Journal of Animal & Plant Sciences, 33(6): 2023, Page: 1367-1373
ISSN (print): 1018-7081; ISSN (online): 2309-8694
https://doi.org/10.36899/JAPS.2023.6.0676

CONTRIBUTION OF IMPROVING NITROGEN USE EFFICIENCY TO AGRICULTURAL ECONOMICS IN EUROPE

F. Ş. Özbek

Turkish Statistical Institute[1], Ankara, Turkiye
Corresponding author's email: fethiozbek@gmail.com,

ABSTRACT

Contribution of improving nitrogen use efficiency (NUE) to the European agricultural economy was evaluated for the year 2020 for all European countries. For this purpose, the economic benefit of using fewer nitrogenous mineral fertilizers has been revealed for a 5% improvement in NUE and attaining maximum NUE. The Eurostat/OECD gross nutrient balance methodology was used to calculate NUE values and the amount of nitrogenous mineral fertilizer that will be used less when the NUE is improved. The results showed that improving NUE would result in significant economic benefits; even if NUE was improved by 20%, the benefit would be greater than half the cost of purchasing nitrogenous mineral fertilizers. Yearly economic benefits from purchasing nitrogenous mineral fertilizers in Europe would be 2.6 and 10.7 billion euros for a 5% improvement in NUE and a maximum NUE in 2020, respectively. According to the findings of the study, increasing NUE by reducing N mineral fertilizer use would result in significant economic benefits.

Key Words: Nitrogen Use Efficiency, Nitrogenous Mineral Fertilizers, Economic Benefit, Agricultural Economics, Europe

Published first online August 20, 2023 Published final December 13, 2023

INTRODUCTION

Nitrogen (N), the most important nutrient for crop growth, is frequently over-applied in order to achieve high grain yield (Zhang *et al., 2*019; Lu *et al., 2*021). Overuse of N fertilizers has posed significant risks to the climate, environment, and public health (Congereves *et al., 2*021), and reactive N has been identified as one of the top five emerging threats to humanity and the planet (UNEP, 2019). Because of these effects, estimating N-fertilizer overuse in agricultural areas is critical. Nitrogen use efficiency (NUE) can be used to calculate overuse of nitrogen fertilizer (e.g. Wang *et al.* 2020).NUE is defined as a measure of the amount of nitrogen (N) taken up by a crop compared to the amount applied (Oenema *et al., 2*015), so increasing NUE in agriculture and food systems allows for the same crop N yield while using less fertilizer. This ensures that agricultural systems are more sustainable (Wang *et al.,* 2020). However, more than 50% of applied N fertilizers are unused by crops at the global scale (Lassaletta *et al.,* 2014).This suggests that measures to increase N use efficiency are required (e.g. Oenema *et al.,* 2015; Benincasa *et al.,*2017).

Özbek (2018) investigated in depth the contribution of NUE improvement to the Turkish agricultural economy. It was discovered that improving NUE by taking the necessary precautions, particularly crop rotation (alternation), taking into account the amount of nitrogen in the soil before fertilization, inclusion of leguminous plants in the production system, use of hybrid or cultivated varieties, proper soil cultivation, use of ammonium as a nitrogen source, timely and foliar nitrogen applications, the implementation of advanced irrigation and fertilization management practices (Büyük, 2016; Karaşahin, 2014) would make significant contributions to the agricultural economy. In order to measure the extent of this contribution in the European agricultural economy, the benefit to be obtained from the improvement of NUE by the reduction of nitrogenous mineral fertilizer use in agricultural areas in Europe was revealed within this study.

11.1 million tons of nitrogen were used as mineral fertilizer out of the 22.1 million tons of nitrogen-containing mineral fertilizers used in agricultural areas in Europe in 2019 (FAOSTAT, 2022a). This usage accounts for 64.6% of total nutrient consumption in mineral fertilizer use (FAOSTAT, 2022b).While the European Union imported 3.6 million tons of nitrogen-containing mineral fertilizers in 2020, accounting for 16.3% of total nitrogen fertilizer use, potash and phosphorus fertilizer imports were approximately 1.8 and 2.4 million tons, respectively, in 2020. (Statista, 2022).This extensive use of nitrogen fertilizer demonstrates that increasing NUE in

[1]The opinions and contents of the article remains the responsibility of the author, not of the Turkish Statistical Institute.

agricultural areas, or providing more plant products with fewer mineral fertilizers, will help to reduce the negative effects of mineral fertilizers on the environment and human health, as well as its contribution to the European economy.

The aim of this study is to quantify the contribution of NUE improvement to the European agricultural economy. For this purpose, the economic benefit of using fewer nitrogenous mineral fertilizers is revealed when the NUE improves by 5% and reaches the maximum level in Europe by 2020.

MATERIALS AND METHODS

In this study, the contribution of the improvement of NUE in agricultural areas at certain rates to the agricultural economy was revealed in the European countries. NUE for European countries was calculated using the Eurostat/OECD gross nutrient balance methodology (Eurostat, 2013) (Equation 1). The data of nitrogen inputs and outputs were obtained from the FAOSTAT database (FAOSTAT, 2022c).

$$\boldsymbol{NUE = \frac{N_{output}}{N_{input}} * 100} \quad \textbf{(1)}$$

Accordingly, nitrogen inputs (N_{input}) consists of mineral fertilizer, farm manure, other organic fertilizers, atmospheric precipitation, nitrogen fixation, nitrogen from seeds and production materials; nitrogen outputs (N_{output}) consist of nitrogen separated from the soil by plants and plant residues.

Using Equation 1, the relationship between nitrogen mineral fertilizer (N_{minfer}) and NUE was expressed as follows (Equation 2). In this equation, ($N_{otherinput}$) denotes nitrogen inputs other than N_{minfer}. The change in N_{minfer} depending on the change in NUE was calculated with Equation 3 (Özbek, 2018). In this equation, NUE_i is the initial NUE, NUE_f is the final NUE, calculating by adding $\Delta NUE$to NUE_i.

$$\boldsymbol{N_{minfer} = \frac{N_{output}*100}{AKE} - N_{otherinput}} \textbf{(2)}$$

$$\Delta N_{minfer} = \frac{\Delta NUE * N_{output}*100}{NUE_i * NUE_f} \quad \textbf{(3)}$$

The economic benefit to be obtained from the less use of nitrogenous mineral fertilizers when the NUE was increased at a certain rates and NUE was increased to the maximum NUE was calculated according to Equation 4. In the calculations, the value of 85% was used as the maximum NUE (Özbek and Leip, 2015). The N_i, N_o, N_{minfer} , ΔN_{minfer} , NUE_i and ΔNUE used in the calculations are given in Table 1.

Since NUE could not exceed NUE_{max}=85%, NUE_{max} value was used for the countries with NUE_f (= NUE_i +ΔNUE) values exceeding 85% in the calculations. In this case, ΔNUE was calculated by subtracting NUE_i from NUE_{max}. If ΔN_{minfer} exceeded the fertilizer used (N_{minfer}), the change in mineral fertilizer was assumed to be as much as N_{minfer}.

$$\boldsymbol{EB = \Delta N_{minfer} * p_{minfer}} \quad \textbf{(4)}$$

In this equation, EB represents the economic benefit to be obtained from less purchase of nitrogenous mineral fertilizer in euros when the NUE is improved, ΔN_{minfer} represents the decrease in nitrogen mineral fertilizer in terms of kgN ha^{-1}, p_{minfer} representsthe annual unit price of the nitrogenous mineral fertilizer in terms of euro $kgN^{-1}ha^{-1}$.p_{minfer} was calculated by using the weighted average of prices of fertilizer types by nitrogen use amounts.

Farmer purchase prices of ammonium nitrate, calcium ammonium nitrate, urea, urea and ammonium nitrate solutions and NPK fertilizers, which constitute 82% of nitrogen fertilizer consumption in Europe in 2020, were used. The average price of these fertilizers was used for the price of other nitrogenous mineral fertilizer. The country classification used in GNB estimations by FAO was used for European countries in the calculations (FAOSTAT, 2022c).

RESULTS

The decrease in the amount of nitrogenous mineral fertilizer would become 13 kg N ha^{-1} and 63 kg N ha^{-1} in Europe when the NUE is improved by 5% and NUE reaches the maximum level, respectively. The results showed that the nitrogenous mineral fertilizer would decrease in all European countries when the NUE reaches the maximum level. While the greatest decreases would be in Belgium, Ireland, Norway with 197, 164 and 132 kg N ha^{-1}, respectively, the lowest decreases would be in Latvia, Lithuania and Finland with 22, 24 and 24 kg N ha^{-1}, respectively (Table 1).

The expenditures for nitrogenous mineral fertilizer by European countries vary according to the amount of fertilizer use depending on the size of the agricultural area, the type of crop production and the amount of organic matter in the soil. The annual expenditure for the purchase of nitrogenous mineral fertilizers in Europe for the year of 2020 was calculated as 14.7 billion euros. When the distribution of the expenditures by the farmers for the purchase of nitrogenous mineral fertilizers was analyzed by countries, it was observed that the country that spent the most was France with a share of 21% in the total. Spain and Germany followed this country with a 10% share, and the least spending country was Malta (Figure 1).

The results showed that it is possible to provide an economic benefit of 2.6 billion euros from the annual expenditure on the purchase of nitrogenous mineral fertilizers in Europe when a 5% improvement in NUE is ensured; this benefit would be10.7 billion euros when the maximum NUE is achieved (Figure 2). This benefit

Table 1. The values of nitrogen input, output, mineral fertilizer use and change, nitrogen use efficiency initial and change values, 2020

Countries	N_i (kgN ha^{-1})	N_o (kgN ha^{-1})	N_{minfer} (kgN ha^{-1})	NUE_i (%)	ΔN_{minfer} (kgN ha^{-1})							
					ΔNUE=5	ΔNUE=10	ΔNUE=15	ΔNUE=20	ΔNUE=25	ΔNUE=30	ΔNUE=35	$\Delta NUE = NUE_{max} - NUE_i$
Austria	152	88	70	58	12	22	31	39	46	52	57	48
Belgium	366	90	197	25	62	106	139	164	185	197	197	197
Bulgaria	130	57	108	44	13	24	33	41	47	53	58	63
Croatia	175	86	124	49	16	30	41	51	59	67	73	74
Czechia	156	84	115	54	13	24	34	42	50	56	62	57
Denmark	175	92	96	52	15	28	39	49	57	64	70	68
Estonia	116	62	83	54	10	18	25	32	37	42	46	43
Finland	63	33	45	52	6	10	14	18	21	23	25	24
France	148	72	92	48	14	25	35	43	50	57	62	64
Germany	151	91	85	60	12	22	30	38	44	50	56	44
Greece	89	26	61	29	13	23	30	36	41	45	48	58
Hungary	138	81	106	59	11	20	28	35	41	47	51	43
Iceland	107	1	73	1	73	73	73	73	73	73	73	73
Ireland	286	92	164	32	38	68	91	110	125	138	149	164
Italy	125	49	63	40	14	25	34	42	48	54	58	63
Latvia	102	68	78	67	7	13	19	24	28	32	35	22
Lithuania	116	78	84	67	8	15	21	27	31	36	40	24
Luxembourg	136	52	82	38	16	28	38	47	54	60	65	75
Malta	196	16	56	8	56	56	56	56	56	56	56	56
Netherlands	247	72	98	29	36	63	84	98	98	98	98	98
Norway	193	33	132	17	44	72	91	105	115	124	130	132
Poland	115	70	69	61	9	16	23	29	34	38	42	33
Portugal	103	19	49	18	22	36	46	49	49	49	49	49
Romania	94	46	64	49	9	16	22	27	32	36	39	40
Slovakia	137	80	102	59	11	20	28	35	41	46	51	42
Slovenia	126	58	66	46	12	22	31	38	44	50	54	58
Spain	103	43	61	41	11	20	27	34	39	43	47	53
Sweden	114	56	82	49	11	19	27	33	38	43	47	48
Switzerland	198	68	68	35	25	44	60	68	68	68	68	68
U. Kingdom	214	79	132	37	26	46	62	76	87	96	105	122
Europe	**141**	**64**	**86**	**45**	**13**	**25**	**34**	**42**	**48**	**54**	**59**	**63**

Note: The source of N_i, N_o, N_{minfer} and NUE_i is FAOSTAT (2022).

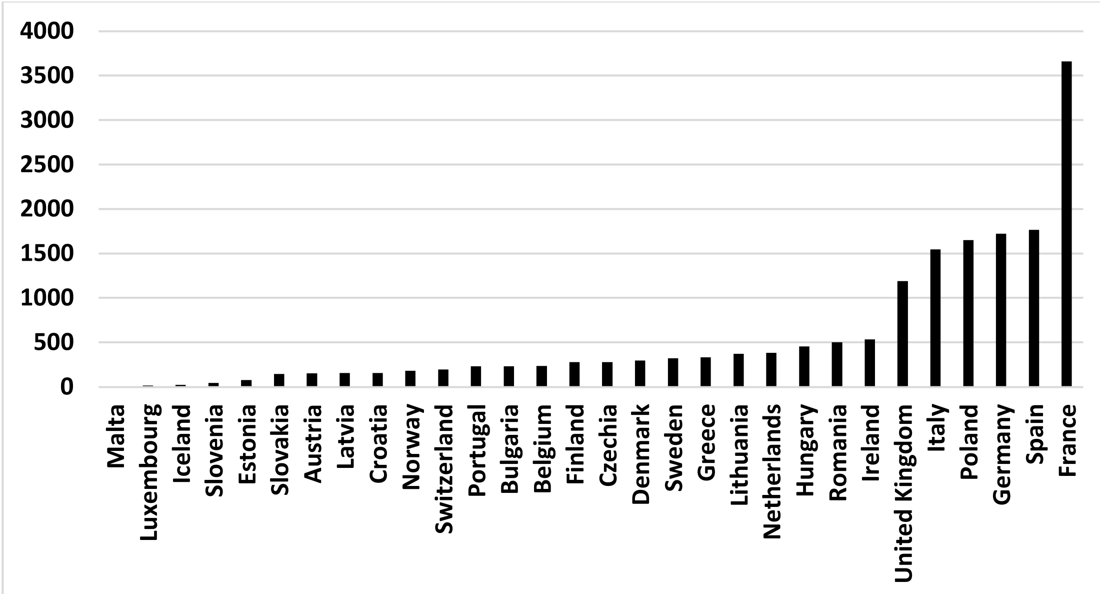

Figure 1. Yearly expense for purchasing of nitrogenous fertilizer by European countries, 2020

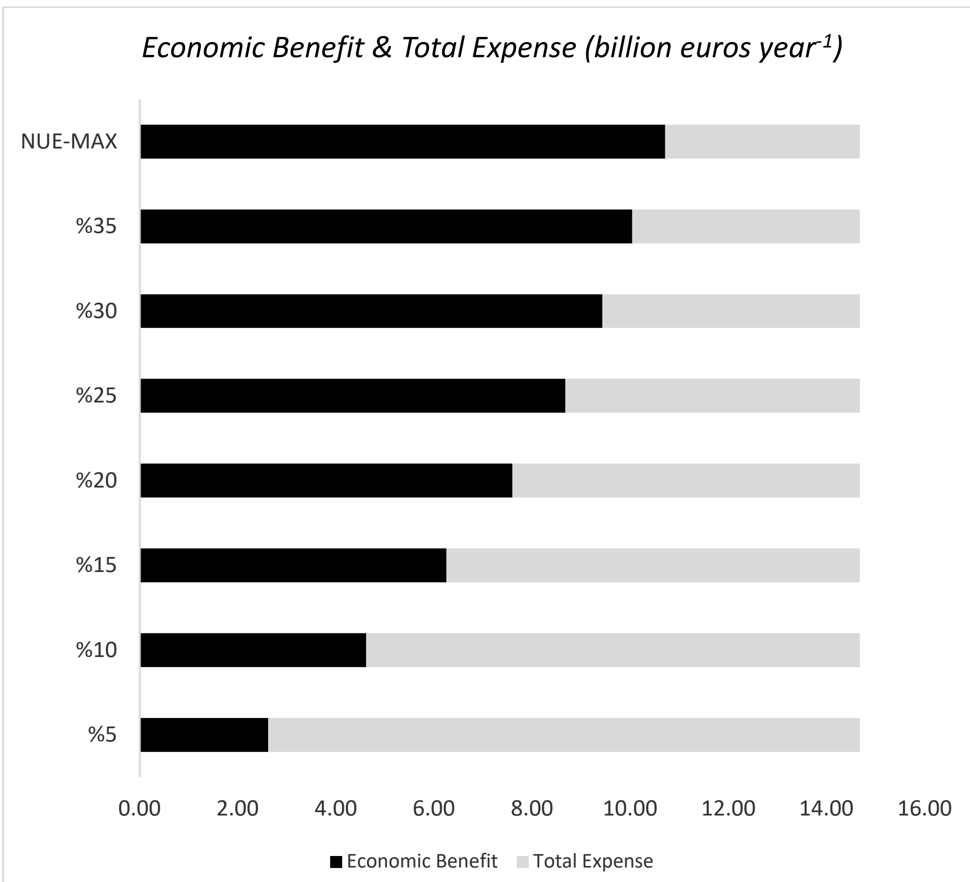

Figure 2. Yearly economic benefit gained from expense for purchasing of nitrogenous fertilizer in Europe, 2020

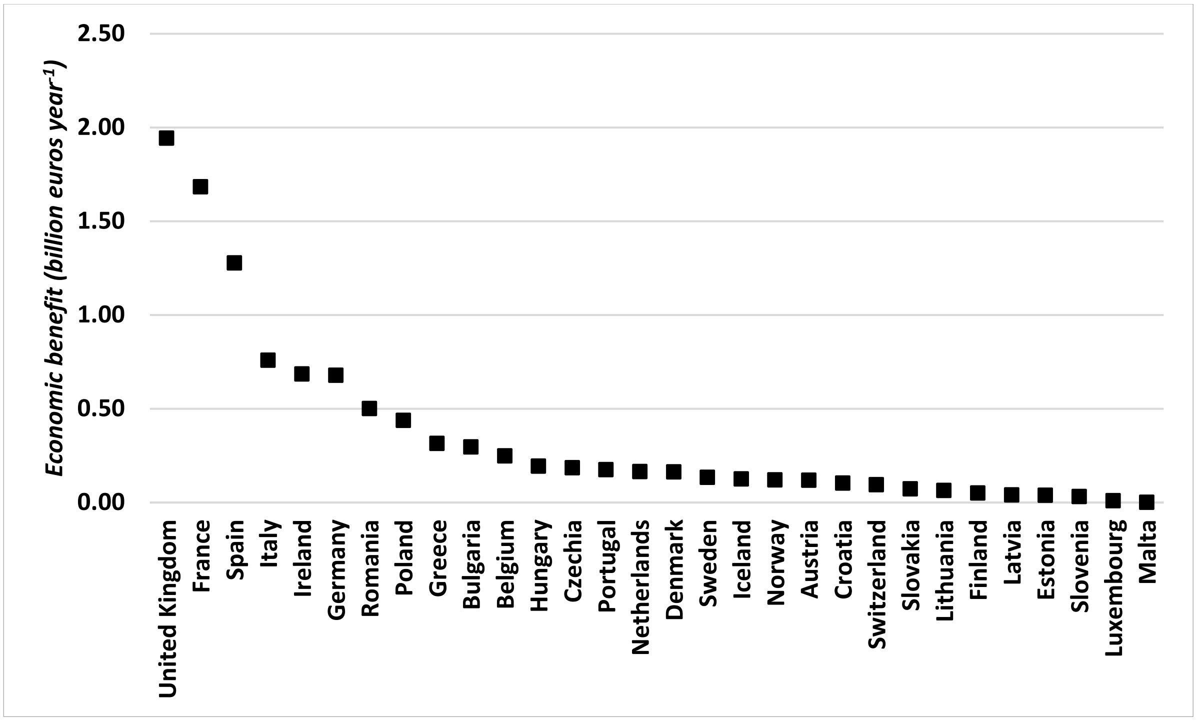

Figure 3. Yearly economic benefit gained from expense for purchasing of nitrogenous fertilizer by European countries when NUE reachesthe maximum level, 2020

would be 4.6, 7.6, 9.4 billion euros with 10%, 20% and 30% improvement in NUE, respectively. The economic benefit in Europe would equal to about three out of four the expenditure on total nitrogenous mineral fertilizer purchase when the NUE reaches the maximum value, and more than half of the expenditure on total nitrogenous mineral fertilizer purchase with the 20% improvement in NUE (Figure 2).

When the distribution of the economic benefit from the expenditure on the purchase of nitrogenous mineral fertilizers was analyzed by European countries, in the event that the NUE is maximized, it is observed that the greatest annual economic benefit would be ensured in England with 1.94 billion euros. This country is followed by France and Spain with 1.68 billion euros and 1.28 billion euros, respectively. When the NUE is maximized, it is observed that the smallest economic benefit would be in Malta with 0.001 billion euros. This country is followed by Luxembourg and Slovenia with 0.01 billion euros and 0.03 billion euros, respectively (Figure 3).

DISCUSSION

In European countries, NUEs vary between 1% and 67% among countries, with significant differences between countries (Table 1). NUEs for all European countries are below 85%, which is accepted as the maximum NUE level (Özbek and Leip, 2015). Taking the necessary steps to improve NUE will reduce nitrogenous fertilizer consumption per agricultural area for the same amount of crop production, resulting in a reduction in fertilizer expenditures. This situation demonstrates that significant economic benefits would be provided by reducing nitrogen fertilizer consumption by improving NUE in all European countries. When the NUE is increased by 20%, this benefit will account for more than half of the total nitrogenous mineral fertilizer purchase expenditure (Figure 2). The use of mineral fertilizers in agricultural production became more uneconomical than before following the COVID-19 pandemic and the Russia-Ukraine war due to drastically increased costs. As a result, it is reasonable to assume that the economic benefit gained after 2020 will be greater.

The NUEs for the world and other parts of the world are 55%, 69%, 72%, 44%, and 57% for the world, Africa, America, Asia, and Oceania, respectively (FAOSTAT, 2022c).For Europe, this figure is 45%. Except for Asia, the NUEs of the rest of the world are higher than the NUE of Europe. This shows that the improvement in NUE in Europe would have a greater impact on agricultural economics than in other parts of the world.

The total annual expenditure on the purchase of mineral fertilizers by the farmers in Europe in 2020 was 17.1 billion euros (Eurostat, 2022). Given that the share of mineral fertilizer consumption including nitrogenous in total mineral fertilizer use in Europe in 2020 was approximately 90% (FAOSTAT, 2022a), the annual expenditure value (14.7 billion TL) calculated by this study for the purchase of nitrogenous mineral fertilizers is consistent with this information.

In 2020, 16.3% of total nitrogenous fertilizer use in Europe was imported. When the NUE is improved by 5%, this ratio is lower than the ratio of the amount of fertilizer to be used less to the total amount used. This means that by improving NUE, Europe can easily reduce its reliance on nitrogenous fertilizer imports. Furthermore, companies producing mineral fertilizers in Europe that intend to maintain their production level will increase exports by shifting from domestic to foreign markets. This situation will result in an increase in net exports (export-imports) and an increase in GDP (Özbek, 2018).

When the NUE reaches its maximum level, the amount of fertilizer that will be used less is equal to nearly 73% of the total amount of fertilizer used in Europe agriculture in 2020. As a result, improving NUE is critical in order to reduce agricultural use of mineral fertilizer. This will result in significant gains in economic, environmental, and human health benefits throughout Europe. There is a widespread belief that using a large amount of chemical inputs in crop production systems results in higher crop yield. Many studies, however, have shown that sustainable/organic agriculture with low chemical input produces high or at least equal crop yields (Parrott and Marsden, 2002; Pretty, 2007). The findings of this study are strongly consistent with the findings of that farmers can significantly reduce their use of chemical inputs without losing profitability(Pretty, 2007; Özbek, 2018).

European Green Deal targets for 2030 that reducing nutrient losses by 50%, while ensuring no deterioration in soil fertility and reducing fertilizer use by at least 20% (EC, 2022). Improving The European Green Deal targets for 2030 include reducing nutrient losses by 50% while maintaining soil fertility and reducing fertilizer use by at least 20%. (EC, 2022). Improving NUE will ensure that these targets are met without reducing crop yield, so the European Commission and local governments should develop policies to improve NUE in agricultural areas by taking the necessary precautions, particularly crop rotation (alternation), taking into account the amount of nitrogen in the soil before fertilization, inclusion of leguminous plants in the production system, use of hybrid or cultivated varieties, proper soil cultivation, use of ammonium as a nitrogen source, timely and foliar nitrogen applications, the implementation of advanced irrigation and fertilization management practices. Farmers, industries, NGOs, citizens and other interested parties should be sufficiently informed on these precautions.

While it is critical to increase agricultural production productivity in order to feed the world's growing population, it is also critical to manage the demand dimension of delivering enough food to people. It is suggested that policies should be developed for regulating consumption habits, preventing excess consumption, food loss and waste, and conveying the consumption surplus to be gained by this way to the population in need through social sensitivity projects to be carried out by NGOs, national governments and international organizations, such as “do help instead of waste”.

Conclusion: The answer to the question "how can we ensure more agricultural production while using less N mineral fertilizer" is to improve NUE by taking the necessary steps. Improving NUE lowers the environmental and economic costs of using N mineral fertilizer. To quantify the contribution of improving NUE to agricultural economics, the economic impact must be thoroughly evaluated. This study concluded that increasing NUE by reducing N mineral fertilizer usage would result in significant economic benefits. When NUE was improved to maximum level, this benefit in Europe would equal to about three out of four the expenditure on total nitrogenous mineral fertilizer purchase. Taking the necessary steps to improve NUE is therefore critical for achieving long-term growth in agricultural economics. The approach presented here is a feasible method that could be tested and applied in other countries, estimating the economic benefit of increasing NUE.

REFERENCES

Benincasa, P., G. Tosti, M. Guiducci, M. Farneselli and F. Tei (2017). Crop rotation as a system approach for soil fertility management in vegetables. Advances in research on fertilization management of vegetable crops, 115-148. https://doi.org/10.1007/978-3-319-53626-2_5.

Büyük, G. (2006). The effect of varying nitrogen doses at different periods to the nitrogen use efficiency, grain yield and quality of the corn genotypes at Çukurova conditions. Cukurova University Graduate School of Natural and Applied Sciences, Ph.D. Thesis, Adana.

Congreves K. A., O. Otchere, D. Ferland, S. Farzadfar, S. Williams and M. M. Arcand (2021). Nitrogen Use Efficiency Definitions of Today and Tomorrow. Frontiers in Plant Sci., 12:637108 doi: 10.3389/fpls.2021.637108.

EC (2022). Nutrients: Commission seeks views on better management. Available inhttps://environment.ec.europa.eu/news/nutrients-commission-seeks-views-better-management-2022-06-03_en. [15November 2022].

Eurostat (2013). Nutrient Budgets – Methodology and Handbook. Version 1.02. Eurostat and OECD, Luxembourg.

Eurostat (2022). Economic accounts for agriculture. Available inhttps://appsso. eurostat. ec.europa. eu/nui/show.do?dataset=aact_eaa01&lang=en. [15 November 2022].

FAOSTAT (2022a). Fertilizers by product. Available inhttps://www.fao.org/faostat/en/#data/RFB. [30 November 2022].

FAOSTAT (2022b). Fertilizers by nutrient. Available inhttps://ww w.fao.org/faostat/en/#data/RFN. [30 November 2022].

FAOSTAT (2022c). Cropland nutrient budget. Available inhttps://www.fao.org/faostat/en/#data/ESB. [30 November2022].

Karaşahin M. (2014).Nitrogen Uptake Efficiency in Plant Production and Negative Effects of Reactive Nitrogen on Environment. J. Engineering and Science,2(3): 15-21. doi: 10.5505/apjes.2014.38247.

Lassaletta L., G. Billen, B. Grizzetti, J. Anglade and J. Garnier (2014). 50 year trends in nitrogen use efficiency of world cropping systems: the relationship between yield and nitrogen input to cropland. Environmental Research Letters, 9:105011. doi: 10.1088/1748-9326/9/10/105011.

Lu J., Y. Xiang, J. Fan, F. Zhang and T. Hu (2021). Sustainable high grain yield, nitrogen use efficiency and water productivity can be achieved in wheat-maize rotation system by changing irrigation and fertilization strategy. Agricultural Water Management, 258: 107177. doi: 10.1016/j.agwat.2021.107177.

Oenema O., F. Brentrup, J. Lammel, P. Bascou, G. Billen, A. Dobermann, J. W. Erisman, T. Garnett, M. Hammel, T. Haniotis, J. Hillier, A. Hoxha, I. S. Jensen, W. Oleszek, C. Pallière, D. Powlson, M. Quemada, M. Schulman, M. A. Sutton, H. J. M. Van Grinsven and W. Winiwarter (2015). Nitrogen Use Efficiency (NUE) - an indicator for the utilization of nitrogen in agriculture and food systems. EU Nitrogen Expert Panel, Wageningen, Netherlands.

Özbek F. Ş. (2018). The Evaluation of Contribution of Improving Nitrogen Use Efficiency to Agricultural Economics in Turkiye. Harran J. Agricultural and Food Science, 22(1): 21-32. doi: 10.29050/harranziraat.311334.

Özbek F. Ş. and A. Leip (2015). Estimating the gross nitrogen budget under soil nitrogen stock changes: a case study for Turkiye. Agriculture, Ecosystems & Environment 2(1): 109. https://doi.org/10.1016/j.agee.2015.03.008.

Parrott N. and T. Marsden (2002). The Real Green Revolution. Greenpeace Environmental Trust, United Kingdom.

Pretty J. (2007). Agricultural sustainability: concepts, principles and evidence. Philosophical Transactions of the Royal Society B, 363: 447–465. doi:10.1098/rstb.2007.2163.

Statista (2022a). Imports of fertilizers to the European Union in 2020 by nutrient. Fertilizers by product. Available inhttps://www.statista.com/statistics/1179309/european-union-fertilizer-imports-by-nutrient/#statisticContainer. [10 November 2022].

Wang C., H. Zang, J. Liu., X. Shi, S. Li, F. Chen and Q. Chu (2020). Optimum nitrogen rate to maintain sustainable potato production and improve nitrogen use efficiency at a regional scale in China. A meta-analysis. Agronomy for Sustainable Development, 40:37.doi: 10.1007/s13593-020-00640-5.

UNEP (2019). Frontiers 2018/19: Emerging Issues of Environmental Concern. Nairobi: UNEP.

Zhang, X., X. Li, L. Luo, O. Ma, Q. Ma, X. Hui, S. Wang, J. Liu and Z. Wang (2019). Monitoring wheat nitrogen requirement and top soil nitrate for nitrate residue controlling in drylands. J. Cleaner Production, 241: 118372. doi:10.1016/j.jclepro.2019.118372.