REVIEW ARTICLE

N ge fe a a d c e a age: a e e g , e d, a d g ee e ga e c

Ad a N S a [1] · Ja a d I ba [2] · M Ta ee [3] · G e g Ya g [1] ·
Wa ee Ha a [4] · S a Fa ad [3] · M a ad Y af [5] · Y g g W [1]

Received: 2 June 2016 / Accepted: 10 October 2016 / Published online: 30 October 2016

Ab ac Cotton is planted worldwide as a "cash crop" providing us fiber, edible oil, and animal feed as well. In this review, we presented a contemporary synthesis of the existing data regarding the importance of nitrogen application and tillage system on cotton growth and greenhouse gas (GHG) emission. Cotton growth and development are greatly influenced by nitrogen (N); therefore, proper N application is important in this context. Tillage system also influences cottonseed yield. Conservation tillage shows more promising results as compared to the conventional tillage in the context of cotton growth and GHG emission. Moreover, the research and knowledge gap relating to nitrogen application, tillage and cotton growth and yield, and GHG emission was also highlighted in order to guide the further studies in the future. Although limited data were available regarding N application, tillage and their interactive effects on cotton performance, and GHG emission, we also tried to highlight some key factors which influence them significantly.

Ke d Cotton · Greenhouse gases · Nitrogen management · Tillage · Sustainable agriculture

Responsible editor: Philippe Garrigues

✉ Guozheng Yang
ygzh9999@mail.hzau.edu.cn

[1] MOA Key Laboratory of Crop Ecophysiology and Farming System in the Middle Reaches of the Yangtze River, College of Plant Sciences and Technology, Huazhong Agricultural University, Wuhan 430070, People's Republic of China

[2] Ghazi University, Dera Ghazi Khan, Punjab 32200, Pakistan

[3] National Key Laboratory of Crop Genetic Improvement, Crop Ecophysiology and Farming System in the Middle Reaches of the Yangtze River, College of Plant Sciences and Technology, Huazhong Agricultural University, Wuhan 430070, People's Republic of China

[4] Department of Soil and Environmental Sciences, Muhammad Nawaz Shareef University of Agriculture, Multan, Pakistan

[5] College of Resources and Environment, Huazhong Agricultural University, Wuhan 430070, People's Republic of China

I d c

Cotton is a tropical crop and plays a considerable role in the economic development worldwide. Cotton is an important source of fiber, oil, and animal feed (Dai and Dong 2014). In China, 5.9 million ha of cropland is cultivated with cotton, corresponding to approximately 4 % of the total cultivating area, and on the other hand, the ongoing economic development has resulted in a sharp rise of inorganic N fertilizer consumption between 1980 and 2007 from 9.3 to 23.0 million t N (China Statistical Year book, 2008). The global 20 years' average (1993/94 to 2013/14) annual planted area is 33 million ha of cotton (source: Bremen Cotton Exchange 2014) producing about 26 million t of lint each year. Different crop husbandry practices such as fertilization especially nitrogen (N) and tillage system greatly influence the cotton yield (Howard et al. 2001). N is an important macronutrient that influences cotton growth significantly (Mokhele et al. 2012). Over and/or under N application from optimum rate resulted in reduced cotton growth and yield (Constable and Rochester 1988; Lokhande and Reddy 2015). Different management practices such as application rate, application methods, N fertilizer types, and their respective use efficiencies also influence cotton production (Larson et al. 2001). Cotton maturity is of big concern while considering N application (Dai and Dong 2014). Excess application of N causes delayed maturity (Pettigrew et al. 1996). Cotton requires high N demand (50–412 kg N ha^{-1}), which can develop suitable conditions for the emission of greenhouse gases (GHGs) associated with high denitrification process (Scheer et al. 2008a; Zhang et al. 2008). Indeed, significant emissions of these GHGs have been observed from cotton fields across the globe (Scheer et al. 2008b). Moreover, greenhouse gas emissions from the cotton fields due to N fertilization and tillage practices were also discussed. Previously, available reports have revealed variable effects of tillage on cotton yield. Some researchers have reported better cotton growth and higher lint yield under conservation tillage as compared with conventional tillage (Daniel et al. 1999; Nyakatawa et al. 2000). However, some studies have observed no significant yield difference between these different tillage systems (Ishaq et al. 2001; Pettigrew and Jones 2001; Schwab et al. 2002). Triplett et al. (1996) have argued that the exact benefits of conservation tillage in cotton can only be observed after several years of conservation tillage practices. The present review attempts to highlight the role of N fertilization and conservation tillage on growth and yield of cotton and on GHG emission.

C g a d e d e a ge a ca

Nitrogen (N) is an important macroelement that plays a crucial role in growth and physiology of plants (Marschner 2001). Nonetheless, N stress in the form of N deficiency or excess greatly influences the cotton growth and yield by disrupting the several growth-promoting processes in cotton (Gerik et al. 1998; Lokhande and Reddy 2015). Jaynes et al. (2001) observed stunted growth of cotton with decreased leaf area, number of fruiting branches, and lint yield under N deficiency as compared to control with optimum N application. Availability of optimum N governs physiological growth and activity of cotton, while N limitation during the early growth stages resulted in reduced leaf expansion associated with decreased cell division and cell expansion (Chapin 1980; Tang et al. 2012).

Nitrogen deficiency also induces the competition for the translocation of N within plant. Lokhande and Reddy (2015) substantiated that during the reproductive growth of cotton, growing bolls have priority for plant assimilates, and as a result, the vegetative growth of cotton was suppressed. Nitrogen deficiency also reduced the fruiting pattern and boll formation in cotton. Gerik et al. (1998) observed the altered fruiting pattern and reduced boll size, boll weight, and number of bolls per plant per unit time with limited N supply as compared to N optimal condition.

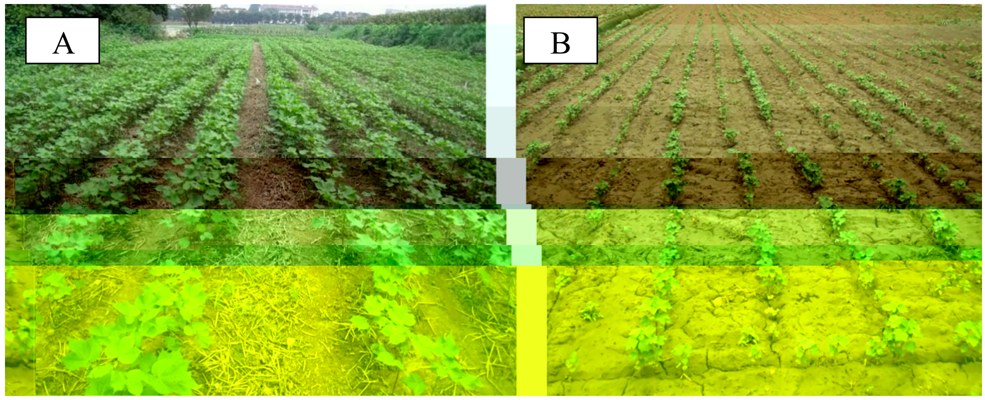
Cotton fiber is the ultimate purpose of farmers in cotton cultivation. Cotton fiber is elongated and thickened single cell of seed epidermis, which achieves its maximum length in the early period of anthesis (15–20 days after anthesis) followed by cellulose deposition on secondary wall, giving rise to strength and maturity (Davidonis et al. 2004). N limitation during fiber development stage resulted in reduced fiber strength and quality. It has been reported that N deficiency decreased the fiber length and strength (Read et al. 2006) while increased the micronaire value (Reddy et al. 2004). A positive relationship was also found between fiber strength and N fertility (Fritschi et al. 2003).

The major portion of N is important for physiological growth of cotton, as leaf N is the major component of chloroplast. N deficiency resulted in reduced chlorophyll production with concomitant decline in photosynthetic activity and carbon assimilation in cotton (Zhao et al. 2003). It has been reported that cotton leaves accumulate about 44 g kg^{-1} of N (Reddy et al. 2004) under well-fertilized conditions. The strong relationship between leaf N and photosynthesis in cotton has been widely recognized and reported. N deficiency decreases leaf area and chlorophyll content, which lowers net photosynthesis rate (Radin and Boyer 1982). In another study, Reddy et al. (1996) reported a strong positive correlation among photosynthetic rate, stomatal conductance, and leaf N. They further substantiated that under limited N, Rubisco enzyme activity was reduced. Some other researchers also reported the strong association between leaf N content and photosynthesis in cotton (Shiraiwa and Sinclair 1993) with N deficiency adversely affecting lint yield through reductions in stem elongation, leaf expansion (Lu et al. 2001), photosynthetic and metabolic activities (Ciompi et al. 1996), and biomass production (Fritschi et al. 2003).

Cotton plants under deficient-N conditions produced significantly lower biomass 23 % per plant as compared to cotton that received sufficient amount of N (Lokhande and Reddy 2015). The reduction in biomass due to the insufficient N supply has been related to the reduction in leaf area (Fernáandez et al. 1996) and CO_2 assimilation rate (Reddy et al. 1997) that in turn restrict the reproductive growth of cotton.

Excess N application induced prolonged vegetative growth and delayed reproductive growth (Marschner 2001). Ayissa and Kebede (2011) observed delayed squaring, flower initiation, and boll opening of cotton plant significantly under higher N fertilization (92 kg ha^{-1}) than the unfertilized plot while intermediate application (68 kg ha^{-1}). The earliness attained in initial boll setting by the intermediate N rate, irrespective of cotton variety, could be due to optimum nitrogen demand of the crop for the heavy nutrient sinks of cotton bolls to be opened. At the same time, higher rate of nitrogen prolonged vegetative growth and delayed opening period of bolls.

Different studies indicated that under different N source and application methods, optimum N rate varies and showed different responses under different N rate (Table 1). Nitrogen use efficiency in cotton can also be influenced by the efficiency of N application methods. Different methods have been studied to supply N in cotton such as broadcasting (Boquet and Breitenbeck 2000), split application (McConnell et al. 1993), and deep banding (Elberhar and Tupper 1988); nonetheless, the efficiency of each method varies with experimental conditions. Moreover, it was observed that split N application method significantly improved N fertilizer recovery (Sower et al. 1994). Cotton biomass and yield are also affected by the N split ratio assuming that the N rate is fixed. Yang et al. (2011) reported that the split ratio of 0 % at preplant, 40 % at first bloom, and 60 % at peak bloom harvested the highest biomass and yield when N was applied at 225 kg ha^{-1}. But cotton biomass accumulated the fastest from first bloom to peak bloom for each of the N split application ratios (Wang et al. 2010; Yang et al. 2011). Guo et al. (2010) found that the treatment of N application splitting into 40 % at preplant, 15 % at squaring stage, 23 % at first bloom, and 22 % at peak bloom4

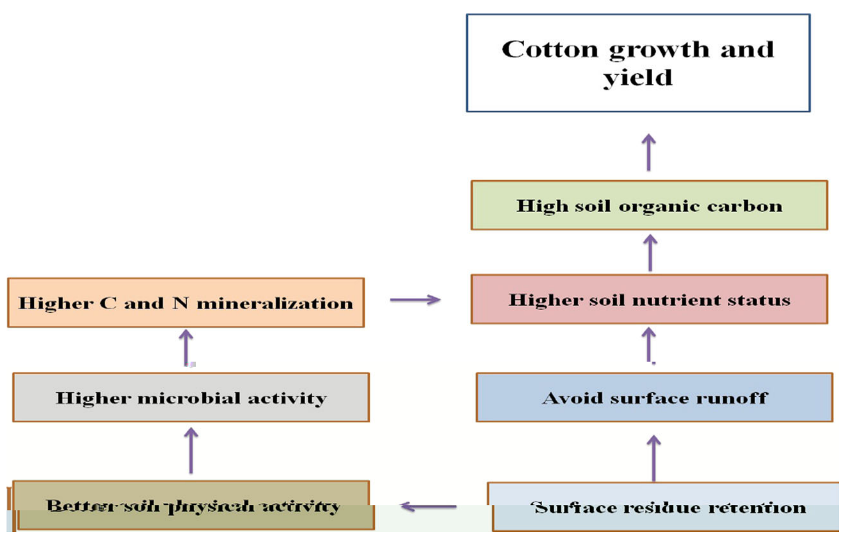


F g. 1 Comparative cotton growth under conservation tillage (**a**) vs conventional tillage (**b**) (picture courtesy; Adnan Noor Shah, Huazhong Agricultural University, China)

systems for sustainable cotton production. Nonetheless, integrated weed management options can be used while adopting conservation tillage for cotton.

Mulching and residue retention on soil surface due to conservation tillage is another crucial factor that can influence plant growth and yield (Yang et al. 2013). Cotton is a tropical summer crop, and water availability during cotton germination is one of the biggest obstacles in maintaining optimum plant population of cotton per unit area (Ayissaa and Kebede 2011). Nyakatawa and Reddy (2000) substantiated that surface residue retention under conservation tillage resulted in increased soil moisture contents, thus increasing the cottonseed germination, root growth, and lint yield compared with conventional tillage. Nonetheless, poor root penetration and difficulties in obtaining adequate stands and weed control have been observed to reduce cotton yields in no tillage (Schertz and Kemper 1994; Triplett et al. 1996). Veiga et al. (2008) reported that the stubble incorporation under conservation tillage improved the soil microbial activity, with concomitant increase in infiltration rate, fast drainage, aggregate stability, hydraulic conductivity, and redox potential. Soil losses due to erosion under conventional tillage occur due to the loosening and pulverizing effects of heavy tillage, while conservation avoids such losses, as soil aggregates bind together due to high concentration of organic matter in soil which ultimately increases the cotton yield (Hutchinson et al. 1995). Soil hydraulic conductivity under conservation tillage is pertained to be more due to increased fauna activity resulting in large macropores, while soil under conventional system exhibited less macropores and hydraulic conductivity (Ferreras et al. 2000). Saturated hydraulic conductivity is found to be high in tilled soils due to the loosening of soil at the beginning of season, while at the end of the season, all particles were settled down and resulted in reduction of hydraulic conductivity (Shaver et al. 2002). Crop residue retention can improve soil nutrient status. For instance, the replacement effects of potassium fertilizer by various wheat straw incorporation rates can at least partly, even totally, replace chemical potash according to soil available K concentration in actual cotton production (Sui et al. 2015). In mulch tillage, stubbles on the soil surface limit raindrop action and hard crust formation (Gilley 1995). In addition, residues slow down surface runoff and increase infiltration rate. Bezborodov et al. (2010) noted that cotton yields were up to 800 kg ha^{-1} higher and crop water productivity (lint + seed) up to 0.47 kg m^{-3} greater in the mulching treatments than the farmers' managed fields with

F g. 2 Summary of the effects of conservation tillage and related factors on cotton growth and yield



conventional practices in the same region. In another study, mulching increased seed cotton yield by 36.1 % as compared to no-mulch or conventional tillage system (Dong et al. 2005). Yoo et al. (1988) found that reduced tillage with winter wheat as cover crop was the most effective in reducing the surface runoff, sediment, and nutrient losses while maintaining comparable cotton yield. They also observed that runoff and sediment concentrations from conventional tillage system were high during the "critical period" (from planting to the last cultivation of the conventional tillage system), while some other researchers (Mueller et al. 1984) have shown the opposite. Differences in runoff volumes among tillage systems have been attributed to the varying effects of tillage on surface conditions and residue cover (Lindstrom and Onstad 1984). Andraski et al. (1985) reported that the tillage practices affect the runoff volumes and peak flows of surface runoff. Besides the amount of residue retention in soil, soil texture also influences nutrient uptake; for example, K uptake by seed cotton and cotton plant increased by 201.65 and 226.7 % than that of control, respectively, while on Dafeng sandy loam, potassium uptake by seed cotton and cotton plant was increased by 47.2 and 37.1 % in response to wheat straw incorporation, respectively.

Sustainability of the farming system can be improved by combining winter cover crops with conservation tillage. Cotton yield is often improved by planting winter cover crops in conservation tillage systems (Hutchinson et al. 1995; Sainju et al. 2006) because cover crops provide additional residues that act as mulch in conservation tillage, thereby improving soil moisture and germination of cotton seedlings (Boquet et al. 2004). Soil carbon (C) mineralization is governed by soil organic matter (SOM) and is important for improving soil fertility. Zero tillage retains sufficient amount of organic residue over soil surface pertained to be efficient in replenishing SOM pool, while conventional tillage decreases SOM because of less incorporation of crop residues in soil (Balesdent et al. 2000). Continuous soil stirring led to oxidation of organic matter; contrarily no tillage sequestered 67 to 512 kg C ha^{-1} per year than conventional tillage (McConkey et al. 2003). Sainju et al. (2006) attributed the higher cotton growth and lint yield under conservation tillage to better soil physical, chemical, and biological properties as compared with conventional tillage. Besides C sequestration, conservation tillage also increases the availability of nutrient in soil. Van Den Bossche et al. (2009) substantiated that no tillage reduced the N losses by increasing N mineralization and enhanced the N use efficiency than conventional tillage (Van Den Bossche et al. 2009). Placement and accumulation of plant residues on soil surface increase the soil organic carbon contents with concomitant increase in microbial activity (Amato and Ladd 1992). The enhanced microbial activity increases N mineralization, pertaining to more in upper soil surface, which consequently increased the crop production (Schimal et al. 2004). Placement and accumulation of plant residues on soil surface increase the soil organic carbon contents with concomitant increase in microbial activity (Qiu et al. 2014). The enhanced microbial activity increases N mineralization, pertaining to more in upper soil surface which consequently increased the crop production (Paul 2014). Studies suggest that conversion of conventional till (CT) to no till (NT) can sequester atmospheric CO_2 by 0.1 % ha^{-1} at the 0–5-cm soil depth every year, a total of 10 t in 25–30 years (Lal and Kimble 1997). Sequestration of C in the soil by adopting no tillage can also conserve N, because soil organic carbon (SOC) and total N levels are highly related (Sainju et al. 2002). However, SOC and STN levels below the 7.5-cm depth can be higher in tilled areas, depending on the soil texture, due to residue incorporation at greater depths (Clapp et al. 2000). Bayet et al. (2006) found that compared to conventionally tilled soil, the C stocks in no-till sandy clay loam Oxisol increased by 2.4 Mg ha^{-1} (C sequestration rate = 0.30 Mg ha^{-1} $year^{-1}$) and in the clayey Oxisol by 3.0 Mg ha^{-1} (C sequestration rate = 0.60 Mg ha^{-1} $year^{-1}$). The mean rate of C sequestration in the no-till Brazilian tropical soils was estimated to be 0.35 Mg ha^{-1} $year^{-1}$, similar to the 0.34 Mg ha^{-1} $year^{-1}$ reported for soils from temperate regions but lower than the 0.48 Mg ha^{-1} $year^{-1}$ estimated for southern Brazilian subtropical soils. Feng et al. (2003) reported that the no-till treatment increased SOC and total nitrogen contents in the surface layer by 130 and 70 %, respectively, thus significantly increased cotton yield. Moreover, zero tillage along with adequate amount of crop residues minimizes N leaching (Sainju et al. 2006). N accumulation in the soil under conservation tillage by cotton may be partially masked by soil potential N mineralization (Sweeney and Moyer 2004). Karlen et al. (2001) showed that tillage system has a direct impact on N transport and its destination by altering soil physical properties peculiarly mineralization of organic contents, macropores, and available water. Cotton lint yield and N uptake were as good as or better in no till than in strip till and chisel till (Sainju et al. 2006). Conclusively, lower production cost and greater environmental benefits of reduced soil erosion and N leaching and increased C sequestration in conservation tillage make conservation tillage more promising for cotton production as compared to conventional tillage (Smart and Bradford 1999; Paxton et al. 2001). Feng et al. (2003) explained that how conservation tillage practices improve soil quality and sustainability in a cotton cropping system and suggested that during the growing season, changes in the microbial community may be primarily determined by soil conditions responding to cotton growth and environmental variables such as moisture and temperature; during fallow or prior to cotton establishment, community changes associated with tillage practices become more pronounced.

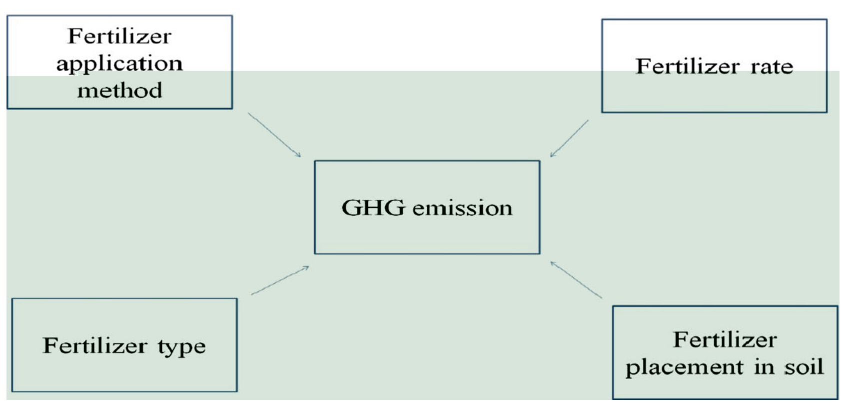
Greenhouse gas emissions

In the current scenario of agriculture and climate change, sequestration of C in the soil is necessary to increase soil C pool for C trading and for mitigating greenhouse gas emissions. This can be accomplished by the adoption of novel soil and crop management practices for a long term, which will not only increase soil C but also improve the soil quality and increase economic crop production. Likewise, N sequestration is another environmental issue and is needed to be investigated to reduce the rate and cost of N fertilization, N leaching, and N_2O emission. Conservation tillage is reported as an effective approach in mitigating emanation of greenhouse gases and sequestration of C and N in soil. Furthermore, N fertilization triggers the release of greenhouse gases from arable crop fields. This section consists of two subsections science pertaining to greenhouse gas emission (1) under conservation vs conventional tillage system and (2) under different N management practices. More possible effects of these greenhouse gases on cotton production and further than can reduce greenhouse gas emissions were also discussed.

G ee e ga e e a N a ca

The release of greenhouse gases can also be affected by the type of N fertilizer application method, timing of application, placement of N, and N rate (Fig. 3). Availability of N and its losses are greatly influenced by its placement in soil and timing of N application. Venterea et al. (2005) found a significant interaction of tillage and N placement method on greenhouse gas emission and observed that N_2O release was higher under no tillage as compared with conventional tillage when N was applied at post emergence by broadcasting, nonetheless an opposite effect was noted when N was either injected or broadcasted at pre-planting. N is volatile in nature, thus its contact with oxygen could result in release of N as N_2O in air but this is not in case conventional tillage. Breitenbeck and Bremner (1986) noted that soil injection of anhydrous NH_3 at the depth of 30 cm caused 107 % higher N_2O release as compared with the soil injection at 10 cm. They also found that the effect of depth of application of anhydrous NH_3 on emission of N_2O was less when this fertilizer was applied at a rate of 225 kg N ha^{-1}. While it is suspected that anhydrous NH_3 may possibly inhibit nitrifying bacteria and allow the accumulation of nitrite in soil. Venterea and Stanenas (2008) observed no increase in denitrification with substantially no release of N_2O at the depth of 30 cm under aerobic conditions. Placement of N on soil surface or at more depth resulted in higher N loss either by volatilization or by the release of N_2O under irrigated conditions. Research comparing the surface-applied urea to urea placed in a band below and to the side of the seed-row showed that N_2O emissions were higher under broadcasting compared with band placement (Hultgreen and Leduc 2003). Conclusively, placement of N at proper depth is of significant importance in the increasing N use efficiency in cotton, thus more research is required to study this aspect under different tillage systems and different agro ecological zones.

N_2O release also depends on the type of chemical fertilizer use; e.g., Tenuata and Beauchamp (2003) compared release of N_2O from different N fertilizer sources under field and laboratory conditions and observed a decreasing trend of N_2O production from urea, ammonium sulfate and calcium sulfate. They further recorded that moisture contents also interferes with the release of N_2O under aerobic conditions for instance release of N_2O was higher when N was supplied from urea than with other fertilizer with only fewer differences at high moisture contents. The authors concluded that this observation warrants more research since ammonium phosphate is commonly used and because of the possible implication of P status impacting N_2O emissions from N fertilizers. Harrison and Webb (2001) stated that it is difficult to say with any certainty if a strategy based on urea or ammonium nitrate would result in the smaller N_2O emissions. Contrarily, More recent comparisons among urea, NH_4-based and NO_3-based N source have shown higher emissions of N_2O from urea (Tenuta and Beauchamp 2003), and higher N_2O emissions from NH_4-based N fertilizers compared to NO_3-based fertilizers (Velthoff et al. 2003; Tenuta and Beauchamp 2003). This higher emission with NH_4-based fertilizers may be related to potential NO_2 accumulation or N_2O production during nitrification (Venterea and Stanenas 2008). Bouwman et al. (2002) reviewed numerous studies and



reported N_2O emissions appear to be lower for NO_3-based fertilizers compared to NH_4-based fertilizers and organic or synthetic-organic sources. Yet, one might expect a potentially higher N loss with an abundance of NO_3-N in soil systems from NO_3-based fertilizers compared to other N fertilizers, since NO_3 and NO_2 are essential for denitrification (Coyne 2008; Alexander 1977). However, anhydrous NH_3 has exhibited higher N_2O emissions in several studies comparing it with other N sources (Breitenbeck and Bremner 1986; Venterea et al. 2005). Different studies reported emission and flux of different GHGs in cotton under different nutrient regimes (Table 2).

G ee e ga e e a c e a age

Intensive tillage facilitates the microbial decomposition of organic matter at higher rates as compared with minimum tillage which produces CO_2 (Reicosky et al. 1997). Different researchers suggested that the reduction in tillage intensity could be beneficial in reducing CO_2 emission from soil and could be helpful in the sequestration of C in soil (Potter et al. 1998; Reicosky et al. 1997). Conservation tillage involves the placement of stubbles on soil surface to avoid soil erosion and addition of organic matter and for moisture conservation (Farooq et al. 2011). This technique can mitigate emission of N_2O gas by affecting directly NO_3 availability or by modifying indirectly the soil microclimate and cycling of C and N. In many regions, soil C storage increased and potential of global warming decreased by appropriate conservation tillage (Lal 2003). There is a conflict among different researchers regarding the extent of the release of greenhouse gases under different tillage systems, and there is no clear positive or negative relation of the mitigation of greenhouse gases and tillage system. It appears that, in some regions, the benefits of minimum tillage include an increase in stored SOM, both organic C and N, to a greater degree than any potential increase in N_2O emissions, so that the net global warming potential (GWP) decreases. In other studies, the GWP was slightly increased by switching from conventional tillage to conservation or no till (Gregorich et al. 2001; Lal 2003). Malhi et al. (2006) observed that in the region of Alberta Parkland, no tillage considerably reduced the emission of greenhouse gases. In a Canadian prairie region, Malhi et al. (2006) noted the higher N losses in the form of N_2O under conventionally tilled plots as compared to no-tilled plots. Halvorson et al. (2002) noted the reduced N_2O emissions under no till compared to conventional till, when averaged across years and four N rates. Hulugallc (2000) observed higher C sequestration under different cotton-based cropping systems under conservation tillage as compared with conventional tillage. Although it is well evident that the conservation tillage reduced the emanation of greenhouses gases, nonetheless, little information has been reported so far pertaining to the release of greenhouse gases in cotton fields and their effects on cotton growth and productivity.

I e ac e effec f N a ca a d c e a age c g a d e d a d GHG e

I e ac e effec f N a ca a d c e a age c g a d e d

The availability and management of N under conservation tillage depend on numerous factors, which ultimately affect the cotton yield. Excess and imbalanced N application under intensive or conventional tillage has been known to cause groundwater contamination through N leaching. Furthermore, overapplication of N increases cost of production by millions of dollars each year (Koch et al. 2004). Howard et al. (2001) stated that the optimum N application is the key for determining a wide range of cotton plant yield variables including plant size, fruiting intensity, boll retention rate, boll size, and total boll number per plant.

Nitrogen fertilization rate for optimizing cotton yield can vary with the type of tillage and cover crop. Boquet et al. (2004) reported that the cotton yields were lower in no tillage than in surface tillage without applied N, but with optimum N

Tab e 2 Reported GHG emission and their fluxes in different countries in cotton

Place of study	GHG under study	GHG emission	GHG flux	Reference
Pakistan	N_2O	3.2 kg ha^{-1}	2.33 g N ha^{-1} day^{-1}	Mahmood et al. (2008)
China	N_2O	2.6 kg ha^{-1}	30 μg N m^{-2} h^{-1}	Liu et al. (2010)
China	NO	0.8 kg ha^{-1}	8.8 μg N m^{-2} h^{-1}	Liu et al. (2010)
Uzbekistan	N_2O	0.9 to 6 kg ha^{-1}	3000 μg N m^{-2} h^{-1}	Scheer et al. (2008a, b)
Australia	CO_2e	127, 127, and 1634 kg ha^{-1} (for solid-plant, double-skip, and irrigated cotton farming systems, respectively)	–	Maraseni et al. (2010)

rate, yields were higher in no tillage. They also found that higher N rate was required to optimize cotton yield following wheat (*Triticum aestivum* L.) or no cover crop in no tillage and surface tillage, but no N was required following hairy vetch (*Vicia villosa* Roth) in either tillage practice. This suggests that N fertilization rates to cotton can be reduced by using legume cover crops, such as hairy vetch and red clover (*Trifolium pratense* L.), regardless of tillage practices (Hargrove 1986; Blevins et al. 1990). On the other hand, it is not surprising to observe higher soil inorganic N with increasing N fertilization rates, because crops are unable to take 100 % of the applied N (Bergstrom and Kirchmann 2004; Bundy and Andraski 2005). Probably, crop N uptake and N loss due to leaching and/or volatilization occurred more rapidly with N fertilization than with cover crops where the rate of N mineralization is slower (Sainju and Singh 2001; Bergstrom and Kirchmann 2004). Boquet et al. (2004) reported that cotton lint yield and N uptake increased with increasing N fertilization rates from 0 to 118 kg N ha^{-1} with wheat cover crop or native cover but decreased with hairy vetch. The tolerance of cotton lint yield following rye to high N rates was probably related to N immobilization caused by high C/N ratio of rye residue (Dabney et al. 2001). It may also be possible that unidentified factors retard cotton's vegetative growth in wheat residue (Hicks et al. 1989). Nitrogen fertilizer rate also affects the cotton maturity, as in case of late-planted cotton, excess N application could not trigger vegetative growth but increase unnecessary growth of unwanted branches and delayed cotton maturity. In another study, Larson et al. (2001) observed that no-tilled cotton followed by hairy vetch cover required 68 lb $acre^{-1}$ less applied N to maximize profits when compared with no cover. This reduction in the N fertilizer requirement for vetch was considerably larger than the N savings estimated for cotton production. Results of Sainju et al. (2005) suggested that conservation tillage with the inclusion of cover crop and reduced rate of N fertilization can sustain cotton lint yield better than conventional tillage with full rate of N fertilization.

Inclusion of cover crops in winter acts as additional source of N fertilization in cotton under conservation tillage system. Larson et al. (2001) reported that improved soil quality with winter covers in cotton and conservation tillage may enhance the yield response to N fertilizer. Roberts et al. (1998) estimated a larger reduction in the N fertilization rate required to maximize profit in the presence of legumes as cover crops. Presence of cover crop considerably influences soil inorganic N; however, the amount of inorganic N depends on the conservation tillage and the type of cover crop. Sainju et al. (2006) observed that inorganic N was higher in soil where hairy vetch was used as cover crop as compared to winter rye in no tillage. They further observed that tillage × cover crop interaction was significant for lint yield and N uptake. Sainju and Singh (2001) found hairy vetch as the most efficient cover crop in increasing N in soil, and this was because of its higher N concentration and lower C/N ratio, rapid decomposition in the soil, and soil N enrichment more than rye. Moreover, hairy vetch releases about half of its N within 2–4 weeks after the residue was incorporated into the soil (Stute and Posner 1995). Other benefit of using cover crops in cotton production is the reduced N losses either by leaching or by volatilization. Different studies have indicated that it is not surprising to observe higher soil inorganic N with increasing N fertilization rates, because crops are unable to take 100 % of the applied N (Bergstrom and Kirchmann 2004; Bundy and Andraski 2005). Probably, crop N uptake and N loss due to leaching and/or volatilization occurred more rapidly with N fertilization than with cover crops where the rate of N mineralization is slower (Sainju and Singh 2001; Bergstrom and Kirchmann 2004).

I e ac e effec f N a ca a d c e a age GHG e

Fertilizer source and tillage interactions can result from differences in soil water content and bulk density and differences in soil nitrite accumulation among N sources and may depend on whether nitrification or denitrification dominates in the crop and soil system (Venterea and Stanenas 2008). Interactions between N sources and tillage systems often occur. Venterea et al. (2005) concluded that emissions of N_2O with urea were higher under no till and conservation tillage compared to conventional tillage, while no differences among tillage systems were observed with urea. With anhydrous NH_3, N_2O emissions were greater with conventional tillage than the other two tillage systems. As reported by Breitenbeck and Bremner (1986), anhydrous NH_3 resulted in higher N_2O emissions compared to the other two sources and their application methods. However, in a study by Venterea et al. (2005), the fertilizer N source effects were more confounded with placement methods. Higher application of N resulted in accumulation of N as nitrate in soil and reduced the N availability to cotton (Legg and Meisinger 1982). The use of appropriate N rates can help to minimize the soil accumulation of NO_3-N. Apparently, reducing the amount of applied N cannot be a solution as N application below economic requirement of plant could result in overmining of SOC and long-term decrease in soil productivity. Furthermore, when N application rate exceeds agronomic N threshold level, the rate of N_2O emission also increases. For instance, Malhi et al. (2006) noted that in a particular cropping study, overdose of N <80 kg ha^{-1} resulted in higher release of N_2O. Likewise, Grant et al. (2006) observed that N rates more than 100 kg ha^{-1} resulted in higher N_2O emission in cornfields. Little information is available regarding the dose-dependent relation of N and N_2O emission in cotton; therefore, future studies should be directed in this regard.

The exact mechanism of N loss has not been identified in cotton; nonetheless, (Chua et al. (2003) identified denitrification as the major process in N losses from cotton fields under irrigated conditions. Rochester et al. (1996) reported that denitrification can cause N fertilizer loss up to 60 %. In another study, Rochester (2003) used ^{15}N balance approach and estimated that roughly 2 kg N ha^{-1} (1.1 % of the N applied) was lost as N_2O during the cotton-growing season. Skiba and Smith (2000), on other hand, found that soil moisture also played a significant role in the release of N_2O or NO by

Buhler DD, Stoltenberg DE, Becker RL, Gunsolus JL (1994) Perennial weed populations after 14 years of variable tillage and cropping practices. Weed Sci 42:205–209

Bundy LG, Andraski TW (2005) Recovery of fertilizer nitrogen in crop residues and cover crops on an irrigated sandy soil. Soil Sci Soc Am J 69:640–648

Larson JA, Jaenicke EC, Roberts RK, Tyler DD (2001a) Risk effects of alternative winter cover crop tillage and nitrogen fertilization systems in cotton production. J Agric and Appl Econ 33:445–458

Larson JA, Roberts RK, Jaenicke EC, Tyler DD (2001b) Profit-maximizing nitrogen fertilization rates for alternative tillage and winter cover systems. J Cotton Sci 5:156–168

Lindstrom MJ, Onstad CA (1984) Influence of tillage systems on soil physical parameters and infiltration after planting. J. Soil and Water Conserv 39:149–152

Liu C, Zheng X, Zhou Z, Han S, Wang Y, Wang K, Yang Z (2010) Nitrous oxide and nitric oxide emissions from an irrigated cotton field in Northern China. Plant Soil 332:123–134

Locke MA, Reddy KN, Zablotowicz RM (2002) Weed management in conservation crop production systems. Weed Biol and manage 2: 123–132

Lokhande S, Reddy KR (2015) Cotton reproductive and fiber quality responses to nitrogen nutrition. Int J Plant Prod 9:191–210

Lu C, Zhang J, Zhang Q, Li L, Kuang T (2001) Modification of photosystem II photochemistry in nitrogen deficient maize and wheat plants. J Plant Physiol 158:1423–1430

Ludwig J, Meixner FX, Vogel B, Förstner J (2001) Soil-air exchange of nitric oxide: an overview of processes, environmental factors and modeling study. Biogeochemistry 52:225–257

Mahmood T, Ali R, Iqbal J, Robab U (2008) Nitrous oxide emission from an irrigated cotton field under semiarid subtropical conditions. Biol Fertil Soils 44:773–781

Malhi SS, Lemke R, Wang ZH, Chhabra BS (2006) Tillage nitrogen and crop residue effects on crop yield nutrient uptake soil quality and greenhouse gas emissions. Soil and Tillage Res 90:171–183

Maraseni TN, Cockfield G, Maroulis J (2010) An assessment of greenhouse gas emissions: implications for the Australian cotton industry. J Agric Sci 148:501–510

Marschner H (2001) Marschner's mineral nutrition of higher plants. Academic Press

McConkey BG, Liang BC, Campbell CA, Curtin D, Moulin A, Brandt SA, Lafond GP (2003) Crop rotation and tillage impact on carbon sequestration in Canadian prairie soils. Soil and Tillage Res 74:81–90

McConnell JS, Baker WH, Miller DM, Frizzell BS, Varvil JJ (1993) Nitrogen fertilization of cotton cultivars of differing maturity. Agron J 85:1151–1156

Mokhele B, Zhan X, Yang G, Zhang X (2012) Review: nitrogen assimilation in crop plants and its affecting factors. Can. J. Plant Sci 92: 399–405

Mueller DH, Wendt RC, Daniel TC (1984) Phosphorus losses as affected by tillage and manure application. Soil Sci Soc Am J 48:901–905

Nadeem MA, Ali A, Tahir M, Naeem M, Chadhar AR, Ahmad S (2010) Effect of nitrogen levels and plant spacing on growth and yield of cotton. Pak J Life Soc Sci 8:121–124

Norton ER, Silvertooth JC (2007) Evaluation of added nitrogen interaction effects on recovery efficiency in irrigated cotton. Soil Sci 172: 983–991

Nyakatawa EZ, Reddy KC, Mays DA (2000) Tillage, cover cropping and poultry litter effects on cotton: II. Growth and yield parameters. Agron J 92:1000–1007

Nyakatawa EZ, Reddy KC (2000) Tillage cover cropping and poultry litter effects on cotton: I. Germination and seedling growth. Agron J 92:992–999

Legg OJ, Meisinger J (1982) Soil nitrogen budgets. Nitrogen in agric soils:503–566

Paul EA (2014) Soil microbiology, ecology, and biochemistry. Academic Press

Paxton KW, Boquet DJ, Hutchinson RL (2001) An economic analysis of best management practice adoption by Louisiana cotton producers. Proceedings of the Beltwide Cotton Conf Anaheim, In, pp. 193–195

Pettigrew WT, Heitholt JJ, Meredith WR (1996) Genotypic interactions with potassium and nitrogen in cotton of varied maturity. Agron J 88:89–93

Pettigrew WT, Jones MA (2001) Cotton growth under no-till production in the lower Mississippi river valley alluvial flood plain. Agron J 93: 1398–1404

Potter KN, Torbert HA, Jones OR, Matocha JE, Morrison JE, Unger PW (1998) Distribution and amount of soil organic carbon in long-term management systems in Texas. Soil and Tillage Res 47:309–321

Qiu Y, Wang Y, Xie Z (2014) Long-term gravel–sand mulch affects soil physicochemical properties microbial biomass and enzyme activities in the semi-arid loess plateau of North-Western China. Acta Agric Scand Section B-Soil and Plant Sci 64:294–303

Radin JW, Boyer JS (1982) Control of leaf expansion by nitrogen nutrition in sunflower plants role of hydraulic conductivity and turgor. Plant Physio 69:771–775

Read JJ, Reddy KR, Jenkins JN (2006) Yield and fiber quality of upland cotton as influenced by nitrogen and potassium nutrition. Eur J Agron 24:282–290

Reddy AR, Reddy KR, Padjung R, Hodges HF (1996) Nitrogen nutrition and photosynthesis in leaves of pima cotton. J Plant Nutr 19:755–770

Reddy KR, Hodges HF, McKinion JM (1997) Crop modeling and applications: a cotton example. Adv Agron:225–290

Reddy KR, Koti S, Davidonis GH, Reddy VR (2004) Interactive effects of carbon dioxide and nitrogen nutrition on cotton growth development yield and fiber quality. Agron J 96:1148–1157

Reicosky DC, Dugas WA, Torbert HA (1997) Tillage-induced soil carbon dioxide loss from different cropping systems. Soil and Tillage Res 41:105–118

Roberts I, Schierhout G, Alderson P (1998) Absence of evidence for the effectiveness of five interventions routinely used in the intensive care management of severe head injury: a systematic review. J Neurol Neurosurgery and Psychiatry 65:729–733

Rochester I, Constable G, Saffigna P (1996) Effective nitrification inhibitors may improve fertilizer recovery in irrigated cotton. Biol Fertil Soils 23:1–6

Rochester IJ (2003) Estimating nitrous oxide emissions from flood-irrigated alkaline grey clays. Soil Res 41:197–206

Sainju UM, Singh BP (2001) Tillage cover crop and kill-planting date effects on corn yield and soil nitrogen. Agron J 93:878–886

Sainju UM, Singh BP, Whitehead WF (2002) Long-term effects of tillage, cover crops and nitrogen fertilization on organic carbon and nitrogen concentrations in sandy loam soils in Georgia, USA. Soil and Tillage Res 63:167–179

Sainju UM, Singh BP, Whitehead WF (2005) Tillage cover crops and nitrogen fertilization effects on cotton and sorghum root biomass, carbon and nitrogen. Agron J 97:1279–1290

Sainju UM, Whitehead WF, Singh BP, Wang S (2006) Tillage cover crops and nitrogen fertilization effects on soil nitrogen and cotton and sorghum yields. Eur J Agron 25:372–382

Saleem MF, Bilal MF, Awais M, Shahid MQ, Anjum SA (2010) Effect of nitrogen on seed cotton yield and fiber qualities of cotton (Gossypium hirsutum L.) cultivars. The Journal of Animal & Plant Sciences 20(1):23–27

Scheer C, Wassmann R, Kienzler K, Ibragimov N, Eschanov R (2008b) Nitrous oxide emissions from fertilized, irrigated cotton (*Gossypium hirsutum* L.) in the Aral Sea Basin, Uzbekistan: influence of nitrogen applications and irrigation practices. Soil Biol Biochem 40:290–301

Scheer C, Wassmann R, Kienzler K, Ibragimov N, Lamers JPA, Martius C (2008a) Methane and nitrous oxide fluxes in annual and perennial land use systems of the irrigated areas in the Aral Sea Basin. Glob Chang Biol 14:2454–2468

Schertz DL, Kemper WD (1994) Report on field review of no-till cotton. USDA ARS NRCS Auburn Univ, Alabama, Huntsville AL

Schimel JP, Bilbrough C, Welker JM (2004) Increased snow depth affects microbial activity and nitrogen mineralization in two Arctic tundra communities. Soil Biol and Biochemis 36:217–227

Schwab EB, Reeves DW, Burmester CH, Raper RL (2002) Conservation tillage systems for cotton in the Tennessee Valley. Soil Sci Soc Am J 66:569–577

Shaver TM, Peterson GA, Ahuja LR, Westfall DG, Sherrod LA, Dunn G (2002) Surface soil physical properties after twelve years of dry land no-till management. Soil Sci Soc Am J 66:1296–1303

Shiraiwa T, Sinclair TR (1993) Distribution of nitrogen among leaves in soybean canopies. Crop Sci 33:804–808

Skiba U, Smith KA (2000) The control of nitrous oxide emissions from agricultural and natural soils. Chemosphere-Global Change Sci 2: 379–386

Smart JR, Bradford JM (1999) Conservation tillage corn production for a semiarid subtropical environment. Agron J 91:116–121

Sowers KE, Pan WL, Miller BC, Smith JL (1994) Nitrogen use efficiency of split nitrogen applications in soft white winter wheat. Agron J 86: 942–948

Stute JK, Posner JL (1995) Synchrony between legume nitrogen release and corn demand in the upper Midwest. Agron J 87:1063–1069

Sui N, Zhou Z, Yu C, Liu R, Yang C, Zhang F, Meng Y (2015) Yield and potassium use efficiency of cotton with wheat straw incorporation and potassium fertilization on soils with various conditions in the wheat–cotton rotation system. Field Crop Res 172:132–144

Sweeney DW, Moyer JL (2004) In-season nitrogen uptake by grain sorghum following legume green manures in conservation tillage systems. Agron J 96:510–515

Tang HY, Yang GZ, Zhang XL, Siddique K (2012) Improvement of fertilizer N recovery by allocating more N for later application in cotton (*Gossypium hirsutum* L.). International Journal of Basic and Applied Sciences 12:32–37

Tenuta EG, Beauchamp M (2003) Nitrous oxide production from granular nitrogen fertilizers applied to a silt loam soil. Can J Soil Sci 83: 521–532

Triplett GB, Dabney SM, Siefker JH (1996) Tillage systems for cotton on silty upland soils. Agron J 88:507–512

Van Den Bossche A, De B, De NS, Hofman G (2009) Effect of tillage intensity on N mineralization of different crop residues in a temperate climate. Soil and Tillage Res 103:316–324

Veiga MD, Reinert DJ, Reichert JM, Kaiser DR (2008) Short and long-term effects of tillage systems and nutrient sources on soil physical properties of a southern Brazilian Hapludox. Rev Brasil de Ci ncia do Solo 32:1437–1446

Velthof GL, Kuikman PJ, Enema O (2003) Nitrous oxide emission from animal manures applied to soil under controlled conditions. Biol Fertil Soils 37:221–230

Venterea RT, Burger M, Spokas KA (2005) Nitrogen oxide and methane emissions under varying tillage and fertilizer management. J Environ Qual 34:1467–1477

Venterea RT, Stanenas AJ (2008) Profile analysis and modeling of reduced tillage effects on soil nitrous oxide flux. J Environ Qual 37: 1360–1367

Wang L, Zhu J, Yang T, Wang B, Chen B, Liu H, Xu Y, Ma X, Zhao D (2010) Effects of using strategy of N fertilizer on dry matter accumulation and yield component of cotton. Xingjiang Agri Sci 47: 1952–1957

Yang G, Tang H, Nie Y, Zhang X (2011) Responses of cotton growth, yield, and biomass to nitrogen split application ratio. Eur J Agron 35:164–170

Yang G, Tang H, Tong J, Nie Y, Zhang X (2012) Effect of fertilization frequency on cotton yield and biomass accumulation. Field Crop Res 125:161–166

Yang G, Zhou X, Li C, Nie Y, Zhang X (2013) Cotton stubble mulching