Assessment of nitrogen fertilizers for sustainable agricultural production

based on the symposium 'current trends and challenges in nitrogen research', 12 & 13 January 2017, ETH Zürich

Sandra Wenger, February 2017

ABSTRACT

Approaches towards sustainable agriculture must depend on local conditions. To reach this target, the integration of natural processes as well as social and economic structures is crucial. Biological and industrial N fixation contributes to environmental pollution and climate change, especially the volatile N compounds, such as NOx or N2O. Industrial fertilizer production requires the combustion of large amounts of natural gas and transforms stable atmospheric nitrogen (N) into reactive forms. Natural processes as well as suboptimal farming practices promote N losses from both, organic and industrial fertilizers, and contribute to the environmental impact from agriculture. In consequence, only 30 to 50% of the applied N is transformed into crop yield. The improvement of the nutrient use efficiency (NUE) is, therefore, an important goal towards sustainable agriculture. Feasible approaches are the build-up of soil organic matter (SOM) by organic manures, integration of legumes into cropping cycles, manure digestion in biogas plants as well as best management practices. Best practice includes fertilization according to the nutritional demand of the crop, considering the nutritional soil content and unavoidable losses. Sustainable agriculture demands for integrated multi-purpose approaches, a holistic view and the adoption of various, locally adapted measures.

CONTENT

1 INTRODUCTION

The symposium ‘current trends and challenges in nitrogen research’, hold at ETH Zürich in January 2017, addressed the topic of processes and drivers of the nitrogen cycle and the various resulting impacts on environment, plant growth and global nutrition.

The role of livestock production, being the main source for nitrogen-based environmental pollution was highlighted by Michael Kreuzer, who referred to the nutritional nitrogen demand of livestock, and Harald Menzi, who talked about the rapidly growing world population, increasing livestock production, landless farming systems and the resulting implications on nitrogen emissions.

Several speakers elaborated the processes of different nitrogen cycles and their environmental impacts. Gaseous emissions and their chemical interactions were the topic of Charlotte Decock (N_2O), Nicolas Gruber (NH_3, N–C interactions) and Richard Ballaman (NH_3). Daniel Hunkeler talked about nitrogen run-offs into ground water, whereas Gaston Theis reported the impacts of nitrogen deposition on surface ecosystems. According to these talks, uncontrolled nitrogen inputs into the environment negatively affect ecosystem services by causing eutrophication, soil acidification, air pollution or changes in the atmospheric composition. In consequence, nitrogen losses and re-deposition are harmful for human health and economically costly.

Subject of many talks were feasible methods to reduce nitrogen losses and to improve the nutrient use efficiency (NUE) of fertilizers. Technological, regulatory and holistic approaches were presented. An insight into the efforts of the fertilizer industries and the production of inorganic fertilizers was given by Andreas Pacholksi, whereas Jochen Mayer presented characteristics of different organic fertilizers and methods to process them. Technological on-farm approaches to improve nitrogen use in agriculture were also supported by Richard Ballaman, who talked about best practice in manure handling, and Frank Liebisch, who outlined the advantages of precision agriculture. Christine Zundel presented regulatory strategies to reduce the nitrogen surplus in Swiss agriculture. The holistic approach focused on the complex interactions between plants, microorganisms and soil. Andreas Lüscher and Joelle Fustec gave talks about the advantages of legume intercropping in forage and food crop production. Sylvie Recous complemented their findings with her focus on soil–microbe interactions and the importance of C:N ratios for decomposition, soil structure and plant nutrition.

The aim of this report is to identify and classify strategies of nitrogen fertilization with regard to increased sustainability in agriculture. It addresses the potentials and limitations of different nitrogen sources and chemical forms with regard to nutrient use efficiency and losses in different farming systems. The report mainly relies on literature research, but is based on the topics and findings of the above presentations and the round table discussion during the symposium. Regarding the complexity of the topic and the large number of influencing factors, only the aspects most relevant to the topic are covered by this report.

Table 1 **Important chemical forms of nitrogen**

Ammonia NH_3
Highly volatile. Rate of volatility depends on temperature and soil moisture. Product of natural or industrial N fixation. Ammonia is the precursor for most industrial N fertilizers and natural N compounds. It forms ammonium after reaction with water. It is toxic to fishes and amphibians.

Ammonium NH_4^+
Due to its positive charge it is retained on soil particles and therefore less mobile than nitrate. In soil, it is gradually released and nitrified by soil bacteria via nitrite into nitrate. For some plant species it is directly available, for others only after nitrification.

Nitrate NO_3^-
N uptake by plants occurs mainly in form of nitrate, because it is immediately available. Losses occur via leaching and denitrification.

Nitric acid HNO_3
The reaction of NO_2 with water produces the highly corrosive nitric acid.

Nitrite NO_2^-
As it can be oxidized or reduced, it is an important intermediate of the N cycle.

Nitrous oxide N_2O
N_2O is an important greenhouse gas and involved in the destruction of atmospheric ozone.

Mono-nitrogen oxides NO_x (NO, NO_2)
They are the product of high-temperature combustion, especially of fossil fuels. They are involved in the formation of acid rain, cause damages in human respiratory systems and produce in combination with sunlight tropospheric ozone.

Organic nitrogen
It is present in all organisms, e.g. in form of amino acids, nucleic acids, amides or in chlorophyll. The large partition of N in biomass has implications for the nutritional demands of humans, animals and plants.

Table 2 **Important processes in N cycling**

Fixation
Atmospheric N_2 is transformed into ammonia by symbiotic or free-living bacteria and archea or by the Haber process. Fixation has a high energetic demand for breaking down the triple bond in N_2. Of main agricultural importance are the symbioses between legumes and rhizobia, and in watered systems between the azolla fern and cyanobacteria.

Nitrification
Bacterial oxidation transforms ammonium NH_4^+ into nitrite NO_2^- and subsequentliy into nitrate NO_3^-.

Denitrification
Nitrate NO_3^- is denitrified under anaerobic conditions by respiration of soil bacteria into atmospheric N_2. This type of loss can prevent environmental damage as leaching, but causes economical and energetic costs.

Mineralization, decomposition
Decomposition of organic matter and transformation of bound organic N into available mineral N (NH_4^+) is performed by microorganisms. Mineralization rates depend on the C:N ratio, because plants and microorganisms compete for N. Only microorganisms need a C supply, plants are heterotroph.

Immobilization, assimilation
Mineralization enables the uptake of N by microorganisms and plants (assimilation), but also the retain of positively charged nutrients in soil (immobilization). These nutrient storages can be re-mobilized by plants and microorganisms in case of demand, e.g. by altering the soil chemistry.

Sources:
Reetz 2016, Galloway et al. 2013, Thangarajan et al. 2013, Masclaux-Daubresse et al. 2010, Diacono & Montemurro 2008, Bohlool et al. 1992

2 DEFINING SUSTAINABLE AGRICULTURE

‘Sustainability’ is not clearly defined and even implies contradicting approaches, depending on local conditions and the boundaries of the regarded system (Schaller 1993). Systems in agricultural sustainability assessments vary in their scale level from crop to planetary boundaries. ‘Sustainable development’ as defined by FAO in 1989 focuses on conversation management of natural resources (land, water, genetic resources) to satisfy the needs of ‘present and future generations’ (FAO 2015). There is a broad consensus, that sustainable agriculture must integrate natural processes as well as communal, social and economic structures in a holistic approach. Technical development and government policies for consumers and producers are needed to maintain health, welfare and natural resources (FAO 2015, Lewandowski et al. 1999, OECD 1999, Schaller 1993).

Specifying the definitions above, the round-table discussion at the ETH symposium emphasized the importance of locally adapted solutions, ethical considerations (e.g. animal welfare), multi-purpose approaches and resource recycling for the optimal integration of social, economic and environmental aspects.

3 RELEVANT PROCESSES IN NITROGEN CYCLING

3.1 N reactants and their environmental impact

Biological and industrial N fixation and combustion of fossil fuels transform stable atmospheric N_2 into reactive N compounds (Galloway 2003). Reactive N accumulates in the environment and disperses by aquatic and atmospheric transport. N reactants contribute to climate change, depletion of the stratospheric ozone, but also to ozone enrichment in the troposphere. Both processes have negative consequences for human health. N deposition on terrestrial ecosystems increases primary production in a first step. But when a critical load is reached, it endangers biodiversity and ecosystem functionality, because N limitation is a property of many ecosystems (Galloway 2003).

N compounds as NO_x, NH_3 and NH_4 (Table 1) have a short residence time in the atmosphere, but can not be re-transformed by denitrification. Consequently, they are deposited on terrestrial surfaces within a time range of hours to days (Galloway et al. 2003). In contrast, derivatives of nitrous oxide N_2O have an atmospheric residence time of up to 100 years and are accumulating in the troposphere at a rate of 0.25% per year (Galloway et al. 2003).

3.2 N fluxes in agronomic production

Minimizing fertilizer losses also minimizes such environmental impacts. According to Galloway (2003), only half of applied N fertilizers are transformed into crop production. The other half is lost to aquatic ecosystems (NO_3^-) or to the atmosphere (NH_3, NO, N_2O, N_2). The processes of N losses from field with the highest environmental impact are therefore leaching, run-off and volatilization. Denitrification losses can be economically important. Losses due to extractions by harvesting have to be supplied for following crops. And immobilization is an important process to slow down the dispersal of reactive N and a nutrient storage for succeeding crops (Rimski-Korsakov et al. 2012, Galloway 2003).

Table 3 **N contents in organic wastes and fertilizers**

1 AMOUNT OF N IN ORGANIC WASTE MATERIAL (G/KG PRODUCT)

Source	N content	Production rate
General		
Livestock manure[1]	20–30	
Dried farmyard manure[2]	19.4	
Cattle		
Cattle manure[3]	5.1	
Dairy cattle manure[1]	5.8	45 kg/head/d
Cattle Slurry*[4]	1.4 ±0.7	
Cattle Manure* [4]	4.6 ±1.4	
Poultry		
Laying hen manure[1]	5.5	8 kg/head/d
Poultry manure[5]	25–30	
Dried chicken manure[2]	40.1	
Pigs		
Fattening pigs manure[1]	4.5	5.5 kg/head/d
Pig manure outdoor **[6]	4.7	
Pig manure conventional** [6]	5.4	
Sheep		
Sheep manure[1]	4	3.5 kg/head/d
Plants		
Crop residues[5]	10–15	

* Averaged content of an eleven year period in loose housing.

** Manure of the outdoor system contained sawdust litter.

2 PERCENTAGE OF N IN ORGANIC WASTE MATERIAL (% OF PRODUCT)

Source	N content	Production rate
Animal waste		
Dried blood[1]	10.0–12.0	
Fish manure[1]	4.0–10.0	
Bird guano[1]	7.0–8.0	
Hoof and horn meal[1]	14	
Bone meal[1]	2.0–4.0	
Cattle manure[7]	2.15	821.2 kg/head/yr
Chicken manure[7]	3.2	10.8 kg/head/yr
Sheep manure[7]	2.5	165.6 kg/head/yr
Pig manure[7]	3.25	173.0 kg/head/yr
Human waste		
Sewage sludge**[1]	<0.1–17.1	
Biosolids[7]	3	50 g/head/d
Plant waste		
Maize residue biomass[7]	0.66	13.8 t/ha
Rice residue biomass[7]	0.67	30.5 t/ha
Wheat residue biomass[7]	0.38	8 t/ha
Oil-seed cakes*[1]	2.5–7.2	

* e.g. cotton seed or rape seed cake

** Highly variable contents; median is 3.3% N

3 N SUPPLY BY BIOLOGICAL FIXATION

Source	N fixation	Unit
Biological N fixation[5]	20–400	kg N/ha/yr
Rhizobia in legumes *[8]	0–360	kg N/ha/crop
In rice production *[8]	10–100	kg N/ha/crop

* averaged over three studies

4 PERCENTAGE OF N IN INDUSTRIAL FERTILIZERS (% OF PRODUCT)

Source	N content
Ammonia[5]	82
Urea[5]	45–46
Ammonium sulphate *[5]	21
Ammonium nitrate[5]	33 –35
Urea ammonium nitrate[5]	28–32
Ammonium phosphate **[5]	11–18
Potassium nitrate ***[5]	13

* Substantial S content

** high P content

*** high K content

5 OTHER TYPES OF MINERAL N SUPPLY

Source	N supply	
Rock weathering[5]	<0.1	
Atmospheric deposition*[9]	10 to >40	kg/ha/a

* Swiss Plateau (Mittelland)

Sources:

1) FAO 1991 2) Mubarak et al. 2010 3) Rieck-Hinz et al. 2013
4) Maltas et al. 2013 5) Reetz 2016 6) Dourmad et al. 2008
7) Thangarajan et al. 2013 8) Bohlool et al. 1992 9) Terrain BFS Geostat

A literature review by Rimski-Korsakov et al. (2012) revealed a highly variable share of fertilizer-N in direct-drilled maize, ranging from 28 to 57%. In average, 24% of fertilizer-N accumulated in grains. N recovery from soil and fertilization decreased with crop stress, e.g. drought or heat. The authors found fertilizer-N ranging from 10 to 30 % in the organic soil fraction. They identified losses of 3 to 30% due to ammonia volatilization and losses of 2 to 12% due to denitrification (Rimski-Korsakov et al. 2012).

4 FERTILIZERS

4.1 Industrial nitrogen fertilizers

Ammonia is the main source of anthropogenic N, due to industrial fertilizer production. The underlying Haber process requires large amounts of natural gas, which is the main hydrogen and energy resource during this process (Galloway et al. 2003). 85% of the NH_3 that is produced by this process is used for fertilizer production, the rest for other industrial purposes. It contributes to about 70% of the N inputs to agro-ecosystems (Galloway 2003).

Global fertilizer demand increased from 111 million tons N in 2013 to 113 million tonnes in 2014 and is expected to be around 119 million tonnes in 2018 (FAO 2015). The highest increase in demand for nitrogen between 2014 and 2018 was in Asia (58%), followed by the Americas (22%). Western Europe was the only region with a slight decline in consumption during this period (FAO 2015).

According to Masclaux-Daubresse et al. (2010), nitrogen is an expensive plant nutrient, contributing substantially to the costs of plant production. FAO points out that low energy prices by increased shale gas production in the United States increased the global demand for fertilizers (FAO 2015). With a share of 54% of the world market, urea is currently the most popular industrial N fertilizer (IFA 2017). Table 3 shows characteristics of common N fertilizers and Table 4 of enhanced fertilizers.

4.2 Organic fertilizers

Organic wastes, originating from humans, animals or plants, can be used as organic fertilizers. Most

Table 4 **Enhanced fertilizers**

Multi-nutrient fertilizers	combine more than one nutrient in the same product, e.g. N, P, K, S, micronutrients
Controlled release fertilizers	various approaches: e.g. derivatives of urea with N in large molecules; polymer encapsula tions, coatings; combinations of differently acting components
Stabilizers	extend the time the fertilizer N remains in its original chemical form
Nitrification inhibitors	prevent the oxidation of ammonium into nitrate; nitrification can be delayed for several weeks to reduce losses by leaching, e.g. by control of microbial activity
Urease inhibitors	suppress the hydrolysis of urea by the enzyme urease into CO2 and ammonia.

Sources:

IFA 2016, Reetz 2016, Halvorson et al. 2014, Shoji et al. 2001 common are manures from animal excreta, slaughterhouse wastes, wastes from food processing and plant residues (He et al. 2016). Green manures, being especially cropped for fertilization purposes, complement the range of organic amendments. They are directly incorporated into the soil or composted. Most of them have a substantial water content, increasing the storage volume and complicating transports. The composition or organic amendments is variable: beneath carbon (C), they usually contain macronutrients (N, P, K), secondary nutrients (e.g. S, Ca), micronutrients and various compounds such us phenols, cellulose or lignin (He et al. 2016, Thangarajan et al. 2013). The variability in contents depends on the raw material, on season, climate, storage and further processing (Table 3). In case of animal manures, the composition is influenced by the rearing system, the breed, nutrition, performance and purpose of the animal (Table 3). In consequence, not every type of amendment provides sufficient and balanced nutrients (Rieck-Hinz et al. 2013). Extraction losses from harvest as well as the nutrient composition of the amendment must be considered and complemented by industrial fertilizers to prevent soil depletion (Reetz 2016).

Organic amendments tend to contain pollutants, e.g. weed seeds, antibiotics, pathogens or heavy metals (Diacono & Montemurro 2010, WHO 2006). The use of human excreta (sewage sludge, biosolids, wastewater) implies substantial health risks, when applied on crop surfaces. Their use is therefore strongly regulated in many countries (WHO 2006). Application of organic amendments is associated with increased soil organic matter (SOM), decomposition rates, mineralization and immobilization and consequently nutrient use efficency (NUE) (Maltas et al. 2013, Diacono & Montemurro 2010, Spiertz 2008). These factors are considered to increase the resilience of an agro-ecosystem. Local nutrient recycling helps to maintain the environmental chemistry due to a stable stoichiometry, if nutrient losses are replaced and the accumulation of imported nutrients (e.g. from feed purchase) is prevented (Reetz 2016, Thangarajan et al. 2013). But organic amendments also contribute to greenhouse gas emissions from agriculture (CO_2, CH_4 and N_2O) (Thangarajan et al. 2013).

4.3 Methods of fertilizer characterization

Online available data from literature research (www.webofkowledge.com) were selected with regard to transparent specification of unit, composition and total N content to assess the range of organic fertilizers, there characteristics and variability as shown in Table 3. Dry matter content was only declared in two studies (Dourmad et al. 2008, Maltas et al. 2013). Units were standardized, if necessary. Some data origin from the 1980s. It can be assumed that more recent data would be influenced by modern feeds and rearing systems.

4.4 Nutrient Use Efficiency NUE

NUE is reduced by microbial, chemical and physical processes as mentioned in chapter 3.1. NUE ranges from 30 to 50% of applied N, depending on crop, climate, soil and management practices (Reetz 2016). Enhancing NUE reduces environmental impacts from agriculture as well as production costs. NUE is improved by ‘best management practices’ (IFA 2016). Disregarding the type of fertilizer, they include 1) fertilization based on the stage of plant growth and the nutritional demand of the crop; 2) split applications to reduce the time gap between fertilization and uptake; 3) determination of soil nutrient contents and replacement of harvesting losses. Managmement systems as cover crops or reduced tillage can also prevent N losses and enhance N storage by accumulation of SOM (Maltas et al. 2013, Diacono & Montemurro 2008). The fertilizer industries developed various technologies to improve the NUE of commercial fertilizers (Table 4).

4.5 Soil organic matter SOM

A high SOM content is widely considered to prevent soil degradation by enhancing chemical, biological and physical soil properties due to microbial activity (Maltas et al. 2013, Diacono & Montemurro 2008). This results in: increased drought resistance, water use efficiency, nutrient retention, N supply over time, microbial activities and is accompanied by decreased nutrient losses and reduced erosion (Diacono & Montemurro 2008). SOM accumulation depends on soil characteristics, climate, C: N ratio and management practices, but is generally improved by organic fertilizers due to their carbon content (Maltas et al. 2013).

5 SYSTEMIC APPROACHES

5.2 Use of legumes

Legumes have a particular position, due to their N fixing rhizobia symbionts. The use of legumes is widespread in traditional and modern integrated agricultural systems (agro-forestry, intercropping, crop rotation). Legumes are also suitable for intense farming systems (grassland, livestock and crop production). For example, 50% of global legume cropping area is covered by soybean, contributing to 75% of N fixation in crops and being commercially produced for feeding purposes (Spiertz et al 2008). In total, biological fixation from legume cultivation contributes to about 30% of N inputs in agro-ecosystems (Galloway 2003). Unlike some industrial fertilizers, they are affordable for the poorest farmers. They fulfill the multi-purpose approach as defined in chapter 2, potentially providing food, feed, fuel and fertilization. For fertilization purposes, they can be used as cover crop, mulch, compost, cattle feed or intercrop, providing N to adjacent and subsequent crops, while N losses are reduced (Mikić et al. 2015, Diacono & Montemurro 2008, Spiertz 2008).

5.3 Biogas production

Decentralized biogas plants can reduce heat sensitive pathogens from organic manures and reduce pollution and losses due to volatilization, if the tanks are sealed. On-farm plants make farmers more independent from energy supply and can create an additional farm income by selling stored renewable energy (Pivato et al. 2016, Battini et al. 2014). Currently developed technologies aim to produce ammonia - according to the Haber process - from biogas (Frattini et al. 2016).

6 ASSESSMENT AND CONCLUSIONS

Neither intense chemically fertilized monocultures nor legume monocultures are sustainable, according to the defined aims in chapter 2. Both crops transform atmospheric N into N reactants, causing negative environmental impacts. But the main difference for sustainability assessment between both systems is the large amount of fossil energy used by the latter. Biogas-based ammonia production can only reduce environmental impacts. Best management practices should be the global standard and are not only ecologically, but also economically interesting. Legumes, organic manure and chemical fertilizers should be used in the necessary amounts to ensure optimal plant growth at minimal losses. But no single measure presented in this report is suitable to make agriculture sustainable. It is crucial to vertically and horizontally integrate all available methods, depending on their availability, on farm and environmental properties, to become more sustainable or even sustainably intensify agriculture.

7 REFERENCES

Battini F, Agostini A, Boulamanti AK, Giuntoli J & Amaducci S (2014). Mitigating the environmental impacts of milk production via anaerobic digestion of manure: Case study of a dairy farm in the Po Valley, Science of The Total Environment. Vol. 481. pp. 196-208. DOI http://dx.doi.org/10.1016/j.scitotenv.2014.02.038.

Bohlool BB, Ladha JK, Garrity DP & George T (1992). Biological nitrogen fixation for sustainable agriculture: A perspective, Plant and Soil. Vol. 141 (1). pp. 1-11. DOI 10.1007/BF00011307.

Diacono M & Montemurro F (2010). Long-term effects of organic amendments on soil fertility. A review, Agronomy for Sustainable Development. Vol. 30 (2). pp. 401-422. DOI 10.1051/agro/2009040.

Dourmad JY, Hassouna M, Robin P, Guningand N, MC; M-S & Lebret B (2009). Influence of pig rearing system on animal performance and manure composition (3:4). pp. 606-616, Animal.

FAO (1991). Manual on fertilizer statistics, manual on fertilizer statistics. Food and agriculture organization of the united nations FAO, Contributors: .

FAO (2015). World fertilizer trends and outlook to 2018, information product. Food and agriculture organization of the united nations FAO, Contributors: .

Frattini D, Cinti G, Bidini G, Desideri U, Cioffi R & Jannelli E (2016). A system approach in energy evaluation of different renewable energies sources integration in ammonia production plants, Renewable Energy. Vol. 99. pp. 472-482. DOI http://dx.doi.org/10.1016/j.renene.2016.07.040.

Galloway JN, Aber JD, Erisman JW, Seitzinger SP, Howarth RW, Cowling EB et al. (2003). The Nitrogen Cascade, BioScience. Vol. 53 (4). pp. 341-356. DOI 10.1641/0006-3568(2003)053[0341:TNC]2.0.CO;2.

Halvorson AD, Snyder CS, Blaylock AD & Del Grosso SJ (2014). Enhanced-Efficiency Nitrogen Fertilizers: Potential Role in Nitrous Oxide Emission Mitigation, Agronomy Journal. Vol. 106 (2). pp. 715-722. DOI 10.2134/agronj2013.0081.

Hassan SED, Liu A, Bittman S, Forge TA, Hunt DE, Hijri M et al. (2013). Impact of 12-year field treatments with organic and inorganic fertilizers on crop productivity and mycorrhizal community structure, Biology and Fertility of Soils. Vol. 49 (8). pp. 1109-1121. DOI 10.1007/s00374-013-0813-7.

He Z, Pagliari PH & Waldrip HM (2016). Applied and Environmental Chemistry of Animal Manure: A Review, Pedosphere. Vol. 26 (6). pp. 779-816. DOI http://dx.doi.org/10.1016/S1002-0160(15)60087-X.

IFA (2016). Nutrient Management Handbook. Contributors: International Fertilizer Industry Association FIA, World Farmer's Organisation WFO, Global Alliance For Climate-Smart Agriculture GACSA.

IFA (2017). Author: international Fertilizer Industry Association FIA. Last Update unknown. Access 4. 2. 2017. www.fertilizer.org.

Lewandowski I, Hardtlein M & Kaltschmitt M (1999). Sustainable Crop Production: Definition and Methodological Approach for Assessing and Implementing Sustainability. Vol. 39. pp. 184-193 Crop Science.

Maltas A, Charles R, Jeangros B & Sinaj S (2013). Effect of organic fertilizers and reduced-tillage on soil properties, crop nitrogen response and crop yield: Results of a 12-year experiment in Changins, Switzerland, Soil and Tillage Research. Vol. 126. pp. 11-18. DOI http://dx.doi.org/10.1016/j.still.2012.07.012.

Masclaux-Daubresse C, Daniel-Vedele F, Dechorgnat J, Chardon F, L G & Akira Suzuki A (2010). Nitrogen uptake, assimilation and remobilization in plants: challenges for sustainable and productive agriculture, REVIEW: PART OF A SPECIAL ISSUE ON PLANT NUTRITION. Vol. 105. pp. 1141–1157, Annals of Botany.

Mikić A, Ćupina B, Rubiales D, Mihailović V, Šarūnaitė L, Fustec J et al. (2015). Models, Developments, and Perspectives of Mutual Legume Intercropping. Vol. 130. pp. 337-419. DOI 10.1016/bs.agron.2014.10.004.

Mubarak AR, Gali EAM, Mohamed AG, Steffens D & Awadelkarim AH (2010). Nitrogen Mineralization from Five Manures as Influenced by Chemical Composition and Soil Type, Communications in Soil Science and Plant Analysis. Vol. 41 (16). pp. 1903-1920. Edt. Taylor & Francis. DOI 10.1080/00103624.2010.495802.

OECD (1999). Environmental Indicators for Agriculture, Volume 1 - Concepts and Framework. Organisation for economic co-operation and development OECD, Contributors: .

Pivato A, Vanin S, Raga R, Lavagnolo MC, Barausse A, Rieple A et al. (2016). Use of digestate from a decentralized on-farm biogas plant as fertilizer in soils: An ecotoxicological study for future indicators in risk and life cycle assessment, Waste Management. Vol. 49. pp. 378-389. DOI http://dx.doi.org/10.1016/j.wasman.2015.12.009.

Reetz HF (2016). Fertilizers and their Efficient Use, Reference guide. FIA IFIA, Contributors. International Fertilizer Industry Association FIA,.

Rieck-Hinz AM, Miller GA & Schafer JW (2013). Nutrient Content of Dairy Manure from Three Handling Systems. Vol. 9 (1), J. Prod. Agric. .

Rimski-Korsakov H, Rubio G & Lavado RS (2012). Fate of the nitrogen from fertilizers in field-grown maize, Nutrient Cycling in Agroecosystems. Vol. 93 (3). pp. 253-263. DOI 10.1007/s10705-012-9513-1.

Schaller N (1993). The concept of agricultural sustainability, Agriculture, Ecosystems & Environment. Vol. 46 (1). pp. 89-97. DOI http://dx.doi.org/10.1016/0167-8809(93)90016-I.

Shoji S, Delgado J, Mosier A & Miura Y (2001). USE OF CONTROLLED RELEASE FERTILIZERS AND NITRIFICATION INHIBITORS TO INCREASE NITROGEN USE EFFICIENCY AND TO CONSERVE AIR ANDWATER QUALITY, Communications in Soil Science and Plant Analysis. Vol. 32 (7-8). pp. 1051-1070. Edt. Taylor & Francis. DOI 10.1081/CSS-100104103.

Spiertz JHJ (2010). Nitrogen, sustainable agriculture and food security. A review, Agronomy for Sustainable Development. Vol. 30 (1). pp. 43-55. DOI 10.1051/agro:2008064.

Thangarajan R, Bolan NS, Tian G, Naidu R & Kunhikrishnan A (2013). Role of organic amendment application on greenhouse gas emission from soil, Sci Total Environ. Vol. 465. pp. 72-96. DOI 10.1016/j.scitotenv.2013.01.031.

WHO (2006). Safe Use of Wastewater, Excreta and Greywater, Guidelines, Volume 1 - Policy and Regulatory Aspects. Contributors: World Health Organization WHO, United Nations Environment Programme UNEP.