

ORIGINAL ARTICLE

CONTENTS

The interconnections of different types of fertiliser consumption on disability-adjusted life years of digestive system diseases in European countries

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ABSTRACT

Aim: This study examines the impact of different fertiliser types – phosphate, nitrogen, and potash –and pesticide use on disability-adjusted life years (DALYs) associated with digestive system diseases in European countries. It focuses on pancreatitis, upper digestive system disorders, and non-alcoholic fatty liver disease (NAFLD), including cirrhosis.

Materials and Methods: Using a balanced panel dataset covering 39 European countries from 2006 to 2021, the study incorporates data from the Global Burden of Disease database (DALYs), the Food and Agriculture Organization (fertiliser and pesticide use), and the World Bank (trade indicators). A fixed-effects regression model was applied to assess the influence of agricultural chemical use and trade dynamics on DALYs.

Results: Pesticide use per hectare was significantly associated with higher DALYs for NAFLD, indicating substantial health risks. Nitrogen fertiliser use showed a protective effect against DALYs for upper digestive diseases and pancreatitis. In contrast, excessive potash application was linked to increased DALYs for pancreatitis. The effects of phosphate use varied by disease type. Trade-related interaction terms demonstrated complex and sometimes amplifying effects on health outcomes.

Conclusions: Agricultural inputs have both beneficial and adverse health implications. While essential for productivity, their misuse can contribute to chronic disease burdens. The findings highlight the importance of sustainable farming practices and regulatory oversight. Integrating health metrics such as DALYs into agricultural and environmental policy could improve public health outcomes across Europe.

KEY WORDS: environmental exposure, agricultural chemicals, gastrointestinal diseases, liver diseases, risk assessment

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INTRODUCTION

Digestive diseases, including pancreatitis, upper gastrointestinal disorders, and NAFLD, are increasing globally due to dietary, lifestyle, and environmental changes. In 2019, they accounted for 18.2% of incidence, 14.2% of deaths, and 10.9% of DALYs, ranking 13th globally, though DALY rates have declined from 1570.35 in 1990 to 1096.99 per 100,000 in 2019 [1, 2].

While lifestyle causes are widely recognized, environmental factors, especially agricultural practices, remain underexamined. DALYs, as defined by the WHO [3], show a global shift from communicable to chronic diseases, including NAFLD [4]. Overuse of fertilisers (nitrogen, phosphate, potash) contributes to water and soil degradation, linked to liver and gastrointestinal diseases [5]. Nitrate runoff from nitrogen fertilisers causes liver toxicity and harmful algal blooms [6].

Pesticides, particularly organochlorines, bioaccumulate in fat tissue, leading to liver dysfunction and metabolic disorders [7]. Chronic exposure increases the risk of pancreatic cancer (OR = 1.4, 95% CI: 1.0–2.0) [8], with supporting evidence from affected agricultural regions such as California and South Africa [9].

The link between agricultural chemicals and human health is central to environmental public health, especially in relation to DALYs. Nitrogen fertilisers, while vital to European agriculture, are linked to nitrate-related groundwater contamination and liver damage [10–14].

Fertiliser use also correlates with increased health spending in Europe, suggesting hidden disease burdens [15].

Pesticides, often used with fertilisers, contribute to synergistic toxicity. Organophosphates trigger oxidative stress, disrupt liver enzymes [16–17], and alter gut microbiota [18], compounding digestive health risks. Their combined use amplifies effects on liver and gastrointestinal diseases [19], including NAFLD and pancreatitis via endocrine and oxidative pathways [20–21].

Digestive diseases represent a significant share of DALYs in regions with intensive agriculture, including parts of Europe [1]. Environmental degradation from overuse of fertilisers, industrialisation, and poor waste management exacerbates these risks [22–23]. Sustainable planning and eco-conscious business practices are essential for public health [24–25].

To mitigate these impacts, research supports precision and organic farming to reduce chemical inputs without compromising yields [26–28]. Data-driven tools such as machine learning and decision-support systems improve contamination monitoring and regulation [29–33], though regulatory gaps remain [34].

Behavioural change and environmental education also play key roles in promoting sustainability [35–36]. Aligning agricultural policy with the UN's Sustainable Development Goals is critical to long-term health and environmental resilience [37–39].

Despite strong evidence linking fertiliser and pesticide exposure to digestive disease burdens, their specific impact on DALYs in Europe remains underexamined, highlighting a significant research gap.

AIM

This research aims to investigate the interconnections between the consumption of different types of fertilisers (phosphate, nitrogen, and potash) and the disability-adjusted life years associated with digestive system diseases, including pancreatitis, upper digestive disorders, and NAFLD, in European countries.

The hypotheses of this research can be inferred as follows:

H1: The consumption of fertilisers (nitrogen, phosphate, and potash) has a significant impact on the DALYs associated with digestive system diseases such as pancreatitis, upper digestive system disorders, and NAFLD, including cirrhosis.

H2: The use of pesticides is significantly associated with an increase in DALYs for digestive system diseases, indicating that excessive pesticide use poses health risks, especially when combined with fertiliser exposure.

These hypotheses guide the study's investigation into the relationships between agricultural practices and public health outcomes measured through DALYs.

MATERIALS AND METHODS

The methodology employed in this study focuses on examining the relationship between the consumption of different types of fertilisers (phosphate, nitrogen, potash) and pesticides and the disability-adjusted life years associated with pancreatitis, upper digestive system diseases, and NAFLD, including cirrhosis. The analysis is based on a panel data approach, utilising a comprehensive dataset across multiple countries and years.

All variables and their sources are presented in Table 1.

The sample of the countries formed by European countries (Albania, Austria, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Georgia, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Moldova, Montenegro, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, and United Kingdom) which are included in European Union, or going to join it, or have harmonised regulation and standards in area of fertilisers in agrarian productions. The timeline was chosen from 2006 to 2021 because some countries have not published the data for 2022, and Serbia and Montenegro separated their data after 2006. This allows the construction of a balanced panel dataset comprising 39 countries over 16 years, resulting in a total of 624 observations.

The study used panel data regression to capture both cross-country and time-based variation. Three models were applied: the Pooling Model (ignores individual effects), Fixed Effects (controls for time-invariant country traits), and Random Effects (assumes no correlation between effects and regressors). The Hausman test confirmed the Fixed Effects model as most appropriate.

Analyses were conducted in R Studio using the *plm* package, with diagnostics for multicollinearity, heteroskedasticity, and autocorrelation. This approach provides a solid framework to assess how agricultural inputs affect health, informing policy and future research.

RESULTS

The summarised data about variables is presented in Table 2.

The estimation results from both the FE and RE models, assessing the influence of various types of fertiliser consumption and pesticide use on DALYs related to NAFLD, including cirrhosis, are presented in Table 3.

The Hausman test rejected the null hypothesis, confirming that the random effects model is inconsistent and that the fixed effects model is more appropriate. This model accounts for unobserved, time-invariant country-specific factors and explains about 10.3% of the variation in NAFLD-related DALYs.

Table 1. Variables

Variables	Indicators	Source
y1	DALYs (Disability-Adjusted Life Years) non-alcoholic fatty liver disease (NAFLD), including cirrhosis, Percent	[39]
y2	DALYs (Disability-Adjusted Life Years) upper digestive system diseases, per cent	[39]
y3	ALYs (Disability-Adjusted Life Years) Pancreatitis, %	[39]
x1	Fertiliser nutrient nitrogen N use per area of cropland	[40]
x2	Fertiliser nutrient phosphate P2O5 use per area of cropland	[40]
x3	Fertiliser nutrient potash K2O use per area of cropland	[40]
x4	Pesticide use per area of cropland	[40]
x5	Food imports (% of merchandise imports)	[41]
x6	Imports of goods and services (% of GDP)	[41]
x7	Food exports (% of merchandise exports)	[41]
x8	Exports of goods and services (% of GDP)	[41]

Table 2. Summarised statistics of input data

Variables	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
y1	0.000340	0.001189	0.001655	0.001844	0.002413	0.006185
y2	0.003260	0.004914	0.005761	0.005932	0.006939	0.011803
y3	0.0008766	0.0015235	0.0021133	0.0026758	0.0031381	0.0108286
x1	6.03	54.95	72.00	78.91	94.92	278.26
x2	0.65	12.89	19.14	21.28	26.02	103.45
x3	0.06	10.02	19.14	23.17	30.58	125.37
x4	0.000	1.130	2.110	3.182	4.555	13.390
x5	2.498	7.840	9.970	10.457	12.815	26.638
x6	23.02	39.72	52.04	58.01	69.23	179.92
x7	1.848	6.175	10.010	13.617	15.893	74.173
x8	18.98	34.72	46.38	56.82	69.84	213.22

Source: authors' calculation in R Studio.

Pesticide use (x4) was the only significant predictor, positively associated with DALYs ($\beta = 2.5997e{-}05$, $p = 0.0015$), supporting previous findings on pesticide-related liver toxicity. A marginally significant effect was found for the interaction between food imports and imports of goods ($x5 \times x6$), suggesting trade-related influences on health. Other fertiliser variables were not statistically significant. These results highlight the health risks of pesticide use and the potential impact of trade on environmental health.

The estimation results from both FE and RE models assessing the relationship between fertiliser consumption and DALYs for upper digestive system diseases are presented in Table 4.

The Hausman test returned a high p-value, indicating no significant difference between the fixed and random effects models; thus, the random effects model is appropriate.

Most variables – including fertiliser types, pesticide use, and trade interactions – were not significantly associated with DALYs for upper digestive diseases ($p > 0.1$), suggesting limited direct impact. However, the interaction between food imports and imports of goods ($x2 \times x4$) was significantly positive ($\beta = 9.8293e{-}07$, $p = 0.0272$), indicating a potential combined effect on disease burden. This finding highlights the importance of assessing joint chemical exposures in understanding environmental health risks.

The results of the FE and RE models examining the association between agricultural chemical inputs and DALYs for pancreatitis are summarized in Table 5.

The Hausman test ($p < 0.001$) confirmed the fixed effects model as appropriate, indicating that unobserved country-level factors affect the results, making the random effects model unsuitable. Most fertiliser and pesticide variables were not significantly linked to DALYs for pancreatitis ($p > 0.1$). However, the interaction between food and total exports ($x7 \times x8$) was highly significant ($\beta = 8.5832e{-}07$, $p < 0.001$), suggesting trade-related pressures may increase disease burden. Table 6 presents pooled OLS results for the impact of agricultural and trade variables on DALYs across three digestive disease categories.

Table 3. FE and RE model outputs for NAFLD-related DALYs and fertiliser/pesticide variables

Variables	FE	RE
(intercept)		2.4651e-03 (<0.0001)***
x1	1.7281e-07 (0.763924)	1.2046e-07 (0.834168)
x2	-1.9906e-07 (0.874472)	-3.0696e-07 (0.807432)
x3	7.8722e-07 (0.571519)	7.2818e-07 (0.599266)
x4	2.5997e-05 (0.001461)**	2.7234e-05 (0.000771)***
x5*x6	3.4302e-07 (0.064244) .	3.5269e-07 (0.057745) .
x7*x8	-8.7547e-08 (0.300610)	-1.0821e-07 (0.199406)
R-Squared		0.097442
Adj. R-Squared	0.10327	0.082719
F-statistic	6.62179 (<0.0001)	
Chisq		66.1811 (<0.0001)
Hausman Test	Chisq = 33.889, df = 10, p-value = 0.0001929 Alternative hypothesis: One model is inconsistent	

Signif. codes: '***' – 0.001; '**' – 0.01; '*' – 0.05; '.' – 0.1; 'No symbol' – not significant.
Source: authors' calculation in R Studio.

Table 4. FE and RE model outputs for DALYs associated with upper digestive system diseases and agricultural chemical inputs

Variables	FE	RE
(intercept)		7.0257e-03 (<0.0001)***
x1	-4.1644e-07 (0.763116)	-5.5333e-07 (0.6860962)
x2	3.8473e-06 (0.203845)	4.3081e-06 (0.1502620)
x3	1.1139e-06 (0.738800)	5.7632e-07 (0.8604760)
x4	-1.1632e-05 (0.551507)	-2.0536e-05 (0.2832155)
x5*x6	1.0892e-06 (0.014514)*	9.8293e-07 (0.0271696)*
x7*x8	1.3149e-07 (0.517220)	7.4771e-08 (0.7085534)
R-Squared	0.070924	0.058833
Adj. R-Squared	-0.0066334	0.043479
F-statistic	4.38946 (<0.0001)	
Chisq		38.3188 (3.3396e-05)
Hausman Test	Chisq = 1.3784, df = 10, p-value = 0.9993 Alternative hypothesis: one model is inconsistent	

Signif. codes: '***' – 0.001; '**' – 0.01; '*' – 0.05; '.' – 0.1; 'No symbol' – not significant.
Source: authors' calculation in R Studio.

Table 5. FE and RE model estimates for DALYs associated with pancreatitis and fertiliser/pesticide variables

Variables	FE	RE
(intercept)		3.3019e-03 (<0.0001)***
x1	2.6578e-07 (0.7163187)	3.0701e-08 (0.9670891)
x2	1.1065e-06 (0.4897261)	1.3362e-06 (0.4120193)
x3	-1.8345e-06 (0.2997306)	-2.0588e-06 (0.2507879)
x4	7.4791e-08 (0.9942277)	-3.0992e-06 (0.7673679)
x5*x6	-8.0969e-08 (0.7307358)	-3.0992e-06 (0.6731230)*
x7*x8	8.5832e-07 (<0.0001)***	8.3610e-07 (<0.0001)***
R-Squared	0.21349	0.20224
Adj. R-Squared	0.14783	0.18923
F-statistic	15.6079 (< 2.22e-16)	
Chisq		155.404 (<0.0001)
Hausman Test	chisq = 324.98, df = 10, p-value <0.0001 Alternative hypothesis: one model is inconsistent	

Signif. codes: '***' – 0.001; '**' – 0.01; '*' – 0.05; '.' – 0.1; 'No symbol' – not significant.
Source: authors' calculation in R Studio.

Table 6. Pooled regression model estimates for DALYs of NAFLD, upper digestive system diseases, and pancreatitis

Variables	Disability-Adjusted Life Years		
	NAFLD, including cirrhosis, %	upper digestive system diseases, %	Pancreatitis, %
(intercept)	2.3926e-03 (<0.0001)***	5.2820e-03 (<0.0001)***	2.6335e-03 (<0.0001)***
x1	-1.1084e-06 (0.463800)	-5.6784e-06 (0,014968)*	-1.4933e-05 (6.889e-12)***
x2	-3.1272e-05 (<0.0001)***	-8.5236e-06 (0,101113)	-2.5971e-05 (<0.0001)***
x3	1.3881e-05 (<0.0001)***	1.8051e-05 (0.0001)***	2.9149e-05 (<0.0001)***
x4	3.6731e-05 (0.006350)**	-2.0428e-04 (<0.0001)	-2.2506e-04 (<0.0001)***
x5*x6	6.6997e-07 (0.204472)	-2.0618e-06 (0,011336)*	-2.4553e-06 (0.00103)**
x7*x8	-1.1113e-06 (<0.0001)***	2,6664e-07 (0,4352197)	6.7946e-07 (0.03043)*
R-Squared	0.30863	0.22545	0.49331
Adj. R-Squared	0.29736	0.211189	0.48505
F-statistic	27.3651 (<0.0001)	17.7503 (<0.0001)	59.6822 (<0.0001)

Signif. codes: '***' – 0.001; '**' – 0.01; '*' – 0.05; '.' – 0.1; 'No symbol' – not significant.
Source: authors' calculation in R Studio.

Pooled regression models for DALYs from NAFLD, upper digestive system diseases, and pancreatitis showed statistically significant results, with adjusted R-squared values between 0.21 and 0.49.

For NAFLD, phosphate fertiliser use had a significant negative association, while potash use and pesticide application were positively linked to higher DALYs. A significant negative interaction between food and total exports suggests a potential protective trade effect.

For upper digestive diseases, nitrogen and pesticide use were negatively associated with DALYs, whereas potash showed a positive association. A negative interaction between food and general imports may reflect trade-related health impacts.

In the case of pancreatitis, nitrogen and phosphate fertilisers had negative effects on DALYs, while potash was positively associated. Pesticide use again showed a negative association. Significant interactions involving both imports and exports further highlight the complex role of trade in shaping health outcomes.

These results collectively underscore the multifaceted relationship between agricultural practices, trade, and public health. They also highlight the importance of disaggregating inputs and interactions to understand the implications of chronic digestive diseases better.

DISCUSSION

This study examines the link between fertiliser and pesticide use and DALYs from digestive diseases, specifically NAFLD, pancreatitis, and upper gastrointestinal conditions, across Europe. Results highlight environmental exposures as significant contributors to non-communicable disease burdens, echoing growing global concern [1, 3, 4].

A strong positive correlation between pesticide use and NAFLD-related DALYs supports earlier evidence of liver toxicity and cancer risks from chronic exposure, particularly to organochlorines [7, 8].

Potash fertiliser consistently predicted higher DALYs, reinforcing findings on phosphate-related liver damage and environmental harm. While nitrogen fertiliser had mixed effects – protective in some cases – it remains linked to nitrate contamination and liver dysfunction [5, 11, 12].

The study also highlights synergistic effects of fertiliser and pesticide use, with trade activity amplifying health impacts, particularly for pancreatitis [19, 20, 26].

Using fixed effects models, the research underscores the role of local agricultural practices and regulation, aligning with calls for precision farming and targeted monitoring [29, 30].

These findings affirm that unregulated agricultural inputs pose real health risks, stressing the need for balanced policies promoting both food security and environmental health [3, 15].

CONCLUSION

This study examined the relationship between agricultural inputs, specifically the use of nitrogen, phosphate, and potash fertilisers, along with pesticides, and the burden of digestive system diseases, measured by DALYs, in 39 European countries from 2006 to 2021. Focusing on NAFLD, pancreatitis, and upper digestive disorders, the research sheds light on the environmental drivers of public health outcomes and offers guidance for sustainable agricultural policy.

A fixed effects regression model was employed, using publicly available data on DALYs, fertiliser and pesticide consumption, and trade variables. The model effectively captured country-specific variations and was implemented in R Studio to ensure robust statistical validity.

Key findings revealed that pesticide use was significantly associated with increased DALYs for NAFLD, highlighting the health risks of chemical exposure. Fertiliser effects were mixed: nitrogen showed potential protective associations, while potash use correlated with higher DALYs, particularly for pancreatitis and upper digestive diseases. Trade-related interactions also influenced health outcomes, reflecting the complexity of environmental and economic factors.

The study underscores the need for a balanced approach to agricultural productivity and health, advocating for sustainable practices, precision agriculture, and stricter regulation of chemical inputs to mitigate health risks and support public well-being.

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CONFLICT OF INTEREST

The Authors declare no conflict of interest

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