Effect of excessive nitrogen application on human health, crop quality and yield of plants: A review

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Abstract

Nitrogen plays a very important role in the growth and development of plants but the use of nitrogenous fertilizer in excessive amount cause harmful effects to the crops as well as human health. In modern agriculture, nitrogen-containing fertilizers are widely used, but their application rate in most fields exceeds crop demand, resulting in short- and long-term negative effects. Due to the higher application of nitrogenous fertilizers, crops accumulate a very high amount of nitrate which is a serious threat to human health as well as to environment. This review mainly focuses on the reduction in crop quality, physiological parameters, yield, and human health due to the application of excessive nitrogenous fertilizers.

Keywords: Nitrogen, Fertilizers, Nitrate accumulation, Human health, Crop quality and yield

Introduction

Nitrogen is an important element in plants. It plays vital role in photosynthesis, amino acid production, genetic material i.e. DNA. The green colour exhibited by plants is due to nitrogen. Plants absorb nitrogen from soil in the form of nitrate (NO_3^-) and ammonium (NH_4^+) which helps plant to grow faster. Nitrogen plays a very important role in plant growth and production. Nitrogen help mainly in the vegetative stage, it increases the chlorophyll content in the crop (Hirel et al., 2007). Nitrogen plays a very important role in the synthesis of many bio chemicals for example nucleic acid, chlorophyll etc. There are lots of nitrogen sources but plants take mainly from the soil. In India, nitrogenous fertilizers are applied on a very large scale. Vegetable plays a very important role in the human diet and for fulfilling this, farmer use excessive amount of nitrogen which may cause health issues. Nitrogen is the most important factor or nutrient that can increase the quality production and the growth of the plant. If a sufficient amount of nitrogen is provided at proper time then production can be increased. And if there is no sufficient dose of nitrogen then there is a significant decrease in the yield of the crop. Some crops tend to uptake more nitrate as compared to others; this is due to an efficient uptake system. There are some vegetables like spinach, lettuce, Chinese cabbage, which has an efficient uptake system as compared to other vegetables. The highest amount of nitrate in the leaf of vegetables is 500mg to 1000mg. These levels are much higher than the reference level of nitrate. The reference amount of nitrate is 420mg per day for a normal adult (Liu et al., 2014).

There are some issues like cardiovascular disease, high blood pressure due to high consumption of nitrogen. It can also cause gastric cancer mainly in infants. It is reported that 80% of nitrogen is consumed from vegetables which can harm the health. There are some nitrogenous fertilizers like urea, calcium nitrate, ammonium nitrate, amide, etc. Normally urea is used in height scale. Urea contains 46% of nitrogen (Montemurro et al., 2007). In vegetables, nitrate accumulation is a big concern because it has potential health hazards like blue baby syndrome in humans (infants) and ingestion problems in live stocks;

it becomes really important to check the nitrate content in such foods to avoid various ailments. Efficient use of nitrogenous fertilizers can overturn the hazardous impact of nitrates and can lead to nourish able and subsistence farming.

Effects on quality of crop

The quality of agricultural commodities is determined based on characteristics like flavour, taste, colour, and look; though, every year new customers are anxious about the nutritional quality of vegetables and fruit products (Schreiner et al., 2013).The consumer idea that fruits and vegetables recommend 'healthy foods' is based mainly on the content of less important plant metabolites, plus glucosinolates, phenolic compounds (other than Brassicaceae), carotenoids and flavonoids (Schreiner et al., 2013), in addition to the nonexistence of harmful compounds like nitrate (Konstantopoulou et al., 2010). Maynard et al. (1976) concluded that nitrates were less in floral parts and rising concentrations were present in leaves, roots, fruit or grain and stems. It has been established that nitrate concentration in lamina of leaf is less than twice as high as in the leafstalk and the distinction might be as high as 6.6-fold in the case of spinach (Anjana et al., 2006). Nitrate content in the stem and petioles was too higher than in the leaves of plant, but the least readings were observed in the roots of cabbage, spinach and rape. Also, nitrate concentration in asparagus chicory leaves was more than in stem of plant (Santamaria et al., 1999). In spinach, the leaf stalk accumulate more nitrates than the leaf laminae, and increasing the lamina/stalk ratio by trimming leafstalks at harvest time(Santamaria et al., 1999) decreases the whole nitrate content of the item for consumption.
The amount of essential elements are decreased as well at high nitrogen application rates, and major changes take place in the calcium contents of cucumbers, apples, tomatoes and kiwis, these changes are significant as the postharvest life of the produce is restricted because of a change in firmness (Nielsen et al., 2009). Higher application of nitrogen fertilizers also decrease the red colour in peaches, apples and nectarines, that is a direct effect associated to reduction in chlorophyll content (Kays, 1999; Wargo et al., 2003; Nielsen et al., 2009; Wang and Cheng, 2011).

Effect on physiological parameters

The nitrate concentration differs strikingly with species of plants, genotypes of different ploidy and cultivars of the same species (Anjana et al., 2006; Grzebelus and Baranski, 2001; Harada et al., 2003). The shoot nitrate content, nitrate content in plants, factors affecting the procedure, and human health implications are found and expected to be controlled by numerous genes (QTLs) (Harrison et al., 2004). The affecting factors might include genetic variations between different genotypes in enzymes of the nitrogen metabolic pathway (nitrate reductase/nitrite reductase), the rate of uptake of other elements, the concentration of nitrate uptake, or differences in production of electron donors required in the assimilative pathway that could lead to the calculated difference in nitrate accumulation. On the other hand, Blom-Zandstra and Eenink (1986) observed no confirmation to found that low assimilation rate of nitrate was a reason for nitrate accumulation in lettuce genotypes which varied significantly in nitrate concentration. The varying capacities of nitrate growth can also be connected with varying locations of nitrate reductase activity and with variations in photosynthetic ability (Behr and Wiebe, 1992), capability to produce and translocate respiratory membrane and decreasing equivalents, or variations in ability to translocate the absorbed nitrate to declining places. Nitrate content reduces with increase in carbohydrate absorption in the vacuoles. Nitrate accumulation is harmfully associated to dry matter content and sugar contents (Blom-Zandstra and Lampe, 1983) and (Reinink et al., 1987), whereas the other two parameters are associated to each other in a positive way with various genotypes. Therefore, genotypes having more dry matter concentration have more carbohydrate content in their vacuoles and hence require little nitrate to keep their osmotic value (Reinink et al., 1987). Each and every factor has to to be considered intensively to find out the fundamental factors for differences in nitrate content between genotypes.

Generally, vegetables eaten with roots stem, and leaves have higher levels of nitrate enrichment, while vegetables eaten only with fruits and melons have lower levels of nitrate enrichment (Zhou et al., 2000). Different parts of plants are different (Santamaria etal., 1999). In fact, by reducing the nitrate content, plant organs can be listed: petiole>leaf>stem>root>inflorescence>tuber>onion>fruit>seed (Santamaria et al., 1999).In lettuce and chicory, inner leaves have less nitrate accumulation than outer leaves, as well as in coriander and spinach. Leaves accumulate fewer nitrates than petioles (Santamaria et al., 1999, 2001). The nitrate concentration in petioles is more than twice that in rocket leaves (Elia et al., 2000). The difference in spinach is 6.6 times greater (Anjana et al.Similarly, the nitrate concentration in the petiole stems is higher than that in the leaves, while the nitrate concentration in the roots of leaf vegetables is lower (Chen et al., 2004). (1999) et al.), as well as separating the parts of vegetables that accumulate high concentrations of nitrates before processing or preparing plant foods; Chen et al. (2004) also showed that the absorption of nitrate has an important influence on the metabolic storage of leaves and the distribution of nitrate in leaf storage. Taking into account the nitrate concentration in the entire leaf (metabolic nitrate pool + nitrate reserve supply), it is assumed that about 90% of nitrate accumulates in the accumulation pool. Functional diversity of nitrate compartmentalization in cells of different species was discussed by Izmailov (2004).

Effect on yield of crop

The excessive application of nitrogen fertilizer gives less nitrogen use efficiency (NUE) and no benefit in the yield of crop. Nitrogen use efficiency ranges from 30 to 50% for most of the plant species, and other 50–70% nitrogen is either consumed by soil microbes, volatilized to nitrous oxide, or lost during leaching (Wuebbles 2009; Ng et al. 2016). Due to nitrogen accumulation and nitrate pollution, this affects the natural ecosystem, surface water, and groundwater and changes biodiversity, and causes greenhouse gas emissions (Ward 2009). After fertilization, the soil begins to mineralize, depending on many factors, such as the type of fertilizer (Lobeli 2007), temperature, soil type, water content, soil microorganisms, and management of field (Griffin, 2008; Fan and Li, 2010).). Excessive nitrogen in the aquatic environment leads to the dense growth of algae in coastal areas and freshwater lakes, thereby limiting the supply of oxygen to the water for many organisms. (Ward 2009; Liu et al.2014). High doses of nitrogen fertilizers can cause a decrease in the yield of various crops, especially fruit trees and fruits and vegetables (such as tomatoes, cucumbers, and zucchini) (Weinbaum et al., 1992;Jackson and Lombard, 1993; Tagliavini et al., 2000; Erel et al., 2008;Stefanelli et al., 2010).In sweet cherry, yield reduction of 6–39% take place at 168 mg N L−1compared with 84 mg N L−1 because of fertigation (Nielsen et al., 2007).In the same way, recent study showed that citrus trees in Florida, the best nitrogen fertilizer rate is 260 kg N ha−1year−1 for maximum yield, with a quadratic prototype in yield reduction at high rates of nitrogen fertilizer (Alva et al., 2006). In olive trees, each increase in the available nitrogen dose in the root zone above 3.4 mm decreases the number of inflorescences per branch, which decreases the fruit set (Erelet al., 2008). Cabello et al. (2009) concluded that the optimum nitrogen fertilization dose for melons is 90 kg N ha−1for a profitable yield of 42.9 Mg ha−1 and that is decreased by 15% by applying nitrogen fertilizer dose at 390 kg N ha−1. A related result was seen in cucumbers, and the drop in profitable yield was related with a reduction in movement of the enzyme nitrate reductase in the leaves of plant and a subsequent decrease in the generation of amino acids to the fruits (Ruiz and Romero, 1999). Excessive use of nitrogen fertilizer will increase the plant nitrate utilization rate of plants, posing a potential risk to human health (Sharifi et al., 2011; Velzen et al.).Scientists have established a strong link between environmental issues and excessive use of nitrogen fertilizers (Gastal and Lemaire, 2002; Wang et al., **2002).** In one experiment, it was concluded that only 4% increase in maize yield improvement was observed by applying 30% excessive N fertilizer application whereas the nitrate accumulation was enhanced by 53%. But when 30% less nitrogen fertilizer were applied, only 10% yield was reduced and the nitrate loss during leaching decreased significantly about 37% (Donner and Kucharik 2003). Likewise, the less in yield was observed in Phleum pretense L. Champ; on increasing the quantity of nitrogen fertilizer rate two times and more nitrogen accumulated in the soil (Sharifi et al. 2011).

Effect on human health

The toxicity of nitrate has been linked to a number of human health problems. The toxicity of nitrate is thought to be caused by its reduction to nitrite and subsequent conversion to nitrosamines and nitrosamides through reactions with amines and amides, both of which are known carcinogens (Walker, 1990). The oxidation of ferrous iron (Fe2+) in haemoglobin to tyrosine is the primary cause of nitrite toxicity. Oxygen supply to human tissues is hampered as a result of methaemoglobin formation (Knobeloch et al., 2000; Mensinga et al., 2003). The reaction that results in the formation of methaemoglobin is as follows:

Hb^{3+} + Red cyt b_5 ------ Hb^{2+} + Oxy cyt b_5

The reduced cytochrome b5 (Red cyt b) is regenerated by the enzyme cytochrome b5 reductase:

Oxy cyt b_5 + NADH --------- Red cyt b + NAD

In order to counteract the effects of nitrate ingestion, the enzyme cytochrome b5 reductase is required. The clinical picture of oxygen deficiency with cyanosis, cardiac dysrhythmias and circulatory failure, and progressive central nervous system (CNS) effects is determined by the percentage of total methaemoglobin in oxidized form. The symptoms of the CNS can range from mild dizziness to coma and convulsions (Agency for Toxic Substances and Disease Registry, 2001). Methaemoglobinemia, previously thought to only affect children, has been identified by Gupta et al. (2000a) in people of all ages with high nitrate ingestion, with the child and over 45 age groups being the most vulnerable to nitrate toxicity. The salivary glands absorb 25% of the total nitrate absorbed from the diet or formed endogenously and secrete it into the mouth (McColl, 2005). Bacteria on the tongue's dorsum transform 10 to 90% of the nitrate in saliva into nitrite. When saliva comes into contact with acidic gastric juice, it is converted to nitro sating species (N2O3 and NOSCN) and then to nitric oxide (NO) by reacting with ascorbic acid in the gastric juice (McColl, 2005), which is potentially mutagenic and carcinogenic (Iijima et al., 2003; Moriya et al., 2002). Functional anomalies associated with gastro esophageal reflux disease are caused by excessive local production of nitric oxide (McColl, 2005).
The global share of nitrogen fertilizers in various crops shows that cereals (wheat + rice + maize + other cereals) receive the most nitrogen fertilizers, followed by fruit and vegetable crops (Source: IFA: 2011/11). Under various lighting conditions, nitrate reductase activity (NRA) affects the rate of nitrate conversion to amino acid, resulting in higher nitrate concentrations (Tamme et al. 2009). The main sources of human exposure to nitrogen fertilizers are ingestion of nitrate-contaminated drinking water and excessive diets of root and leafy vegetables (Jones et al. 2016), which cause adverse health effects such as thyroid cancer (Ward et al. 2010; Bivolarska and Gatseva 2015), hypertension (Majumdar and Gupta 2000), testicular cancer (Kristensen et al. 1996), stomach cancer (Zal e (Majumdar 2003), neural tube defects (NTDs) (Manassaram et al. 2006), diabetes (Bahadoran et al. 2016), and blue baby syndrome (methemoglobinemia) (Majumdar 2003). Three mechanisms may describe the adverse effects of nitrates on health caused by ingestion of nitrate-contaminated drinking water (Ward 2009). The first mechanism explains the production of methemoglobin, which when at an elevated level causes hypoxia, a disorder in which the body or a portion of the body is deprived of sufficient oxygen. The formation of endogenous N-nitroso compounds is the second process. In acidic stomach conditions, the conversion of nitrate to nitrite results in the formation of various nitro sating agents. Third, high nitrate levels in drinking water obstruct iodine intake, causing hypertrophic changes in the thyroid gland (revealed in animal model). Endogenous formation of N-nitroso compounds can play a role in the development of human cancer (IARC 2010).

Table: Commercially available different nitrogen fertilizers with estimated nitrate contents

Nitrogen fertilizers	N content	Nitrate (%of total N)	other nutrients
CAN (calcium ammonium nitrate)	**27%**	**50%**	**4% MgO**
AN (ammonium nitrate)	**34%**	**50%**	**---**
NPK	**Various**	**~ 50%**	**P and K**
CN (calcium nitrate)	**15.5%**	**93%**	**19% Ca**
Urea (car amide)	**46%**	**0%**	**---**
UAN (Liquid urea ammonium nitrate)	**28%**	**25%**	**---**
ASN (ammonium sulfate nitrate)	**26%**	**25%**	**13% S**
AS (ammonium sulfate)	**21%**	**0%**	**24% S**

CONCLUSION

It is clear from the literature cited that excessive nitrogen fertilizer use to boost crop production does not always result in higher yields, as much of the nitrogen is lost by denitrification, leaching, or volatilization. It endangers human health and has significant environmental consequences. Endogenous nitrosation is caused by nitrate accumulation in groundwater, leafy or root vegetables, beer, processed food, fish, drugs, and some pathological conditions, which may lead to different types of human cancers and other medical conditions. Vitamin C and antioxidants found in a variety of fruits and vegetables can reduce the mutagenic effects of nitrate exposure, thereby protecting people from the carcinogenic effects of N-nitroso compounds.

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