10.7251/AGSY13031143C

NITROGEN FERTILIZERS IN THE MEDITERRANEAN REGION: USE TRENDS AND ENVIRONMENTAL IMPLICATIONS

Roberto CAPONE[1], Hamid EL BILALI[1*], Philipp DEBS[1],
Gianluigi CARDONE[2], Sinisa BERJAN[3]

[1]Department of Sustainable Agriculture, Food and Rural Development; Italy
[2]Department of Mediterranean Organic Agriculture; Mediterranean Agronomic Institute of Bari; International Centre for Advanced Mediterranean Agronomic Studies (CIHEAM), Italy
[3]Faculty of Agriculture, University of East Sarajevo, Bosnia and Herzegovina
*(Corresponding author: elbilali@iamb.it)

Abstract

Humans have caused unprecedented changes to the global nitrogen cycle. The increased use of nitrogen as fertilizer has allowed increasing food production for a growing world population but has had also considerable adverse effects on the environment and human health. The paper aims at analysing nitrogen use trends in the Mediterranean region. The work is mainly based on secondary data from different databases such as the FAOSTAT and the World Development Indicators (WDI). Two main indicators were considered: fertilizer consumption and nitrogen fertilizers use. According to the WDI, nitrogenous, phosphate and potash fertilizers consumption increased in the period 2002-2009 in almost all Southern and Eastern Mediterranean countries. Fertilizer consumption in the Mediterranean ranged in 2009 from 7.8 to 502.8 kg per ha of arable land, in Algeria and Egypt, respectively. However, there was a general decrease of nitrogen fertilizers consumption between 2002 and 2010 in Mediterranean countries with few exceptions (*e.g.* Egypt). Nevertheless, nitrogen use is still high *e.g.* 388.2 kg N/ha of agricultural land in Egypt (2010). High nitrogen use is exacerbated by food waste; which implies the loss of large amounts of resources and inputs, such as fertilizers. About 80% of nitrogen used in food production is lost before consumption and the remainder is lost as human waste. Nitrogen lost to the environment affects water quality, air quality, greenhouse balance, ecosystems and biodiversity, and soil quality. These negative externalities call in question the dominating agricultural development paradigm and food production system sustainability.

Keywords: nitrogen fertilizers, Mediterranean region, environment

Introduction

Environmental degradation has reached in the Mediterranean proportions that require immediate action (UNEP, 2010). Much of today’s discourse about environmental problems revolves around reducing greenhouse gas emissions and water usage. According to Rockström *et al*. (2009) stratospheric ozone, biodiversity, chemicals dispersion, ocean acidification, land system change, atmospheric aerosol emissions and nitrogen and phosphorus discharge should also be considered.

The present food system delivers low cost food at a high cost to the environment (Kickbusch, 2010). Food costs include also environmental impacts of food production, distribution and consumption (Ingram, 2011). Therefore, the need to improve the efficiency of inputs, such as nitrogen, in agricultural systems is well recognised (*e.g.* Ahrens *et al*., 2010). Nitrogen is an essential nutrient for the growth of plants. Although nitrogen occurs naturally and is essential for life, human activities are releasing excessive and polluting amounts into the environment (Leach *et al*., 2012). The largest sources of nitrogen pollution come from food production and the burning of fossil fuels (Erisman *et al*., 2008). Reactive nitrogen derives mainly from artificial nitrogen fertilizer production through the Haber-Bosch process (Woods *et al*., 2010).

Of all the chemical elements, nitrogen is one whose abundance has been increased the most by human activity (Erisman *et al*., 2008). Over the past century humans have caused unprecedented changes to the global nitrogen cycle (Sutton *et al*., 2011). The total amount of reactive N created by human activities has increased ninefold over the last 100 years due to the increased use of fertilizers (Millennium Ecosystem Assessment, 2005). In the last 50 years, global use of artificial nitrogen fertilizer has increased seven times (FAO, 2011). Present global food supply depends on artificial nitrogen fertilizer. Globally, around half of the nitrogen in soils comes from artificial nitrogen (Liu *et al*., 2010).

The human use of reactive nitrogen (Nr) has profound beneficial and detrimental impacts (Leach *et al*., 2012). The beneficial impacts of the agricultural use of Nr are related to food production using nitrogen fertilizer and human-enhanced biological nitrogen fixation (Erisman *et al*., 2008). Artificial nitrogen fertilizers have allowed increasing crop yield (Ibarrola-Rivas and Nonhebel, 2011). The detrimental impacts occur because most of the Nr used in food production is lost to the environment where it causes a cascade of environmental changes that negatively impact both people and ecosystems (Sutton *et al*., 2011, Leach *et al*., 2012).The paper aims at analysing fertilizers and mineral nitrogen use trends in the Mediterranean region. It also investigates the environmental implications of excessive nitrogen use.

Material and methods

The paper is mainly based on secondary data from different databases such as the FAOSTAT and the World Development Indicators (WDI) of the World Bank. Two main indicators were considered: fertilizer consumption and nitrogen fertilizers use. The geographical coverage of this study is similar to that of the Mediterranean Strategy for Sustainable Development (UNEP/MAP, 2005) including 11 Northern Mediterranean Countries (Albania, Bosnia and Herzegovina, Cyprus, Spain, France, Greece, Croatia, Italy, Montenegro, Malta and Slovenia) and 10 Southern and Eastern Mediterranean Countries (Algeria, Egypt, Israel, Lebanon, Libya, Morocco, Palestinian territories, Syria, Tunisia and Turkey).

Fertilizer consumption measures the quantity of plant nutrients used per unit of arable land. Fertilizer products cover nitrogenous, potash and phosphate fertilizers (including ground rock phosphate) (World Bank, 2013). Data are available, on a yearly basis, for the period 2002-2009 and are sourced from the World Development Indicators (World Bank) based on elaboration of FAOSTAT data.

Mineral nitrogen consumption accounts for nitrogen input that implies the use of nitrogen fertilizers in agricultural production. It is calculated as the average quantity of mineral nitrogen (in kg) used per hectare of national agricultural land. Data are available - on a yearly basis - from FAOSTAT-Resources database for the period 2002-2010.

Results and discussion

During the period 2002-2009, fertilizers consumption ranged from 6.0 kg/ha of arable land recorded in Algeria (2003) to 696.6 kg/ha recorded in Egypt (2008). In the same period, average fertilizer consumption ranged between 11.6 kg/ha recorded in Algeria and 563.0 kg/ha recorded in Egypt. Fertilizer consumption in Egypt is even 4.5 higher than that recorded in the European Union. That can be explained by the fact that almost the whole arable land in Egypt is irrigated and agriculture is intensive. In the period 2002-2009, the average fertilizers consumption in the 21 target Mediterranean countries was 188.0 kg/ha so higher than the worldwide average (116.3 kg/ha of arable land). During the same period the average fertilizers consumption in the Middle East & North Africa (90.6 kg/ha) was lower than the levels of fertilizers consumption in the Euro area (179.9 kg/ha) and the European Union countries (155.5 kg/ha).

Considering the same period, fertilizers consumption decreased in almost all target Mediterranean countries. It slightly increased only in Egypt, Cyprus, Montenegro, Tunisia and Turkey. The highest decrease was recorded in Lebanon and Slovenia (Figure 1).

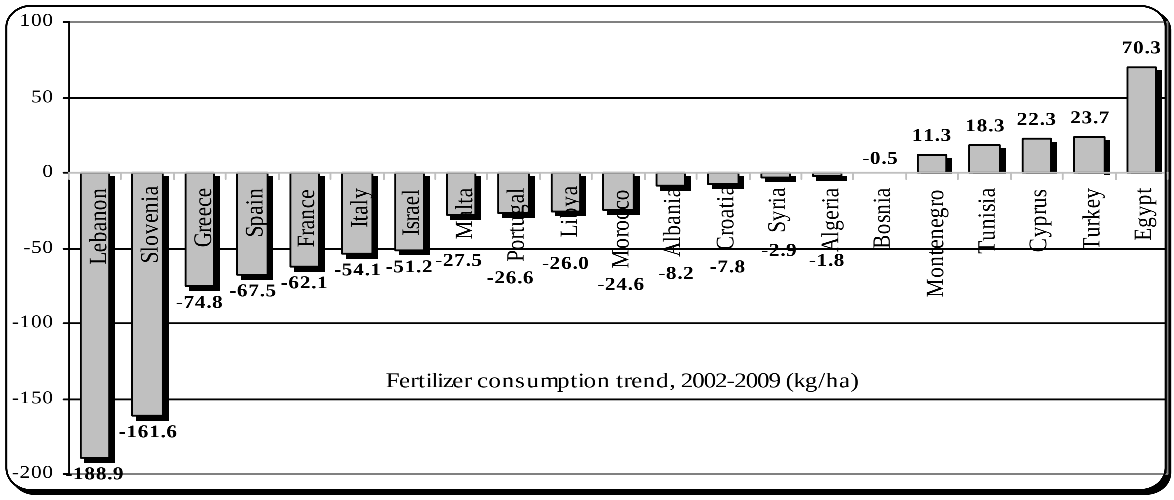

Figure 1. Trend of fertilizer consumption in the target Mediterranean countries, 2002-2009. Data are not available for the Occupied Palestinian Territories (OPT).

In the period 2002-2010, mineral nitrogen consumption ranged between 0.1 kg/ha recorded in Algeria in 2005 and 468.9 kg of mineral nitrogen/ha of agricultural land recorded in Egypt in 2003 (Table 1). In the Mediterranean region 52.9 kg N/ha are used on average. During the same period, the highest average nitrogen use was recorded in Egypt (373.0 kg N/ha) while the lowest use was recorded in Algeria (0.9 kg N/ha).

Table 1. Mineral nitrogen consumption in the target Mediterranean countries (kg of mineral nitrogen/ha of agricultural land). Data are not available for Cyprus and the OPT.

Country	2002	2003	2004	2005	2006	2007	2008	2009	2010
Albania	33.3	33.1	31.9	34.2	26.8	27.7	23.8	27.9	25.7
Algeria	0.7	0.4	2.5	0.1	1.1	0.9	0.6	0.5	1.1
Bosnia	8.8	5.0	15.5	11.4	7.2	10.0	5.5	10.7	8.4
Croatia	109.9	103.3	123.7	103.1	155.4	176.7	204.4	135.0	50.1
Egypt	312.5	468.9	396.4	416.7	293.9	312.7	441.2	326.8	388.2
France	74.5	80.0	78.5	74.6	74.7	81.7	71.6	65.2	70.3
Greece	32.2	62.2	27.0	51.3	20.9	29.1	21.3	16.1	17.9
Israel	79.4	91.1	102.0	94.8	93.4	114.6	89.0	69.1	58.4
Italy	55.3	56.8	58.2	54.3	56.2	57.4	46.4	34.9	34.8
Lebanon	31.9	26.8	27.4	13.4	11.8	19.5	14.7	19.0	23.6
Libya	4.9	2.1	3.0	4.8	2.4	4.4	2.7	3.0	3.0
Malta	59.8	50.1	64.3	62.2	100.7	61.4	36.5	41.9	32.3
Montenegro	-	-	-	-	3.4	2.7	2.6	2.1	2.7
Morocco	8.2	6.7	7.7	11.2	10.7	10.2	9.2	6.5	4.5
Portugal	42.6	28.9	33.0	26.9	23.2	30.3	25.7	26.8	34.4
Slovenia	65.3	66.7	60.9	56.7	61.0	58.7	50.6	59.9	56.1
Spain	34.9	41.1	36.9	31.7	33.9	35.2	26.3	27.9	34.2
Syrian	16.1	17.5	16.3	19.3	19.9	18.9	19.4	15.1	8.6
Tunisia	3.8	5.4	4.9	6.3	6.6	4.0	5.9	7.8	6.9
Turkey	29.1	33.0	33.2	33.3	34.7	34.4	29.0	36.3	34.4
Mediterranean	*54.5*	*61.8*	*57.2*	*56.4*	*50.0*	*53.7*	*54.7*	*44.7*	*43.4*

In the period 2002-2010, average mineral nitrogen consumption decreased in the Mediterranean area from 54.5 to 43.4 kg of mineral nitrogen/ha of agricultural land. Mineral nitrogen consumption decreased in all Mediterranean countries except in Algeria (+0.4 kg N/ha), Tunisia (+3.1 kg N/ha), Turkey (+5.3 kg N/ha) and Egypt (+75.7 kg N/ha). The highest decrease was recorded in Croatia (-59.8 kg N/ha).

Mineral nitrogen trade balance (export - import) is negative in the Mediterranean area. Considering the period 2002-2010, mineral nitrogen trade deficit increased from -1,275,809 to -1,441,037 tonnes of nitrogen *i.e.* +165,228 N tonnes. As of 2010, almost all the Mediterranean countries are net mineral nitrogen importers except Israel, Jordan, Tunisia, Croatia, Libya, Morocco and Egypt. The top net mineral nitrogen exporters are Egypt (1,381,065 tonnes of nitrogen) and Morocco (327,023 tonnes of nitrogen). Meanwhile, the top net mineral nitrogen importers are France (-1635,446 N tonnes), Turkey (-967175 N tonnes), Italy (-409540 N tonnes), Spain (-369243 N tonnes) and Greece (-124780 N tonnes).

High fertilizers, especially nitrogen ones, use and imports as well as their increasing prices without forgetting price volatility - as fertilizers prices are strongly linked to the energy prices - puts at risk food availability and affordability and calls in question the environmental as well as the economic sustainability of the current Mediterranean food consumption patterns.

Excess in nitrogen represents a serious risk to the environment. The increased use of N_r as fertilizer has considerable adverse effects on the environment and human health (N-Print, 2010). Of the N used to produce food, about 80% is lost before consumption, and the remainder is lost after consumption as human waste (Sutton *et al*., 2011). The major risk is that nutrients, particularly nitrate, will run off into surface water or percolate into groundwater. Moreover, some nitrogen, is lost to the air through volatilisation of ammonia (a contributor to acidification) or as nitrous oxide (N_2O) (a powerful greenhouse gas) (Pau Vall and Vidal, 1999). Reactive nitrogen affects water quality, air quality, greenhouse balance, ecosystems and biodiversity, and soil quality. Nitrogen fertilization leads to the contamination of drinking water, algal blooms, eutrophication, etc. (N-Print, 2010). Once lost to the environment, nitrogen moves through the Earth’s atmosphere, forests, grasslands and waters causing a cascade of environmental changes that negatively impact both people and ecosystems. These changes include smog, acid rain, forest dieback, coastal ‘dead zones’, biodiversity loss, stratospheric ozone depletion and an enhanced greenhouse effect (Galloway *et al*., 2008). The deposition of N, P and other contaminants is expected to have an impact on biodiversity. Nitrogen pollution damages ecosystems and affects human health, including respiratory diseases and the risk of birth defects (N-Print, 2010) and causes local environmental problems such as eutrophication, biodiversity loss, soil acidification, and ground and surface water pollution (Eickhout *et al*., 2006).

Excessive nitrogen surpluses can pose a threat to the environment. The integration of environmental concerns into agricultural policies and practices can help reducing pollution. Nitrogen losses to the environment can be minimised if a reasoned fertilization is used, together with sustainable agricultural practices, such as crop rotation, planting cover crops, and ploughing in crop residues. Reasoned fertilization means applying fertilizers in the correct weather conditions (to avoid run off) at the appropriate stage in crop growth (so that plants take up the nitrogen quickly) and at the correct doses (Pau Vall and Vidal, 1999).

Nitrogen-related environmental footprint is exacerbated by food losses and wastage. It is estimated that 10-15% of non-perishables (*e.g.* grains) and up to 60% of perishables are lost during the whole production chain. In addition, post-cooking losses are also significant (FAO/RNE, 2011). Wasting food means losing not only life-supporting nutrition but also precious resources, including land, water and energy. Food losses and waste imply that large amounts of land, energy, fertilizers and water have also been lost in the production of foodstuffs which simply end up as waste (Institution of Mechanical Engineers-UK, 2013;

FAO, 2012). Reducing the amount of food wasted throughout the food chain in the entire Mediterranean area would contribute to easing pressure on natural resources. According to Ingram (2011), reducing waste across the whole food system will increase the amount of food available for human consumption for the given level of inputs, thereby improving input use efficiency.

Conclusions

Over the past decade, great progress has been made in communicating to the public the role that their actions have on the carbon and water cycle. This did not happen yet in the case of nitrogen. Essentially all the reactive N created is lost to the environment, where some portion accumulates in soils, waters, biomass and the atmosphere. Nitrogen footprint increases as a result of artificial nitrogen fertilization, manure runoff and the burning of biomass. Anthropogenic reactive nitrogen increases ozone and particulate matter; increases the acidity of soils, streams and lakes; changes the ecosystem productivity; increases global warming potential; and decreases stratospheric ozone. Nitrogen can contribute to each of these environmental changes in sequence thus affecting ecosystem integrity and human health.

The average fertilizers consumption in the Mediterranean countries is higher than the worldwide average. Fertilizers consumption in the European Mediterranean countries is still higher than in the Middle East & North Africa. Nevertheless, fertilizers consumption in Egypt is among the highest in the whole Mediterranean. In general, fertilizers consumption decreased in Mediterranean countries during the last decade.

In the period 2002-2010, average mineral nitrogen consumption decreased in the Mediterranean area. Nevertheless, it remains high in many Mediterranean countries especially those that rely on intensive irrigated agriculture (*e.g.* Egypt). The Mediterranean region is a net mineral nitrogen importer due mainly to the negative nitrogen trade balance of Northern Mediterranean countries and Turkey.

It is crucial to link the reactive nitrogen losses in agricultural fields to their effects on the environment. For this reason there is a need to estimate the losses to the environment in terms of emissions to the air (ammonia and NOx) and the run-off and leaching to groundwater and rivers (nitrate) in the different Mediterranean agro-ecological zones. Additionally, this should be linked to the cascading nitrogen effects to provide quantitative estimates of the relationship between the virtual N and the environmental impacts. Nevertheless, it should be highlighted that the assessment of the impact of nitrogen use should not be limited to the agricultural site, as large improvements in the nitrogen cycle can be achieved by changing food consumption patterns and reducing food losses and waste along the food chain.

References

Ahrens T.D., Lobell D.B., Ortiz-Monasterio J.I., Li Y., and Matson P.A. (2010). Narrowing the agronomic yield gap with improved nitrogen use efficiency: a modeling approach. *Ecological Applications*, 20, 91-100.

Eickhout B., Bouwman A.F. and Van Zeijts. H. (2006). The role of nitrogen in world food production and environmental sustainability. *Agriculture, Ecosystems & Environment*, 116(1-2), 4-14.

Erisman J.W., Galloway J.N., Sutton M.A., Klimont Z. and Winiwarter W. (2008). How a century of ammonia synthesis changed the world. *Nature Geocience*, 1, 636-639.

FAO (2011). FAOSTAT statistical database. Retrieved on 01-10-2011 from http://faostat.fao.org/site/567/default.aspx#ancor

FAO (2012). Towards the Future We Want: End hunger and make the transition to sustainable agricultural and food systems. Food and Agriculture Organization (FAO), Rome. Available online at: http://www.fao.org/docrep/015/an894e/an894e00.pdf

FAO/RNE (2011). Regional Priority Framework for the Near East. FAO Regional Office for the Near East, Cairo.

Galloway J.N., Townsend A.R., Erisman J.W., Bekunda M., Cai Z., Freney J.R., Martinelli L.A., Seitzinger S.P. and Sutton M.A. (2008). Transformation of the nitrogen cycle: recent trends, questions and potential solutions. *Science*, 320, 889-892.

Ibarrola-Rivas M.J. and Nonhebel S. (2011). Methodology to evaluate the impact of the nitrogen footprints in the dietary transition. IGS-SENSE Conference: Resilient Societies - Governing Risk and Vulnerability for water, Energy and Climate Change; 19 - 21 October 2011, University of Twente, Enschede, The Netherlands.

Ingram J.S.I. (2011). From food production to food security: developing interdisciplinary, regional-level research. PhD Thesis, Wageningen University.

Institution of Mechanical Engineers-UK (2013). Global food, waste not, want not. Institution of Mechanical Engineers, London. Available online at: http://www.imeche.org/Libraries/Reports/IMechE_Global_Food_Report.sflb.ashx.

Kickbusch I. (2010). The food system: a prism of present and future challenges for health promotion and sustainable development. Triggering the debate – white paper. Promotion Santé Suisse, Bern.

Leach A.M., Galloway J.N., Bleeker A., Erisman J.W., Kohn R. and Kitzes J. (2012). A nitrogen footprint model to help consumers understand their role in nitrogen losses to the environment. *Environmental Development*, 1, 40-66.

Liu J, You L., Amini M., Obersteiner M., Herrero M., Zehnder A.J.B. *et al.* (2010). A high-resolution assessment on global nitrogen flows in cropland. *Proceedings of the National Academy of Sciences of the USA*, 107(17), 8035-8040.

Millennium Ecosystem Assessment (2005). Ecosystems and human well-being: synthesis. Island Press, Washington DC.

N-Print (2010). Background information. Available online at: www.n-print.org.

Pau Vall M. and Vidal C. (1999). Nitrogen in agriculture. Agriculture, environment, rural development: facts and figures – A challenge for Agriculture. Eurostat. Available online at: http://ec.europa.eu/agriculture/envir/report/en/nitro_en/report.htm

Rockström J., Steffen W., Noone K., Persson Å., Chapin F.S., Lambin E., Lenton T. M., Scheffer M., Folke C., Schellnhuber H., Nykvist B., De Wit C. A., Hughes T., van der Leeuw S., Rodhe H., Sörlin S., Snyder P.K., Costanza R., Svedin U., Falkenmark M., Karlberg L., Corell R.W., Fabry V.J., Hansen J., Walker B., Liverman D., Richardson K., Crutzen P. and Foley J. (2009). Planetary boundaries: exploring the safe operating space for humanity. *Ecology and Society*, 14(2): 32.

Sutton M.A., Howard C.M., Erisman J.W., Billen G., Bleeker A., Grennfelt P., Van Grinsven H. and Grizzetti B. (eds) (2011a). *The European nitrogen assessment: Sources, effects and policy perspectives*, Cambridge university press, UK.

Sutton M.A., Oenema O., Erisman J.W., Leip A., van Grinsven H. and Winiwarter W. (2011). Too much of a good thing. *Nature*, 472, 159-161.

UNEP (2010). Here and Now - Education for Sustainable Consumption: Recommendations and Guidelines. Paris.

UNEP/MAP (2005). Mediterranean Strategy for Sustainable Development: a framework for environmental sustainability and shared prosperity. Tenth Meeting of the Mediterranean Commission on Sustainable Development (MCSD), Athens.

Woods J., Williams A., Hughes J.K., Black M., Murphy R. (2010). Energy and the food system. *Phil. Trans. R. Soc.*, B 27, vol. 365 no. 1554, 2991-3006.

World Bank (2013). World Development Indicators: Agriculture and rural development. Available online at: http://data.worldbank.org/indicator/AG.CON.FERT.ZS.