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Review: Nitrogen Utilization Features in Cotton Crop

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Abstract

Cotton is one of the important cash crops and a fiber crop most widely grown and the highest yielding as well. Cotton fiber is woven to be the fabrics commonly used in our daily life due to its excellent performance and great production in the world, especially in China. To access to such high quantities must ensure the requirements of materials such as nutrients for plant growth and take care of the smallest details to make the production cost less, to improve the utilization efficiency, such as nitrogen (N) fertilizer. Hence, N fertilization studies are not only about the dosages, timing and ratio, but also the uptake processes by the plant, N effect on cotton yield and its formation, as well as the movement and metabolism within the plant. As economic and ecological issues are concerned, economizing N fertilization is paid more and more attention. Many approaches have been done and suggested in order to improve NUE like combine the plant sensing techniques and precision application. Simulations and recent field trials demonstrate that site-specific nitrogen management helped reduce technological constraints to higher AE achievement, profit and more sustainable N management. Therefore, improving nitrogen use efficiency (NUE) is one of the key points to ensure cotton production development sustainable. In this review, we try to highlight the accomplishments of N effect on cotton growth and yield, NUE and factors related to NUE in cotton production based on the current knowledge, and from our viewpoint we propose some possible approaches to improve NUE through N managements in terms of application splits, rates, and timing.

Keywords

Cotton, Growth, Yield, Nitrogen, Nitrogen Use Efficiency (NUE)

1. Introduction

Cotton (*Gossypium* L.) is one of the most sources of textile natural fiber in the world [1], grown worldwide in

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the temperate and tropical regions in more than 50 countries [2]. There are two cotton species grown for a good quality fiber, *G. hirsutum* and *G. barbadense*, accounting for 90% and 5%, respectively, of the world cotton fiber production [3].

N fertilization has contributed greatly to cotton production, because it plays a pivotal role to cotton growth and yield. N is always the most applied fertilizer regarding the others in cotton cultivation, used in different amounts, applied in many ways and various timing, but what is common in all those methods and dates is the high cost of the fertilizer itself [4] with rapidly high consumption. The world fertilizer consumption was increased over 2 percent yearly from 2008 to 2012, equivalent to an increment of 19.3 million fertilizer nutrient tones [5]. Therefore, it is essential to manage the N application in way that does not cause symptoms resulted from either deficiency or excessive [6]-[8]. In addition, N management faces many problems especially the cost, and the negative impacts on both environmental and economic sides (USDA, 2008), and on plant growth as well [9]-[12] due to its global rapid increase of consumption.

In conventional farming of cotton, N fertilizer was applied in three splits, pre-plant, first blooming and peak blooming application [13], but N rates to achieve the highest yield were different based on regions [14], soil types [15], and cultivars.

In this concept, many studies aimed to reduce the N application splits and N amount without yield reduction, while other researches discussed N allocation, metabolic pathways and enzymes involved in plant and the changes in N forms in the soil.

2. Cotton Growth as Affected by N

2.1. Cotton Vegetative Growth and N

High nitrogen supply had obvious inhibitory effects，manifested as the decreasing of root dry weight and root length and root surface, as well nitrogen supply had no effect on average root length density [16]. Low nitrogen and high nitrogen had promoting effect on the increasing of root length and root surface area, With nitrogen supp1y increased，root surface area of whole soil layers increased. Tang *et al*., (2012) [17] reported that the greater efficiency of late-season vs. pre-plant fertilizer N may explained by more extensive root system, and better photosynthetic supply, and suggested that a higher ratio of N for PBA (0% PPA + 40% FBA+ 60% PBA treatment) creates a mutually-beneficial relationship between above- and below-ground growth for nutrient absorption to sustain vigorous plant leaf function and to produce more photo-products for a longer period of root absorption.

Nitrogen is an essential element for canopy area development and photosynthesis [18]. Providing the right N amount during the plant growth will provide healthy leaves with the photosynthetic capacity needed to support the growing of the reproductive components [19]-[23]. In other hand an inadequate N supply will slow or stop leaf development. N deficient supply will produce few leaves on the plant resulting in reduction in photosynthesis and formation of sugars for boll set and maturation, and plant height [22] [24]. But the primary detriment is when surplus N encourages excessive vegetative growth, resulting in poor boll set caused by vegetative shading and insect attractiveness, and lodging, late maturity and difficulty in defoliation [25]-[27]. Ramzan *et al*. (2013) [28] found that application of 250 $kg \cdot ha^{-1}$ nitrogen fertilizer produced the tallest plants (84.88 cm). Hallikeri *et al*. (2010) [29] showed that cotton height was significantly affected by application of N levels, as taller plants were observed with N up to 120 $kg \cdot ha^{-1}$. Kumbhar *et al*. (2008) [30] who found that subsequent increase in N levels from 50 to 150 $kg \cdot ha^{-1}$ resulted in proportionate increase in the plant height in which taller plants were recorded in the treatments where 150 $kg \cdot N \cdot ha^{-1}$. Soomro and Waring (1987) [31] reported significant differences in plant height with different levels of N application, as a result of inter-node elongation rather than increases in main stem node number. Ramzan *et al*. (2013) [28] indicated that maximum number of node (15.29) was recorded N rate of 225 $kg \cdot ha^{-1}$ which were statistically different with 0 and 75 $kg \cdot ha^{-1}$ nitrogen fertilizer rates, as well Clawson, *et al*. (2006) [32] also reported that main stem nodes·$plant^{-1}$ was significantly increased with higher N rates. In the other hand Emara and El-Gammaal (2012) [24] showed that the inter-node length average values were insignificantly affected by nitrogen fertilizer levels 0 - 60 kg/fed (0 - 140 $kg \cdot ha^{-1}$).

Higher fertilizer rates provided the plants with more nutrients, which improved No. of monopodial/plant Kumbhar *et al*. (2008) [30] found and that maximum number of monopodial branches was observed in experimental units where 150 $kg \cdot N \cdot ha^{-1}$ was applied. Oosterhuis *et al*. (1983) [33] found a distinct differences in plant dry weight and leaf area at 120 $kg \cdot N \cdot ha^{-1}$ treatment, in which maximum dry matter production was 114 $g \cdot plant^{-1}$

and leaf area index had attained a maximum of 3.7 after 115 days from sowing. Dong *et al*. (2012) [34] reported that high N rate increased the biological yield as 10% relative to low rate, as well increased the net photosynthetic rate (Pn) by 3 and 13%, and Bt protein content by 16.4% and 42.1% relative to moderate (225 kg·ha^{-1}) and high (300 kg·ha^{-1}) N rates.

Nevertheless Howard *et al*. (2001) [35] reported that higher doses of N lead to more vegetative growth and causes delay in maturity and ultimately reduction in the crop yield. Dong *et al*. (2012) [34] showed that increasing N rate reduced earliness. Setatou and Simonis (1996) [36] found that N fertilization caused a delay in the maturity of cotton plants, ranging from 0.2 to 2.5 days in comparison to the control in most of the experiments. However, this delay is important only when the harvesting conditions are unfavorable.

2.2. Cotton Reproductive Growth and N

At the reproductive growth, failure to ensure the right amount of N during the square development period will eventually decrease the yield [37] [38]. In the flowering period, increasing the soil-N rate has positive effect on the N content in the flower, but it does not lead to increase its size [39]. N has indirect effects on boll and seed formation. Increasing of the canopy's size leads to increase the total photosynthesis area and form bigger source for nutrients that increase the size and weight of the bolls and seed [40]-[43]. Ramzan *et al*. (2013) [28] reported that the maximum number of sympodial branches plant^{-1} (7.51) was recorded in 225 kg·ha^{-1} nitrogen fertilizer and control (0 kg·ha^{-1}), while Kumbhar *et al.* (2008) [30] reported that the highest number was observed at 150 kg·N·ha^{-1} treatment. Emara and El-Gammaal (2012) [30] found that increasing nitrogen rate up to 60 kg N/fed (140 kg·ha^{-1}) increased No. of sympodial/plant. This may be resulted from increasing plant growth on the expense of fruiting characters which induced at higher nitrogen rate.

The flower represents the central point of the cotton plant's reproductive growth, it has been speculated that the effect of imbalances in plant nutrition in the flower may be the cause of lowered yield and unpredictable year-to-year yield variability. Oosterhuis *et al*., in experiment conducted in 2007 [44] showed that increasing soil-applied N rate (from 0 to 135 kg·ha^{-1}) resulted in a corresponding increase in the N content of cotton flowers, but it did not appear to be associated with flower size, and suggested more investigations in the effect of soil-N status on the N content and polyamine concentration of cotton flowers in relation to successful fertilization and seed set. Yang *et al*., (2011) [13] reported that N ratio (0% PPA + 60% PBA) promoted an earlier squaring and flowering but delayed the opening stage, so prolonged the boll setting and filling period. In contrast, N ratio (40% PPA + 20% PBA) delayed the squaring and flowering, but promoted an earlier opening stage, so shortened the boll setting and filling period. Zhao *et al.*, (2012) [45] concluded that as the flowering date is delay, fiber length and strength first increased and then decreased, fiber maturity and micronaire decreased N application increase boll number per plant and slight increase boll weight by the application at various rates and split ratio, Sawan *et al*. 2006 [46] explained the increasing in boll weight may be due to increase in N rate and increases mineral uptake, photosynthetic assimilation and accumulation in sinks in the other hand high N rates have been linked to increased incidence of boll rot which has been attributed to additional vegetative growth that traps moisture underneath the canopy and increases infection [47] [48]. Dong *et al*. (2012) [34] reported that increasing the N rate to 225 or 300 kg·ha^{-1} improved the boll size by 4.8% or 3.5% relative to the low N rate. Saleem *et al*. (2010) [43] showed that the maximum boll weight was (2.9 g) at the rate of 120 kg·ha^{-1}. Rashidi *et al*. (2011) [42] reported that 200 kg·ha^{-1} N application rate resulted significant increased in the boll number (19.8), and boll weight (6.26 g) compared to low rates.

2.3. Cotton Yield and N

Nitrogen fertilization had significant impacts on plant growth, lint yields and fiber quality [49]. Maximum yield often requires application of large amounts of N fertilizers, which would increase the risk of N leaching, as well increase the production cost unless it managed in way that insure the present of nitrogen in the right amount at the right time.

N application usually split into a pre-plant application (PPA), a first bloom application (FBA), and a peak bloom application (PBA), at percentages of 30%, 40%, and 30% respectively. However, Yang *et al*. (2011) [13] reported that the split ratio of 0% at pre-plant, 40% at first bloom, and 60% at peak bloom harvested the highest biomass and yield when N was applied at 225 kg·ha^{-1}. Hallikeri *et al*. (2010) [29] indicated that application of N with recommended method of three splits (2267 kg·ha^{-1}) was similar to application seven times (2237 kg·ha^{-1}).

The results of two-year field trial conducted by Tang *et al*. (2012) [17] showed that treatment of 225 kg·ha^{-1} N split in to 0% PPA + 40% FBA+ 60% PBA had produced the highest yield and accumulated the most N.

Results were reported by Mullins *et al*. (2003) [50] and Knowles *et al*. (1999) [51] in which split application of fertilizer produced the same yield as a one-time application, yet with a lower cost. Yang *et al*. (2012) [52] reported that application of 120 kg/ha N once at first bloom produced similar cotton yield (1328 kg·ha^{-1}) to the conventional fertilization treatment twice (FII) at pre-plant and first bloom with 50% each, or thrice (FIII) at pre-plant (30%), first bloom (40%), and peak bloom (30%).

Many studies indicated that higher crop yield and quality were always associated with the N application. Nelson (1949) [53] and Sawan *et al*. (1988) [54] showed that cotton yield and cottonseed N concentration increased linearly with increasing N fertilizer rates. Saleem *et al*. (2010) [43] showed that the maximum seed cotton yield per plant, and seed cotton yield kg/ha were (69.3 g, 3002.4 kg) respectively recorded when nitrogen was applied at the rate of 120 kg·ha^{-1}. Rashidi *et al*. (2011) [42] reported that 200 kg·ha^{-1} N application rate resulted significant increased seed cotton weight of boll (4.49 g), seed cotton yield (4363 kg·ha^{-1}) and lint yield (1659 kg·ha^{-1}). Ramzan *et al*. (2013) [28] found that application of 225 kg·ha^{-1} nitrogen fertilizer produced the maximum yield (1731.06 kg), the highest number of bolls per plant (5.61), while the maximum boll weight observed in 150 kg·N·ha^{-1} (9.18 g).

Setatou and Simonis (1996) [36] studied the effect of time of nitrogen application on cotton yield as they applied different nitrogen rate at three different time before sowing, when the plants had 3 - 4 leaves and 20 days later, they found that the split application of N fertilizers, compared to a single pre-sowing application did not differ, however split applications increased yields in some experiments, but only at high rates of applied N fertilizer.

Cotton fiber quality is mainly influenced by genotype of the cultivars but agronomic practices and environmental conditions are the secondary factors influencing fiber quality [55]. Increases in lint length from N fertilizer treatments had been reported [56]. However, other investigators stated reductions in both fiber length and strength [57] or no effect of fertilizers upon fiber properties [58].

Hussain *et al*. (2000) [59] reported that nitrogen rate had no effect on fiber uniformity. Saleem *et al*., 2010 [43] indicated that different fiber quality characteristics except ginning out turn remained unaffected by nitrogen application rates.

3. Nitrogen Use Efficiency (NUE)

Each year more great amounts of N fertilizer are applied to croplands and cost billion. While the estimated efficiency of applied N ranges from about 30% to about 70% [60] which means the rest is lost. So in order to increase the crop production and conserve energy as well reduce the costs and minimize the potential for adverse effect on the environment. It is critical to maximize the efficiency of plant use of the applied N [61].

Nitrogen use efficiency (NUE) is so complicated to define, due to different terms [62]-[64] giving it different contexts. According to Moll *et al*. (1982) [64] there are two primary components of N use efficiency: the efficiency of absorption (uptake), and the efficiency with which the N absorbed is utilized to produce grain.

The efficiency of uptake is known as (NUpE) which expressed as total nitrogen accumulation divided by root dry weight and is equivalent to physiological efficiency (PE).

In agronomic terms, the physiological efficiency (PE) or Uptake efficiency (NUpE) used to provide a reflection of the overall efficiency of up taking the applied N and use it in producing grain yield. It can be viewed as the efficiency of crops in using N to increase the yield. It shows the plant ability to transform the N into economic yield.

For the efficient in utilization Siddiqi and Glass (1981) [65], Gerloff and Gabelman (1983) [66] defined Nitrogen utilization efficiency (NUtE) as total plant dry weight divided by nitrogen concentration. Beside the PE, Dobermann (2007) [67] defined another concept of NUE; the agronomic efficiency (AE) is the increase of yield (kg) to each increasing of applied N (kg). AR reflects the efficiency of the crop in obtaining N-based fertilizer from the soil.

Partial factor productivity (PFP) is defined as the harvested product (kg) per kg of applied N. It is really important to integrate the use efficiency of both indigenous and applied N, is an aggregate efficiency index that includes contributions to crop yield derived from uptake of indigenous soil N, fertilizer N uptake efficiency and the efficiency of converting it into economic yield [67]. As well Xu *et al*. (2012) [68] defined the apparent nitrogen recovery rate (ANR) o as: the ratio of net increased total N uptake by the plant with and without N fertilization to total amount of fertilizer N, which can be used as index of N uptake capacity. Mosier *et al*. (2004) [10] described crop removal efficiency as removal of N (REN) in harvested crop as percentage of N applied, it is commonly used to explain NUE. In general, NUE indicates the ratio of N recovered by the crop plant to that applied to the field [26].

However, to understand NUE and its different concepts, we should get a deep knowledge of the N forms absorbed by the plant in terms of vector transitions, pathways and enzymes participating in the processes of assimilation [69].

3.1. N Uptake

There are many sources of the N, atmospheric N2 [70], organic matter dissolution [71] [72] and industrial fertilizers (**Table 1**).

The source of soil N is derived from the atmosphere, where di-nitrogen (N_2) is the predominant gas (79%). N_2 is fixed as NH_3 by biological process, and then to N-containing organic compounds to be available to all forms of life [73].

Soil N is comprised of both mineral and organic N forms, in which the organic forms formed almost 80% - 90% of the total [74]. Organic N becomes available to the plant after it is mineralized [75]. Plants uptake N as nitrate (NO_3^-) as main source, or ammonium (NH_4^+) such as in rice paddy fields [76].

NO_3^- and NH_4^+ (Nitrate is the dominant form of N acquired by cotton) are both water soluble, and taken by the plant roots from different sources [77]. To be available for plant, NH_4^+ should be transformed into NO_3^- through "nitrification" process carried out two reactions by bacterial organisms *Nitrosomonas* and *Nitrobacteria*, respectively:

1) $2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 2H_2O + 4H^+$ (Then)

2) $2NO_2^- + O_2 \rightarrow 2NO_3^-$

To assimilate nitrate, the plant must first take it up from the soil using transporters located in the plasma membrane of the epidermal and cortical cells of the root. Two types of nitrate transporters, NRT1 and NRT2, have been isolated from higher plants. The *NRT1* transports nitrate, peptides and some amino acids, while the *NRT*2 transports both nitrate and nitrite [78].

While in the plants that use NH_4^+ as main N resource, physiological studies showed evidences for the existence of two transport systems for NH_4^+, a high affinity transport system (HATS) and low affinity transport system (LATS) [79]-[81], those transporters are encoding by the Amt genes [76] [79].

3.2. N Assimilation

Usually most of the nitrate absorbed is reduced in the shoots, while a small fraction is done in roots [82]. Nitrate is reduced into ammonia and incorporated into cells by series of assimilatory enzymes, while ammonium is incorporated into amino acids via the glutamine synthetase-glutamate synthase (GS-GOGAT) pathway, nearly all the ammonium incorporated into amino acids at the root itself [83].

The activity of N assimilation is affected by different factors and can be regulated at different levels, the synthesis of mRNA and protein, and the activity of the enzyme (**Table 2**).

From Nitrate to Nitrite: After the nitrate transported from the root to the shoot, in the cytoplasm of the young leaves and by the means of NR the converting of NO_3^- to NO_2^- begins, where the NR transfer two electrons from NADPH to the NO_3^- ion and form NO_2^-.

NR activity is controlled by many factors such as the availability of nitrate, the availability of biosynthetic precursors for N assimilation, and the plant's need for the products of N assimilation, also the expression of the NR is regulated by nitrate abundance, light levels, circadian cycles, and the phytohormone cytokinins [84].

From Nitrite to Ammonium: then NO_2^- will turn to NH_4^+ by NiR which is nuclear encoded enzyme that transport to the stoma of chloroplasts of the green tissues and the plastids of the roots, where it transfer six electrons from reduced ferredoxin (Fd) to NO_2^- to form NH_4^+ [85].

From Ammonium to Amino acids: NH_4^+ (both generated by nitrate/nitrite reductase or absorbed) is assimilated by the activity of the enzymes GS-GOGAT.GS has two forms; GS2 found in the plastids assimilates NH_4^+ generated from nitrate and the photorespiratory cycle, and GS1 found in the cytosol assimilates the NH_4^+ pro-

Table 1. Biological and non-biological N sources.

Type of fixation	N2 fixed (106 metric tons per year)
Non-biological	
Industrial	about 50
Combustion	about 20
Lightning	about 10
Subtotal of non-biological	about 80
Biological	
Agricultural land	about 90
Forest and non-agricultural land	about 50
Sea	about 35
Subtotal of biological	about 175
Total	about 255

Source: Blackwell Scientific Publications 1998, Food and Agriculture Organization.

Table 2. The N assimilatory enzymes.

Enzyme	Reactions catalyzed
NR	$NO_3^- + NAD(P)H + H^+ = NO_2^- + NAD(P) + H_2O$
NiR	NO_2^- +6Fd(red) +8 H^+ = NH_4^++6Fd(ox) = $2H_2O$
GS1/GS2	glutamate + NH_4^+ + ATP = glutamine + ADP + Pi
Fd-GOGAT	glutamine + 2-oxoglutarate + 2 Fd (red) = 2 glutamate + 2 Fd (ox)
NADH-GOGAT	glutamine + 2-oxoglutarate + NADH = 2 glutamate + NAD
GDH	glutamate + H_2O + NAD/NADP = NH_4^+ + 2-oxoglutarate + NADH/NADPH
AspAT	glutamate + oxaloacetate = aspartate + 2-oxoglutarate
AS	glutamine + aspartate + ATP = asparagine + glutamate + AMP +PPi

Source: (Zheng, 2004; Céline *et al*., 2010; McAllister *et al*., 2012).

duced from nitrate [86]. Those two enzymes lead the glutamine synthesis by incorporate NH_4^+ to glutamate. In the Fd-GOGAT and NADH-GOGAT cycle the amide group transfer onto a 2-oxoglutarate molecule producing two glutamates. Furthermore transminations are carried out by AspAT and AS make other amino acids specially asparagine. (GDH) takes part in nitrogen remobilization and protects the mitochondrial functions during periods of high nitrogen metabolism [80].

3.3. N Mobility and Storage

NO_3^- enters epidermal and cortical cells of the root via nitrate transporters, where some of it converted to glutamate and glutamine in the root cell and some is transported via the xylem to the photosynthetically active green leaves and metabolized to glutamate and glutamine in the mesophyll cells.

The xylem is the principal pathway for long range transport of N from roots to the leaves and bolls. This physiological tendency of loading NO_3^-into the xylem and petioles facilitates the petiole NO_3^- test assessment of plant N nutrition status as an N fertilization guide [87].

Plants store N as both a short-term buffer against imbalances between demand and uptake, and a longer-term reserve (in storage organs such as seeds, roots, and tubers, for example) to provide amino acids for biosynthesis when new growth occurs [88].

N is stored in short term as nitrate in the vacuole, and can accumulated to high concentrations when in plentiful supply, and exported to the cytosol for metabolism when circumstances change. N is also stored in the short to medium term in the form of amino acids, commonly asparagine, which has high N content like glutamine, and moves in the xylem and phloem.

Symptoms of N deficiencies occur initially in the older leaves, due to N translocation from old leaves to new ones. N deficiency most often results in stunted growth, slow growth, and chlorosis, also exhibit a purple appearance on the stems, petioles and underside of leaves from an accumulation of anthocyanin pigments (**Figure 1**).

3.4. N Losses

The crop use less than half of the fertilizer N applied [89], while the other half is lost from the system through either denitrification or leaching or ammonia volatilization.

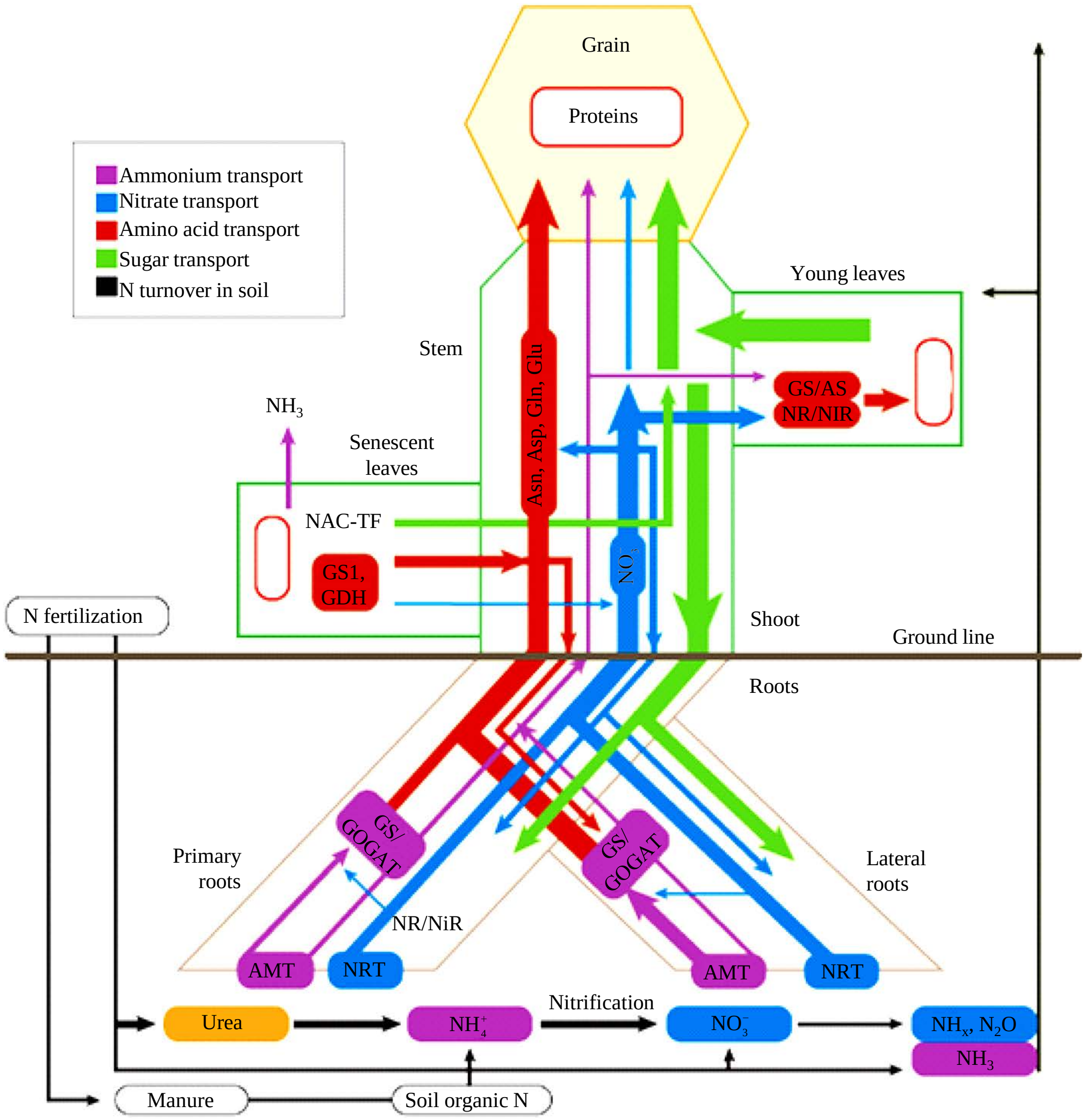

Figure 1. Schematic routes of N uptake from the rhizosphere including the source of fertilizer N to be acquired, mainly in the form of ammonium and nitrate by roots, transportation and assimilation, and remobilization inside the plant. The thicknesses of the arrows schematically represent the relative amounts of N and sugar inside the plant. Abbreviations: AMT, ammonium transporter; AS, asparagine synthetase; Asn, asparagine; Asp, aspartate; GDH, glutamate dehydrogenase; Gln, glutamine; Glu, glutamate; GOGAT, glutamine-2-oxoglutarate aminotransferase; GS, glutamine synthetase; NAC-TF, certain transcription factors belonging to the NAC family; NiR, nitrite reductase; NR, nitrate reductase; NRT, nitrate transporter. Source: Plant N Assimilation and Use Efficiency, Annu. Rev. Plant Biol. 2012.

Denitrification is a biological process of NO_3^--N being converted to N gases and lost to the atmosphere. It is the most significant N loss process in clay soils. After flood irrigation or heavy rain, the soil becomes saturated, low oxygen, and the denitrifying microorganisms are encouraged to start using nitrate as a source of oxygen and reduce NO_3^--N into N_2 [84].

As for leaching, NO_3^- is being apt to leach due to its negative charge which makes it less attached to the soil clay particles, while NH_4^+ has a positive charge, easily attracted to soil particles, and hard to leach.

Winter is the most likely time for leaching to occur due to the heavy rain. Soil characteristics play role in the leaching rate, as soils differ greatly in the extent and manner in which they transmit water [90]. There are also other factors that increase the leaching including weather conditions [91], irrigation [92], and fertilizers adding methods [93].

Ammonia volatilization ($NH_4^+ \leftrightarrow NH_3 + H^+$) can result in significant N loss from alkaline soils [94] where high concentrations of ammonium exist at the soil surface. Volatilization is a purely chemical process driven by environmental parameters such as temperature (higher than 21˚C will encourage the risk of volatilization) and wind speed. Soil characteristics have effects on the volatilisation rate [95] like soil pH (less than 7% of the NH_4^+-N are in the form of NH_3 if the pH is 7.5) [96], soil moisture (negative effect), NH_4^+ concentration, the cation exchange capacity, crop residue, etc.

4. Cotton NUE

NUE can help in predicting the quantities of fertilizer to be added to any agricultural system in any area and thus maintain the N balance between inputs and outputs without any losses at either the economic or environmental levels [97]. Crops differ in the value of the NUE, which may be a return of genetic traits [98]-[100], and the agronomic and environmental conditions.

Due to the escalating N fertilizers costs and the environmental impacts [101], there were many researches had been done to improve the NUE and understand the factors affect it the most [102] [103].

4.1. Temperature

It has indirect effects on the NUE. It affects the losing rate of the N through the nitrification process in the soil, which is faster as the soil temperature is more than 4.44˚C depend on the crop type [104]-[108].

4.2. Soil Characteristics

The soil type has effects on the N present in the soil and the losing rate [109]. The higher cation exchange capacity comes with higher soil buffering capacity and for that the ammonium can be absorbed more and the lose rate will be lower. In the other hand, lower anion capacity can lead to losses in the negative charged molecules like nitrate [110] [111]. The activity of the bacteria which lead the mineralization process depends on the soil pH. The optimum pH to save the N from leaching, nitrification and to be available to the plant is around 7 [112].

4.3. Humidity and Irrigation Systems

The field capacity and wilting point have effects on NUE, through affecting the leaching of NO_3^-, and the nitrification rate [113]. NUE also varies from how efficient the irrigation system is. Studies showed that N recovery reached 75% with subsurface irrigation system and 12% with furrow system, due partial to more efficient N delivery, and reduction of N lose by leaching, denitrification and ammonia volatilization [114]-[117].

4.4. Cropping Systems

It is important to use agricultural system that achieves a balance between the input and output of N by a greater uptake and a lower lose from soil [118].

In many cropping systems, the size of the organic and inorganic N pools has reached steady-state or it is changing very slowly. If the applied N is not taken up by the crop or immobilized in soil organic N pools, it's vulnerable to be lost through volatilization, denitrification, or leaching.

In systems that hasn't reach the steady-state, adoption of new management practices can affect the soil carbon (C) balance and the N balance [119] [120] because the soil organic matter is relatively constant. In such cropping systems, the overall NUE of the cropping system must include changes in the size of soil organic and inorganic N pools in addition to the nitrogen recovery efficiency (RE_N).

4.5. The Carbon-Nitrogen Balance

The link between C and N is critical, unless there is sufficient C available, improving the plants' ability to take up and utilize N may be compromised, as well, N levels can significantly affect C fixation [120] [121].

Large quantities of N are stored in photosynthetic proteins such as Rubisco and phosphoenolpyruvate carboxylase (PEPc), so N uptake, assimilation and remobilization is in partly regulated and controlled by photosynthetic rates. Thus to achieve higher NUE, the photosynthetic rates should be higher [119] [120].

4.6. N Fertilizer Type

There are different types of N fertilizers that can be used to secure the needs of the plant during growth [122], but it is important to select the appropriate type. Appropriate type reduces the losses arising from volatilization [122]-[124] or denitrification, and as well reduces the financial costs associated with the need of compensate. The common N fertilizers are anhydrous ammonia (82% N), urea (45% - 46% N), ammonium sulfate (21% N) and ammonium nitrate (34% N).

Anhydrous ammonia converts to nitrate N slowly, with the least chance of N loss due to leaching or denitrification; while urea converts to nitrate N fairly fast. Denitrification can be serious on wet or compacted soils; leaching or volatilization can be a problem in coarse soils or no-till situations if the urea is not placed in contact with the soil and it is dry for several days after spreading [125].

As for ammonium sulfate (21%) is source with little or no surface volatilization loss when applied to most soils. While ammonium nitrate (34%) is 50% ammonium N and 50% nitrate N, when it is added the ammonium N quickly converts to nitrate N. For soil subjected to leaching or denitrification, ammonium nitrate would not be preferred. But for ammonium nitrate, surface application would be a good choice where volatilization of urea is expected.

4.7. N Applied Amounts

Cotton need to accumulate approximately 250 - 300 kg N/ha to achieve maximum yield potential, and it uses less than half of the N applied during that season, obtaining most of their N from soil N rather than applied N, as an average 33% of applied N is recovered [68], 25% remains in the soil at crop maturity and the remainder (approximately 42%) is lost from the system [17].

Studies have showed that both N deficiency and excessive use had negative effects on plant growth and the final yield. N deficiency reduces the leaf area and the total biomass, bolls and low fiber quality [126]-[128], and conversely the excessive use of N leads to excess vegetative growth by creating bigger leaf structures with larger surface areas for the photosynthesizing pigment, and so the energy for reproductive growth is redirected to vegetative proliferation. So plants may not even produce their necessary reproductive organs during the growing season [129].

Plants cannot absorb the entire excess N in the soil; those extra N levels slowly leach out of the soil through water runoff. As a result, groundwater and drinking water become contaminated from the nitrate levels.

4.8. N Rates

Selecting optimum N rates for cotton production varies by soil type; production, climate, and various other soil and crop management factors [130] [131]. However, the N rate for maximum economic yield [132] depends on the fertilizer N cost and the market price received from the crop [133].

Due to the chemical changes that influence the N as its mobility, leaching, denitrification and volatilization, it is hard to accurately predict the amount of N, whereas soil should be tested each year for NO_3^--N to estimate the amount of available N. N can be applied in split applications which generally results in greater NUE. N is applied one-third to one-half for pre-plant and the remainder side dressed in squaring, or a single application as close as possible to the period of rapid crop uptake (from first square to first bloom).

4.9. N Timing

Timing of N applications has important effects on NUE. Usually N fertilization added in three different times correspond to the phases of plant growth, pre-plant application, first bloom application and peak bloom application.

The first application added before planting to provide the sufficient time for N to turn into absorbable forms, but this application is subject to higher risks of N losses especially if the temperature is getting lower or due to the heavy rain in the end of autumn [134], through this period the young seedlings don't require too much N, and the applied N remains exposed to leaching rains for more than 60 days before demand begins to peak. Heavy applications early in the season can lead to excessive vegetative growth and delayed fruiting.

Second application is about 45 - 50 days after emergence (at the first bloom), nutrient uptake increases rapidly until it reaches a prolonged peak about two weeks after first bloom, when the processes of flower production, boll filling, and boll maturation create a heavy demand for nutrients.

The last application is after two weeks of the first bloom, and N should be provided till the maturity, but too much N late in the season may cause excessive vegetative growth.

Also the soil and petiole N test as well as the other application managements such as N rate, timing, and fertilizer types must all be at concerned to improve the NUE and decreases the cost of production.

5. Approaches for Improving NUE

Increasing NUE and protecting environmental quality are two challenges facing cotton plant nutritionists, and as described earlier, NUE is explained by different complex interdependent parameters that need close monitoring in order to improve it.

NUE is a multi-genic trait, in addition, signaling targets and regulatory elements have recently emerged as prospective candidates for biotechnological interventions, which create various transgenic ways to improve NUE by manipulating those genes and regulatory elements.

Many approaches have been done and suggested in order to improve NUE like combine the plant sensing techniques and precision application. Simulations and recent field trials demonstrate that site-specific nitrogen management helped reduce technological constraints to higher AE achievement, profit and more sustainable N management.

The agronomic managements of the field should be considered as main factors affecting the NUE. In general, it could be said that with increasing applied N lead to decreasing in AE and PE while RE_N increases, as well the plant density could have effects through the competition between the plant in N up taking and utilization.

These agronomic managements should come along with researches to identify genes that improve the NUE of crop plants, with candidate NUE genes existing in pathways relating to N uptake, assimilation, amino acid biosynthesis, C/N storage and metabolism, signaling and regulation of N metabolism and translocation, remobilization and senescence.

Yield will continue to be the major farm commodity, and N fertilizers will be essential, NUE improvements will be widely heralded, particularly if the price of N fertilizers rises as might be expected in an energy-short future.

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