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BIOCHEMICAL FEATURES OF PLANT NITROGEN USE EFFICIENCY

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Abstract

Nitrogen (N) fertilizer has a significant impact on crop yields. A vital macronutrient in agriculture, N, restricts plant growth and development. Nitrate and ammonia are typical inorganic N forms that can be digested by all plants, and plants may use both organic and inorganic forms of N. The need for a "Second Green Revolution" has highlighted the need for crops that require lower amounts of nitrogen fertilizer, and research into nitrogen-use efficiency (NUE) has continued to increase.

Soil nitrogen availability, its absorption and assimilation, photosynthetic carbon and reductant supply, carbon–nitrogen flow, nitrate signaling and control by light and hormones are just a few of the many elements that play a role in plants' nitrogen use efficiency (NUE). It provides an overview of the physiological, biochemical, and molecular components of NUE in crops and model plants, as well as QTL mapping studies and transgenic initiatives to increase NUE through genetics.

Keywords: *biochemical, plants, nitrogen fertilizer, NUE*

Introduction

Increases in agricultural yields have been followed by enormous increases in the use of synthetic nitrogen, which has resulted in significant implications on the environment over the course of the last 40 years. In addition, the production and application of nitrogen fertilizers demand vast amounts of energy, and an excessive amount of either can have a negative impact on the natural environment. The need for crops that use less nitrogen fertilizer has led to an increase in the amount of research conducted on the topic of nitrogen-use efficiency (NUE), also known as nitrogen fertilizer efficiency.[2] Each stage of nitrogen use, which includes N absorption, translocation, assimilation, and remobilization, is controlled by a range of genetic and environmental factors, which is one of the reasons why it is an inherently difficult characteristic. Both a low and a high N supply have separate limiting requirements for improving NUE, which demonstrates that existing cultivars have a significant amount of opportunity for increasing NUE. A reduction in crop-acquired nitrogen (N) losses is possible through the coordination of the metabolism of carbohydrates and N in order to achieve maximum output.[3]

The presence of nitrogen (N) in the soil is required for the growth and development of plants. This is an important nutrient. India comes in third place for the amount of nitrogen fertilizer it uses and second place for the amount it produces.[1] One of the most pricey ways to obtain nitrogen is through the use of commercial nitrogen fertilizers, which make up the bulk of the expenses associated with producing plants. In spite of the fact that the use of nitrogen fertilizers may result in increased agricultural yields, the rising use of nitrogen fertilizers may have a detrimental effect not only on global nitrogen cycles but also on the thinning of the ozone layer. The remaining 30–40 percent of nitrogen provided to food production is consumed solely by crop plants, which results in hazardous environmental pollution caused by the contamination of nitrogen. [4]

Both a low and a high N supply have separate limiting requirements for improving NUE, which demonstrates that existing cultivars have a significant amount of opportunity for increasing NUE. [5] A reduction in crop-acquired nitrogen (N) losses is possible through the coordination of the metabolism of carbohydrates and N in order to achieve maximum output. This has resulted in the hunt for genes that boost the NUE of agricultural plants, and possible NUE genes have been discovered in pathways such as nitrogen (N) absorption and assimilation, amino acid biosynthesis, carbon (C) and nitrogen (N) storage, and NUE. The investigation of a broad variety of plant species has led to the discovery of genetic variations in nitrogen absorption and/or grain output per unit of nitrogen fertilizer applied. [3]

When nitrogen is sprayed to rice, a significant amount of it is lost in the form of gaseous nitrogen, which has a detrimental effect on the surrounding environment and lowers the economic efficiency of the nitrogen application. Species and genotypes that have a high nitrogen consumption efficiency (NUE) are the ones that are able to grow and produce more in low nitrogen conditions. NUE stands for nitrogen usage efficiency. [4]

It has been demonstrated in the past that rice possesses genetic variation in its capability of making optimum use of nitrogen. It is essential to discover or generate genotypes with a high NUE for rice production that makes use of methods of crop management that are both inexpensive and protective of the environment. [3]

Because of a lack of knowledge of the molecular basis for nitrate absorption management, biotechnological methods to increasing crop NUE have had very limited success up to this point. In addition to this, [5] it includes the interactions that take place between the routes for N-assimilation and other metabolic processes that occur outside of the metabolic cascade. It is vital to have an integrated strategy that combines various methods to fertilizer management with biotechnology treatments in order to achieve the goal of optimizing nitrogen flow and nitrogen use efficiency in Indian crop cultivars.

The Nutritional Importance of Nitrogen and Its Effects on the Environment

For the purpose of developing cultivation techniques, and in particular for the purpose of producing lettuces with a low nitrate content, a better knowledge of the influence that environmental conditions have on the growth and accumulation of nitrates in plants is important. This investigation was carried out with the purpose of analyzing the influence of nitrogen supply on the interception and conversion of the PAR in dry matter, as well as on the nitrate and water accumulations in the fresh tissues of the lettuce, under a range of temperature and radiation circumstances. [6]

The use of manures and fertilizers is an essential step in crop cultivation. The use of manures helps to enhance the general physical condition of the soil and also increases the ability of the soil to retain water.

On their own, however, manures are not sufficient to satisfy the plants' demanding nitrogen requirements. For this reason, it is essential to combine the use of manures and chemical fertilizers in order to achieve desirable crop yields. The grain production of many crops, such as Zea mays, B. juncea, and Hordeumvulgare, may only be increased to completely exhibit their high producing potential if they are provided with suitable quantities of nutrients at the appropriate time.

The usage of nitrogen fertilizer in excessive amounts can have a negative influence on the surrounding environment and comes at a financial cost to the producer. The production of nitrogen fertilizers via the Haber-Bosch process takes a significant quantity of fossil fuel energy, which is normally derived from natural gas. Furthermore, a significant amount of diesel oil is utilized in the fertilizer distribution process.

Utilization of the Haber-Bosch method in the manufacture of fertilizer Measurements were taken of the growth, as well as the concentrations of water and nitrate, in two soilless cultures of lettuce that were exposed to two different levels of radiation and two different amounts of nitrogen input. The RUE was anything from 2.12 to 3.50 gMJ1, with a greater value being seen when the radiation intensity was low and when there was a plentiful supply of nitrogen. There was a strong relationship between the amount of nitrate in lettuce and the amount of water it contained. [3] The slope of this connection was not influenced by the environmental conditions, which indicates that there is a significant interdependence between the accumulation of nitrate and water in lettuce.

The oxidation of nitrogen in fertilizer results in the production of gaseous ammonia and nitrogen oxides, which play important parts in the chemistry of the troposphere and stratosphere, and which are the primary contributors to air pollution. [4] These losses, in terms of urea that has been administered, can surpass forty percent. Nitrate ions contained within the soil system are highly mobile and have the ability to be quickly leached into both groundwater and surface waters. The leaching of NO3-ions can cause an over enrichment of freshwater and drinking water supplies, as well as problems for human health; it can also cause eutrophication and hypoxia conditions in marine ecosystems, which can endanger fisheries, change the species composition, and reduce biodiversity in non-agricultural systems. [6] As a result of an increased risk of lodging as well as weed, insect, and disease infestations, the excessive use of nitrogen fertilizers in systems that are not well managed can have a detrimental, and in some cases disastrous, influence on production. [7]

Nitrogen-Use Efficiency and Its Physiological Foundations

The term "nitrogen-use efficiency" has been defined in a number of different ways, the majority of which refer to a system's capacity to transform nitrogen inputs into nitrogen outputs. It is also possible to define it as the greatest economic yield generated per unit of nitrogen that is either provided to the plant, [8] absorbed by the plant, or used by the plant in order to create grain and straw yields. In a system with a large amount of nitrogen input, a high uptake efficiency is a desired attribute that describes NUE. In a system with a low amount of nitrogen input, on the other hand, the creation of cultivars with a high utilization efficiency is thought to be more desirable. The crop species, soil type, temperature, amount of nitrogen fertilizer used, amount of water in the soil, crop rotation, and other factors can all have an impact on nitrogen utilization efficiency. [6]

In order to generate NUE varieties, it is essential to have a full understanding of the physiological, biochemical, and molecular elements of NUE, particularly in low N environments. Root transporter systems are responsible for the uptake of nitrogen in the form of nitrate (NO3) and ammonia (NH3) from the soil by plants. This nitrogen is then assimilated by a series of nitrate assimilatory enzymes, including nitrate reductase (NR), nitrite reductase (NiR), glutamine synthetase (GS), and glutamate synthetase (GS (GOGAT). An essential enzyme in the process of ammonia absorption, glutamine synthetase (GS) converts ammonium into glutamine. Ammonium can also be formed by a handful of internal metabolic events, such as photorespiration, the reduction of nitrate and nitrite, the formation of storage molecules, and the transformation of amino acids. [1]

GS may be found in two different types, namely cytosolic GS (GS1) and chloroplastic GS (GS2). GS1 is essential for proper development and grain filling, whereas GS2 is responsible for recycling absorbed ammonia. Assimilated ammonia is a byproduct of photorespiration and plays a role in photosynthesis as well. In C3 plants, such as tobacco, the oxidative decarboxylation of glycine was the source of the photorespiratory production of ammonium. The quantity of primary nitrogen that a plant consumes is approximately ten times less than the amount of ammonia that is produced as a byproduct of photorespiration. [2]

In earlier research, it was shown that the cytosolic GS played an important part in the remobilization of nitrogen for grain filling in wheat, rice, and maize. [5] Nitrate reductase (NR), which is located in the cytoplasm of plants, is one of the most important metabolic enzymes in plants and is responsible for the conversion of nitrate to nitrite. There is a significant amount of variation in the activity of this enzyme at various concentrations of N, and there are also genotypic variances in the NR activity of rice.

Methods Based on Biochemistry and Genetics for Increasing the Productivity of Nitrogen Use

The efficiency with which higher plants utilise nitrogen is influenced by a number of different metabolic pathways that work together. Before delving into the specifics of the mechanisms that influence nitrogen use efficiency (NUE), it is vital to have a solid foundational knowledge of both the NUE and its component parts. [6] The examination of NUE provides information on how plants react to varying levels of nitrogen availability in the environment. Because nitrogen use efficiency may be broken down into two subcomponents, known as nitrogen uptake efficiency (NUpE) and nitrogen utilization efficiency (NUtE), in order to get an accurate estimate of NUE, it is necessary to compute both of these subcomponents. NUpE is determined by dividing the total amount of above-ground nitrogen content at harvest by the amount of accessible N in the soil, and NUtE is determined by dividing the amount of nitrogen present in grain tissues at harvest by the amount of nitrogen present in above-ground plant biomass. Therefore, NUE is determined at the time of harvest, often known as the conclusion of the crop cycle. To develop such cultivars, it is very important to understand the details of various traits which affect NUpE and NUtE. Keeping this in mind, the processes and traits related to NUE are discussed below. However, yield and grain protein content, which represent the nitrogen use efficiency, are inversely related.[4] Therefore, it is very important for breeders to design cultivation programs to achieve comparatively successful NUE without compromising grain yield.

Root Structure of Architecture

Root development and the architecture of the root system are both highly dependent to the availability of nutrients. To this day, we do not have a good understanding of the root architectural plasticity features, genetic foundation, mechanism, regulation, or function linked with nutrient absorption.[5] It is widely acknowledged that the development of NUE will benefit from a focus on root architecture. The root systems of cereal crops including wheat, rice, and maize may be broadly split into two parts:

a) embryonic roots (also known as germinal roots)
b) post-embryonic roots (also known as crown roots).

The "steep, inexpensive, and deep" root architecture of a plant is an excellent explanation for nutrient absorption, especially nitrogen. It states that primary roots are engaged in the acquisition of nitrogen from deeper horizons, whilst lateral roots with steep angles are involved in covering a broader volume of soil.[6] This is because primary roots grow at shallower angles than lateral roots. It has been found that lateral roots are more sensitive to changes in the plant's nitrogen concentration, as well as to biotic and abiotic stress. A low nitrogen level in the plant's soil during its early stages can have a beneficial effect on the start of lateral roots, but a severe nitrogen deficit might impede the root's ability to emerge and grow. A high nitrate to ammonia ratio in the soil was shown to have a beneficial influence on the lateral root length of the plant. [4]

N roots transporter systems

Ammonium (NH_4^+), nitrate (NO_3^-), amino acids (peptides), and urea are all types of nitrogen that are taken up by substrate-specific transporters. A unique type of transport protein for nitrogen absorption is involved in root nitrogen buildup. The NPF family, the NRT2 family, the Chloride Channel (CLC) family, the Slow Anion Associated Channel Homolog family, and the aluminum-activated malate transporter all play a role in nitrate absorption and transport in plants, respectively. NPF and NRT2 are two of the five families described above that have been linked to nitrate intake and plant location.[5] Therefore, inorganic forms of NO_3^- and NH_4^+ can be taken up by the root apoplast by diffusion or mass flow, respectively. Nitrogenous substances are transported to the plant's vascular system by active transport, which is a key process in the ground tissue (xylem). Involvement of plasma membrane-associated transporter proteins in active transport has been documented and categorised into high and low affinity transporters. In higher plants, three types of transport systems are active, based on affinity and NO_3^- concentration in the rhizosphere: iHATS, cHATS, and LATS. [4]

Metabolism of Nitrogen on plants

The intake, storage, mobilization, and transport of micronutrients and macronutrients, including nitrogen, is essential to plant nutrition enrichment. Multiple genes work in concert to control these intricate processes. Using ionomic techniques, researchers discovered that plants' macro- and micronutrient statuses were affected by changes in the rhizosphere. Nitrogen supply in soil also altered micro and macronutrient profiles, [7] which in turn influenced photosynthesis rate and NUE, growth, and yield.... Nitrogen utilization can be improved by increasing mineral absorption in tandem with nitrogen intake. On the surface, it appears that a decrease in nitrogen concentration reduces absorption and utilization of other mineral nutrients such as phosphorus, potassium, magnesium, calcium, copper, iron, and manganese. Although the environment, genotype, tissue, and nutrition all influence nitrogen metabolism and its interactions with other nutrients, this is not the case for all organisms. Root K and P content was shown to be impacted by nitrogen levels, although the variation in K content in shoot Mg content was considerably lower than the variation in K content in root. Transporter proteins for coordinated absorption of nutrients such as nitrogen, phosphorous, and sulfur were reported to be induced by a lack of nutrients. Nitrogen fertilizer treatment had a synergistic impact, causing nutrients including P, K, Ca, Fe, Cu, and Mn to accumulate in leaves and roots, where they were absorbed in combination. [8]

Nitrate reductase (NR) is critical for the conversion of nitrate to nitrite. Growth conditions, nitrite ion availability, phosphorylation, and hormone stimulation are all factors that influence NR activity.[6] A component of the Mo-cofactor, molybdenum is critical to plant growth and development because of its function in the synthesis of enzymes involved in the process. Glutamate synthase enzymes use mo as cofactors to incorporate ammonia into amino acids.

N shortage has also been shown to affect plant growth and N metabolism. Nitrate deficit enhanced the root/shoot biomass ratio and the total free amino acid content, but lowered the nitrate concentration and NR activity in roots and leaves. [7]

The problem of increasing the effectiveness of nitrogen usage in plants

The most recent advances and future prospects for better understanding the regulation of nitrogen usage efficiency in the world's most commonly grown crops are discussed. Plant nitrogen economy regulation systems are critical in these crops in order to improve nitrogen usage efficiency and reduce excessive fertilizer input while maintaining an appropriate yield level. Plants grown under agronomic conditions with low and high nitrogen fertilization regimes can now be used to develop whole-plant physiological studies combined with gene, protein, and metabolite profiling to build up a comprehensive picture depicting the various steps of nitrogen uptake, assimilation, and recycling to the final deposition in the seed.[9] Understanding the physiological and molecular regulation of N absorption under changing environmental circumstances in crops has been enhanced by the use of integrated techniques, mostly based on whole-plant physiology, quantitative genetics, and forward and backward genetic approaches. The current state of knowledge and future possibilities for agronomic development and application for breeding crops adapted to decreased fertilizer input in the next century are examined in light of global economic and environmental restrictions. [10]

Conclusion

As a starting point, this article provides a brief summary of how agronomy and molecular genetics have helped to increase our understanding of N absorption in some of the most common crop species produced throughout the world. Because it focuses on crops that do not fix nitrogen under symbiotic circumstances. While symbiotic N fixation has been predicted to contribute around half of the N used in inorganic N fertilizers, this review will not include this topic, [9] even though it might be an ecological alternative to inorganic N fertilization in some regions. A number of evaluations focused on selection criteria, breeding methods, and genetic engineering approaches have addressed prospective advancements in legume crops that would benefit not only the environment and farmers, but also consumers in both developed and developing nations.

Soil microbial activities play an important role in determining how much fertilizer can be recovered from a given amount of N taken up by crops. Soil texture, climate, interactions between soil and bacterial activities, and the kind of organic or inorganic N sources should all be taken into account when calculating a crop's NUE.

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