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Role of proper management of nitrogen in cotton growth and development

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Abstract

Cotton is important cash crop grown for fiber. Cotton fiber is used in fabrics and other things used in daily life. The production of many industries in the world and, especially in china is related to fiber. Proper nutrition plays great role in growth and high-quality fiber production. Different macro and micro nutrients are applied to cotton for high quality fiber production. Nitrogen is the highly utilizing nutrient among that. High growth, yield and quality of cotton depend on proper management of nitrogen. Due to increasing prices of nitrogen fertilizers researchers are working to increase nitrogen use efficiency (NUE) of cotton to benefit farmers. Nitrogen is applied through different methods at different rates. Mostly split application at PPA (Pre plant application), FBA (First bloom application) and PBA (Peak bloom application) with different rates according to soil and plant condition are in practice by farmers. Many organic and inorganic sources of nitrogen are available with different properties. NUE is affected by different factors like genotype, cropping system, soil, volatilization and leaching, N amount application and fertilizer timing. Prior to nitrogen fertilizer application nutrient status of soil must be analyzed to prevent nitrogen losses from the system. Different methods like soil testing, tissue testing, Leaf area index (LAI), normalize difference vegetation index (NDVI) and satellite imagery are suggested to improve NUE. Many researches proved that proper management of nitrogen increase farmers profit and NUE. This review highlights nitrogen response to cotton growth, yield, quality, NUE and factors affecting NUE and how to improve NUE through nitrogen management.

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Introduction

Cotton (Genus *Gossypium*) is a leading cash crop and is considered as "white gold and cultivated in above 80 countries all over the world (Maiti *et al.*, 2012). According to International cotton Advisory Committee 2015 report cotton production in Asia and America is more than 80% of total world production while Asia is largest cotton producing continent of the world by producing 70% cotton of the world (Zhang and Dong, 2019). Cotton species are grouped according to their ploidy in diploids and tetraploids. Diploids (2n = 2x = 26) include *Gossypium herbaceum* L. and *Gossypium arboreum* L. while Tetraploids (2n = 4x = 52) have *Gossypium barbadense* L. and *Gossypium hirsutum* L. The world 95% or more cotton production is from *Gossypium baradense* L. and *Gossypium hirsutum* L. species (Smith and Cothren, 1999; Zhang *et al.*, 2008). *Gossypium hirsutum* is also known as upland cotton, American and Mexican cotton which contribute more than 90% in cotton production while *Gossypium barbadense* contribute about 5% to cotton production and is also known as Egyptian or Pima cotton (OECD 2010). Cotton is perennial but commercially it is grown as annual crop and have indeterminate growth. Cotton is the unique crop which provide vegetable oil and clothes to humans, chaff for livestock feed, organic matter to soil and many other products to industries (Abdurakhmonov 2018). Currently more than half of clothes people wear is made of cotton fiber (Zhang and Dong, 2019).

Cotton needs different macro and micro nutrients for better growth and yield. Nitrogen is the first important macronutrient in agriculture production and its fertilization is necessary for good production of cotton (Hou *et al.,* 2007). Nitrogen is one of the most limiting factor in cotton production (Arnall and Boman, 2019). N cost more in cotton production as compared to other fertilizers (Chaudhry 2007). Total fertilizer demand of the world increases 1.8% per year from 2014-2018 (FAO, 2015). Plants utilize nitrogen in the form of NO_3^- and NH_4^+. It is the element which greatly contribute to growth of plant and increase yield and quality of crop (Laghari *et al.,* 2016).

Nitrogen enhances photosynthesis and leaf growth and result in increase of vegetative growth. Nitrogen reduction effect boll production due to premature senescence (Dong *et al.*, 2012). Nitrogen deficiency first appears on older leaves.

The main deficiency symptoms of cotton are chlorosis due to main part of chlorophyll molecule (Fig. 1). It reduces growth of cotton and mostly plants remain stunted. N deficiency also negatively affect yield of cotton. Shedding of bolls in first 10-12 days after flowering shows deficiency of nitrogen. Shortened of fruiting branches, reddening of middle canopy at late season, short flowering period, enhance leaf senescence and reduction in boll retention at late season are symptoms of nitrogen deficiency in cotton.

In cotton farming, Nitrogen fertilizer was mostly applied in three splits at field preparation, early flowering and peak bloom stage but it rates are different from region to region, cultivar to cultivar and soil type (Fritschi *et al.*, 2003; Yang *et al.*, 2011; Boquet and Breitenbeck, 2015).

Many researchers are working to find the nitrogen efficient variety of cotton (Zhang *et al.,* 2018) and reduces nitrogen split application and amount without decreasing the yield.

Nitrogen management

Source of nitrogen

Nitrogen is available to the plant from different sources. Some are natural which include atmospheric fixation, biological fixation and organic sources of N while artificial are inorganic sources which are fixed in industries chemically.

Atmospheric N Fixation

Air consist of 79% of N gas (N2) but plants cannot use this. During the lightening or thunderstorm the energy break down the N molecules and their atoms combine with oxygen in the air to form nitrogen oxide. Nitrogen oxide dissolves in rain forming nitrates. Atmospheric N fix about 5-8% of total fixed N.

Biological N Fixation

Biological N Fixation process is carried out by bacteria and actinomycetes. These organisms reduce N2 to ammonia with the help of nitrogenase enzyme they produce. These microorganisms form symbiotic relation with other organisms or live free because the process needs energy (ATP) (Hillel 2008). The biological N fixation has complex reactions but the overall reaction is given below:

$N_2 + 16ATP + 8e^- + 8H^+ \rightarrow 2NH_3 + H_2 + 16ADP + 16P_i$

Organic sources of Nitrogen

The organic sources of nitrogen are presented in (Fig 2) include animal manure, alfalfa meal, compost, fish meal, soya bean meal, blood meal, green manure and seed cotton meal. Along with this nitrogen fixed by rhizobium bacteria is also included in natural available nitrogen.

Inorganic sources of Nitrogen

Inorganic sources are mostly produced through industrial fixation. Harber Bosch process is used for industrial fixation. Mostly conventional farming depends on inorganic N sources.

The inorganic sources of nitrogen include Urea, Urea Ammonium Nitrate (UAN), Ammonium Sulfate, Anhydrous Ammonia, Ammonium Nitrate, Potassium Nitrate, Mono-Ammonium Phosphate (MAP), Di Ammonium Phosphate (DAP) and NPK whose nitrogen percentage is presented in (Table 1).

Table 1. Inorganic sources of Nitrogen.

Fertilizer	Nitrogen Percentage
Urea	46%
Urea Ammonium Nitrate (UAN)	32%
Ammonium Sulfate	21%
Anhydrous Ammonia	82%
Ammonium Nitrate	34%
Potassium Nitrate	14%
Mono-Ammonium Phosphate (MAP)	11%
Di Ammonium Phosphate (DAP)	18%
NPK	23%

Nitrogen fertilizer application

Nitrogen fertilizer is required by each crop for high growth and yield. Different fertilizers types are applied with different methods. The types of fertilizer application are presented in Fig. 3.

Broadcast application

Broadcast application method is an old and easy way of fertilizer application. Fertilizer is applied uniformly throughout the field and is mostly adopted in fields with dense population. This method requires large amount of fertilizer. Broadcast method is further divide into basal application and top dressing.

Basal application

In this method nitrogen fertilizer are applied uniformly at time of sowing so that it mix in soil properly.

Top dressing

In this method nitrogenous fertilizer is uniformly distributed in densely populated field to make it readily available to the plant for uptake and mostly applied in closely sown crops like wheat and rice. This method is less applicable in cotton production.

Placement application

In this method nitrogen fertilizer are placed at specific position and is mostly used when fertilizer is applied in less amount. This method is applicable in soil with low fertility in which root development is slow. This method reduces weed infestation, leaching of nutrients and utilization remains high as compared to broadcast. Placement application is further divide into deep placement and localized placement.

In deep placement ammonical nitrogen fertilizers are placed deep in soil so that ammonical nitrogen become available to plant while in localized placement nitrogenous fertilizers is applied closely to seed/plant. So that plant roots utilize it easily.

Foliar application

This method is used for application of liquid nitrogen to the plant. It is applied directly on plant leaves either by sprayer or aerial spraying.

This method is adopted by many farmers and provides significant results.

Fertigation

In this method nitrogen solution is applied through irrigation. This method is applicable through furrow, sprinkler and drip irrigation and show high efficiency.

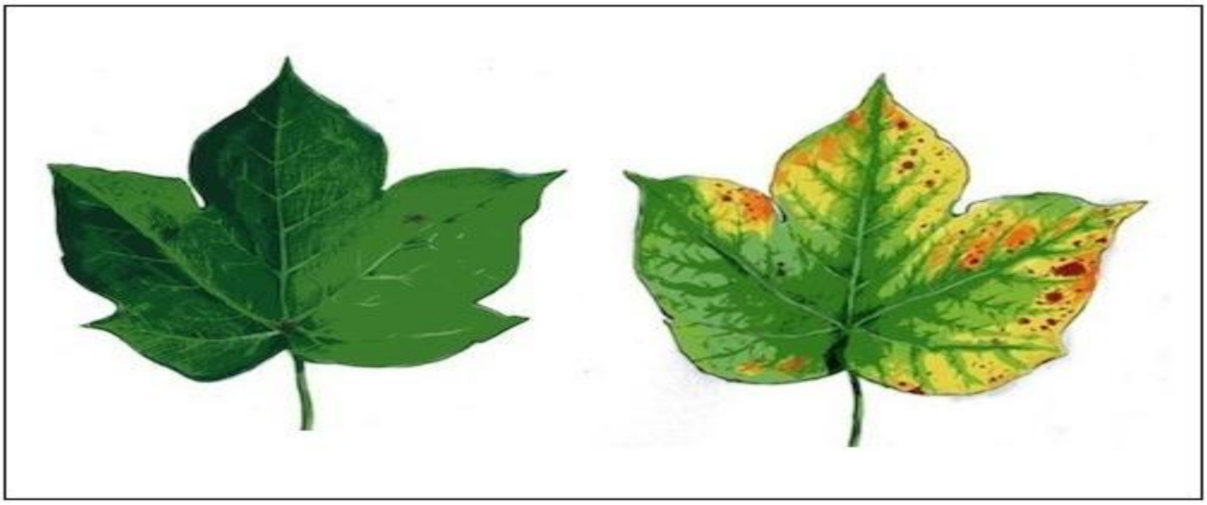

Fig. 1. Nitrogen deficiency symptoms of cotton leaf (early stage, severe stage).

Nitrogen Use efficiency (NUE)

According to (Daigger *et al.*,1976) NUE is the efficiency of plants to use and retain nitrogen in soil. Another definition of NUE is the efficiency of nitrogen application either natural or artificial which is utilize by plant and not used for other purposes like anaerobic bacteria (Djaman *et al.*, 2016). NUE are measured through different ways.

Agronomic NUE, nitrogen recovery efficiency, physiological NUE and internal NUE but among these aNUE and NRE are most common. Agronomic NUE is the increase in yield per unit of nitrogen fertilizer applied (NOVOA and LOOMIS 1981) while NRE is defined as the amount of applied N fertilizer taken up by the crop and is expressed in percentage of total applied fertilizer (Rochester *et al.,* 2007). NUE calculate nitrogen uptake by plants along with nitrogen lost from plants through nitrous oxide emission. In short efficient use of nitrogen is NUE. Fertilizer NUE between 13-18 kg lint/kg N shows efficient N use (Dowling 2014). NUE of leguminous crops remains high because they store N in body nor release it into atmosphere (Hocking and Reynolds 2012; Kumar *et al.*, 2016).

The NUE of conventional agriculture system is very low (Raun and Johnson 1999).

The N fertilizer use increase from 79 million pound in 2002 to 99 million pound in 2012 which shows inefficiency of N. Nitrogen use efficiency of cotton is affected by different factors given below;

Genotype

Cotton NUE varies from genotype to genotype. Each genotype has different response to nitrogen uptake.(Araújo *et al.*, 2013) also concluded that NUE is different for different genotypes and with increase in nitrogen less nitrogen was recovered by cotton.

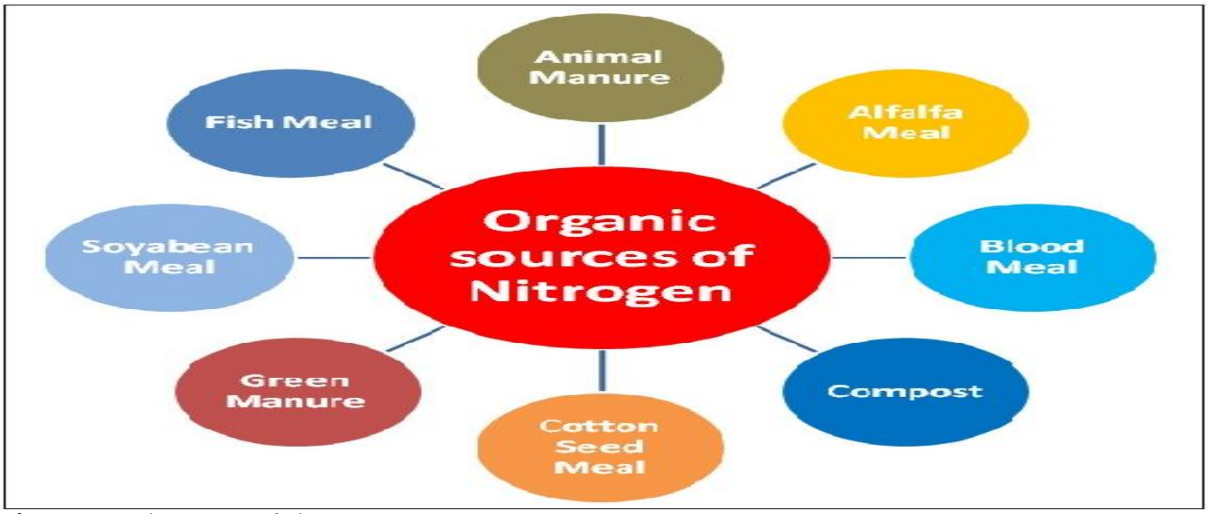

Fig. 2. Organic sources of nitrogen.

Cropping system

NUE of cotton is affected by different cropping system. The wheat cotton cropping system is most common among farmers. Wheat cotton rotation negatively affect nitrogen accumulation rate as compared to monoculture cotton while high nitrogen accumulated in preceding wheat in wheat cotton rotation and hence improve N accumulation in wheat cotton rotation (Du *et al.,* 2016).

Irrigation

NUE depends upon the efficiency of irrigation system. According to (Bronson 2009) cotton nitrogen recovery efficiency is 12%-75% under furrow and sub-surface drip irrigation.

Mostly surface applied nitrogen fertilizer volatize or leach down with different irrigation systems and affect NUE (Holcomb *et al.,* 2011).

Soil

Soil texture and structure affect N availability. NUE vary with soil texture. (Ye *et al.,* 2007) found higher physiological NUE in sandy soil as compared to clay soil and also reported that aNUE and pNUE decreased both in clay and sandy soil with increase in nitrogen.

Soil PH is also important factor for bacteria in the process of mineralization. Soil with pH 7 is best for plants and prevent leaching and nitrification (Leroy Wullstein 1969).

Volatilization and Leaching

Volatilization and leaching affect NUE and majority of N deficiency is caused by these factors.

Some nitrogenous fertilizers applied to cotton volatilize due to non-availability of moisture or due to high temperature while most of nitrogen are leached down and not available to plant. Some N fertilizers like anhydrous ammonia convert to nitrate N slowly and probability of leaching is high as compared to urea, ammonium sulfate and ammonium nitrate which convert to nitrate N quickly.

Nitrogen amount application

Nitrogen requirement of cotton depend on soil type, climate and genotype. In china cotton absorb more nitrogen (515 kg N/ha) and gave yield upto 3000 kg/ha. In Syria cotton gave 2221 kg/ha yield and absorb 417 kg N/ha (Janat 2005). In Australia cotton use 200kg N/ha and yield upto 2600 kg/ha (Constable *et al.,* 1992). Cotton use about 33% of applied nitrogen in the season, 25% remains in soil while 42% lost from the system (Tang *et al.,* 2012).

As excessive nitrogen applied to crop which will not utilize by plant and will either loss through leaching, Volatilization, immobilization and denitrification by effecting NUE. Application of the required amount of nitrogen to crop increase NUE (R Keeney 1982).

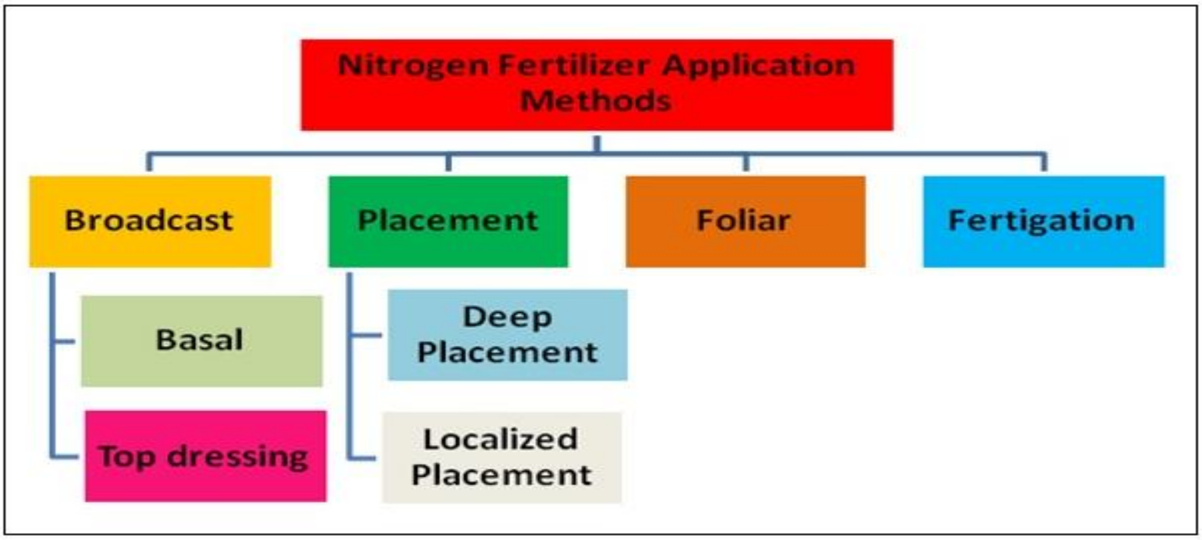

Fig. 3. Nitrogen fertilizer application methods.

Timing

Timing of N application also affect NUE of cotton. Farmers apply N before planting so the time between nitrogen application and its absorption by plants gave enough time to nitrogen to loss through leaching, volatilization, denitrification, immobilization and clay fixation (Scharf and Lory 2002).

In cotton nitrogen is commonly applied in three splits at pre planting, early bloom and peak bloom (Tang *et al.,* 2012; Wang *et al.,* 2010). In the first application the nitrogen go waste and volatilize or leach down because seedling did not require too much nitrogen due to small plant size. Second application at early bloom, plant producing flower and need high amount of nutrients for high blooming and process after blooming of boll formation and filling. Third split is applied at peak bloom stage or two weeks after early bloom and plant need high uptake of nitrogen for better yield formation but very high dose may increase vegetative growth. The N absorbed by plant at early stage is used for vegetative growth while absorbed at late growing stage is used for formation of reproductive parts. N is conventionally applied in split application with a ratio of 30:40:30. (Tang *et al.,* 2012) studied split application of N in cotton cultivation keeping FBA (40%) as used conventional and concluded that less application of N at PPA and high application at PBA increase N absorption and accumulation in cotton and also increase crop FNR (Fertilizer Nitrogen Recovery) and decrease FNL (Fertilizer Nitrogen Loss)rate. (Yang *et al.,* 2011) also found that in split application keeping FBA (40%) and increasing rate at PBA as compared to PPA.

Improving Nitrogen Use Efficiency

Cotton NUE improvement is a challenge for researchers due to increasing cost of nitrogen. Upto yet NUE has not been enhanced to a high level but researchers predict 33% through nitrogen management tools. Nitrogen loss cannot be measured through a single method. Different methods like soil testing, tissue testing, LAI, NDVI, satellite imagery and handheld sensors were tested for NUE improvement but most were found time consuming and not accurate. Among different methods precision agriculture (drone, satellite imagery) was found better tool to improve NUE as compared to conventional tool like soil testing (Sharma and Bali 2017). Improvement of agronomic factors related to NUE and breeders should also work on nitrogen efficient varieties for NUE improvement.

Nitrogen management through remote sensing

Remote sensing is new emerging technology in precision agriculture which observe crop without touching it. Remote sensing is used for estimating yield, biomass, temperature, moisture stress, weeds and insect pest infestation and nutrient status of crop. Different sensors, light reflectance and color photography are used to measure changes and parameters of crop.

Canopy sensors is good opportunity for farmers to apply N according to crop requirement. N stress decrease chlorophyll production which take part in production of nicotinamide adenine dinucleotide phosphate and triphosphate (Clay *et al.,* 2006). Rubisco -1-5-bisphosphate carboxylase use this compound in CO2 fixation. Reduction of chlorophyll content leads to enhancement of PAR reflectance (Gitelson *et al.,* 2005) which shows N stress in plants. The SPAD chlorophyll meter measure light in near infrared (NIR) and RED region of light spectrum. This meter use leaf tissue for measurement of N status of plant. The GS 505 sensor is used for field crop N nutrition which also measure reflected light. It is less laborious and works faster than SPAD chlorophyll meter. Cropscan sensor (Cropscan Inc, Rochster MN USA) was used by (Clay *et al.,* 2006) to find out effect of water and N stress on canopy light reflectance. He found that reflectance and N changed with growth stage and wavelength. (Ballester *et al.,* 2017) used unmanned aerial system to check spatial and temporal changes in N status and estimate yield. He found lower NDVI of high N treatments as compared to low.

Nitrogen uptake and assimilation

Plants consist of leaves, stem and roots. Nitrogen is mostly absorbed by roots while a little bit through leaves from atmosphere or from foliar application. Plants take N in the form of ammonia (NH_4) or nitrate (NO_3). Plants need metabolic energy for N uptake and external factors like temperature and PH affect its absorption. N is fixed through atmospheric, biological and industrial fixation. Soil have both organic and mineral N but organic N can be used by plants after mineralization (Chie *et al.,* 2008). Plants root take NO_3 and NH_4 due to its solubility in water. Nitrobacteria and Nitrosomonas change NH_4 to NO_3 through nitrification to take up by the plant. Plants take nitrate from the soil. NRT1 transport nitrate and amino acids while NRT2 transport nitrate and nitrite (Segonzac *et al.,* 2007).

NH_4 at low level is toxic to plant tissues and is assimilated in roots. The N translocate as organic compound. NO_3 assimilate in roots and transported to shoots where it stored. When external N source deplete the NO_3 in the roots vacuole become available for assimilation and thus the stored nitrate play role in N metabolism(Below 2001). NO_3 must be reduced to NH_4 which is used for synthesis of amino acid. NO_3 reduction process to NH_4 requires energy and occurs at root or shoot. The process consists of two steps *viz.* NO_3 reduction to NO_2 by using nitrate reductase, and NO_2 reduction to NH_4 by using nitrite reductase

Role of nitrogen in cotton

Cotton Growth and Nitrogen

Nitrogen is an essential element for cotton growth and affect it positively (Mokhele *et al.,* 2012). It play role in photosynthesis (Bondada and Oosterhuis 2001) and other physiological processes (Laghari *et al.,* 2016). Both excess and deficiency affect cotton growth (Gerik *et al.*,1998). Nitrogen deficiency reduce growth and cause yellowing (chlorosis) of leaves while excess of nitrogen also negatively affect the crop (Van Der Eerden 1998). Nitrogen speed up early growth, improve yield, quality and root growth. The root growth of cotton is also affected by different nitrogen rates and is sensitive to nitrogen stress. Nitrogen has significant effect on root length and surface area and with increase in N level root surface area also increases. The root growth increase upto some limit with increase in N rate while further increase in nitrogen decrease root growth (Chen *et al.*, 2018). (Liaqat *et al.*,2018) found highest plant height (121.3 cm) and nodes (25.3) per plant with the application of 165 kg N/ha. (Ali *et al.,* 2012) found that application of 225 kg N/ha increased plant height (129.53 cm) and number of nodes (22.94). (Main *et al.,* 2013) reported highest plant height of cotton (88.2 cm) and maximum number of nodes with the application of 134 kg N/ha. (Reddy *et al.,* 2007) reported from the five years study that urea, fresh and composted poultry manure as source of N positively improve growth parameters like plant height, number of main stem nodes number of nodes above white flower.

(Kumbhar *et al.,* 2008) found that cotton grown in rotation with leguminous crop along with 150 kg N/ha application increase plant height (102.63 cm), monopodial (2.61) and sympodial branches (13.70). (Luo *et al.,*, 2015) reported that soil plus foliar application of nitrogen to cotton under salinity stress enhance plant biomass, leaf area per plant and photosynthesis. (Bibi *et al.*, 2011) found that application of nitrogen at 150 kg/ha enhance plant height and sympodial branches per plant. (Ali and Hameed 2011) examined that application of nitrogen at 160 kg/ha increase plant height, nodes per plant and number of flowering buds per plant.

Cotton yield and Nitrogen

Nitrogen application increase yield and quality of cotton. The fruiting organ bolls require more nitrogen for better yield and is deficiency effect growth and flowering of cotton crop (Gerik *et al.,*1998). In conventional cotton farming nitrogen is mostly applied in three splits at pre-planting, first bloom and peak bloom at ratio of 30%, 40% and 30%. (Yang *et al.,* 2011) performed an experiment on split application of nitrogen and obtained high yield with the application of 225 kg N/ha at pre plant (0 %), first bloom (40%) and peak bloom (60%). (Luo *et al.,* 2018) reported maximum yield at 264 kg N/ha which was not significantly different from 330 kg N/ha, and also found the highest agronomic nitrogen use efficiency and nitrogen recovery efficiency at 264 kg N/ha. (Kumbhar *et al.,* 2008) reported increase in boll per plant (26.40), seed cotton yield (2538.25%) and oil content (23.10%) by application of 150 N kg/ha and rotation with leguminous crop. (Ali *et al.,* 2012) reported maximum yield (1731.06 kg) and more number of bolls per plant (5.61) with the application of 225 kg N/ha while obtained maximum boll weight (9.18 g) with the application of 150 kg N/ha. (LI *et al.,* 2017) performed an experiment on N split application and found maximum yield at 270 kg N/ha with 30% basal and 70% top dressing application. (Zhang *et al.,* 2012) reported that 210 kg N/ha produced more yield at moderate salinity while at high salinity 120 kg N/ha produced best yield as compared to other treatments and application of 210 g N/ha have high agronomic NUE (aNUE), physiological NUE (pNUE), N recovery efficiency (NRE) and internal NUE at moderate salinity while 120 kg N/ha have highest aNUE, NRE, pNUE and iNUE at high salinity as compared to other higher N treatments. (Liaqat *et al.,* 2018) found highest yield (1977.8 kg) with the application of 165 kg/ha nitrogen in north-west of Pakistan. (Alitabar *et al.,* 2013) found that application of 225 kg N/ha produced maximum yield (1731.06 kg) and number of bolls (5.61) as compared to other N treatments. According to (Wang *et al.,* 2010) N at 300 kg/ha gave highest yield with drip irrigation and plastic mulching in Xinjiang region China while according to (Xue *et al.,* 2006) 240 kg/ha N produce highest yield at Yangtze river valley and 360 kg/ha produce highest yield in Yellow river valley China. (Singh *et al.*, 2010) performed an experiment and found that nitrogen at 200 kg/ha produce high yield (3065 kg) under drip irrigation. Excess nitrogen application negatively affects yield and fiber quality (Gardner and Tucker, 1967). Excess nitrogen with late season high moisture delay maturity, reduce ginning percentage, boll shedding and promote insect and disease damage (Harris and Smith, 1980). Five years study was conducted by (Reddy *et al.,* 2007) on different nitrogen sources (Urea, fresh and composted poultry manure) and found that fresh and composted poultry manure enhance lint yield as like urea. According to (Halevy *et al.*, 1987) dry matter production and nitrogen uptake enhanced with increasing nitrogen application upto 180 kg/ha. (Chen *et al.,* 2018) investigated nitrogen fertilization effects on boll development and Bt toxin content and found that high dose under nitrogen deficiency increase boll weight, boll volume, boll shell amino acid and protease while negatively affect boll shell Bt protein content, soluble protein content, glutamic pyruvic transaminase (GPT) and glutamate oxaloacetate transaminase (GOT) activities. (Read *et al.*, 2006) observed that nitrogen deficiency affect cotton yield due to quick termination of reproductive growth. (Saleem *et al.,* 2010) found high boll weight, seed cotton yield and GOT at 120 kg/ha. (Bibi *et al.,* 2011) examined that application 150 kg N/ha positively increased bolls per plant, boll weight and seed cotton yield. (Sui *et al.,* 2017) found that application of different nitrogen rates positively affect lint yield and use of excess nitrogen decrease yield and fiber quality. (Afzal *et al.,* 2019) performed an experiment on different nitrogen rates and obtained high yield with the application of 150 kg nitrogen/ha. (Ali and Hameed 2011) performed an experiment which showed increase in total dry mass, seed cotton, cotton seed and GOT percentage with increase in nitrogen rate upto 160 kg/ha.

Fiber quality and nitrogen

Fiber is the main product of cotton cultivation for farmers. Nitrogen affects fiber development during early stages and reduces its quality. Nitrogen deficiency decrease fiber strength and length (Davidonis *et al*., 2004). (Read *et al*., 2006) reported that nitrogen deficiency negatively affect fiber length, strength and micronaire. (Tewolde and Fernandez 2003) investigated that increasing nitrogen enhance fiber length, elongation, micronaire and colour while decrease fiber uniformity ratio. (Kumbhar *et al.,* 2008) found high GOT (34.57%) and Staple length (28.65 mm) with the application of 150 N kg/ha and rotation with leguminous crop.(Madani and Oveysi 2015) reported that optimum nitrogen application for high yield is less than nitrogen application for good quality fiber.

According to (Lokhande and Reddy 2015) fiber length and strength improved with increasing nitrogen while micronaire and uniformity decreased with increase in leaf nitrogen concentration. He also investigated that fiber micronaire is more responsive to nitrogen stress followed by strength, length and uniformity.

Conclusion

From the above discussion, it is concluded that nitrogen is an important factor in cotton production. Nitrogen fertilizer prices are increasing day by day so proper management of nitrogen is necessary to improve NUE and obtain high quality yield. Soil nitrogen analysis should be done before application of fertilizer to apply nitrogen at right time, right method and right amount.

The selection of nitrogen source is also important having less leaching and volatilization.

Most researches discussed in the above study showed split application of nitrogen at PPA, FBA and PBA with different rates according to soil and climate of that region. So, application of nitrogen to cotton should be done according to soil and plant nutrient conditions at the field.

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