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RESEARCH ARTICLE

Fertilizer use in conventional cereal production in northern Greece: Mapping gaps for improving sustainability

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Summary
Optimizing fertilizer use in intensively cropped soils is essential, but knowledge of related issues among farmers is lacking. The present study assessed farmers' perceptions of fertilizers and practices of fertilizer use in intensive cereal production in rural areas of Evros in northern Greece. In total, 250 cereal farmers were chosen for this study, and more than half of the farmers (53.6%) perceived that chemical fertilizers are hazardous, corroborating a general perception of chemophobia. Nevertheless, almost all farmers (98.8%) stated that they applied fertilization in their cereal production. Among them, 82.8% applied inorganic fertilizers, 9.2% applied green manure, 4.4% applied animal manure, and 3.6% applied commercial organic fertilizers. Most farmers used rates within the recommended rates in cereal production, while 12.9% and 6.2% of the farmers reported fertilization rates that were significantly lower or higher than those recommended for the area, respectively. Almost half of the farmers (48.8%) stated that they often use slow-release fertilizers and 30.8% stated that they frequently use foliar-applied fertilizers in cereals. Most farmers (57.2%) never kept records of annual fertilizations, while two-thirds of the farmers (66.4%) never asked for a soil analysis. Overall, most farmers (52.0%) showed traditional behavior, while only 5.2% showed innovative behavior in fertilizer use. Multiple regression analysis revealed that the innovative behavior was promoted by large-scale farmers, farmers who applied crop rotation, and farmers who perceived inorganic fertilizers as harmful. Moreover, large farm size and favorable attitudes concerning organic fertilizers were significantly associated with organic fertilizers use.

Keywords: behavior; chemical fertilizers; farmers' knowledge; soil analysis; survey

Introduction

Fertilizers play a crucial role in enhancing crop output and improving livelihoods. They are necessary to support plant growth and contribute to an increase of crop yield as high as 50% (Stewart *et al.*, 2005). Fertilizers provide basic macroelements for crop growth, such as nitrogen (N), phosphorus (P), and potassium (K), while specialized fertilizers can also have different combinations of macro- and micronutrients to satisfy the specific needs of different crops. Commercial fertilizers are necessary to maintain or increase global crop productivity. However, a yield-based approach for the management of nitrogen (N) fertilizer is inherently flawed by the underlying assumption that soil N provides a constant proportion of crop N uptake (Lory and Scharf, 2003; Mulvaney *et al.*, 2006). In this regard, the global use of fertilizers is highly unbalanced, with intensive use shifting from North American and European countries to eastern Asia (mostly China and India), while African countries are still characterized by low fertilizer use

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along with expanding cultivated land (Lu and Tian, 2017). Although genetics could improve nutrient uptake efficiency and thus increase crop yields, conventional commercial fertilizers can have an adverse effect on soil quality. For example, the long-term use of synthetic N has been found to deplete soil organic C and N in numerous cropping experiments (Khan *et al.*, 2007; Mulvaney *et al.*, 2009). Also relevant is the effect of potash (KCl) fertilizer in collapsing the clay fraction, which hardens the soil by increasing bulk density and reduces cation-exchange and water-holding capacities (Khan *et al.*, 2014).

Albeit necessary for most crops, application of conventional commercial fertilizers can also lead to negative outcomes. Excessive application of conventional commercial fertilizers boosts production costs and increases the risk of environmental pollution. This trend occurs because much of the fertilizers applied yearly are not absorbed by plants. For example, a review of P loss from fields found that losses via runoff ranged between 0.7 and 42% of the fertilizer applied (Hart *et al.*, 2004). Moreover, ammonia volatilization can lead to serious N loss from rice paddies fertilized with synthetic urea or even ammonium sulfate (Mikkelsen *et al.*, 1978). About 30% of the total N was lost in the form of ammonium in a rice-growing season, while only 3% was lost in the form of nitrate (Wang *et al.*, 2018). It should be also mentioned that fertilizer N uptake efficiency (FNUE) is inherently limited for upland cereal production (Raun and Johnson, 1999). Conventional commercial fertilizers showed cumulative P and N losses of 38% and 46%, respectively (as a percentage of nutrients applied), while biosolids showed losses of 3% of P and 6% of N (Silveira *et al.*, 2019). Besides, excessive application of chemical fertilizers leads to nitrate accumulation in crop products. Nitrates tend to accumulate differently in crop plants and distinct components of agricultural commodities depending on numerous factors including fertilizer application rate (Ahmed *et al.*, 2020). Therefore, there is an increasing need for better use of limited resources (i.e., recycling waste) in the European Union to prevent or minimize pollution (European Commission, 2015).

Research on improving the utilization efficiency of chemical fertilizers and minimizing the negative effects on the environment is essential. To this end, improving fertilization methods and reducing unreasonable inputs for promoting sustainable agriculture is highly important. For example, fertilization limits per unit area should be rationally formulated according to soil conditions, crop yield potential, and nutrient management in different regions to reduce the behavior of blind fertilization. Taking into account the soil's inherent capacity for nutrient supply, which can exhibit substantial spatial variation, is a critical prerequisite for increasing utilization efficiency for fertilizer inputs (Ruffo *et al.*, 2006). Alternatively, the use of organic fertilizers can improve soil quality and plant nutrition, avoiding adverse environmental and health effects by conventional commercial fertilizers (Quynh and Kazuto, 2018). A recent study found that complementary use of compost with less conventional commercial fertilizers in wheat could prevent N losses and decrease gas emissions, without compromising grain yield and quality (Guangbin *et al.*, 2021). This finding is rather expected because N release occurs much more rapidly in the case of the inorganic fertilizers, liberating a substantial quantity of ammonium or nitrate that becomes subject to serious N loss. In contrast, organic N sources undergo gradual mineralization to inorganic N, avoiding rapid accumulation that is conducive to loss by volatilization of ammonium or the leaching or denitrification of nitrate. Similarly, while the conventional way of fertilization caused the most N loss, replacing partial urea with nitrogen-fixing cyanobacteria significantly reduced the leaching losses of N (Song *et al.*, 2021).

Improper decisions on crop fertilization may have numerous disadvantages on crops, including stem lodging (Mohr *et al.*, 2007), potential delays in the growth cycle (Korboulewsky *et al.*, 2002), and sensitivity to pest attacks (Culjak *et al.*, 2011), while some nutrients may alter or negatively affect the quality features of plant products (e.g., essential oils) (Burducea *et al.*, 2018). Given that most farmers target high output agroecosystems, such decisions usually tend to boost the economic return to the farmers (McGuire *et al.*, 2013) and stabilize farm income (Lastra-Bravo *et al.*, 2015). Thus, soil fertility techniques that are based on research and fit to farmers' actual

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concerns need to identify how farmers form perceptions on soil quality and crop response to inputs. In addition, decision-making is affected by perception of risk, values, and attitudes, which must also be considered (Vignola *et al.*, 2010). Thus, studying and utilizing stakeholders' engagement in the use of fertilizers as an opportunity for improving environmental sustainability are needed.

Attitudes affect farmers' decision-making process and are important parameters to model farmers' behavior (Sheeder and Lynne, 2011). Obviously, current practices and local behavioral influences of farmers must be considered when recommending suitable fertilization practices. In addition, strengthening farmers' knowledge about the potential benefits and limitations of such practices in the local context is essential for more effective use of mineral fertilizers. Nevertheless, while blind fertilization behavior typically resulting in overfertilization is often suspected among farmers, solid evidence is highly limited in the literature. One study from China confirmed the problem of excessive fertilization in almost 70% of the farmers in Heilongjiang province (Peng *et al.*, 2019). However, no similar study on fertilizer use has been conducted in Greece. In this setting, the current study attempts a critical appraisal of farmers' knowledge and behavior in fertilizer use, for which limited research exists in the literature. Because experimental data are normally difficult to obtain, surveys are a unique way of gathering large amounts of information that can help improve farm operations and reveal future targets for extension services. Thus, the current study may provide useful data for bridging this knowledge gap, by summarizing the relevant experience from the study area and communicating it with a wider audience in an effort to point out the advantages and address the disadvantages for cleaner and sustainable production in agriculture.

The objective of this survey was to evaluate current fertilization practices and farmers' awareness of fertilizers in cereal cultivation in order to provide some insights into what can affect attitudes in common fertilization practices in the rural area of Evros. The research question of the study was set as follows: do farmers know of good fertilization practices and how do they behave in the use of fertilizers in cereal production? Findings are expected to improve our knowledge of farmers' behavior in fertilizer use, for which limited literature exists, and could be useful not only for the study area but also for other areas with similar climatic conditions and production practices.

Materials and Methods

Study area

The area of northern Evros was selected for the survey (Supplementary Material Fig. S1), which was conducted in 2018. Evros is the northernmost regional unit of Greece. It borders Turkey to the east, across the river Evros, and Bulgaria to the north and the northwest (40.837 to 41.744 N, 25.618 to 26.634 E). The regional unit of Evros ranks among the top regional units of Greece in terms of cropping lands to the total area, representing 5.38% of the total agricultural land in Greece. The main crops in the area are cereal grains, cotton, and sunflower. Forage production is rather limited and consists mainly of alfalfa. Extensive livestock farming is a fundamental activity in the area, especially for the north part of Evros region. Livestock usually graze at natural and seminatural grasslands and woodlands.

The Evros region is crossed by Evros River and Erythropotamos River. Evros River is an important water body, protected by the international legislation, but it is susceptible to numerous pollution sources that have led to the deterioration of its environmental status (Dimitriou *et al.*, 2012). For example, high concentrations of nitrates upstream can be attributed to the intensive cultivation of soil in the northern part of the catchment and especially to the presence of irrigated cropland. Other significant threats in the area are soil degradation through groundwater salinization and uncontrolled operation of pumping stations to drain land. All these activities are resulting in the gradual degradation of the ecosystems and the landscape.

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Sampling procedure and data collection

For defining a representative sample for the project, the districts and villages of the study area were targeted. The districts were selected on purpose as ordered by the local authorities and villages were chosen randomly. A multistage sampling was followed. Altogether, 250 cereal farmers participated in the project, calculated following the sampling table of Krejcie and Morgan (1970). With this sample, a margin of error ±5.5% at $p < 0.05$ was calculated, which was acceptable for the survey (Fowler, 2015). Participants were active farmers who were responsible for farming decisions. Personal contact with the farmers assisted in the collection of the data using a structured questionnaire.

The questionnaire was constructed based on experience from previous projects (Damalas and Hashemi, 2010; Damalas and Koutroubas, 2014; Toubou *et al.*, 2020) and assessed sociodemographic data like age, gender, education, and farm size, perceptions of fertilizers, fertilization practices, and attitudes of farmers concerning organic fertilizers, including manure. Attitudes concerning organic fertilizers was assessed using five statements on the advantages of organic fertilizers that farmers scored on a 5-point scale from 1 = totally disagree to 5 = totally agree. An average score was calculated for each statement, and an overall score of attitudes was calculated across all statements. The internal consistency of the set of the attitudes items was examined with Cronbach's alpha. The questionnaire was approved by professors and teaching staff of the university. Questionnaires were pilot-tested to a small sample size (10 farmers) before the main survey to assess the clearness of the questions included. Feedback was used for applying minor corrections in wording. Data of the pilot test were included in the analysis. All volunteer farmers could participate in the survey, while specific age groups that were hesitant to take the survey were not observed. Data were collected with face-to-face interviews with the farmers at their fields or with acceptable alternates who were very familiar with the household farm. Some farmers were interviewed at their places, after a scheduled appointment. In case of refusal, the interviewers contacted the next farmer on the list. Interviews were conducted by the authors in Greek language.

Oral consent to participate was obtained by all participants, but no written informed consent was required, since the research did not present any risk of harm to the subjects and did not involve procedures for which written consent is normally required outside the research context. Similarly, ethical approval was not required for a fully anonymous survey of academic purpose.

Data analysis

Descriptive statistics of the sample

Descriptive statistics were used to describe data and draw conclusions. Simple descriptive statistics (e.g., frequencies and contingency tables) were calculated. Respondents were grouped according to the levels of fertilizer amounts (compared with the recommended rates for the area) using the Interval of Standard Deviation from the Mean (ISDM) to obtain a three-level distribution of farmers as below:

- A: Less than recommended, that is, $A < \text{Mean} - \text{SD}$
- B: Recommended, that is, $\text{Mean} - \text{SD} \leq B \leq \text{Mean} + \text{SD}$
- C: More than recommended, that is, $C > \text{Mean} + \text{SD}$

The ISDM is a simple and particularly useful data classification method when attempting to show the deviation from the mean of a data array (Allahyari *et al.*, 2016; Alotaibi *et al.*, 2020). It shows how much an attribute's value varies from the mean, based on different classes defined by adding and subtracting the standard deviation from the mean of the dataset (Klosterman *et al.*, 2018). This classification method requires datasets that show a normal distribution, which was confirmed in this study with the one-sample Kolmogorov–Smirnov test at $p < 0.05$.

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Farmers' classification according to fertilization practices

The simple non-weighted addition of five variables (i.e., perform soil analysis before fertilization, keep records for fertilizer use, types of fertilizers used, use slow-release fertilizers, and use foliar-applied fertilizers) was used to discriminate farmers' behavior in fertilizer use. The selection of these variables was based on empirical evidence in the study area in order to reflect basic concepts of knowledge about alternative fertilizers and critical points of farmers' behavior in fertilizer use. Given that the five variables are quite different, their non-weighed incorporation into a single variable was necessary for capturing the variation in farmers' behavior in fertilizer use, which was the main objective of the study. A singe value ranging between 0 and 1 was calculated for the behavior of each farmer using the formula below, according to Damalas and Abdollahzadeh (2016):

$$\text{Behavior} = \frac{\text{actual value} - \text{minimum value}}{\text{maximum value} - \text{minimum value}} \tag{1}$$

where actual value is the average use score calculated from the five selected variables for each farmer (i.e., the mean of the five values scored by each farmer for each one of the five selected variables), minimum value is the lowest use score of the five variables for each farmer, and maximum value is the greatest use of the five variables for each farmer. Then, behavior of farmers was grouped into three levels of 0.33 points each, totaling 1 as follows: innovative behavior (0.67–1.00), intermediate behavior (0.33–0.66), and traditional behavior (0.00–0.32).

Determinants of farmers' behavior

Multiple regression analysis (ordinary least squares method) was employed to examine determinants of farmers' behavior as dependent variable. Multiple regression uses several predictor variables on the outcome of a response variable. The goal is to model the linear relationship between the explanatory (independent) variables and the response (dependent) variable. It allows the determination of the relative influence of one or more predictor variables to the target value and the identification of outliers or noise data (Montgomery *et al.*, 2012).

The multiple regression model is specified as follows:

$$Y = f(X1, X2, X3, X4, X5, X6, X7, X8, X9, U) \tag{2}$$

where Y = level of farmers' behavior in fertilizer use, $X1$ = gender (dummy variable: 1 = male, 0 = otherwise), $X2$ = age-1 (dummy variable: 1 = less than 40 years old, 0 = otherwise), $X3$ = age-2 (dummy variable: 1 = between 40 and 60 years old, 0 = otherwise), $X4$ = education-1 (dummy variable: 1 = low level of education, 0 = otherwise), $X5$ = education-2 (dummy variable: 1 = intermediate level of education, 0 = otherwise), $X6$ = farming as main profession (dummy variables: 1 = yes, 0 = otherwise), $X7$ = farm size (hectare), $X8$ = apply crop rotation (dummy variable: 1 = yes, 0 = otherwise), $X9$ = perception of fertilizers hazard for human health (dummy variable: 1 = harmful, 0 = otherwise), and U = error term. Constant variance, absence of influential outliers, and distribution of the data were examined using plots (Neter *et al.*, 1990), and the one-sample Kolmogorov–Smirnov test was calculated to examine normality. No significant departures from the assumptions were observed. In addition, variation inflation factor values revealed no significant multicollinearity among independent variables. Statistical analysis was done using the SPSS18 package. The level of significance was set at $p < 0.05$ or otherwise stated.

Determinants of organic fertilizers use

Binary logistic regression was used to assess potential predictors of using organic fertilizers. In this model, use of organic fertilizers was the dependent variable (no = 0, yes = 1), and the measured variables, $X1$ = gender, $X2$ = age, $X3$ = education, $X4$ = main profession, $X5$ = farm size, and $X6$ = attitudes, concerning organic fertilizers were the dependent variables. Logistic regression

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Table 1. Socioeconomic background of the respondents

Variable	Frequency	%
Gender		
Male	168	67.2
Female	82	32.8
Age		
Young farmers (less than 40 years old)	30	12.0
Middle-aged farmers (between 40 and 60 years old)	142	56.8
Old farmers (more than 60 years old)	78	31.2
Education		
Low level of education	100	40.0
Intermediate level of education	125	50.0
High level of education	25	10.0
Farming as main profession		
Yes	235	94.0
No	15	6.0
Farm size		
<10	48	19.2
10–20	58	23.2
21–30	48	19.2
31–40	25	10.0
41–50	26	10.4
>50	45	18.0

forms a best-fitting equation or function using the maximum likelihood method, which maximizes the probability of classifying the observed data into the appropriate category given the regression coefficients. Logistic regression provides a coefficient 'B', which measures each independent variable's partial contribution to variations in the dependent variable. The binary logistic regression model is specified as follows (we use the logit of Y as the response in our regression equation instead of just Y):

$$\text{Logit}(Y) = \text{Ln}\left(\frac{P}{1-P}\right) = bo + b1X1 + b2X2 + b3X3 + b4X4 + b5X5 + b6X6 \quad (3)$$

Statistical analysis was done using the SPSS18 package. The level of significance was set at $p < 0.05$ or otherwise stated.

Results

Socioeconomic background of the respondents

In total, 250 cereal farmers participated in the study with a high male–female ratio among the study population (67.2% and 32.8%, respectively) (Table 1). Concerning age distribution of the respondents, most farmers were middle-aged. Farmers' level of education varied from no formal education up to tertiary education and more, but half of the farmers had intermediate level of education. The majority of the farmers (94.0%) had farming as main profession. Farm size ranged from less than 10 ha (19.2% of farmers) to more than 50 ha (18.0% of farmers).

Farmers' perceptions of conventional commercial fertilizers

Most farmers (53.6%) mentioned that conventional commercial fertilizers are hazardous, 30.0% mentioned that conventional commercial fertilizers are not hazardous, while 16.4% were undecided (Table 2). This question referred to any acute or long-term health effects of commercial chemical fertilizers on humans according to farmers' perception. Moreover, it referred only to commercial chemical fertilizers, irrespective of the manufacturing quality of these fertilizers.

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Table 2. Perceptions of fertilizers among respondents

Variable	Frequency	%
Chemical fertilizers are hazardous for human health[a]		
Yes	134	53.6
No	75	30.0
Do not know	41	16.4
Chemical fertilizers are necessary for high crop yield		
Yes	244	97.6
No	2	0.8
Do not know	4	1.6
Fertilization use in cereals		
Yes	247	98.8
No	3	1.2

[a]Do you think that commercial chemical fertilizers have acute or long-term health effects on humans?.

Almost all (97.6%) perceived necessity of conventional commercial fertilizers in crop production (Table 2). Consequently, almost all farmers (98.8%) stated that they applied fertilization in their cereal production (Table 2).

Farmers' fertilization practices

Conventional commercial fertilizers were used both in basal (broadcast-incorporated) application and in top-dressed application by the majority of the farmers (92.0%) (Table 3). Among farmers, 82.8% applied conventional commercial fertilizers, 9.2% applied green manure, 4.4% applied animal manure, and 3.6% applied commercial organic fertilizers. Almost half of the farmers (48.8%) stated that they frequently use slow-release fertilizers and 30.8% stated that they frequently use foliar-applied fertilizers in cereals. More than half of the farmers (57.2%) never kept records of fertilizer application, while 26.0% were always keeping records of fertilizer applications (Table 3). Almost two-thirds of the farmers (66.4%) never performed a soil analysis for fertilization, while only 5.2% were often performing soil analysis (Table 3).

According to the reported amounts of chemical fertilizers, most farmers used rates within the recommended rates of fertilization in cereal production, while 12.9% and 6.2% of the farmers reported fertilization rates that were significantly lower or higher than those recommended for the area, respectively (Table 4).

Farmers' behavior in fertilization and determinants of behavior

Based on the simple non-weighted addition of five variables, farmers' behavior in fertilizer use was discriminated in three levels, traditional behavior (52.0%), intermediate behavior (42.8%), and innovative behavior (5.2%) (Table 5). The main source of information about fertilization practices for most farmers was the personnel of agricultural supply centers, while multiple sources of information were reported by one-fifth of the farmers (20%).

Following regression analysis, the innovative behavior was promoted by large-scale farmers, farmers who applied crop rotation, and farmers who perceived conventional commercial fertilizers as harmful (Table 6). On the other hand, male farmers and low education discouraged innovative behavior.

Farmers' attitudes regarding organic fertilizers

Farmers expressed slightly favorable attitudes (overall mean = 3.523) concerning organic fertilizers (Table 7). The logistic regression model provided a better fit than the model without the independent variables. Young farmers ($p < 0.05$), large farm size ($p < 0.01$), and favourable

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Table 3. Fertilization practices of the respondents

Variable	Frequency	%
Fertilization methods in cereals		
Broadcast-incorporated annually	12	4.8
Top-dressed application annually	6	2.4
Both methods annually	230	92.0
Missing data	2	0.8
Types of fertilizers used		
Inorganic (mineral)	207	82.8
Organic (commercial)	9	3.6
Manure	11	4.4
Green manure	23	9.2
Using slow-release fertilizers		
Often	122	48.8
Rarely	44	17.6
Never	84	33.6
Using foliar-applied fertilizers		
Often	77	30.8
Rarely	68	27.2
Never	105	42.0
Keeping records of fertilizer applications		
Never	143	57.2
Sometimes	41	16.4
Always	65	26.0
Missing data	1	0.4
Performing soil testing		
Never	166	66.4
Rarely	66	26.4
Often	13	5.2
Only once	3	1.2
Missing data	2	0.8
Apply crop rotation		
Yes	227	90.8
No	23	9.2

Table 4. Farmers' grouping according to the levels of fertilizer amounts (compared with the recommended rates for the area)

Fertilization amount	Frequency	%
Less than recommended	31	12.9
Within the recommended	195	80.9
More than recommended	15	6.2
Missing data	9	–
Total	250	100.0

Table 5. Farmers' behavior in fertilizer use based on simple non-weighted addition of five variables (i.e., perform soil analysis, keep records for fertilizer use, types of fertilizers used, use slow-release fertilizers, and use foliar-applied fertilizers)

Behavior	Frequency	Percent
Traditional	130	52.0
Intermediate	107	42.8
Innovative	13	5.2
Total	250	100.0

Behavior is expressed from 0.00 to 1.00 and divided to traditional behavior (0.00–0.32), intermediate behavior (0.33–0.66), and innovative behavior (0.67–1.00).

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Table 6. Regression analysis of factors influencing farmers' behavior in fertilizer use

Independent variable	B	SE	beta	***t*-ratio**	Sig.	VIF
(Constant)	8.214**	0.743		11.052	0.000	
Gender (male)	−1.096**	0.241	−0.222	−4.546	0.000	1.042
Young farmers	−0.148	0.437	−0.021	−0.338	0.735	1.642
Middle age farmer	0.170	0.276	0.036	0.616	0.538	1.525
Low level of education	−1.217**	0.435	−0.257	−2.797	0.006	2.694
Intermediate level of education	−0.501	0.397	−0.108	−1.263	0.208	2.198
Farming as main profession	−0.835	0.482	−0.085	−1.731	0.085	1.066
Farm size	0.031**	0.003	0.531	10.757	0.000	1.064
Apply crop rotation	1.213**	0.391	0.154	3.099	0.002	1.080
Perception of fertilizers health risk	0.531*	0.226	0.114	2.353	0.019	1.030

$R = 0.672$, $R^2 = 0.451$, adjusted $R^2 = 0.431$, standard error of the estimate = 1.753, F = 21.92** *Significant at $p < 0.05$, **Significant at $p < 0.01$, VIF: variation inflation factor.

Table 7. Farmers' attitudes regarding organic fertilizers

Attitude (alpha = 0.744)	Mean	SD
Organic fertilizers are friendly to the environment	4.092	0.833
Using organic fertilizers enhance the yield of crops	3.184	0.981
Using organic fertilizers enhance the quality of produce	3.024	0.896
Organic fertilizers enhance the biological activity of soils	3.324	0.929
Organic fertilizers reduce dependency on chemical inputs	3.392	0.873
Overall mean value	3.523	0.635

Means on a scale from 1 (=totally disagree) to 5 (=totally agree).

attitudes concerning organic fertilizers ($p < 0.01$) were positively associated with organic fertilizer use (Table 8). On the other hand, low or intermediate education was negatively associated ($p < 0.01$) with organic fertilizer use

Discussion

This study assessed current fertilization practices in cereal cultivation. The aim was to provide some insights into farmers' behavior in cereal fertilization and reveal what can affect common fertilization practices in the rural area of Evros, Greece. The survey provides a set of data on fertilizer use in the area of Evros, which could be useful also for other areas of Greece and includes detailed information on fertilizer use in the study area. The collected information offers a highly useful snapshot of farmers' situation in fertilizer use, given that similar studies are lacking in the area. This information could be used to target education programs to improve fertilizer management in the area both in terms of production and in terms of environmental goals. Moreover, the study assessed how farmers see conventional commercial fertilizers in terms of health risk, for which limited information exists in the literature. More than half of the farmers perceived that conventional commercial fertilizers are hazardous, while almost all perceived a necessity of conventional commercial fertilizers in crop production. This perception is generally expected, given that perception of chemicals among the general population tends to be rather negative founded on misconceptions and fear (Kraus *et al.*, 1992). In general, irrational fear of chemicals fuels the negative perceptions of chemical products in the population (Francl, 2013). However, it is worth mentioning that most farmers have good experience of agricultural production and usually take full responsibility for the agronomic practices they implement. Workers in different jobs have been found to perceive the threat of chemical risks as high, but they are resigned to accepting the risks (Hambach *et al.*, 2011). From this point of view, due to lack of a

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Table 8. Logistic analysis of factors influencing farmers' use of organic fertilizers

Variables	B	SE	Wald	Sig.	Exp(B)
Constant	−4.771	1.845	6.686	0.010	0.008
Gender					
Male	−0.487	0.445	1.19	0.265	0.619
Female (reference)					
Age					
Young farmers (less than 40 years old)	1.349*	0.617	4.779	0.029	3.853
Middle-aged farmers (between 40 and 60 years old)	0.638	0.517	1.523	0.217	1.892
Old farmers (more than 60 years old) (reference)					
Education					
Low level of education (some schooling and elementary school)	−1.493*	0.598	6.220	0.013	0.225
Intermediate level of education (lower secondary, vocational education, and upper secondary)	−2.220**	0.566	15.405	0.000	0.109
High level of education (technical education, tertiary education, and master or above) (reference)					
Farming as main profession					
Yes	−0.638	0.840	0.576	0.448	0.529
No (reference)					
Farm size	0.025**	0.007	13.669	0.000	1.026
Attitudes	1.093**	0.364	9.025	0.003	2.983

Hosmer and Lemeshow test: Chi-square = 4.79, df = 8, Sig. = 0.78, −2 log-likelihood = 160.93, Cox & Snell $R^2 = 0.38$; Nagelkerke $R^2 = 0.49$; overall percentage of right prediction = 85.6%; sample size = 250 farmers. *Significant at $p < 0.05$, **Significant at $p < 0.01$.

widely accepted substitute for agricultural chemicals, farmers may feel compelled to use chemicals, irrespective of perceived risk (Padgitt and Kaap, 1987).

The majority of the farmers used conventional commercial fertilizers both in basal (broadcast-incorporated) application and in top-dressed application using conventional commercial fertilizers, while relatively few used green manure, animal manure, and commercial organic fertilizers. Farmers' behavior in fertilizer use was discriminated in three levels, traditional behavior (52.0%), intermediate behavior (42.8%), and innovative behavior (5.2%). Evidently, there is room for increasing innovative behavior of farmers in the use of fertilizers. First, soil testing must be encouraged. A previous study in a different area of Greece also confirmed a void in the use of soil testing for better fertilization decisions among farmers (Lithourgidis *et al.*, 2016). A common reason for the nonperformance of soil testing by the majority of farmers was the cost, but this reasoning requires further examination based on a specific and predefined hypothesis. Soil testing allows farmers to find out the critical amounts of nutrients and monitor the success of nutrient management practices. Soil testing for P and K availability allows growers and crop advisers to evaluate whether a soil is likely to respond to fertilization, (Geisseler and Miyao, 2016), even though other studies (Khan *et al.*, 2014, 2015) underline that soil testing is of no value for predicting the response of K fertilizer. Such knowledge can assist farmers to design a suitable nutrient management plan for their farms. In China, wheat yield was increased from 5970 kg ha^{-1} to 6672 kg ha^{-1}, when conventional inorganic fertilization (N, P_2O_5, and K_2O) was converted into fertilization based on soil testing, with an average increment of wheat yield being 11.76% (Wu *et al.*, 2019). In the United States, performing soil tests and calculating K fertilizer rates were useful for soybean producers, contributing to less use of K fertilizer without significantly sacrificing yield (Popp *et al.*, 2020). Nevertheless, it also should be kept in mind that soil testing can have a number of pitfalls and limitations, since many soil tests are lacking in calibration relevant to current management practices and sampling depth may not always represent the zone of active rooting. Moreover, test results can easily be misinterpreted if they do not adequately characterize plant-available forms, as is especially problematic for soil K testing.

Second, records of fertilizer applications must be encouraged. Such records are very useful because they document the annual amounts of applied N and P and can help minimize

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applications and reduce the potential loading of N and P to natural waters. Fertilizer records not only document N and P application amounts but also are useful in overall fertilizer management, including the troubleshooting of fertilizer-related crop growth problems. Therefore, good records lead to better decisions, a better plan for the future, and hopefully higher returns. Third, the use of organic fertilizers for reducing the environmental impact of excessive nutrient loads and relieving nutrient limitation should be promoted. The important role of manure as a soil amendment in sustaining soil fertility has been shown in previous research (Majhi *et al.*, 2021; Singh *et al.*, 2019). Nevertheless, combined use with conventional commercial fertilizers is recommended due to the low capacity of manure to supply N (Li *et al.*, 2020; Zingore *et al.*, 2008) and the beneficial effect of the combined application (conventional commercial fertilizers plus farmyard manure) on soil fertility (Majhi *et al.*, 2021; Singh *et al.*, 2019). In this context, sustainable interventions should facilitate the management of the natural resource base because global consequences of conventional commercial fertilizers overconsumption challenged the capacity of natural resources, namely soil and water (Pandey and Diwan, 2021).

Farmers often do not consider soil testing to be cost-efficient as it does not provide sufficient information for more efficient fertilizer allocation. Similarly, farmers often do not keep records of fertilizer use and simply trust their memories to keep that information. However, this tactic can work but only for a short while. In addition, modern farmers have ceased the traditional practice of applying organic fertilizers, tending to apply high amounts of conventional commercial fertilizers to compensate potential decline in yields. Thus, in case the crops do not yield according to expectations, they translate that response into the need for more fertilizers. Previous research highlighted that improving farmers' knowledge and ensuring cost-effectiveness of alternative fertilization techniques are main challenges in crop fertilization (Ladha *et al.*, 2005). Employees of the farm supply stores are normally the major information source of farmers for most agricultural supplies in Greece (Lithourgidis *et al.*, 2016; Toubou *et al.*, 2020). Considering the main source of information, farm supply stores in the study area could improve farmers' knowledge of fertilizers. Concerning the adoption of organic fertilizer use, this practice has some limitations. First, farmers must find raw material and produce the fertilizer by themselves (Tittonell and Giller, 2013). In addition, such fertilizers contain low levels of macronutrients and release nutrients slowly, and farmers fail to secure quantities that will satisfy their needs (Harris, 2001; Tittonell and Giller, 2013). Previous research highlighted unpleasant odor, nutrient content variability, and difficulty in use as important barriers to adoption of organic waste as fertilizers (Case *et al.*, 2017). These challenges emphasize the need to combined application of organic material with mineral fertilizers. On the other hand, technological solutions, which provide processed organic products less odorous than their raw substrate, may overcome some barriers.

According to the reported amounts of chemical fertilizers, most farmers used rates within the recommended rates of fertilization in cereal production, and 12.9% and 6.2% of the farmers reported fertilization rates that were significantly lower of higher than those recommended for the area, respectively. Following recommended amounts and timing of top-dressing of fertilizers can enhance fertilization efficiency without loss to leaching. The proportions of fertilization overuse found in this study are much lower than in other countries. Overfertilization was severe in the Lake Tai region in China, accompanied by inappropriate application methods (Yang *et al.*, 2012). Similarly, more than 75% of the grape growers in China were overusing chemical fertilizers, but overfertilization was lower when households had good knowledge on accurate fertilization time and matching fertilizers with nutrient needs (Xue *et al.*, 2020). Overfertilization in the production of three cereal grains (wheat, maize, and rice) showed an upward trend from 2010 to 2018 in China, but varied across regions, with excessive application noted in wheat in the Huang-Huai-Hai region and in maize in Southwest China (Shen *et al.*, 2021). Unfortunately, overfertilization reduces nutrient use efficiency (Peng *et al.*, 2006) and causes economic and environmental problems (Ju *et al.*, 2006). Increasing fertilizer use efficiency requires an improved scientific

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knowledge base in fertilizer use. Therefore, knowledge of alternative routes of plant nutrient delivery and alternative nutrient uptake forms should be improved to better address crop needs.

Following regression analysis, the innovative behavior was promoted by large-scale farmers, farmers who applied crop rotation, and farmers who perceived conventional commercial fertilizers as harmful (Table 8). On the other hand, male farmers and low education discouraged innovative behavior. Reducing fertilization rates and using novel application techniques can sustain crop yields. Crop rotation, cover cropping, and application of livestock manure or compost are useful techniques for better nutrient management in crop fertilization. However, these techniques must be adapted to soil and climatic conditions as well as to social and economic perspectives of the producers of an area. Thus, participation in organic fertilizer management training positively is expected to improve the adoption of those approaches. For example, free training of smallholder farmers to support organic fertilizer adoption would be useful. Previous research showed a positive association between training and rice farmers' adoption of soil testing and formulated fertilizer products (Liu *et al.*, 2019). Moreover, training promoted careful behaviors of farmers in the use of agrochemicals (Damalas and Koutroubas, 2017). Alternative fertilizer products could easily be integrated in farmers' current practices, without increasing production costs. From this point of view, recycling nutrient fertilizers should be encouraged in light of the finite nature of mined nutrients. Prompting the uptake of nutrients by crops through nutrient recycling could increase global food production with the use of less mineral nutrients (Withers *et al.*, 2014). Moreover, the application of precision farming techniques related to fertilization, such as the variable rate treatment, could be useful in saving resources and boosting crop yields without wasting expensive therapies. Nevertheless, this technology has grown at a slower rate on field crops farms in developed countries, compared to other precision farming technologies (Nowak, 2021).

Conclusions

This study assessed current fertilization practices in cereal cultivation in the rural area of Evros in northern Greece. The aim was to provide some insights into farmers' behavior in cereal fertilization and to reveal what can affect common fertilization practices. Overall, most cereal farmers (52.0%) showed traditional behavior, while only 5.2% showed innovative behavior in fertilizer use. The innovative behavior was promoted by large-scale farmers, farmers who applied crop rotation, and farmers who perceived conventional commercial fertilizers as harmful. Fertilization with the use of specially formulated forms of fertilizer (e.g., slow-release fertilizers) and the integrated use of fertilizers, manures, and crop residues should be improved in cereal production, also taking into account soil differences in nutrient availability, which is a critical prerequisite to sustainable fertilization.

The current study has some weaknesses that should be taken into account for better understanding of findings. First, the research, due to its own nature, does not determine cause and effect relationships among variables. Therefore, causal research properly planned, designed, and formatted is required in future studies to test hypotheses about cause-and-effect relationships. Second, the research pointed out trends related to the time of the survey, and thus further surveys in time are necessary to see possible changes in farmers' behavior. Nevertheless, the study used a representative sample of the farmers of the study area, and the findings illustrate useful trends that could serve as a guide for future studies.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S0014479723000133

Data availability statement. The data that support the findings of this study are available from the corresponding author upon reasonable request.

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