtained in a monoculture (Rasche Alvarez et al., 2015). However, in our research, peanuts suffered the lowest yield reduction (30%) when associated with cotton in the established populations and planted 13 days after cotton. While corn in association with cotton suffered the greatest yield reduction with 65%. Despite the yield reduction, there was more production than that obtained by Araújo et al. (2006), who did not achieve peanuts yield when they planted it 15 days after cotton, as a consequence of the strong competition pressure imposed by cotton, either by shading, competition for water and other resources, so they concluded that it is better to plant peanuts at the same time as cotton. It would be important to pay special attention to planting dates in associated crops as part of good agricultural management. In this subject, the scientific literature cites several studies to determine the appropriate planting time for each crop in the association (Pinto, 2011).

The statistical analysis of the LER averages showed significant differences ($P<0.05$), and according to the Tukey test (≤ 0.05), the ratio of the cotton-peanut association (1.71), was significantly higher from the ratios of the cotton-cowpea and cotton-field corn associations (Table 3). In this study a positive synergistic effect was observed in the cotton-peanut association, in contrast to the cotton-cowpea intercropped whose Index of >1 indicates antagonism or competition (Willey, 1979; Teixeira et al., 2005). In contrast, (Khan et al., 2020), states that the intercropping of mung bean in late-sown cotton is a valuable option to increase the productivity and income of farmers. Abd El-Hady and El-Khatib, (2002), state that intercropping can increase land use efficiency and is generally successful under harsh soil and climate conditions found in Egypt.

Finally, the economic analysis corroborated the results described above, since the association of cotton with peanuts presented the best MRR (120.56%). These results are consistent with those cited by Araújo et al. (2006), who claim that associations with food crops, not only provide benefits in the farmer's diet, but also improve their economy, obtaining in our case, the cotton-peanut association, the best yield of raw cotton, higher LER and better MRR (Table 4), making this association an appropriate option for small producers with limited area to produce crops (Pinto et al., 2011). This technology could be easily adopted by family cotton farmers, who know how to produce peanuts, maximizing available resources such as usable area, labor, inputs, and minimizing the risk of production losses by diversifying production. As mentioned by Rezende et al. (2005), one of the great challenges for the success of production in associated systems is to determine which are the most convenient associations, from the environmental, productive, and economic point of view.

CONCLUSIONS

Cotton yield was not affected by the association with peanut. Regarding the yield of intercropped food plants, there was a reduction in relation to monocultures; however, it was the peanut in association with cotton that experienced the least reduction and had the best Land Equivalent Ratio -LER- (1.71) and the best Marginal Rate of Return (120.56%), which suggests this association as a viable alternative and easy to adopt by small cotton farmers.

Acknowledgements

The authors wish to express their gratitude to the Trilateral South-South Cooperation Project GCP/RLA/199/BRA "Fortalecimiento del Sector Algodonero por medio de la Cooperación Sur-Sur", also known as the Proyecto +Algodón, signed between the Government of Brazil, through the Brazilian Cooperation Agency of the Ministry of Foreign Affairs (ABC/MRE), the Brazilian Cotton Institute (IBA) and the FAO Regional Office for Latin America and the Caribbean (FAO RLC), for their cooperation in the development of this study, which is part of the country project "Fortalecimiento del Sector Algodonero en Ecuador por medio de la Cooperación Sur-Sur, para fomento de lossistemas de agricultura familiar". To the Escuela Superior Politécnica Agropecuaria de Manabí (ESPAM MFL). Also, to the agricultural technician Alfredo Pinoargote for field assistance, and Dr. Carlos Banchón for proofreading this manuscript.

REFERENCES

1. Abd El-Hady, S.A.A., El-Khatib, F.K. 2002. Studies on the effect of intercropping cotton and wheat on growth, yield and quality of Egyptian cotton. Minufya Journal of Agricultural Research, 27(1), 19–33.

2. Agegnehu, G., Ghizaw, A., Sinebo, W. 2006. Yield performance and land-use efficiency of barley and faba bean mixed cropping in Ethiopian highlands. European Journal of Agronomy, 25(3), 202–207. https://doi.org/10.1016/j.eja.2006.05.002
3. Ahmad, M., Muhammad, W., Sajjad, A. 2020. Ecological Management of Cotton Insect Pests. In: S. Ahmad & M. Hasanuzzaman (Eds.), Cotton Production and Uses: Agronomy, Crop Protection, and Postharvest Technologies, 213–238. https://doi.org/10.1007/978-981-15-1472-2_12
4. Aguirre, S. 2017. Policultivos y silvopastoreo como estrategias agroecológicas de productores familiares en Colonia Gestido. Universidad de Antioquia. https://bibliotecadigital.udea.edu.co/handle/10495/8887
5. Alegre, J. 2017. La Agroforestería en la Amazonía Peruana para recuperar suelos degradados y mitigar efectos de Cambio Climático. XVI Congreso Nacional y VII Internacional de la Ciencia del Suelo “Crian¬za del suelo para el buen vivir”. Ayacucho.
6. Alegre, J., Lao, C., Silva, C., Schrevens, E. 2017. Recovering degraded lands in the Peruvian Amazon by cover crops and sustainable agroforestry systems. Peruvian Journal of Agronomy, 1(1), 1–7. http://dx.doi. org/10.21704/pja.v1i1.1005
7. Araújo, A., de M. Beltrão, N., Bruno, G., Moraes, M. 2006. Cultivares, épocas de plantio e componentes da produção no consórcio de algodão e amendoim. Revista Brasileira de Engenharia Agrícola e Ambiental, 10(2), 357–363. https://doi.org/10.1590/S1415-43662006000200016
8. Awaad, H., El-Naggar, N. 2018. Role of Intercropping in Increasing Sustainable Crop Production and Reducing the Food Gap in Egypt. In: Negm A.M., Abu-hashim M. (eds) Sustainability of Agricultural Environment in Egypt: Part I. The Handbook of Environmental Chemistry, Springer, Cham, 76. https://doi-org-443.webvpn.fjmu.edu.cn/10.1007/698_2017_164
9. Beltrao, N., Santana, J., Crisostomo, J., Araujo, J., Sousa, R. 1986. Avaliacao de cultivares de caupi para o consorcio com algodoeiro herbaceo. Pesquisa AgropecuariaBrasileira, 21(11), 1147–1153.
10. Calegari, A., Ralich, R. 2007. Uso adequado de plantas de cobertura, rotação de culturas e seus benefícios no sistema do plantio direto. Revista PlantioDireto, 1(97), 13–16.
11. Cañarte-Bermúdez, E., Sotelo-Proaño, R., Navarrete-Cedeño, B. 2020. Generación de tecnologías para incrementar la productividad del algodón Gossypium hirsutum L. en Manabí, Ecuador. Revista Ciencia UNEMI, 13(33), 85–95. https://doi.org/10.29076/issn.2528-7737vol13iss33.2020pp85-95p
12. CIMMYT - Centro Internacional de Mejoramiento de Maíz y Trigo. (1998) La formulación de recomendaciones a partir de datos agronómicos: un manual metodológico de evaluación económica. Ed. (s.e). Programa de Economía. CIMMYT. México, DF, 22.
13. Chamorro Viveros, D., Rey, A.M. 2017. Los sistemas silvopasoriles como estrategia de ganaderíaeco-lógica y productiva en Colombia. In: A. Fernández Mayer (Ed.), Producción de carne y leche bovina ensistemassilvopastoriles, 52-54. EdicionesInstitutoNacionaldeTecnologíaAgropecuaria.https://repositorio.inta.gob.ar/xmlui/handle/20.500.12123/7668
14. Ebel, R., Castillo-Cocom,J.A. 2013. X-Pichil: From traditional to “modern” farming in a Maya community. Memories of the VIII International Conference on Sustainable Agriculture, Environment and Forestry. Roma, Italia. http://www.scielo.org.mx/pdf/tl/v35n2/2395-8030-tl-35-02-00149.pdf
15. Ebel, R., Pozas Cárdenas, J.G., Soria Miranda, F., Cruz González,Y.J. 2017. Manejo orgánico de la milpa: rendimiento de maíz. frijol y calabaza en monocultivo y policultivo. Terra Latinoamericana, 35(2), 149–160. https://doi.org/10.28940/terra.v35i2.166
16. FAO –Organización de las Naciones Unidas para la Agricultura y la Alimentación. (2018a) Curso de autoaprendizaje “Estrategias de fortalecimiento del sector algodonero para el desarrollo de la agricultura familiar”: Unidad 1. Tendencias y perspectivas regionales y globales del sector algodonero, 55.
17. FAO. 2018b. El cultivo del algodón casi ha desaparecido en Ecuador. La Hora. Ec. 11 02. Online: t.ly/RllK
18. FAO. 2018c. Curso de autoaprendizaje “Estrategias de fortalecimiento del sector algodonero para el desarrollo de la agricultura familiar”: Unidad 1. Tendencias y perspectivas regionales y globales del sector algodonero, 55.
19. Farias, J.C.F., Beltrão, N.E. de M., Freire, E.C. 1999. Caracteres de importância econômica no melhoramento do algodoeiro. In: Beltrão, N. E. de M. (org.). O agronegócio do algodão no Brasil. Brasília: EMBRAPA - Comunicação para transferência de tecnológia, 1, 361–370.
20. Furtado, G. de F., Sousa A. dos S., Sousa Jr, J.R., Lacerda, R., Silva, S.2014. Rendimento e correlações da mamoneira consorciada com feijão-caupi e gergelim no semiárido paraibano. Revista Brasileira de Engenharia Agrícola e Ambiental, 18(9), 892–898. http://dx.doi.org/10.1590/1807-1929/agriambi.v18n09p892–898 https://www.scielo.br/j/rbeaa/a/W9gStpByjH9SVkg6Hh3ZnfN/?format=pdf&lang=pt
21. Gentleman, R., Ihaka, R. 2019. R Project for Statistical Computing. Online: t.ly/bzRq
22. GómezRodríguez, O., Zavaleta Mejía, E. 2001. La Asociación de Cultivosuna Estrategia más para el Manejo de Enfermedades, en Particular con Tagetes spp. Revista Mexicana de Fitopatología, 19(1), 94– 99.

https://www.redalyc.org/pdf/612/61219114.pdf

23. Haymes, R., Lee, H.C. 1999. Comparation between autumn and spring planted grain intercrops of wheat (*Triticum aestivum*) and field bean (*Vicia faba*). Field Crops Research, 72, 185–196. https://doi.org/10.1016/S0378-4290(99)00016-7
24. ICAR - INSTITUTE CENTRAL RESEARCH COTTON. 2010. Retrieved from Integrated Pest, Disease and Nematode Management website. Online: t.ly/mD2R
25. INIAP - Instituto Nacional de Investigaciones Agropecuarias. 2018. Informe Técnico Anual del Proyecto +Algodón INIAP-FAO. Estación Experimental Portoviejo-INIAP, 133.
26. INIAP - Instituto Nacional de Investigaciones Agropecuarias. 2019. Informe Técnico Anual del Proyecto +Algodón INIAP-FAO. Estación Experimental Portoviejo-INIAP, 254.
27. Khan, M.N., Shoaib, M., Ashraf M.S., Qamar, E. 2020. Mungbean (*Vigna radiata*) intercropping enhances productivity of late season irrigated cotton in Punjab. Asian Journal of Agriculture & Biology, 8(4), 472–479. https://10.35495/ajab.2020.03.18
28. Li, W., Zhou, Z., Meng, Y., Xu, N.,Fok, M. 2009. Modeling boll maturation period, seed growth, protein, and oil content of cotton (*Gossypium hirsutum* L.) in China. Field Crops Research, 112(2–3), 131–140. https://doi.org/10.1016/j.fcr.2009.02.009
29. Molina-Anzures, M.F., Chavez-Servia, J.L., Gil-Muñoz, A., López, P.A., Hernández-Romero, E., Ortiz-Torres, E. 2016. Eficiencias productivas de asociaciones de maíz, frijol y calabaza (*Curcubita pepo* L.), intercaladas con árboles frutales. Phyton, International Journal of Experimental Botany, 85, 36–50. http:// www.revistaphyton.fund-romuloraggio.org.ar/vol85/Molina_Anzures.pdf
30. Nicholls, C. 2009. Bases agroecológicas para diseñar e implementar una estrategia de manejo de hábitat para control biológico de plagas. In: Altieri, M. (Ed.), Vertientes del pensamiento agroecológico: fundamentos y aplicaciones. SOCLA, Medellín (Colombia).https://www.fao.org/3/i8864es/I8864ES.pdf
31. Pinto, C., de Oliveira, O., Sizenando, F. 2011. Mamona consorciada com girassol em plantios defasados: eficiência biológica. Revista Verde de Agroecologia e DesenvolvimentoSustentável, 6(5), 166-176.
32. Rajendran, T., Birah, A., Burange, P.S. 2018. Insect Pests of Cotton. In: Pests and Their Management, 1–1078. https://doi.org/10.1007/978-981-10-8687-8
33. Ramalho, F., Gonzaga, J. 1990. Efeitos do consõrcio de algodão com milho, e piretroide contra o bicudo-do-algodoeiro. PesquisaAgropecuariaBrasileira, 25(2), 191–199.
34. Rasche, J., Fatecha, D., Gaona, N., Ibarra, J.,Rolón, G. 2015. Tártago asociado a cultivos anuales: una opción para la agricultura familiar. InvestigaciónAgraria, 17(1), 27–35.
35. Rezende, B., Cecílio Filho, A.B., Canato, G.H.D., Martins, G. 2005. Análise econômica de consorciados de alface x tomate, em cultivo protegido, Jaboticabal-SP. Científica, 33(1), 42–49.
36. Teixeira, I.R., Mota, J.H., Silva, A.G. 2005. Consórcio de hortaliças. Semina: CiênciasAgrárias, 26(4), 507–514.
37. Teixeira, I.R., Silva, G.C., Oliveira, J.A., Timossi. P.C. 2012. Arranjos de plantas do feijoeiro-comum consorciado com mamona. Revista Caatinga, 25(2), 85–89.
38. Willey, R.W. 1979. Intercropping - its importance and research needs. Part 1. Competition and yield advantagens. Field Crop Abstracts, 32(1), 1–10.