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RESEARCH ARTICLE

INFLUENCE OF AGRICULTURAL PRACTICES ON SOIL FERTILITY AND CONTAMINATION BY PESTICIDE RESIDUES IN COTTON PRODUCTION SYSTEMS IN THE NORTHERN PLATEAUX OF TOGO

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ABSTRACT

Cotton production is a major agricultural activity in Togo, particularly in the Northern Plateaux, where agricultural intensification threatens soil fertility and may increase soil contamination by pesticides. Studies conducted in Togo have documented declining soil fertility under continuous cropping, the limitations of mineral fertilizer inputs, and the presence of pesticide residues. However, these studies generally investigate soil fertility and contamination separately, sometimes focus on areas outside the Northern Plateaux, and pay limited attention to the relationships between agricultural practices, soil quality, and pesticide fate. This review examines the influence of agricultural practices on soil fertility and contamination in cotton-growing soils of the Northern Plateaux. The literature search followed the PRISMA 2020 guidelines. The PICO framework was adapted as follows: cotton-growing soils were considered the population/problem, agricultural practices the intervention/exposure, different management systems the comparison, and soil fertility and contamination indicators the outcomes. Publications from Togo, West Africa, and other cotton-producing regions were examined across four main areas: tillage practices and crop residue management, fertilization and nutrient dynamics, pesticide use and fate, and effects on the biological and physicochemical properties of soils. The synthesis highlights declining soil fertility despite mineral fertilizer application and the presence of pesticide residues in soils in Togo. Soil conservation, organic matter replenishment, crop rotation diversification, and improved fertilizer-use efficiency contribute to maintaining soil quality. No study in the reviewed corpus addressed all these dimensions simultaneously in cotton production systems in the Northern Plateaux. This gap highlights the originality of this review and the need for integrated studies to support the sustainable management of cotton-growing soils in the Northern Plateaux.

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INTRODUCTION

Cotton production plays an important role in Togo's agricultural systems and constitutes a major source of income for many farmers. In the cotton-growing areas of the Northern Plateaux, cotton is generally integrated into cropping systems that also include maize and other food crops. The sustainability of these systems largely depends on the ability of soils to maintain their fertility despite repeated nutrient removal and the various cropping practices employed. Agricultural intensification relies in particular on tillage, the use of mineral fertilizers, the retention or removal of crop residues, and the application of pesticides. These practices can modify the physical, chemical, and biological properties of soils. Repeated cropping cycles, when not accompanied by sufficient replenishment of organic matter and nutrients, may contribute to a decline in organic carbon and the progressive depletion of certain mineral elements. Long-term experiments conducted in Togo have shown a decline in soil fertility and productivity under continuous cropping, whereas the introduction of fallow periods helps limit this degradation (Kintché *et al*., 2015a). Maize–cotton systems are also characterized by substantial use of mineral fertilizers. However, fertilizer application does not necessarily compensate for carbon and nutrient losses associated with continuous land cultivation. A twenty-year experiment conducted in Togo notably showed that the long-term use of mineral fertilizers and the incorporation of maize residues did not fully compensate for carbon and nutrient losses from a Ferralsol under continuous maize–cotton cropping (Kintché *et al*., 2015b). Soil fertility also depends on interactions between organic matter, soil structure, nutrient availability, and biological activity.

Organic amendments therefore constitute an important complement to mineral fertilizers, particularly in agricultural systems where organic matter stocks are low. Conservation practices combining reduced tillage, residue retention, and crop diversification can help preserve organic carbon and improve certain physical, chemical, and biological soil properties, although their effects depend on local soil and climatic conditions (Page *et al*., 2020). In cotton production systems, pesticides represent another important aspect of agricultural management. Their use helps control pests, but some compounds may persist in soils and be transferred to other environmental compartments. In Togo, several studies have reported pesticide residues in agricultural soils. Bafai *et al*. (2018), in particular, investigated soil contamination in a cotton-growing area at the Kolokopé experimental station and identified several organochlorine pesticides. A subsequent study directly investigating soils from cotton-growing areas in Togo also detected several residues, including simazine, atrazine, lindane, β-endosulfan, dieldrin, endrin, heptachlor, heptachlor epoxide, DDT, and DDE (Bafai *et al*., 2022).

However, pesticide residues in soils do not depend solely on the quantities applied. Their fate is influenced by their physicochemical properties as well as soil texture, organic matter content, pH, moisture, and biological activity. Organic matter may modify the sorption and mobility of certain compounds, while microbial activity contributes to their transformation and degradation. Soil fertility and pesticide contamination are therefore closely interconnected issues. Agricultural practices that modify organic matter stocks, soil structure, moisture, or microbial activity may also influence the fate of contaminants. Nevertheless, the literature on cotton production systems in Togo generally addresses these two dimensions separately. This systematic review therefore aims to analyse the influence of agricultural practices on soil fertility and contamination by pesticide residues in cotton production systems in the Northern Plateaux of Togo. Specifically, it seeks to characterize the main agricultural practices, examine their effects on the physical, chemical, and biological properties of soils, identify pesticide residues reported in agricultural systems in Togo, and determine which practices may simultaneously contribute to maintaining soil fertility and reducing contamination risks.

MATERIALS AND METHODS

Type of review: This study is a systematic literature review structured in accordance with the PRISMA 2020 guidelines. This approach aims to ensure transparent identification, selection, and synthesis of relevant studies (Page *et al*., 2021).

Research question based on the PICO framework: The PICO framework was adapted to the environmental and agronomic issue under investigation.

Table 1. Research question based on the PICO framework

Element	Definition
P – Population/Problem	Soils and cotton production systems in the Northern Plateaux of Togo
I – Intervention/Exposure	Tillage, mineral and organic fertilization, residue management, crop rotation, and pesticide use
C – Comparison	Agricultural systems or practices with different levels of intensification or different soil and pesticide management approaches
O – Outcomes	Soil fertility and quality, organic carbon, nutrient availability, physical and biological properties, and the presence and concentration of pesticide residues

The main research question was:

"What is the influence of agricultural practices on soil fertility and contamination by pesticide residues in cotton production systems in the Northern Plateaux of Togo, compared with agricultural systems or practices involving different management approaches?"

The secondary questions concerned the main agricultural practices used in cotton production systems; their effects on the physical, chemical, and biological properties of soils; the consequences of fertilization and residue management for carbon and nutrient dynamics; the pesticide residues detected in soils; and the agricultural factors that may influence their persistence, mobility, or degradation.

Literature search strategy

The literature search focused on scientific publications dealing with cotton production systems, soil fertility, and pesticide contamination. The main search concepts combined terms relating to cotton, soils, fertility, agricultural practices, fertilization, tillage, crop residues, pesticides, pesticide residues, and contamination. The search was extended to Togo, West Africa, and other cotton-producing regions in order to identify general mechanisms and practices that could be transferable to the context of the Northern Plateaux. The reference lists of the selected articles were also examined to identify additional relevant studies.

Period considered: The search covered scientific publications available up to 2026. Older studies were retained when they provided fundamental data on long-term changes in soil fertility, nutrient balances, or pesticide fate.

Inclusion criteria

The following studies were included:

Studies dealing with cotton production systems; Studies investigating soil fertility or soil quality; Studies analysing the effects of agricultural practices on soil properties; Studies investigating the presence, concentration, or fate of pesticide residues in agricultural soils; Studies dealing with fertilization, tillage, residue management, or crop rotations in cotton–cereal systems; Studies conducted in Togo or in comparable agroecological settings in West Africa; Studies providing information relevant to understanding soil fertility conservation mechanisms or soil contamination. International studies were also considered when they provided useful information for interpreting mechanisms related to organic carbon, nutrients, pesticide dynamics, or soil biological properties.

Exclusion criteria: Studies that did not address soils or agricultural practices, publications without usable information on the variables under investigation, duplicate records, and documents whose scientific content did not establish a relevant link with the research question were excluded.

Article selection process: The selection process was organized according to the four phases of the PRISMA 2020 flow diagram: identification, screening, eligibility, and inclusion.

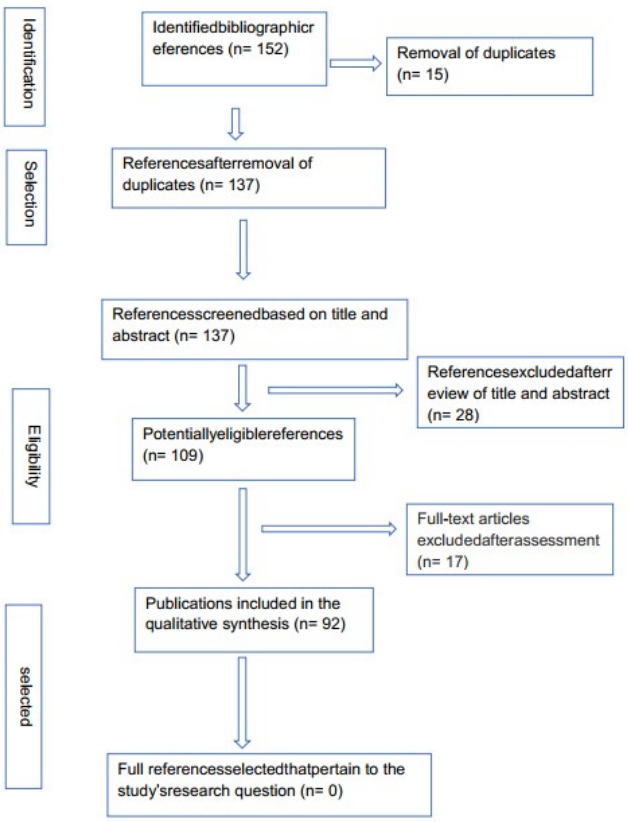


Figure 1. Summary of the article selectionprocess

Data extraction: The extracted information included authors, year of publication, study location, cropping system, agricultural practices investigated, soil properties analysed, pesticides screened, analytical methods used, and main findings. The data were grouped into four areas: tillage practices and residue management, fertilization and nutrient dynamics, pesticide use and fate, and the effects of agricultural practices on the biological and physicochemical properties of soils.

Assessment of study quality: The quality of the publications was assessed using several criteria: clarity of objectives, description of the study site, methodological precision, characterization of agricultural practices, relevance of analytical methods, and consistency between the data and conclusions. For pesticide-related studies, particular attention was paid to extraction, identification, and quantification methods, especially when analyses involved gas chromatography coupled with mass spectrometry or liquid chromatography coupled with mass spectrometry.

Data synthesis: Given the heterogeneity of agricultural systems, soils, pesticides investigated, and analytical methods, the findings were synthesized narratively. Data from Togo were compared with those obtained in West Africa and other cotton-producing regions.

RESULTS

Selection process: Of the 152 records initially identified, 15 duplicates were removed. The remaining 137 records were screened based on their titles and abstracts. Twenty-eight records were excluded, resulting in 109 full-text articles being assessed. Following detailed examination, 17 publications were excluded, and 92 studies were retained for the synthesis. Further analysis of the corpus showed that none of the 92 selected studies simultaneously matched the strict combination of "Northern Plateaux of Togo + cotton production systems + soil fertility + pesticide residues**".** This absence highlights the fragmented nature of the available knowledge.

Effects of agricultural practices on soil fertility: Studies conducted in Togo show that continuous cropping can lead to a progressive decline in soil fertility. Long-term experiments carried out in northern Togo indicate that productivity and certain soil fertility parameters decrease when land is continuously cultivated, whereas the introduction of short fallow periods helps limit these trends (Kintché *et al*., 2015a). In maize–cotton systems, mineral fertilizer inputs and residue incorporation are not always sufficient to compensate for carbon and nutrient losses associated with continuous cropping. Findings obtained on a Ferralsol in Togo highlight long-term losses despite fertilizer application and the return of maize residues to the soil (Kintché *et al*., 2015b). Soil fertility management must therefore consider the balance between nutrient inputs and removals, as well as the maintenance of organic carbon and biological activity.

Tillage and residue management: Tillage directly influences soil structure, porosity, infiltration, and organic matter dynamics. Conservation practices combining reduced tillage, residue retention, and crop diversification can help preserve organic carbon and improve certain physical and biological soil properties when local conditions are favourable (Page *et al*., 2020). In maize–cotton systems in West Africa, however, the effects of tillage, residue management, and nitrogen inputs depend on the context. Nafi *et al*. (2020) notably showed that the effects of these practices on soil properties may vary according to site conditions. These findings indicate that reduced tillage should not be considered a universal solution, but rather a practice that must be adapted to soil properties, climate, cropping systems, and farmers' constraints.

Fertilization and nutrient dynamics: Mineral fertilizers are an essential source of nutrients in cotton production systems. However, their effectiveness depends on the relationship between nutrient inputs, crop removal through harvests, and the various pathways of nutrient loss. The findings of Kintché *et al*. (2015b) show that long-term mineral fertilizer application in a maize–cotton rotation does not necessarily maintain soil carbon and nutrient stocks. Mineral fertilization should therefore be incorporated into a broader strategy combining available organic resources, residue retention, crop diversification, and appropriate management of soil resting periods.

Pesticide use and soil contamination: Available studies show the presence of several pesticide groups in agricultural soils in Togo. Bafai *et al*. (2018) investigated soil contamination in a cotton-growing area at the Kolokopé experimental station and identified several organochlorine pesticides. Bafai *et al*. (2022) also directly investigated soils from cotton-growing areas in Togo. Analyses conducted in the 0–20 cm soil layer identified several residues, including simazine, atrazine, lindane, β-endosulfan, dieldrin, endrin, heptachlor, heptachlor epoxide, DDT, and DDE. Another study conducted in the Plateaux Region reported organochlorine residues in agricultural soils, particularly in areas used for vegetable production. This study is relevant to understanding soil contamination in the region, but it should not be considered a study exclusively devoted to cotton-growing soils (Kolani *et al*., 2017).

Table 2: Characteristics and main findings of some studies included in the systematic review

Authors, year	Country/region	Cropping system	Study type	Practice investigated	Parameters studied	Main findings	Theme
Kintché et al. (2015a)	Togo	Agricultural systems	Long-term experiment	Continuous cropping/fallow	Fertility, productivity	Declining fertility under continuous cropping; mitigating effect of fallow periods	Soil fertility
Kintché et al. (2015b)	Togo	Maize–cotton	Long-term experiment	Fertilization + residues	Carbon, nutrients	Mineral inputs and residues do not fully compensate for losses	Fertilization
Bafai et al. (2018)	Togo	Cotton	Contamination study	Pesticides	Organochlorine residues	Detection of several pesticides in soils at Kolokopé	Pesticides
Bafai et al. (2022)	Togo	Cotton	Analytical study	Pesticide use	Pesticide residues	Detection of several compounds in cotton-growing soils	Pesticides
Nafi et al. (2020)	West Africa	Maize–cotton	Experiment	Tillage + residues + nitrogen	Soil properties	Interactive effects depending on the context	Agricultural practices
Page et al. (2020)	International	Agricultural systems	Review	Conservation agriculture	Organic carbon, soil properties	Potential beneficial effects of conservation practices depending on the context	

Pesticide fate in soils: The presence and persistence of pesticides in soils depend on the properties of the compounds themselves and on environmental characteristics. Sorption onto organic matter and fine particles may limit the mobility of certain compounds, whereas degradation processes may progressively reduce their concentrations. Soil texture, clay content, pH, organic matter, moisture, and microbial activity are therefore important factors influencing pesticide fate. Agricultural practices that modify these parameters may indirectly affect the persistence and mobility of contaminants.

Potential effects on soil biological functions: Pesticides can affect various biological components of soils, including microorganisms, certain enzymatic activities, and soil macrofauna. Their effects depend on the compounds involved, concentrations, application frequency, and environmental conditions. Assessments of soil quality in cotton production systems should therefore not be limited to physicochemical parameters. Biological indicators can also provide important information on the medium- and long-term effects of pesticide practices.

Interactions between soil fertility, agricultural practices, and contamination: The review findings show that the agronomic and environmental dimensions are closely interconnected. Organic matter contributes both to soil fertility and to the behaviour of many contaminants. Residue management influences carbon inputs, microbial activity, and potentially the processes involved in pesticide transformation. Tillage, fertilization, crop rotation, and residue management practices may therefore simultaneously affect soil properties and contaminant fate. This interaction justifies an integrated approach to the management of cotton production systems.

DISCUSSION

Soil fertility is an important constraint in cotton production systems in the Northern Plateaux of Togo. Repeated land cultivation, nutrient removal through crop harvests, and insufficient organic matter replenishment can lead to a progressive decline in organic carbon and certain nutrients. Long-term studies conducted in Togo show that continuous cropping can result in reduced productivity and declining soil fertility parameters, whereas short fallow periods help mitigate this degradation (Kintché *et al*., 2015a). Organic matter plays a central role in this process by contributing to structural stability, water retention, nutrient availability, and soil biological functioning. Its replenishment through crop residues, manure, or compost can improve several indicators of soil quality.

However, findings from maize–cotton systems in Togo show that residue incorporation combined with mineral fertilization is not always sufficient to compensate for long-term carbon and nutrient losses (Kintché *et al*., 2015b). Tillage practices also influence soil structure, porosity, infiltration, and organic carbon dynamics. Conservation systems may promote organic carbon retention and improve certain physical, chemical, and biological soil properties, but their effects vary according to soil and climatic conditions and the way in which the different components are combined (Page *et al*., 2020). Findings from West Africa confirm this dependence on local conditions. In maize–cotton rotations, the combined effects of tillage, residue management, and nitrogen fertilization vary according to site characteristics. Nafi *et al*. (2020) notably showed that certain combinations of practices can modify soil properties, although their effects remain dependent on local conditions. Mineral fertilization remains essential for compensating for part of the nutrient removal, but its effectiveness depends on the overall nutrient balance. Fertilizer use therefore cannot be separated from organic matter replenishment, residue management, and crop diversification. Long-term experiments conducted in Togo clearly show that mineral inputs alone cannot indefinitely maintain soil carbon and nutrient stocks in systems subjected to continuous cropping (Kintché *et al*., 2015b).

Regarding pesticides, several studies conducted in Togo have reported residues in agricultural and cotton-growing soils, particularly organochlorine compounds. The findings of Bafai *et al*. (2018) in Kolokopé and those of Bafai *et al*. (2022) in cotton-growing areas confirm that certain contaminants can be detected in agricultural soils in Togo. However, the presence of residues does not necessarily mean that all compounds have the same persistence or level of risk. Pesticide fate depends on the properties of each substance and on soil characteristics. Organic matter, texture, pH, moisture, and biological activity may notably influence sorption, mobility, and degradation processes. The study by Kolani *et al*. (2017) also provides useful information on soil contamination in the Plateaux Region. However, its context must be interpreted appropriately, since it concerns agricultural soils associated notably with vegetable production rather than exclusively cotton production systems. Pesticides may also modify certain soil biological functions. Effects on microbial communities, enzymatic activities, and soil organisms have been reported depending on the substances, doses, and exposure conditions. The integration of biological indicators into soil quality assessments would therefore complement physicochemical analyses and provide a better understanding of the long-term consequences of pesticide practices. Soil fertility and contamination must ultimately be considered as two interdependent dimensions.

Organic matter influences both nutrient availability and the behaviour of many pesticides, while the return of plant residues can modify microbial activity and contaminant transformation processes. Agricultural practices are therefore a common factor that may simultaneously influence soil productivity and contaminant dynamics. The synthesis highlights the value of an integrated approach based on residue retention, improved organic inputs, balanced fertilization, crop rotation diversification, adaptation of tillage to local conditions, and responsible pesticide use. Conservation agriculture can contribute to maintaining organic carbon and certain soil properties when appropriately adapted to local soil, climatic, and agronomic conditions (Page *et al*., 2020).

The main finding of this review, however, is the fragmented nature of the available knowledge. The 45 studies retained address different aspects of the research question, including soil fertility, cotton–cereal systems, nutrient management, and pesticide contamination. None of these 45 studies simultaneously investigates agricultural practices, soil fertility, and pesticide residues in cotton production systems in the Northern Plateaux of Togo. The value n = 0 obtained for this exact match therefore highlights a significant gap in the available literature. It does not mean that these different dimensions have never been studied in Togo, but rather that they are addressed separately in the reviewed corpus. This fragmentation justifies the development of integrated studies to jointly assess the effects of agricultural practices on soil fertility and pesticide fate in cotton production systems in the Northern Plateaux.

Limitations of the review

The main limitation of this review lies in the heterogeneity of the available studies. The studies differ in soil types, cropping systems, agricultural practices, pesticides investigated, sampling periods, and analytical methods. The available information on pesticide treatment history, application rates, application frequency, initial soil properties, and exposure duration also varies across studies. This heterogeneity limits the possibility of direct quantitative comparisons between the studies. Another important limitation is the absence of a study simultaneously integrating agricultural practices, soil fertility, and pesticide residues within the specific context of the Northern Plateaux of Togo. This gap prevents the precise determination of interactions between the different factors under local conditions. Field studies combining agronomic assessments, nutrient balances, soil physicochemical and biological parameters, and multi-residue pesticide analyses are therefore needed.

CONCLUSION

The findings of this review show that agricultural practices play a decisive role in changes in soil fertility and pesticide fate in cotton production systems. Continuous cropping, nutrient removal, and insufficient organic matter replenishment may contribute to a progressive decline in certain soil fertility indicators. Mineral fertilizer inputs and residue incorporation do not always sustainably compensate for carbon and nutrient losses in systems subjected to continuous cultivation. Studies on pesticides have also demonstrated the presence of several residues in agricultural and cotton-growing soils in Togo, particularly organochlorine compounds and triazines. The persistence and mobility of these substances depend both on their physicochemical properties and on soil characteristics, including organic matter content, texture, pH, and biological activity. Sustainable management of cotton production systems therefore requires an integrated approach combining organic matter maintenance, residue retention, balanced fertilization, crop rotation diversification, adaptation of tillage to local conditions, and responsible pesticide use. These practices may help preserve soil fertility while limiting the risks associated with contamination by pesticide residues. Finally, the absence of a study in the reviewed corpus simultaneously integrating agricultural practices, soil fertility, and pesticide residues in cotton production systems in the Northern Plateaux constitutes an important scientific gap. This situation justifies conducting integrated field studies to establish relationships between agricultural practices, nutrient dynamics, soil biological and physicochemical quality, and pesticide contamination.

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