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Role of nitrogen (N) in plant growth, photosynthesis pigments, and N use efficiency: A review

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Abstract

Context: N is the vital element for the growth and development of plants out of all the required nutritious compounds. This element plays a key role in most plant metabolic processes.

Objective: To review the literature related to the role of nitrogen in growth, yields, levels of chlorophyll pigments and efficiency in the use of nitrogen is carried out.

Methods: In this article, an attempt has been made to provide a comprehensive review of nitrogen status in agriculture. Also, since nitrogen is the most used element by farmers, this research seeks to know its effects and impact on Nitrogen Use efficiency.

Results: N deficiency affects plant growth, photosynthesis, and ultimately production. However, excessive N consumption reduces the quality of the product. Furthermore, N is one of the main components of chlorophyll structure in the plant. Chlorophyll content and N content in plants are closely related. Chlorophyll content plays a vital role in determining the plant's rate of photosynthesis and production. Leaf N content increases when N fertilizer is applied. Higher N content in leaves is associated with higher chlorophyll content and increased chloroplast activity and thus increased photosynthetic productivity.

Conclusions: It is possible to reduce environmental pollution and increase productivity by understanding management methods that increase Nitrogen Use efficiency (NUE).

Keywords: *Plant growth, Photosynthesis, Environment pollution, Nitrogen use efficiency*.

Introduction

In sustainable agriculture, a new trend is to reduce the use of different inputs, especially chemical inputs, and thereby reduce the adverse effects on the environment. There is no doubt that N is one of the essential elements for plant growth and that its deficiency is one of the most important factors limiting crop production worldwide (Fathi & Zeidali, 2021). N fertilizers provide food directly or indirectly to half the world's population(Yadav et al., 2017). The amount of synthetic N applied to crops has increased dramatically over the past 40 years, leading to significant yield increases with a significant environmental impact(McAllister et al., 2012). Currently, it is estimated that rice, wheat, and corn consume more than 90% of all N fertilizer applied to cereals (Yadav et al., 2017). An oversupply of N leads to various consequences for the soil and the environment, while an undersupply is associated with poor crop production. Farmers need to apply large amounts of N fertilizer to crops because only 30-50% of the N is recovered due to the various losses in the soil-plant system (Fageria, 2002). To meet this high crop N demand, growers worldwide use about 120 million tons of N fertilizer each year (Yadav et al., 2017). There is a general N deficiency in almost all agricultural soils and cropping systems globally, making the use of external N supply (N fertilizer) essential to produce the crops that meet the ever-increasing demand of the human population (Mohan et al., 2015). Although N_2 gas makes up about 78% of the gaseous composition of the atmosphere, crops cannot use this element as such unless it is converted to plant-usable forms (Barbieri et al., 2000). N can be generally taken up from the soil in two inorganic forms: Nitrate (NO_3^-) and Ammonium (NH_4^+) (Guo et al., 2019). Although the latter is an intermediate element in many metabolic reactions, it can cause toxicity symptoms in many higher plants when supplied as the individual source of N (Guo et al., 2019). Plant physiological and metabolic processes can be affected by various forms of N, such as nutrient absorption, enzyme activity, photosynthetic and respiration rate, water balance, and signaling pathways, that ultimately affect plant growth and crop yield (Guo et al., 2007; Ding et al., 2015). Many legumes and soil microorganisms can convert N into plant-usable forms. To meet the high N demand, farmers usually use chemical N only. The excessive use of N negatively affects plant growth and development and environmental pollution. They were leading to rapid N loss from the agroecosystem, eutrophication of water bodies (Hamilton et al., 2018), resulting in severe environmental pollution such as soil acidification(Guo et al., 2010) and increased greenhouse gas emissions (Cassman et al., 2003).

Since the 1960s, the global use of synthetic N chemical fertilizer has increased ninefold (Lu & Tian, 2017). studies show that 76% of the total anthropogenic N applied to the global land surface returned to the atmosphere or percolated to the surface, and subsurface water bodies (Schlesinger, 2009) and that this part of N accounts for nearly 40% of the global total N inputs with biological N fixation accounted (Liu et al., 2010). Massive losses of N are detrimental to the diversity and function of recipient agroecosystems (Van Meter et al., 2017; Lu et al., 2019). With the increasing N loss and improving crop N use efficiency, increasing plant harvest per unit N input is one of the unique ways of increasing crop productivity and alleviating environmental degradation (Davidson & Kanter, 2014; Lu et al., 2019). The study of crop N use efficiency is critical to addressing the challenges of environmental degradation, food security, and climate change from the perspectives of both socioeconomics and technology (Zhang et al., 2015; Lu et al., 2019). An improvement of 20% in "full*chain" NUE by 2020 could save nearly 20 million tons (Mt) of global nitrogen fertilizer annually (Sutton et al., 2013). Numerous countries have proposed the use of NUE as an indicator to measure agricultural sustainability progress (Norton et al., 2015; Lu et al., 2019).

Plant growth

N is one of the crucial nutrients for the growth and development of crops that, if not consumed in sufficient quantities, will limit plant growth (Fathi et al., 2013). On the other hand, it has been reported that excessive consumption of N in the soil has a negative effect on crop growth and production (Valentinuz & Tollenaar, 2006). Growth is a complex process influenced by the absorption of nutrients and moisture provision. Since N is one of the most consumed elements, it plays an essential role in assimilating and transferring to growing organs (Fathi & Zeidali, 2021). The presence of this element always increases growth and performance by providing the required water. Also, the abundance of soil N stimulates the production of new leaves from the terminal meristem of the stem and lateral buds of older leaves. It ultimately increases the yield of aerial parts (Fathi, 2020).

N is one of the main components of organic compounds such as amino acids, proteins, and nucleic acids. Its deficiency delays phenological development in vegetative and reproductive stages (Fathi & Zeidali, 2021). Applying the right amount of N fertilizer can significantly increase biomass, and also high biomass is only possible under N fertilization conditions (Fathi et al., 2016). N appears to maintain leaf surface survival; as leaf surface durability increases, the duration and rate of leaf photosynthesis also increase, allowing the plant to produce more dry matter (Zebarth & Sheard, 1992). N deficiency stimulates competition for the transfer of this element in the plant, impairs timely and complete formation of reproductive organs by decreasing crop growth rate (CGR), delays plant phenology, lowers harvest index, and ultimately reduces grain yield of plants (Fathi & Zeidali, 2021), and slows the rate of pure assimilation (Echarte et al., 2008) and accelerates leaf senescence (Ding et al., 2005).

Yield

It is crucial to managing N consumption correctly to increase plant production, as N plays a vital role for plants (Karami et al., 2018; Taheri et al., 2021). The shortage of N decreases leaf size, which is the cause of the lower amount of light absorption and light use efficiency for plant photosynthesis that leads to decreased biological yield and vice versa (Nasim et al., 2012). N intake should be commensurate with plant needs. Excessive use of N due to leaching, low N efficiency, lack of plant use of excess N increases N loss in the soil (Ghobadi et al., 2018). Therefore, proper management means providing the optimal N required by the plant to use it. N has a positive effect on grain yield by affecting plant morphological traits, and the best plant yield will be achieved when N is used in different phenological stages of the plant (Fageria et al., 2013). Typically, farmers apply N fertilizer at a higher rate than recommended because they believe that increasing N will always increase crop yields, which will adversely affect the sustainability of the production system and raise production costs (Djaman et al., 2018). From the point of view of biomass production and yield, the optimal N level is the amount that leads to the highest growth rate and yield. But usually, the quality and health indicators of the product, such as the amount of nitrate in the product, determine the desired N level (Goodarzi et al., 2020). Increased N consumption causes more dry matter production and grain yield, root expansion and bulking, and soil moisture absorption. Also, increasing N consumption accelerates green growth, increases the volume of the aerial plant part, and increases plant evapotranspiration (Mirzaei et al., 2018). Ying et al. (1998) stated that as plant yield and biomass increase, the plant should absorb more N; for example, a plant that produces more than 13 tons of biomass per hectare needs to absorb more than 250 kg of N per hectare. Researchers report that increasing the application of N fertilizer increases the accumulation of this element in the grain and the shoots of wheat cultivars. This condition eventually leads to an improvement in the protein content of the grains (Hosseini et al., 2013).

Photosynthesis

The photosynthetic apparatus of plants consists mainly of N, a widely used fertilizer in plants (Bassi et al., 2018). Photosynthesis is the plant's most crucial process for growth and biomass production; therefore, it drives yield formation (Chen et al., 2018). In other words, crop yield is determined by photosynthesis, assimilation, and distribution efficiency. Hence, N ions are essential in these processes (Olszewski et al., 2014). In addition to increasing leaf area, N fertilization also affects growth habits and leaf longevity, ultimately affecting photosynthetic efficiency(Olszewski et al., 2014). An adequate amount of N taken up in the late stages of plant growth delays the degradation of chlorophyll and protein solutions and prolongs the duration of photosynthesis, increasing the defenses of leaves and preventing leaf senescence (Qing et al., 2002). When growing cereals, the flag leaf stays on the plant the longest and contributes significantly to the yield. In flag leaves, photosynthetic activity is prolonged for a long time, which is crucial as older leaves die off during grain filling (Loss & Siddique, 1994). At grain filling, the primary nutrients are derived from photosynthetic products accumulated in the latest emerging leaves. According to some research, crop yield increases from applying N fertilizer can be explained by photosynthetic regulation (Zhang et al., 2017). Leaves' biochemical composition and structural characteristics can influence their photosynthetic capacity (Wright et al., 2004). Two of the key traits to determine photosynthetic capacity are specific leaf area and leaf N content (Hikosaka 2004; Poorter et al., 2009). Researchers have examined the relationship between leaf nitrogen content and photosynthesis (Evans, 1989). As a result of increased cell division and meristem cells, N increases vegetative growth and plant branching. In turn, more leaves are produced in the plant, increasing the photosynthetic level. These changes will affect the processes of photosynthesis and materialization (Arvin, 2019).

Chlorophyll

N is the main component of chlorophyll, and protein in the plant cells. Chlorophyll content is vital in determining the photosynthetic rate and dry matter production. Chlorophyll content and N content in plants are closely related because 70% of leaf N is accumulated in chloroplasts, which produce the chlorophyll pigments (Fathi & Zeidali, 2021; Moeinirad et al., 2021). N is the main component in amino acids, nucleic acids, proteins, and chlorophyll structure (Mendoza-Tafolla et al., 2019). As foliar chlorophyll content are directly related to leaf N concentrations; consequently, monitoring plant chlorophyll and N concentrations during production would be useful in enhancing growth, yield, and marketability (Zebarth et al., 2002; Gitelson et al., 2003; Mendoza-Tafolla et al., 2019). A number of plant species have shown high correlations between chlorophyll and nitrogen concentrations, including cabbage (Westerveld et al., 2002), corn (Hurtado et al., 2010; Sawyer et al., 2011), wheat (Kızılgeçİ et al., 2015; Shah et al., 2017) and rice (Huang et al., 2016). Moeinirad et al. (2021) reported that the consumption of N improved pigments as the rate of chlorophyll (a, b) increased by using N. They also reported a significant and positive correlation between chlorophyll indexes, N nutrition index, N concentration, chlorophyll. Chlorophyll fluorescence is directly related to chlorophyll activity in the reaction centers of photosystems. Existence of any disturbance or change in structure and photosystem II pigments leads to reduced quantum performance of the photosystem under dark conditions, and one of the important elements of plant chlorophyll formation is plant N (Fracheboud & Leipner, 2003). The the decrease in quantum yield under N deficiency conditions can be attributed to the decreased photosynthetic capacity of the plant, which is due to the reduction of the synthesis of key enzymes in the photosynthesis process, the most important of which is Robisco enzyme (Qi et al., 2013). Also, sufficient N in the plant increases quantum yield through enhancing leaf area index, and subsequent carbon assimilation during photosynthesis in the chloroplast thylakoid while maintains high efficiency in energy conversion and photosynthetic electron transfer chain (Qi et al., 2013; Moeinirad et al., 2021). Researchers report that with increasing N fertilizer, chlorophyll b levels in corn increased (Haghjoo & Bahrani, 2015).

NUE

Use efficiency plays a vital role in plant growth and survival in the face of environmental changes. However, sometimes an increase in the efficiency of one source leads to a decrease in the efficiency of other sources (negative relationship between light efficiency and N) (Hirose & Bazzaz, 1998). For example, Field et al. (1983) proposed an agreement on the efficiency of water and N consumption that any increase in stomata conductance leads to an increase in intracellular CO_2, which leads to an increase in N and a decrease in consumption efficiency. NUE is the relationship between the amount of N a crop takes in and retains until harvest and the amount of N available to the crop. This relationship is particularly emphasized when comparing how much fertilizer is applied to soils with how much N crops retain (Fathi, 2020). As a metric, NUE has been widely used to relate N uptake with N application (Sharma & Bali 2017). Under these conditions, where plants require large quantities of nitrogen fertilizer to maximize yields, improving NUE is a difficult task, as NUE is estimated to be lower than 50% (Raun & Johnson, 1999; Dehpouri et al., 2022). Physiological mechanisms controlling N utilization in plants under different N management practices are crucial to improving N utilization efficiency as well as reducing excess fertilizer application while maintaining acceptable yields and environmental quality (Ciampitti & Vyn, 2011; Sharma & Bali, 2017). Efficiency in uptake and utilization are the two components of NUE. In low N conditions, efficiency of uptake is more important than efficiency of utilization (Witcombe et al., 2008; Khan et al., 2017). Nitrous oxide emissions create an adverse environmental impact in the form of nitrate, which is more mobile than any other nutrient (Shimono & Bunce, 2009). It is, therefore, essential that nitrogen be used efficiently in order to reduce the risk of unproductive and polluting N loss in cropping systems as well as increase their productivity and profitability (Cassman et al., 2003; Good et al., 2004; Khan et al., 2017). Gaudin et al. (2015), in a study of NUE in wheat, corn, and soybean, found that the lowest NUE is obtained in the case where the highest amount of N fertilizer is used. The highest value for NUE was observed in treatments that did not receive fertilizer, or the amount of fertilizer received was low. In addition, they found that plant N uptake increased slightly as fertilizer N levels increased. Some experiments show that adjusting the amount of N chemical fertilizer application or its division is an excellent way to increase the efficiency of N consumption (Fathi, 2020).

Conclusions

Highlights in this study show that N plays a vital role in plant growth and development. N deficiency reduces plant growth and ultimately reduces yield. However, lack of understanding of the proper use of N fertilizer causes problems. Excessive use of required N reduces plant yield. Therefore, before applying N fertilizer, it is necessary to test the N in the field soil and use the fertilizer recommended for each plant based on the expert's recommendation. Improving NUE is a key strategy for developing sustainable agricultural systems that leads to maximum yields in exchange for minimal inputs and N loss.

Author contribution

Amin Fathi: Research planning, template design, analysis of results, redaction of the manuscript, final review.

Conflicts of interest

There are no conflicts of interest.

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