Research Article

A Study for Estimation of Greenhouse Gas Emissions of Cotton in Central Greece

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Cotton is an economically significant crop in Greece; however, there is a paucity of systematic quantification of greenhouse gas emissions associated with Greece's cotton production and analysis of the underlying causes. This study employed the Cool Farm Tool (CFT) to ascertain the principal constituents and motivating factors underlying the greenhouse gas (GHG) emissions associated with cotton production in Greece between 2020 and 2021, with reference to statistical data. The findings indicated that the greenhouse gas (GHG) emissions per unit of cotton cultivated in the Sterea Hellada and Thessaly regions of Central Greece reached 2,126. This equates to a reduction of 10 kg CO2 eq ha^{-1} or 460.8 kg CO2eq t^{-1} yield, respectively.

From 2020 to 2021, greenhouse gas (GHG) emissions increased by 107.7 kg CO2-eq ha^{-1} or 32.9 kg CO2 eq t^{-1} yield due to an increased number of irrigation events and pesticide applications, which were necessitated by the extremely high temperatures that occurred during the flower to open boll period. The multiple regression model demonstrated that fertilizers exerted the most significant influence on carbon emissions. Enhancing the efficiency of cotton fertilization and guaranteeing the robust advancement of the cotton industry through the implementation of high-quality cultivation strategies will prove an effective approach to reducing the carbon footprint of cotton cultivation in the future.

Introduction

In recent years, there has been a notable increase in awareness among consumers and the general public regarding the environmental impact of the production of goods and services they consume. This is evidenced by the growing attention paid to the emissions of greenhouse gases, which are

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measured as carbon dioxide equivalent (CO2e). Global corporate businesses, whether driven by a desire to measure and reduce their carbon footprint or by market forces, are at the forefront of this effort. In doing so, they are placing pressure on suppliers to reduce their own footprints. The impact of carbon emissions from agricultural enterprises and the role that the agricultural industry plays in the level of carbon emitted or sequestered remains a topic of ongoing debate. However, current estimates suggest that greenhouse gas emissions from agriculture account for approximately 24% of total greenhouse gas (GHG) emissions (IPCC, 2007). An increasing number of farmers are expressing concern and interest in establishing and monitoring their farm business's carbon emissions. There are several reasons for undertaking this process aside from the desire to assess and reduce one's carbon footprint. These include the identification of opportunities to improve nutrient utilization in a cropping enterprise, feed management, and livestock use, as well as the provision of confirmation to domestic and overseas markets. This may be done either to obtain access to a market or to receive a premium for the produce (FAO, 2015; OECD, 2011).

The burning of fossil fuels (such as coal and oil) and deforestation are among the human activities that are responsible for the increasing concentrations of greenhouse gases (GHGs) in the atmosphere. Greenhouse gases (GHGs) absorb some of the energy radiated from the Earth's surface, thereby trapping it. The atmosphere serves as a blanket, warming the Earth's surface to a degree that would otherwise not be possible. The primary greenhouse gases (GHGs) responsible for global warming are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and three groups of fluorinated gases: sulfur hexafluoride (SF_6), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs) (Myhre et al., 2013).

The global food production and distribution chain, from farm to fork, is responsible for approximately 21–37% of annual anthropogenic emissions (Poore et al., 2018; Mbow et al., 2019). However, these emissions are dominated by methane (CH4) and nitrous oxide (N2O), which account for 50% and 75% of all anthropogenic methane and N2O emissions, respectively (Mbow et al., 2019; Han et al., 2019). The net effect of carbon dioxide emissions from agricultural activities is offset by the absorption of CO_2 by crops. The greenhouse gases that are responsible for the greenhouse effect play a pivotal role in the phenomenon of climate change. Farming activities have been identified as a significant source of greenhouse gas emissions from the soil into the atmosphere. This is due to various agricultural practices, including irrigation and fertilization, which have been shown to affect the biogeochemical processes of carbon and nitrogen in the soil (Oertel et al., 2016).

In the agricultural sector, CO_2 arises from the microbial decomposition of organic matter occurring in the soil or from the combustion of crop residues. Methane (CH4) is derived from the anaerobic decomposition of organic matter. The primary sources of CH4 are the digestive processes of ruminants, the storage of manure produced in intensive livestock farming, and the cultivation of rice in beds (Mosier et al., 1998). Nitrous oxide (N_2O) is derived from the transformation of available nitrogen in soil and manure and is often emitted when soil nitrogen exceeds the plant's absorption capacity, particularly in wet conditions (Oenema et al., 2005). Moreover, agriculture is the primary driver of ongoing changes in land use, largely through deforestation for crop production or pasture. The net CO_2 emissions associated with deforestation are estimated to account for approximately 14% of the annual anthropogenic CO_2 (Le Quéré et al., 2018), which is directly linked to agricultural production by 10% (Mbow et al., 2019).

The consequence of elevated concentrations of greenhouse gases and rising temperatures will have direct and indirect effects on crop production. These effects may be mediated by the availability of water (rainfall and relative humidity) and the frequency of pests and diseases in crops (FAO 2015). It is of the utmost importance to reduce greenhouse gas emissions during agricultural practices without compromising yields, as this is a crucial and immediate objective for all crops. It is recommended that cultivation practices be improved as a strategy for reducing greenhouse gas emissions from cultivated regions. However, this strategy is contingent upon the specific farming techniques employed, given the variability in farming practices across different crops (Malhi et al., 2021). Cotton is a significant global crop, providing fibers for textile industries worldwide. Cotton cultivation necessitates a substantial input of nitrogen (N) in addition to irrigation, and the combination of these two factors has the potential to result in elevated emissions of nitrous oxide (N2O) and nitric oxide (NO), thereby contributing to the accumulation of greenhouse gases in the atmosphere (Liu et al., 2010).

These two factors are identified as the primary sources of greenhouse gas emissions in the context of cotton production. The Greek cotton industry is characterized by a high level of labor, water, and energy intensity. Cotton production necessitates the utilization of energy for a multitude of processes, including plowing, input application (fertilizers, herbicides, insecticides, and plant growth regulators), planting, irrigation, crop cultivation, harvesting, slashing, and transportation. It is a fallacy to assume that crop intensification, mechanization, and modernization are greenhouse gas (GHG) emission-free. The very processes that are supposed to reduce emissions actually require the use of more fuel, farm machinery, and inputs.

Because 80% of the cotton produced in Greece is exported (European Commission, 2018), it is imperative that its production maintain product quality in order to remain globally competitive. Furthermore, it must demonstrate efficiency in the utilisation of scarce resources and demonstrate environmental sustainability. In light of the growing awareness of climate change and the forthcoming implementation of the Greek Government's Carbon Pollution Reduction Scheme (UNFCCC 2020), it is imperative that the cotton industry (along with other agricultural activities) conduct research to provide comprehensive data on GHG emissions associated with all inputs on farms. The objective of the present study is to estimate greenhouse gas (GHG) emissions from three cotton farm plots located in the major cotton-producing regions of Greece.

In particular, the present study estimated greenhouse gas (GHG) emissions resulting from: The following factors were considered in order to ascertain the relative contribution of each to the overall carbon footprint: (1) soil-derived nitrous oxide (N2O) from nitrogen (N) fertilizer usage; (2) agrochemical uses in cotton production; (3) electricity usage and combustion of fossil fuels used in cotton farm operations; (4) residues management; (5) transportation.

Materials and Methods

Geographical locations and climate of the study area

The farm plots were situated in three distinct cotton-producing regions within the Kopaida area: Agios Dimitrios (38.45424° N, 22.9575° E), Fthio-Tida - Elatia (38.62552° N, 22.75706° E), and Thessaly - Farsala (38.62552° N, 22.75706° E). Local farmers employed traditional farming techniques, including planting, management, and harvesting.

In the central and southern regions of Greece, the climate is Mediterranean, with an average temperature of 24.5°C during the period of cotton cultivation, which spans from mid-April to mid-October.

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Month	Apr	May	Jun	Jul	Aug	Sep	Oct
Average high °C	16.3	20.9	25.25	28.38	28.6	24.1	18.63
Daily mean °C	14.80	20.33	25.53	27.37	26.40	22.27	16.83
Average low °C	7.68	12.0	16.17	19.13	19.51	16.46	12.23
Average precipitation mm	38.13	33.40	19.17	15.63	16.67	24.73	62.63

Table 1. Climatological data for Central Greece (Sterea Hellas and Thessaly).

Area / Cordinates	No of Plots	Average Size of Plots ha 2020	Average Size of Plots ha 2021	Average Yield tn per ha 2020	Average Yield tn per ha 2021
Kopaida Sterea (38.45836^{0},22.96997^{0})	4	8.97	9	4.85	4.55
Elatia Sterea (38.6243^{0},22.75981^{0})	4	7.58	7.87	4.97	4.9
Farsala Thessaly (39.36232^{0}, 22.2478^{00})	4	8.57	8.62	4.3	4.3

Table 2. Information for farm's plots

Cultivation Practices

Land Preparation

The process commences in either the early winter or autumn months. The process commences with the cutting of stalks and plowing to displace plant residues and loosen the soil to a depth of approximately 20 centimetres. When soil moisture conditions permit during the winter season, chisels are employed to loosen the soil surface and eradicate weeds. In late winter or early spring, one

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or two disc or tooth harrows are employed to smooth the soil surface, improve its structure, and cover fertilizers, pesticides, and herbicides.

Planting

The optimal planting period is between the 10th and the 30th of April. Four-row planters are typically utilized for planting, and are often equipped with a fertilizers and pesticides applicator. The distance between rows is 90 centimetres. The number of plants per hectare (ha) varies considerably, from 200,000 to 250,000, depending on the variety and other factors, such as early maturing, soil type, and so forth.

Fertilizer Application

A fertilization program that is commonly implemented by many cotton growers involves the application of 300-450 kg N-P-K 20-10-10 per hectare at sowing, which is typically done via the sowing machine. Additionally, another 250-350 kg N-P-K 20-10-10 per hectare is applied during flowering, which occurs during the early summer.

Foliar fertilization in conjunction with insecticides is typically employed, particularly during the initial phases of plant development.

The mean yield was 4.46 tons per hectare in response to the mean fertilizer dose of 703 kg per hectare.

Pesticide Application

The most prevalent insect infestations of cotton in Greece include cutworms (Agrotis spp.), wireworms (Agriotes spp.), thrips (Thrips tabaci), spider mites (Tetranychus urticaceae), whiteflies (Bemisia tabaci), jassids (Amrasca biguttula), bollworms (Heliothis armigera), and pink bollworms (Pectinophora gossypiella).

The data on pesticide application in the field was recorded in terms of the number of applications and the active ingredients used. A comprehensive range of pesticides was utilized in the observation plots. Table 3 provides an overview of the types of pesticides utilized, the number of sprays applied, and the active ingredients utilized.

Corp Protection Input Active Ingredients	2020	2021
Pentimethaline	Yes	Yes
Fluometuron	Yes	Yes
Chloropyrethos	Yes	Yes
Abamectin	Yes	Yes
Sulfoxafloc	Yes	Yes
Flonicamid	Yes	Yes
Chlorantraniliprole	Yes	Yes
Thiachloprid	Yes	Yes
Pyrethroids	Yes	Yes
No of sprays per ha	7 to 9	9 to 11
Active Ingredient in kg per ha	2,3 to 3	2,8-3,6

Table 3. Information on the types of pesticides used in the farm plots.

Harvest

Harvesting typically commences in mid-September and concludes at the end of October, contingent upon the specific variety and prevailing meteorological conditions. The harvesting process is conducted with the aid of mechanical harvesting equipment.

Soil Type and Irrigation

The soil in the region of the plot is characterized as having a fine texture, good drainage, and an organic matter content of less than 1.72%. The pH level ranges between 7.3 and 8.5.

Table 4 presents the soil type and the total quantity of water in millimeters per hectare for each plot.

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REGION	SOIL TYPE	2020 IRRIGATION mm	2021 IRRIGATION mm
kopaida 1	loamy	345	450
kopaida 2	loamy	480	350
kopaida 3	loamy	343	314
kopaida 4	sandy loam	397	479
elatia 1	loamy	228	416
elatia 2	sandy loam	265	438
elatia 3	loamy	253	420
elatia 4	sandy	304	451
farsala 1	sandy loam	302	309
farsala 2	sandy loam	301	311
farsala 3	loamy	257	311
farsala 4	loamy	303	320

Table 4. Soil Types and net Irrigation water

Data collection

A total of twelve farmers from the three regions were selected for inclusion in the data collection process. The farmers of the sample plots were contacted directly in order to obtain the requisite information. The farm data were collected via a questionnaire that was divided into five sections.

In Group 1 (Cultivation Details), the cultivation area, quantity of fresh product (whole plant), and quantity of final product were recorded. Group 1 was also furnished with data pertaining to waste management.

Group 2 entailed the recording of soil characteristics, including soil texture (e.g., clay, silty, sandy), soil organic matter, soil moisture, soil drainage (assessed as "good"), and soil pH (not assessed).

In regard to group 3, the selection of the fertilization method and plant protection applications was made. Specifically, the type of fertilizer employed, the dosage applied, and the evaluation of the

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measure (fertilizer units or product) were selected. The method of application was selected from the following options: application in solution, dispersion, incorporation, or hydro-lubrication (underground drip). Additionally, the utilization of nitrification inhibitors was documented. With regard to the implementation of plant protection measures, a category was selected to describe the temporal and methodological aspects of the treatment, including whether it was applied to seeds, the soil, or post-emergence, as well as the number of applications or doses for each operation, such as weed control, leafing, and so forth.

In Group 4 (Fuels), the direct utilization of energy was observed. This entailed the selection of the energy source and the quantification of the energy (in liters) employed for this specific crop. For each task, the consumption was noted separately (plowing, cultivator, harrow, sowing, digging, fertilizing, growth regulator-plant protection-defoliation, irrigation, supervision visits and harvesting).

With respect to Group 5 (water use), the number of irrigation cycles, the irrigation method (shaft, pipe, flood, or drop), and the water source (natural lake/pond, reservoir, river/stream/ditch, or well drilling) were recorded. Ultimately, the energy source utilized for irrigation of the cotton was identified. This encompassed the selection of whether the energy was derived from oil, electricity, or gravity.

Estimation of GHG emissions during the cultivation phase

The estimation of greenhouse gas (GHG) emissions during the cultivation phase was conducted using the Cool Farm Tool (https://coolfarmtool.org/). The Cool Farm tool is a calculator that estimates greenhouse gas emissions and carbon footprints in agricultural fields based on yield and marketable yield, crop area, fertilizer application (type and rate), number of pesticide applications, and energy use (electricity and fuel). The utilisation of the Cool Farm Tool engenders incentives for climate-friendly agricultural practices and enhanced supply chain efficiency. The Cool Farm Tool has been employed primarily in the estimation of greenhouse gas emissions associated with the cultivation of potatoes, maize, vegetables, coffee, and cotton. The tool was developed by the Cool Farm Alliance, which is engaged in ongoing efforts to enhance its functionality. The Cool Farm Alliance is comprised of 58 members, including food retailers, manufacturers, input suppliers, non-governmental organizations (NGOs), academic institutions, and consultants.

Results and Discussion

GHGs Emissions of inputs

The mean greenhouse gas (GHG) emissions for the 2020 period were 2,018.37 kg of carbon dioxide equivalent (CO2e) per hectare and 427.9 kg of CO2e per ton of seed cotton produced. For the 2021 period, the mean GHG emissions were 2,126.10 kg of CO2e per hectare and 460.79 kg of CO2e per ton of seed cotton produced (Table 5). In other related studies, the total emission has been reported as 2,674 kg CO2e ha^{-1} for cotton production in Australia (Marseni T. et al., 2010), 1,195 kg CO2e ha^{-1} for cotton production in Iran (Pishgar-Komleh S. et al., 2012), and a range between 2,958–6,220 CO2e ha^{-1} for cotton production in China (Weibin H. et al., 2021).

The following graphs illustrate the emissions per year resulting from different sources (Figures 1a and 1b).

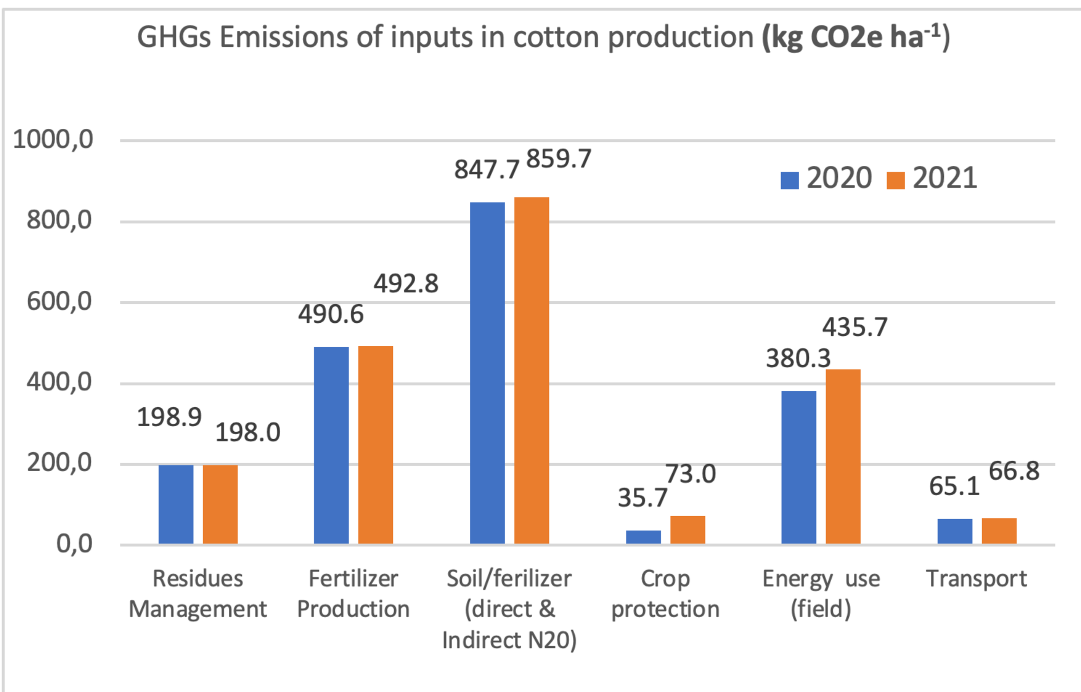

Figure 1a. CO2e (kg) emissions per hectare for residues management, fertilizer production, fertilizer application, crop protection, energy use and yield transportation to ginning mills.

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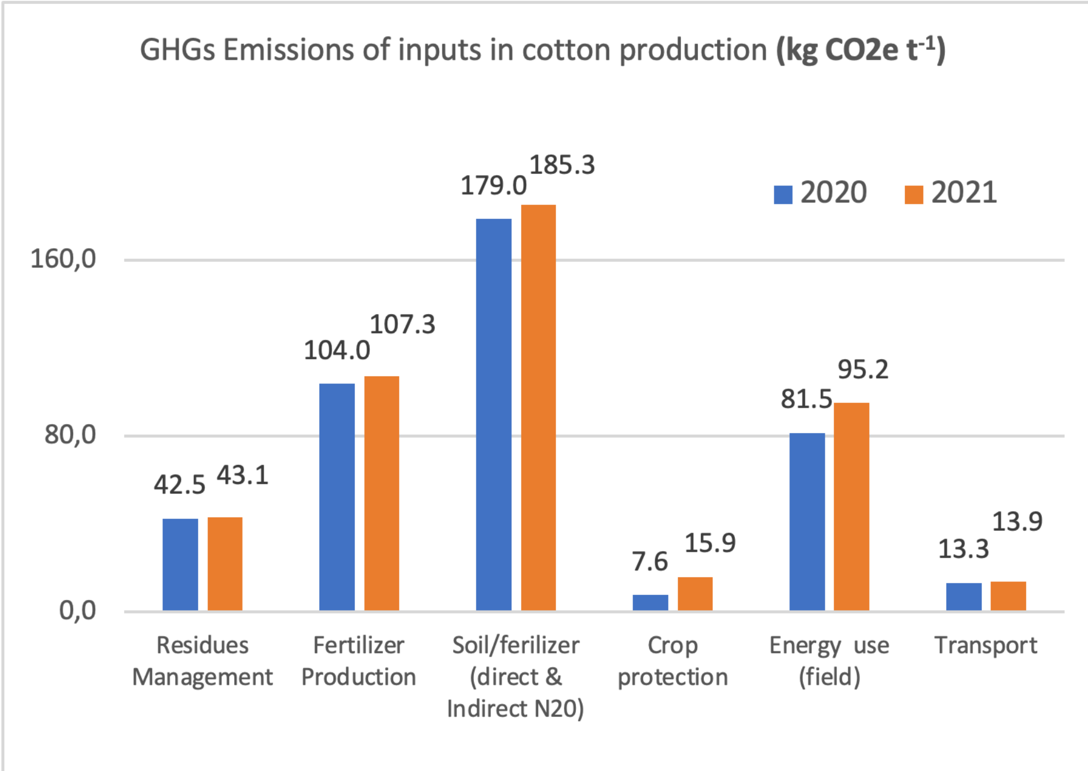

Figure 1b. CO2e (kg) emissions per tons of seed production for residues management, fertilizer production, fertilizer application, crop protection, energy use and yield transportation to ginning mills.

The data clearly demonstrates that the emissions resulting from fertilizer production, as well as fertilizer application (including both direct and indirect N2O emissions), represent the primary contributor to the overall carbon footprint in cotton production. There is a notable discrepancy in emissions from energy usage between 2020 and 2021. It is worth noting that emissions resulting from transport are negligible in comparison to other sources.

As illustrated in Figure 2, fertilizer was the primary source of GHG emissions (representing 66% of the total), followed by energy used in machinery operations and irrigation (19%), residue management (10%), and transportation (3%). Crop protection inputs had the lowest GHG emissions at 2%. The results clearly demonstrated that the majority of GHG emissions for cotton production were caused by fertilizers. Previous research studies have also indicated that fertilizers are a significant contributor to GHG emissions in cotton production (Marseni T. et al., 2010; Pishgar-Komleh S. et al., 2012).

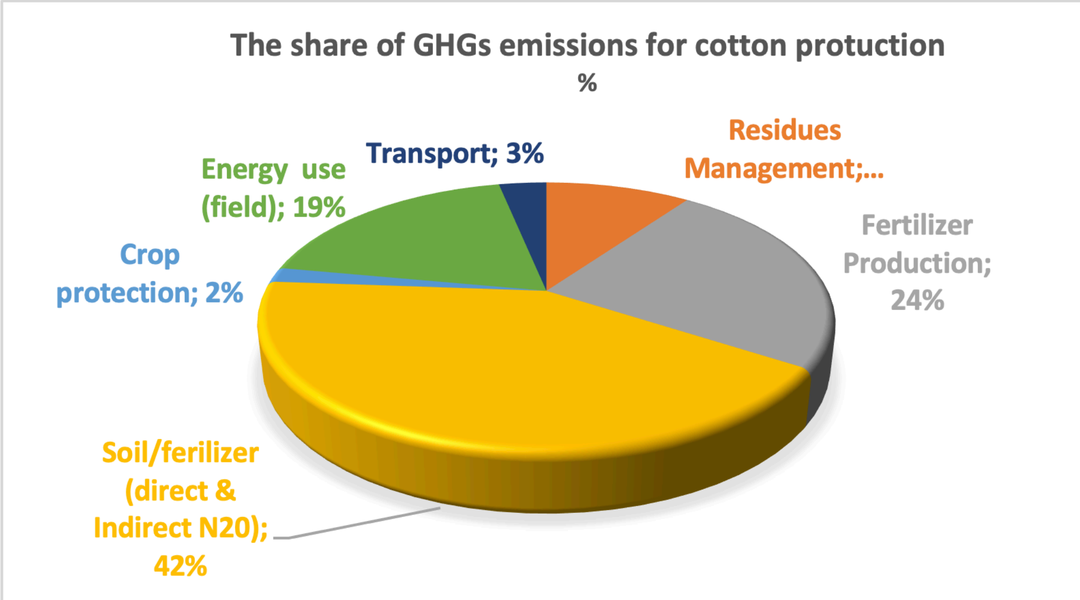

Figure 2. The share of GHGs emissions for cotton production

A paired sample t-test was conducted to compare the 2020 and 2021 GHG emissions data presented in Table 5. The results indicated a statistically significant difference in GHG emissions.

2020	Kg CO2e ha^{-1}	t(11)=-3.812, p=0,003*
2021	Kg CO2e t^{-1} yield	t(11)=-3.160, p=0,009*

Table 5. GHGs emissions in 2020 and 2021

*significant at $p < 0.05$

The subsequent increase in GHG emissions was primarily driven by the rise in water demand and pesticide inputs associated with the exceptionally high temperatures experienced in 2021. This resulted in an increase in carbon intensity per unit of output.

GHGs Emissions per region

The average GHG emissions per unit in Kopaida, Elatia, and Farsala were 1,467.38 kg CO2e ha^{-1}, 2,851.4 CO2e ha^{-1}, and 1,897.92 CO2e ha^{-1}, respectively. The average GHG emissions per unit yield

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were 312.84 CO2e -t^{-1}, 577.94 CO2e t^{-1}, and 441.38 CO2e t^{-1} (Figure 3).

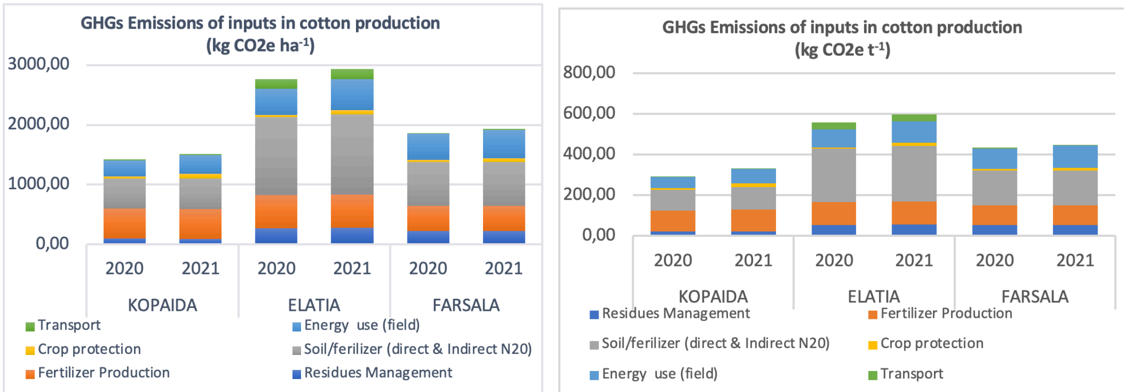

Figure 3. GHGs emissions per region in 2020 and 2021

In comparison to the average GHG emissions of Elatia, the emissions of Kopaida were 95% lower and 50% lower in Farsala. The findings revealed an excessive use of fertilizers for cotton production in Elatia.

A one-way ANOVA was conducted to ascertain whether the GHG emissions from the three regions in 2020 resulted in disparate test scores.

The ANOVA demonstrated that there was a statistically significant discrepancy between the regions (Table 6).

Year	DF	MS	EV%	F
2020	2	1886781.636**	96%	122.60
2021	2	2131333.521**	96%	97.518

Table 6. Multiple comparisons of GHGs emissions in the regions

DF (Degrees of Freedom), MS (Mean Squares) EV% (percentage of the sum of squares)

*Major drivers of GHGs emissions in the three cotton regions., ** significant at $p < 0.05$*

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Analysis of GHG emissions from different sources in the cotton field

We conducted an analysis to determine the impact of GHG emission sources, including the use of fertilizer, energy consumption, and pesticide application, on overall emissions in both years' plots. We have not included GHG emissions from two other sources (transport and residue management) in our analysis because they have an insignificant impact on net emissions. To ascertain the relationship between overall emissions and those from fertilizer, energy uses, and pesticides, we conducted a multiple regression analysis.

Rl. No	Regressions Relations	adj.R^2
1	$E = -221.436 + (1.268 * F) + (1.422 * En) + (0.148 * Pe)$	0.99
2	$E = -216.050 + (1.267 * F) + (1.432 * En)$	0.99
3	$E = 21.037 + (5.241 * En) - (1.599 * Pe)$	0.61

Table 7. Effect of fertilizer applications, energy uses and pesticide spraying on GHG emissions in plots.

E= Overall emissions in kg CO2 e ha^{-1}, F= emissions from fertilizers in kg CO2 e ha^{-1}, En= emissions from energy use in kg CO2 e ha^{-1}, Pe= emissions from pesticides use in kg CO2 e ha^{-1}.

A subsequent analysis of each of the functions (emissions from fertilizers, energy use, and pesticide emissions) is presented in Table 7. The step-down process eliminates each variable in turn (as illustrated by the multiple regression relationships) in order to demonstrate the impact of that variable on overall emissions in its absence. In regression relation (Rl. No. 3), where fertilizer emissions are stepped down, there is a notable decline in the R2 value (from 0.99 to 0.61). This indicates that emissions from fertilizers are the primary factor influencing overall emissions.

It is clear that fertilizer management is the most crucial practice in terms of emissions. Figure 4 illustrates that emissions from fertilizer application (a sum of direct and indirect N2O emissions and emissions due to fertilizer production) contribute significantly to the overall emissions represented in kg CO2e/ha.

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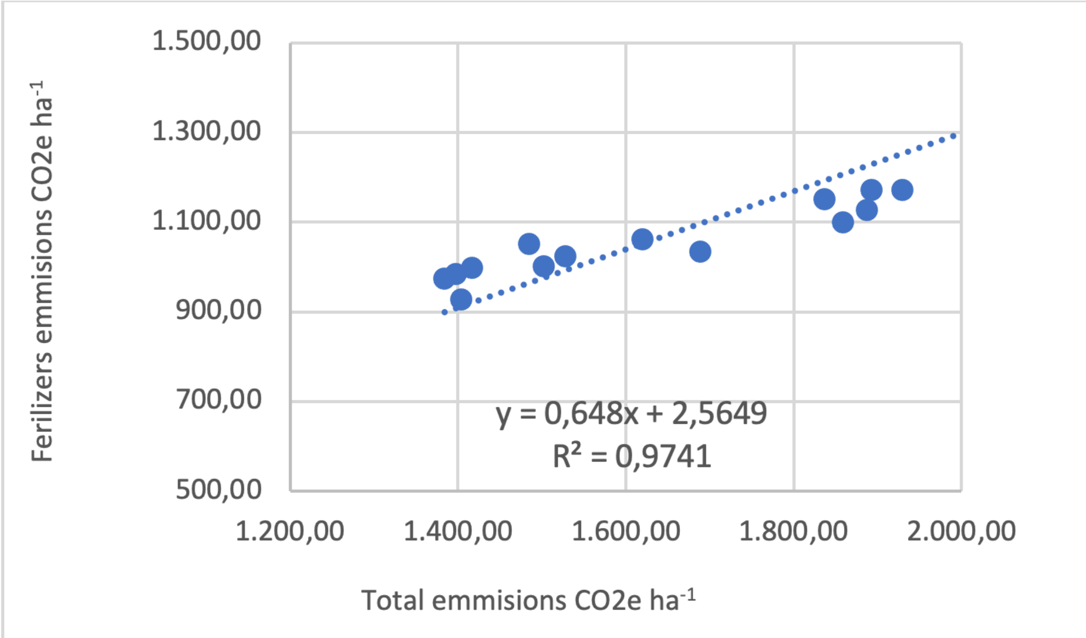

Figure 4. Regression between total emissions and emissions from fertilizers applications

The objective of the study was to identify the sources of GHG emissions in selected cotton regions. The average GHG emissions per unit in Kopaida, Elatia and Farsala reached 1,467.38 kg CO_2e ha^{-1}, 2,851.4 CO_2e ha^{-1}, 1,897.92 CO_2e ha^{-1}, respectively. The average GHG emissions per unit yield reached 312.84 CO_2e t^{-1}, 577.94 CO_2e t^{-1}, and 441.38 CO_2e t^{-1} (Figure 1). The data indicates that fertilizer is the primary source of GHG emissions, accounting for 66% of the total.

Conclusions

The results indicate that to improve energy efficiency and reduce GHG emissions in cotton production, enhanced management of fertilizer (particularly nitrogen), diesel fuel, machinery, and water for irrigation is necessary (Pishgar-Komleh et al., 2012).

There are several ways to minimize N_2O emissions from soils due to applied N-fertilizers, including:

(1) Maintain water-filled pore space at <0.4; (2) Reduce soil compaction and increase oxygen diffusion in soils; (3) Reduce readily available carbon supply to enhance microbial proliferation and N_2O emissions; and (4) Remove residual nitrate from the soil by growing cover crops (Dalal et al., 2003). Furthermore, the practice of injecting biochar into soils is becoming a popular method for reducing

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N_2O emissions and fostering long-term soil carbon sequestration (Lehmann et al., 2006; Yanai et al., 2007).

New techniques and technological advancements have enabled growers to become more efficient with their nitrogen fertilizer use. This ensures that the plant receives exactly what it needs, when it needs it, and not more. Precision agriculture management is the key to lowering nitrogen-based GHG emissions. It uses a range of technologies to better measure and predict their crop's fertilizer needs, including sensors, drones, and sophisticated mapping and measurement tools (Balafoutis et al., 2017).

Similarly, the increased adoption of conservation practices has the effect of reducing the quantity of applied nitrogen fertilizers (NASS Highlights, 3, May 2019).

The GHG emission estimates observed in the farm plots are directly related to the inputs applied. These figures are subject to change depending on the inputs applied in different geographical regions. As a result, they cannot be considered definitive figures for cotton cultivation in the region. The results clearly indicate the potential for agricultural best management practices (BMPs) to reduce GHG emissions through balanced fertilization.

In conclusion, the implementation of a balanced fertilizer application at the recommended dose, an Integrated Pest Management System (IPM), and Precision Agriculture has the potential to result in a reduction of GHG emissions.

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