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REVIEW

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Effect of nitrogen application level on cotton fibre quality

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Abstract
The nitrogen (N) requirements of cotton are well understood and have been extensively studied since 1887, with practical guides, decision support systems, models and recent reviews providing information on the importance of providing cotton crops with a sufficient supply of nutrients and improving nitrogen use efficiency. Given that the financial return to the grower depends on both the cotton quantity and quality and the growing importance of the latter, this review focusses specifically on information and knowledge about the effect of nitrogen application level on fibre quality.

Keywords: Cotton, Nitrogen, Fibre quality

Introduction

Although the United Nations has indicated that there will be a dramatic slowdown in population growth, it is still estimated that the world population will increase to 8.3 billion in 2030 and 9.3 billion in 2050. However, despite this slowdown in population growth, the demand for food, fibre and fuel continues to grow (Bruinsma 2003; Snyder et al. 2009). As the global agricultural and arable land has remained fairly stable, any increase in such demands need to be met by either increasing the areas of land that may not be suitable for crop production or else by increasing yield, which can be achieved in a number of ways, including multiple cropping and reduced fallow periods, improved tillage (zero, minimum, low tillage, plant spacing) and soil fertility, increased mechanisation, improved varieties, applications of biotechnology, integrated pest management (IPM), improved irrigation and nutrition, either in terms of crop rotations with legumes, increased applications of natural manure (plant or animal based) or commercial (chemical/synthetic) fertilisers, mainly including nitrogen (N), phosphorus (P) and potassium (K) (Bruinsma 2003; Ayissa and Kebede 2011; IAEA 2008; Boquet et al. 2004; Pettigew and Meredith 1997; de Oliveira Araujo et al. 2013; Gerik et al. 1998).

Due to the fact that most soils do not provide sufficient N for the economical production of fibre and seeds (McConnell et al. 1996), the additional supplementation of N, P, K fertilisers are key inputs in maintaining productive, profitable, and sustainable cropping industries (Tucker 1999; Khan et al. 2017). A total of 190 million tonnes of fertilisers were used globally in 2018; of which 188 million tonnes were chemical fertilisers, which was 40% higher than in 2000 (FAO 2020). A breakdown of chemical fertiliser use showed that 58% was N, 22% was P and 21% was K (FAO 2020). It has been stated that, together with water, N is the single most important growth limiting factor, excluding weather, for crops (IAEA 2008; de Oliveira Araujo et al. 2013; Shah 2008; Rosolem and van Mellis 2010; Malik 1998; Bronson and Green 2003). The contribution of fertilisers to cotton yield has been estimated at about 56% for rainfed (dryland) and 102% for irrigated cotton (Malik 1998). A study conducted in 1990 showed that eliminating N fertiliser would result in a drop in the yield of cotton by 37% (Knutson et al. 1990). Nevertheless, as only a fraction of the N applied (on average less than 50% for irrigated cotton and less than 40% for rainfed cotton) is taken up

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by the crop, there is a need to improve fertiliser use efficiency as excessive levels can result in substantial losses as well as potential environmental, ecological and health risks (IAEA 2008; Bronson and Green 2003; Eed et al. 2018; Galloway et al. 2003; Rochester 2014; Antile and Moody 2021).

In terms of fibre, despite the fact that cotton's share of the global fibre market is decreasing (ICAC 2018a), cotton still remains one of the most important textile fibres in the world, with its production and consumption continuing to increase annually. Cotton is a global commodity that is either grown or used in virtually every country in the world and is traded in the form of fibre, yarn, fabric, or finished goods. It has been stated (Yafa 2005) that just about everyone on the planet wears at least one article of clothing made from cotton. Similarly, the by-products from cotton (such as seed oil, seed meal, seed hulls and seed linters) are also used on a daily basis by most people on the planet. Cotton is sought after by consumers as it is a natural fibre with excellent comfort against the skin, moisture absorption, soft hand feel and versatility (Thiry 2011; van der Sluijs and Johnson 2011; Werber 1988; Wakelyn et al. 2006; Peter and Bowes 1988).

Cotton growth and yield as affected by the application of fertiliser

Although the average global yield of cotton has stabilised at around 800 kg·ha^{-1} over the last 14 years (ICAC 2018b), it has been shown that cotton could consistently yield lint at 3 500 kg·ha^{-1} or even as much as 5 000 kg·ha^{-1}(Constable and Bange 2015). There are many factors that are required for such high yields, including water and nutrient supplies. In terms of nutrition, almost 50% of the global cotton area is now under irrigation, with almost 6.8 million tonnes of fertiliser used on cotton in 2019, at an average cost of 0.31 cents·kg^{-1}, or 23% of the production cost of lint (ICAC 2015, 2016a,b). Surveys conducted in Australia found that nutrition was the single largest cost item for cotton production (Welsh et al. 2015) accounting for as much as 50% of production costs (Hernandes-Cruz et al. 2015), with N contributing the most to this cost. Worryingly, the increased use of N has not resulted in increased yields which has been attributed to changes in cotton breeding objectives and adverse environmental conditions during recent growing seasons (Nichols 2003a).

Optimum N application in terms of the amount, timing, and source (and irrigation) is mostly applied prior to planting and then during growth and fruit formation (squaring and boll setting). N plays a major role in influencing cotton yield and facilitating beneficial crop growth, in terms of root growth, plant size; with increased stem and branch length as well as stem diameter, the number of leaves and fruiting intensity, boll retention rate, boll size, the total number of bolls per plant (Ayissa and Kebede 2011; Gerik et al. 1998; Tucker 1999; Boquet et al. 1993; Gadhiya et al. 2009; Gardner and Tucker 1967; Halevy et al. 1987; McConnell et al. 1995; Schwab et al. 2000; Growther 1934; Dong et al. 2010; Omadewu et al. 2019; Bibi et al. 2011; Brown and Pope 1939; Pettigew 2014, 2015; Zhou and Yin 2014), seed size and index, fibre quality (especially maturity and hence micronaire, but also length, strength and uniformity), ginning costs and lint turn out (ICAC 2015; Gadhiya et al. 2009; Growther 1934; Bennett et al. 1967; Benson et al. 1998; Wang et al. 2012). The amount of N used is thus contingent on the expected/theoretical yield which can be greatly influenced by various factors, such as the varieties used for either Upland (*Gossypium hirsutum* L.) or Extra Long Staple (ELS), Pima type (*Gossypium barbadense* L.) cottons, the plant population (plants·m^2), residual N already present in the soil (determined by pre-sowing analysis and/or in-crop tissue analysis), cover crops, row spacing, environmental conditions, including weather and soil types, as well as crop management, such as appropriate irrigation, and damage by herbicide and insects (Bibi et al. 2011; Boman et al. 1997; Gerik et al. 1994; Howard et al. 2001; Koli and Morrill 1976b; Stewart et al. 2005; McConnell et al. 1993; McFarland et al. 1999; Mubarak and Janat 2018; Tewolde et al. 1994; Bauer et al. 1994; Mascagni et al. 1993; Hons et al. 2003; Luo et al. 2018; Rochester 2011). In terms of soil type, heavy textured (clayey) soil negatively influences the uptake of applied N due to denitrification because of poor aeration (Rochester 2007). It has also been stated that at a low yield of < 560 kg·ha^{-1}, the application of N provided no significant yield increase (Boman et al. 1997). It has also been reported that around 5% of the world area planted with cotton receive no application of N, this being due to affordability or high fertile soils (ICAC 2015, 2016b).

It has been stated that N is the most difficult nutrient to manage in cotton production as it has a greater impact on yield, crop maturity and lint quality than any other primary plant nutrient (Hons et al. 2003, 2004; Bondada and Oosterhuis 2001; Ducamp et al. 2012). The management of N, in terms of the rate and timing, is thus important, especially for dryland cotton, where stripper harvesters are used as well as for cotton grown in Ultra Narrow Row (UNR) spacing, as excessive application or deficiency can adversely affect the cost, plant growth and environment due to their inorganic nature and greenhouse gas emissions, especially nitrous oxide (Shah 2008; Rochester 2014, 2011; Boman et al. 1997; McConnell et al. 1993; Ali 2015; Boquet 2005; Lokhande and Reddy 2015; Rinehardt et al. 2004; MacDonald et al. 2012; Zhang et al. 2018; Yin et al. 2019). The increase in carbon dioxide

(CO_2) concentration will also affect the application of N in the future (Reddy et al. 2004). It has been stated that N deficiency in a cotton crop is not particularly difficult to diagnose and correct, whereas an excess application of N, which can damage final crop productivity and profitability, is more difficult to detect and correct (Ali 2011). The accurate prediction of crop yields is thus important and can assist growers to make decisions on crop management, pricing, and marketing (Zhou and Yin 2014).

N deficiencies will reduce root growth, stunt plant height, slow down the plant vegetative (small leaves) and reproductive processes (lack of vigour) due to reduced photosynthetic activity, increase leaf and fruit shedding due to elevated levels of ethylene. With a N deficiency, the leaves are pale-to-yellowish-green in colour and as the deficiency increases the lower leaves turn brown and die (Fig. 1). A N deficiency also leads to early senescence (cut-out), yield loss and increased sensitivity to water stress (Gerik et al. 1998; McConnell et al. 1993, 1995, 1996; Tucker 1984, 1999; Omadewu et al. 2019; Howard et al. 2001; Mubarak and Janat 2018; Bauer et al. 1994; Hons et al. 2004; Ali 2011, 2015; Lokhande and Reddy 2015; Boquet and Breitenbeck 2000; Echer et al. 2020; Girma et al. 2007; Madani and Oveysi 2015; Rashidi and Gholami 2011; Rutto et al. 2013; Wullschleger and Oosterhuis 2008; Guinn 1982; Nelson 1949; Radin and Mauney 1991; Ebelhar and Ware 2003; Hutmacher 2017). In certain cases, N deficiency may be desirable to limit vegetative growth, improve maturity and produce optimum ELS cotton yields, which is generally more determinate, taller, and later maturing than Upland cotton (Tewolde et al. 1994; Tewolde and Fernandez 1997, 2003; Silvertooth 1994; Unruh and Silvertooth 1996a). N deficiency can also increase drought resistance by limiting leaf area, slowing growth, and increasing stomatal sensitivity to water stress (Radin and Mauney 1991).

Cotton is a perennial crop, managed as an annual crop, which means that adverse reactions are possible from an excess application of N (Ebelhar and Ware 2003). The consequences of the excessive application of N have been extensively studied, with researchers already identified as early as 1934, that too much N will result in excess vegetation, thereby reducing the harvest index (ratio of harvested product (lint and seed) to the above ground plant dry weight or biomass (stem, leaves and fruit)) and delayed maturity (ICAC 2015; Growther 1934; Harris and Smith 1980) and reduced the rate at which fruit is set initially (Hearn 1975a). Later studies have shown that the excessive application of N results in larger plants, increased number of nodes and nodes above the cracked boll, more vegetative growth, and a dense canopy, resulting in poor boll setting, reduced boll size, boll rot and shedding caused by vegetative shading (Fig. 2).

Fig. 1 Image of N deficient cotton plants (Courtesy Baird, Jonathan C.)

It also encourages diseases, such as wilt, reduces pesticide efficacy, increases insect attractiveness (specifically aphid, whitefly and flea hopper), delays crop and fruit maturity, due to reduced photosynthesis, encourages regrowth, and thereby increasing trash levels, resulting in issues with defoliation, prolongs effective flowering leading to delayed defoliation and lower yield than expected, due to larger seeds with increased weight and the increasing need for growth regulators (Gerik et al. 1998; McConnell et al. 1993, 1995, 1996; Rosolem and van Mellis 2010; Malik 1998; Omadewu et al. 2019; Howard et al. 2001; Koli and Morrill 1976b; Tewolde et al. 1994; Bauer et al. 1994; Ali 1975b, 1998a, 2011, 2015; Boquet and Breitenbeck 2000; Girma et al. 2007; Madani and Oveysi 2015; Rutto et al. 2013; Guinn 1982; Nelson 1949; Ebelhar and Ware 2003; Hutmacher 2017; Tewolde and Fernandez 2003; Bentz et al. 1995; Blua and Toscano 1994; Boman and Westerman 1994; Hodgson and MacLeod 1988; Jackson and Tilt 1968; Scarsbrook et al. 1959; MacKenzie and Schaik 1963; Main et al. 2011, 2013; Perkins and Douglas 1965; Saleem et al. 2010; Saranga et al. 1997; Sui et al. 2017; Waddle 1984; Cisneros and Godfrey 2001a, b; Rochester et al. 2001b; Constable and Rochester 1988; Constable and Hearn 1981; Hearn 1986; Anas et al. 2020; Nichols 2003b; Bruce et al. 2020; Williams et al. 2019; Parajulee et al. 2020; Matis et al. 2008; Munshi and Sundaram 1985; Godfrey et al. 2000a) (Fig. 3).

Excessive application of N can also increase seed protein and decrease seed oil content (Main et al. 2013; Bruce et al. 2020). Furthermore, the excessive application of N can lead to soil salinization and increase the negative effects of soil salinity on plant performance (McCarty and Funderburg 1990) as well as contributing to global warming due to the emission of nitrous oxide (N_2O–N) and nitrogen oxides (NO_x–N) (MacDonald et al. 2018), with N losses of up to 100 kg·ha^{-1} possible due to denitrification and leaching (Rochester 2003). The potential for NO_3 leaching also increases as plants under salt stress do not absorb and/or utilize the applied N efficiently (McConnell et al. 1996; Waddle 1984; Chen et al. 2010). Excessive use of N can also lead to ground and surface water contamination, making the water unsafe for drinking (Zhang et al. 2018; Fritschi et al. 2003; McConnell 2008).

From the above it's clear why the application and management of N are becoming of importance with the cotton industry needing to focus more on the efficient use of N (Snyder et al. 2009).

Cotton nitrogen fertiliser use-efficiency (NUE)

From the above it is clear that the amount of N applied is critical, with the optimum application very important in terms of yield and other factors. The amount of N applied to cotton crops can range from less than 100 kg·ha^{-1}to over 500 kg·ha^{-1} (Tucker 1999; Rochester 2011, 2014; Omadewu et al. 2019; Bibi et al. 2011; Girma et al. 2007; Saleem et al. 2010; Rochester et al. 2001b; Constable and Rochester 1988; Hearn 1986; Ockerby et al. 1993; Smith et al. 2014; Welsh et al. 2017; Braunack 2013), with 222 kg·ha^{-1} recommended to achieve 2324 kg·ha^{-1} lint, 270 kg·ha^{-1} to achieve 3 500 kg·ha^{-1} lint 330 kg·ha^{-1} to achieve 4 400 kg·ha^{-1} lint and 384 kg·ha^{-1} to achieve 5 000 kg·ha^{-1} lint (Constable and Bange 2015; Rochester et al. 2001b; Rochester and Constable 2015). An overview of reported application levels has been provided (Rochester 2007) with the levels very much dependent on the factors mentioned previously in the review, as well as high levels of N available

Fig. 2 Left plants with 0, 200 and 400 kg·ha^{-1} N. Right shows the number and size of bolls for 0 and 300 kg·ha^{-1} N(Courtesy Weaver, Timothy B.)

Fig. 3 Defoliated leaf caught in canopy (courtesy van der Sluijs, Marinus H. J.)

in the soil due to excessive N fertiliser applications in previous years (Scheer 2018). For this reason, NUE, as defined below, is a more reliable and realistic measure of N fertilisation efficiency. NUE is a fairly simple measure for evaluating efficiency of the conversion of N fertiliser into cotton lint (Eq. 1).

$$\mathrm{NUE} = \frac{\mathrm{Lint\ produced\ (kg \cdot ha^{-1})}}{\mathrm{N\ fertiliser\ applied\ (kg \cdot ha^{-1})}} \tag{1}$$

The excess application of N is common, with trials on Upland cotton in Australia showing that, on average, an excess N of 50~110 kg·ha^{-1} was applied, and that the application of N can be reduced by 15%~25% without affecting the yield, an NUE of 13~18 was recommended for irrigated cotton (Rochester 2011, 2014; Welsh et al. 2015; Rochester and Constable 2015;). In Australia, N application levels above 200~250 kg·ha^{-1} do not result in increased yields for both conventional and Bollgard 2 varieties (Rochester 2007; Buster 2019a, b, c; Rochester et al. 2006; Afzal et al. 2018; Hutmacher et al. 2004) and reduce N_2O losses and improve NUE (MacDonald et al. 2015). This was also found in trials conducted in the Yangtze River Valley in China where increasing the application of N above 180 kg·ha^{-1} actually resulted in a dramatic decrease in yield (Song et al. 2020). Indeed, according to a recent study in the US the increased application levels of N did not result in an increase in yield at 45% of their trial sites and that, on average, an excess of 22~138 kg·ha^{-1} N was applied at 64% of their trial sites (Farmaha et al. 2021). It has been stated that Australia uses 421 kg·ha^{-1} N, which seems excessively high, as opposed to the 63 kg·ha^{-1} in the US, which seems very low (Kranthi 2020; ICAC 2019), with 375 kg·ha^{-1} being recommended for high yielding cotton fields in Xinjiang, China (Luo et al. 2018). It has been recommended that in the US maximum cotton yields can be achieved with 235 kg·ha^{-1} N for Upland cotton and 190 kg·ha^{-1} N for Pima cotton (Geisseler and Horwarh 2016). Other studies have shown that 10~29 kg of N was required per 100 kg of cotton lint produced (Gerik et al. 1998; Main et al. 2013; Hutmacher et al. 2001; Bassett et al. 1970; Halevey 1976; Unruh and Silvertooth 1996b).

An NUE greater than 18 indicates that insufficient N has been added, and an NUE below 13 indicates that too much N has been applied or that other production constraints, such as water, pest, soil, and nutrient management, are hindering yield (Rochester 2007, 2014). It has been found that the amount of N required could be reduced by up to 80 kg·ha^{-1} if the cotton crop follows legumes, peanuts, or soybean crops (Nichols 2003b; Rochester et al. 2001a), whereas higher amounts of N are required when cotton follows small grain cover crops (Ducamp et al. 2012).

Regional grower and Development Officers as well as industry surveys conducted in Australia from 2008 to 2020 showed that, on average, industry-wide NUE levels were below the optimum range of 13~18 across all regions under irrigation (Welsh et al. 2017; Anon 2013a, b, 2014, 2016a, 2017, 2018, 2019, 2020a; b; Rochester 2012a; Roth 2011). This indicated that for irrigated cotton systems, more N was applied on average than that required, with the excess N most likely lost through denitrification and volatilisation. It has been stated that this excess application of N amounts to a direct cost to the Australian industry of A$10 million a year, with the indirect costs many times this amount (Rochester 2008), indicating a potential saving of A$130·ha^{-1} by not applying excess N (Buster 2019c). However, due to the low cost of N, the extra cost incurred is often interpreted as an insurance policy for losses from the system and to cover potential errors in calculation in terms of the rate required to achieve maximum yield (Welsh et al. 2015; Hutmacher et al. 2003; Goulding et al. 2008). However, it has been stated that the increased cost of additional growth regulators, insecticides, and defoliation applications are often not considered (Nichols 2003b). It has also been suggested that measuring the concentration of N in seed can provide insight into whether the optimum amount of N was applied (Rochester 2012b; Egelkraut et al. 2004).

Fibre quality

Motivation

From the above it is clear that the agronomic N requirements in terms of plant growth, health, yield etc. of cotton are well understood and has been studied since 1887 (Maples et al. 1990), with practical guidelines (Anon 2001), decision support systems (Gerik et al. 1998; Deutscher et al. 2001), models (Zhao et al. 2010) and recent reviews (Khan et al. 2017; Ali 2015; MacDonald et al. 2018; Soomro et al. 2020) providing information on the importance of providing crops with sufficient supply of nutrients and improving NUE. Given that the financial return to the grower in most crop production systems depends on crop quantity and quality and due to the growing importance of fibre quality, it was considered important to undertake a more recent and focussed review than that published previously (Bradow and Davidonis 2000), of published work and knowledge related more specifically to the effect of N application on fibre quality, including lint turn out.

Fibre quality properties

Due to the greater demands of modern spinning, in terms of speed and automation, the cost of raw material and the increasingly competitive global textile market, cotton fibre quality is of utmost importance to the spinner. As a consequence, there are a number of physical properties that have been identified by the cotton trade and spinning industry as the most important which includes fibre length, length uniformity, strength, micronaire (a combination of maturity and fineness), colour and trash. As a consequence, cotton is bought and sold depends on these fibre properties. Indeed, a study concluded that on average at 30%, colour had the highest contribution to the price of cotton, followed by cleanliness/trash at 23%, micronaire at 22%, length at 20%, and strength at 5% (Chakraborty et al. 2000). Other studies found that the textile industry paid 0.38% to 1% more for cotton that was 1% less gray and 0.13% to 0.63% for cotton that was 1% less yellow, i.e., brighter (Chakraborty and Ethridge 1999; Ethridge et al. 2000; Chen et al. 1997). Indeed, it has been shown that in Australia the difference between a Middling (31) and Strict Low Middling (41) can result in A$760 loss per hectare for a grower (McVeigh 2017).

Another important quality aspect is lint turn out, which is the percentage of the weight of usable fibre to the weight of un-ginned seed cotton, which is normally calculated using module and ginned bale weights.

Fibre length

Fibre length and other aspects of fibre length distribution, e.g., short fibre (fibres ≤ 12.7 mm) content and fibre length uniformity, are amongst the most important fibre quality attributes of cotton lint (Starbird et al. 1987). As it is considered one of the easiest to measure (Sever 1932), it was the first physical parameter to be measured for cotton quality determination (May 1999; Smith et al. 2010; Nickerson and Griffith 1964). As can be seen in Table 1, as a consequence, several methods were developed and used by the trade and industry, ranging from a human classer using a manual technique to direct measurement to more rapid methods for mill use and currently the use of automated, fast methods. From Table 1 it appears that the effect of N application levels on fibre length and length uniformity are rather varied and often inconsistent. This is not surprising as fibre length is primarily a genetic trait, with short fibre content, which will affect length uniformity, dependent upon genotype, environmental and growing conditions, harvesting, and ginning methods and conditions (Bradow and Davidonis 2000; Percy et al. 2006). Studies have shown that cultivar selection accounts for 75% of fibre length variation with 25% of the variation attributed to weather, environment

Table 1 Effect of N level on fibre length

Year	Location	Country	N levels in kg·ha^{-1}	Instrument	Remarks	References
1927–1929	College Station, Texas	US	0,56,112,168 & 224	Fibre arrays	No significant differences in fibre length with increased N application levels	Reynolds and Killough (1933)
1944–1946	Rocky Mount, North Carolina	US	11,39 & 67	Fibrograph	Increase in UHML from 11 to 39 kg·ha^{-1} and small but significant difference from 39 to 67 kg·ha^{-1}. Also, a slight reduction in length uniformity from 11 to 39 kg·ha^{-1} and a slight increase from 39 to 67 kg·ha^{-1}	Nelson (1949)
1951–1960	Brawley, California	US	0, 107, 214 & 321	Classer	No significant differences in fibre length or length uniformity with increased N application levels	Bennett et al. (1967)
1956–1962	Thorsby, Alabama	US	0, 107, 214 & 321	Classer	The application of N increased UHML, with increased applications. No effect on length uniformity	Bennett et al. (1967)
1959–1960	Brawley, California	US	0, 107, 214 & 321	Classer	No significant differences in fibre length or length uniformity with increased N application levels	MacKenzie and Schaik (1963)
1961–1963	Magnum, Oklahoma	US	0, 44, 67, 90 & 112	Digital fibrograph	No significant differences in fibre length with increased N application levels	Murray et al. (1965)
1961–1963	Altus, Oklahoma	US	0, 44, 67, 90 & 112	Digital fibrograph	No significant differences in fibre length with increased N application levels	Murray et al. (1965)
1961–1963	Unknown	US	0, 28, 54, 80, 120, 134, 161 & 187	Fibrograph	Increase in UHML from 11 to 28 kg·ha^{-1} with no further increase with increased N application levels	Perkins and Douglas (1965)
1963–1965	Yuma, Arizona	US	84 & 224	Unknown	Increase in UHML with increased N application levels	Jackson and Tilt (1968)
1965–1980	Eight locations	Greece	0,60,50,100,120,150,180 & 200	Digital fibrograph	No clear trend with increased N application levels	Setatou and Simonis (1994, 1995)
1967	Fresno County, California	US	56, 105, 224, 343 & 392	Fibrograph	Slight increase in UHML with increased N application levels	Grimes et al. (1969a, b)
1967	Kent County, California	US	0, 41, 140, 239 & 280	Fibrograph	Slight increase in UHML with increased N application levels	Grimes et al. (1969a, b)

Table 1 (continued)

Year	Location	Country	N levels in kg·ha^{-1}	Instrument	Remarks	References
1972–1973	Kimberley, Western Australia	Australia	34, 112, 168 & 225	Digital fibrograph	Increase in fibre length and length uniformity with increased N application levels	Hearn (1976)
1973–1974	Unknown[b]	US	0, 45 & 90	Digital fibrograph	No significant differences in 2.5% Span length with no clear trend for uniformity index with increased N application levels	Koli and Morrill (1976a)
1974	Narrabri, New South Wales	Australia	0, 40, 80 & 160	Digital fibrograph	Significant increase in 2.5% Span length with increased N application levels	Constable and Hearn (1981)
1975–1978	Narrabri, New South Wales	Australia	0, 50, 100 & 150	Digital fibrograph	Significant increase in 2.5% Span length with increased N application levels	Constable and Hearn (1981)
1982–1983	Morena, Madhya Pradesh	India	0, 40, 80 & 120	Unknown	No significant differences in fibre length with increased N application levels	Shrivastava and Singh (1988)
1984–1986	Altus, Oklahoma	US	0, 56, 112 & 224	High volume instrument (HVI™)	No significant differences in fibre length or length uniformity with increased N application levels	Boman and Westerman (1994)
1989–2004	Altus, Oklahoma	US	0, 45, 90, 135, 180 & 225	HVI	No significant differences in fibre length or length uniformity with increased N application levels	Girma et al. (2007)
1991–1992	Stoneville, Mississippi	US	112 & 150	Digital fibrograph	No significant differences in fibre length or length uniformity with increased N application levels	Pettigew et al. (1996)
1991–1992	Uvalde, Texas[b]	US	0, 67, 135, 202 & 269	HVI	Increase in 2.5% Span length up to 135 kg·ha^{-1} and thereafter a slight reduction with increase N application levels. Uniformity reduced with increased N application rates	Tewolde and Fernandez (2003)
1991–1992	Lakhasti	India	0, 40, 80 & 120	Unknown	No significant differences in fibre length with increased N application levels	Chand (1997)
1992–1996	Mississippi Delta	US	101, 135, 168 & 202	HVI	No significant differences in fibre length or length uniformity with increased N application levels	Ebelhar et al. (1996)

Table 1 (continued)

Year	Location	Country	N levels in kg·ha^{-1}	Instrument	Remarks	References
1995–1998	Hama	Syria	0, 60, 120, 180 & 240	Unknown	No significant differences in fibre length with improved length uniformity with increased N application levels	Janat and Somi (2002)
1996–1998	Florence, South Carolina	US	0, 78 & 112	HVI	No significant differences in fibre length or length uniformity with increased N application levels	Bauer and Roof (2004)
1997–2000	Winnsboro, Louisiana[b]	US	90, 112, 134 & 157	HVI	No significant differences in fibre length, length uniformity and short fibre index with increased N application levels	Boquet (2005)
1998–2000	San Joaquin Valley, California	US	56, 112, 168 & 224	HVI	No significant differences in fibre length with increased N application levels	Fritschi et al. (2003)
1999	Thrall, Texas[b]	US	0, 56, 112 & 224	HVI	No significant differences in fibre length with increased N application levels	McFarland et al. (1999)
1999–2000	Mississippi, Louisiana	US	Small scale trial with control and 20% at first flower & 0% at first flower	Digital fibrograph	No significant differences in fibre length with increased N application levels	Read et al. (2006)
1999–2000	Fresno, California[a]	US	56, 112, 168 & 224	HVI	No significant differences in fibre length with increased N application rates	Fritschi et al. (2003)
1999–2000	Giza	Egypt	95 & 143	Digital fibrograph	Small but significant increase in 2.5% and 50% Span length with no affect on uniformity ratio with increased N application levels	Sawan et al. (2006)
2001–2002	Unknown	Syria	50, 100, 150, 200 & 250	Unknown	No significant differences in fibre length with improved length uniformity with increased N application levels	Janat (2008)
2003–2004	Adana	Turkey	0, 80 & 160	HVI	No significant differences in 2.5% Span length or uniformity index with increased N application levels	Gormus (2005)
2001–2004	Stoneville, Mississippi	US	112 in four different application methods	Digital fibrograph	No significant differences in fibre length or length uniformity	Pettigew and Adamczyk (2006)

Table 1 (continued)

Year	Location	Country	N levels in kg·ha^{-1}	Instrument	Remarks	References
2005	Nanjing, Jiangsu	China	0, 240 & 480	HVI	Significant increase in fibre length with increased N application levels, with 240 kg·ha^{-1} the optimal amount	Zhao et al. (2012)
2005	Xuzhou, Jiangsu	China	0, 240 & 480	HVI	Significant increase in fibre length with increased N application levels, with 240 kg·ha^{-1} the optimal amount	Zhao et al. (2012)
2007	Anyang, Henan	China	0, 240 & 480	HVI	Significant increase in fibre length with increased N application levels, with 240 kg·ha^{-1} the optimal amount	Zhao et al. (2012)
2005–2006	Khedbhrahma, Gujarat	India	160, 200 & 240	Unknown	No significant differences in 2.5% Span length with increased N application levels	Gadhiya et al. (2009)
2005–2006	Multan, Punjab	Pakistan	0, 50, 100 & 150	HVI	No significant differences in fibre length or length uniformity with increased N application levels	Afzal et al. (2018)
2006	Faisalabad, Punjab	Pakistan	0, 60, 120 & 180	HVI	No significant differences in fibre length or length uniformity with increased N application levels	Saleem et al. (2010)
2007–2008	Multan, Punjab	Pakistan	0, 60, 110 & 160	HVI	No clear trend on fibre length with no significant differences for length uniformity with increased N application levels	Ali (2011)
2009–2012	Stoneville, Mississippi	US	0, 56 & 112	HVI	Slight but significant increase in fibre length with increased N application levels	Pettigew (2012) and Pettigew and Zeng (2014)
2008–2010	Varamin, Tehran	Iran	200, 300, 350 & 400	HVI	No clear trend with increased N application levels	Madani and Oveysi (2015)
2008–2010	Gorgan, Golestan	Iran	200, 300, 350 & 400	HVI	Small but significant increase in both 2.5% and 50% Span length and uniformity ratio with 350 kg·ha^{-1} with reduction with increased N application levels	Madani and Oveysi (2015)

Table 1 (continued)

Year	Location	Country	N levels in kg·ha^{-1}	Instrument	Remarks	References
2009–2010	Varamin, Tehran	Iran	0, 100, 200 & 300	HVI	No significant differences in fibre length with increased N application levels	Rashidi and Gholami (2011), Hossein et al. (2014) and Seilsepour and Rashidi (2011)
2009	Mississippi State University	US	0 & 100	HVI	Small but significant decrease in fibre length with no change in uniformity with increased N application levels	Lokhande and Reddy (2015)
2010–2011	Adana	Turkey	0, 60, 120, 180 & 240	HVI	Significant increase in fibre length with 60 kg·ha^{-1} with a reduction in fibre length with increased N application levels	Gormus et al. (2016a)
2012–2013	Adana	Turkey	0, 60, 120, 180 & 240	HVI	Significant increase in fibre length with 60 kg·ha^{-1} with a reduction in fibre length with increased N application levels	Gormus and El Sagagh (2016b)
2011	Torreón, Coahuila	Mexico	0, 50, 100 & 150	Unknown	No significant differences in fibre length with increased N application levels	Hernandes-Cruz et al. (2015)
2011–2012	Yellow River Delta, Hebei	China	0, 120, 240, & 480	HVI	No significant differences in fibre length with increased N application levels. There was, however, a significant increase in uniformity with increased N application levels	Chen et al. (2019)
2012–2013	Chapadão do Sul, Mato Grosso do Sul	Brazil	0, 40, 80, 120 & 160	HVI	No significant differences in fibre length with increased N application levels. There was, however, a significant reduction in uniformity with increased N application levels	Leal et al. (2020)
2013	Stoneville, Mississippi	US	0, 39, 67, 101, 135 & 168	HVI	Significant decrease in fibre length with increased N application levels	Sui et al. (2017)
2014	Stoneville, Mississippi	US	0, 56, 112, 168 & 224	HVI	Significant decrease in fibre length with increased N application levels	Sui et al. (2017)

Table 1 (continued)

Year	Location	Country	N levels in kg·ha^{-1}	Instrument	Remarks	References
2013–2014	New Delhi	India	100, 125, 150 & 175	Ball's comb sorter	Significant increase in 50% Span length and decrease in uniformity ratio with increased N application levels	Verna et al. (2017)
2016–2018	Suffolk, Virginia	US	0, 45, 90, 135 & 180	HVI	No significant differences in fibre length or length uniformity	McClanahan et al. (2020)
2016–2017	Lewiston-Woodside, North Carolina	US	0, 45, 90, 135 & 180	HVI	No significant differences in fibre length or length uniformity	McClanahan et al. (2020)
2018	Yale, Virginia	US	0, 45, 90, 135 & 180	HVI	No significant differences in fibre length or length uniformity	McClanahan et al. (2020)
Unknown	Giza[a]	Egypt	107 & 161	Digital fibrograph	No significant difference in 2.5% and 50% Span length or uniformity ratio with increased N application levels	Sawan et al. (1997)

[a] Pima

[b] Ultra narrow row

and management (Meredith 1986, 1994; Eaton 1947). This was highlighted by a recently published study conducted in Mato Grosso, Brazil from 2012 to 2013, which concluded that increased N applications increased fibre length in 53% of the thirteen varieties used in their study, and that 46% of the varieties maintained their fibre length with a reduction in N application levels (Echer et al. 2020). An Ordered Logit model showed that the application of N can result in a significant, but small increase in fibre length (Zhao et al. 2010). The application of N will only generally tend to improve fibre length when there is some severe deficiency and hence the application above NUE does not provide any potential for economical gain (Deckard et al. 1984). However, if the fibre length is below base grade (depending on the staple length but ranges from 27.2 to 28.7 mm) this can influence the price of the product and will determine the spinning system, yarn count, and twist.

Fibre strength

The inherent breaking strength of individual cotton fibres is considered to be one of the most important factors in determining the strength of the yarn, especially rotor-spun, produced from those fibres (Moore 1996; Patil and Singh 1995). As a consequence, as can be seen in Table 2, several methods were developed and used by the trade and industry. From Table 2 it appears that the effect of N application levels on fibre strength and elongation are also rather varied. There is however a clearer indication than fibre length that fibre strength is not affected by N application levels. Again, this is not surprising as fibre strength, like fibre length, is also primarily a genetic trait, other factors such as ginning, environment and weather as well as management can affect fibre strength (Meredith 1994; Moore 1996).

If the fibre strength is not reduced below the base grade (depending on the staple length) but generally > 28 $g{\cdot}tex^{-1}$ this will not affect the price and processability of the fibre.

N application levels did not seem to influence elongation. This being said elongation is a difficult measurement as generally there are issues with high replicate variation, fibre slippage, and crimp and that this is a noncalibrated measurement.

Micronaire and maturity

Micronaire (no unit) is amongst the most important fibre quality attributes of cotton lint and has a substantial influence on processing performance in terms of ends breakages, processing waste, yarn and fabric quality, dyed fabric appearance as well as end-use (van der Sluijs et al. 2008). Micronaire will determine the spinning system to be used (i.e., ring, rotor, or air-jet), the specifications in terms of yarn count and twist, as well as processing speeds (van der Sluijs et al. 2008; El Mogahzy et al. 1990; Hunter 1980, 2006). Excessive micronaire variation could lead to streakiness or barré due to differences in dye absorbency and retention, and hence the levels within a laydown or blend should not vary excessively (≥ 0.2 units) (Hunter 2006; Chellamani et al. 2001).

The majority of studies have concluded that there was either no significant differences in micronaire with increased N application levels or that there was no clear trend—see Table 3. This being due to contrasting results between years as well as within a year, where micronaire either increased, decreased, or did not change with N application levels. Some studies concluded that micronaire decreased with increased N application levels (Pettigew and Zeng 2014; Boman et al. 1997; Lokhande and Reddy 2015; Echer et al. 2020; Tewolde and Fernandez 2003; Sui et al. 2017; Fritschi et al. 2003; Ebelhar et al. 1996; Hearn 1976; Janat and Somi 2002; Koli and Morrill 1976a; Leal et al. 2020; McClanahan et al. 2020; Pettigew 2012; Sawan et al. 1997; Zhao et al. 2012) most likely due to a delay in maturity as shown in Table 4. Other studies concluded that micronaire increased with increased N application levels (Bennett et al. 1967; Rashidi and Gholami 2011; Sawan et al. 1997; Bauer and Roof 2004; Hossein et al. 2014; Seilsepour and Rashidi 2011). These results are also unsurprising as although the selection of variety is important, some 51% of the variation in micronaire is attributed to weather (i.e., temperature, overcast and cloudy conditions) and management (i.e., planting date, irrigation, weed & insect control, growth regulators, defoliation, and nutrients) (Bradow and Davidonis 2000; Meredith 1986, 1994; Eaton 1947; Cathey and Meredith 1988).

If the micronaire is not reduced below the base grade (G5) this will not affect the price and processability of the fibre.

Colour

Colour is determined either visually or objectively. Since the 1900s visual classification is conducted either by using Universal Upland and American Pima Grade Standards established by the United States Department of Agriculture (USDA-AMS). In some instances, cotton is also sold depend on physical grades and shipper types represented by actual samples, which are used for reference purposes against the shipped cotton. Objective measurements are determined by High Volume Instruments (HVI™) that provide information on colour in terms of reflectance (Rd) and yellowness (+b) as well as the resultant colour grade.

Table 5 shows that only a small number of studies have been conducted on the effect of N application levels

Table 2 Effect of N level on fibre strength

Year	Location	Country	N levels in kg·ha^{-1}	Instrument	Remarks	References
1944–1946	Rocky Mount, North Carolina	US	11,39 & 67	Pressley	Significant reduction in Pressley Index from 11 to 39 kg·ha^{-1} and significant increase in Pressley Index from 39 to 67 kg·ha^{-1}	Nelson (1949)
1951–1960	Brawley, California	US	0, 107, 214 & 321	Pressley	No significant differences in fibre strength with increased N application levels	Bennett et al. (1967)
1956–1962	Thorsby, Alabama	US	0, 107, 214 & 321	Pressley	No significant differences in fibre strength with increased N application levels	Bennett et al. (1967)
1959–1960	Brawley, California	US	0, 107, 214 & 321	Stelometer with 3.2 mm gauge	No clear trend with increased N application levels	MacKenzie and Schaik (1963)
1961–1963	Magnum, Oklahoma	US	0, 44, 67, 90 & 112	Stelometer with 3.2 mm gauge	No significant differences in fibre strength with increased N application levels	Murray et al. (1965)
1961–1963	Altus, Oklahoma	US	0, 44, 67, 90 & 112	Stelometer with 3.2 mm gauge	No significant differences in fibre strength with increased N application levels	Murray et al. (1965)
1961–1963	Unknown	US	0, 28, 54, 80, 120, 134, 161 & 187	Stelometer with 3.2 mm gauge	No significant differences in fibre strength with increased N application levels	Perkins and Douglas (1965)
1963–1965	Yuma, Arizona	US	84 & 224	Pressley	No clear trend with increased N application levels	Jackson and Tilt (1968)
1965–1980	Eight locations	Greece	0, 60, 50, 100, 120, 150,180 & 200	Stelometer	No clear trend with increased N application levels	Setatou and Simonis (1994, 1995)
1967	Fresno County, California	US	56, 105, 224, 343 & 392	Stelometer with 3.2 mm gauge	No significant differences in fibre strength and elongation with increased N application levels	Grimes et al. (1969a, b)
1967	Kent County, California	US	0, 41, 140, 239 & 280	Stelometer with 3.2 mm gauge	No significant differences in fibre strength and elongation with increased N application levels	Grimes et al. (1969a, b)
1972–1973	Kimberley, Western Australia	Australia	34, 112, 168 & 225	Stelometer with 3.2 mm gauge	No significant differences in fibre strength with increased N application levels	Hearn (1976)
1973–1974	Unknown[b]	US	0, 45 & 90	Stelometer with both 0 and 3.2 mm gauge	No significant differences in fibre strength with increased N application levels	Koli and Morrill (1976a)

Table 2 (continued)

Year	Location	Country	N levels in kg·ha^{-1}	Instrument	Remarks	References
1974	Narrabri, New South Wales	Australia	0, 40, 80 & 160	Stelometer with 3.2 mm gauge	No clear trend with increased N application levels	Constable and Hearn (1981)
1975–1978	Narrabri, New South Wales	Australia	0, 50, 100 & 150	Stelometer with 3.2 mm gauge	No clear trend with increased N application levels	Constable and Hearn (1981)
1984–1986	Altus, Oklahoma	US	0, 56, 112 & 224	HVI	No significant differences in fibre strength and elongation with increased N application levels	Boman and Westerman (1994)
1989–2004	Altus, Oklahoma	US	0, 45, 90, 135, 180 & 225	HVI	Slight but significant increase in fibre strength with increased N application levels	Girma et al. (2007)
1991–1992	Stoneville, Mississippi	US	112 & 150	Stelometer	No significant differences in fibre strength and elongation with increased N application levels	Pettigew et al. (1996)
1991–1992	Uvalde, Texas[a]	US	0, 67, 135, 202 & 269	HVI	No significant differences in fibre strength and elongation with increased N application levels	Tewolde and Fernandez (2003)
1992–1996	Mississippi Delta	US	101, 135, 168 & 202	HVI	No significant differences in fibre strength and elongation with increased N application levels	Ebelhar et al. (1996)
1995–1998	Hama	Syria	0, 60, 120, 180 & 240	Stelometer & Pressley	No significant differences in fibre strength as measured by stelometer and elonga-tion as measured by pressley with increased N application levels	Janat and Somi (2002)
1996–1998	Florence, South Carolina	US	0, 78 & 112	HVI	Significant increase in fibre strength with increased N application levels	Bauer and Roof (2004)
1997–2000	Winnsboro, Louisiana[b]	US	90, 112, 134 & 157	HVI	No significant differences in fibre strength and elongation with increased N application levels	Boquet (2005)
1999–2000	Fresno, California[a]	US	56, 112, 168 & 224	HVI	No significant differences in fibre strength with increased N application levels	Fritschi et al. (2003)

Table 2 (continued)

Year	Location	Country	N levels in kg·ha^{-1}	Instrument	Remarks	References
1999–2000	Giza[a]	Egypt	95 & 143	Stelometer with 3.2 mm gauge	Small but significant increase in fibre strength with increased N application levels	Sawan et al. (2006)
1998–2000	San Joaquin Valley, California	US	56, 112, 168 & 224	HVI	No significant differences in fibre strength with increased N application levels	Fritschi et al. (2003)
1999	Thrall, Texas[b]	US	0, 56, 112 & 224	HVI	No significant differences in fibre strength with increased N application levels	McFarland et al. (1999)
1999–2000	Mississippi, Louisiana	US	Small scale trial with control and 20% at first flower & 0% at first flower	Stelometer	No clear trend with increased N application levels	Read et al. (2006)
2001–2002	Unknown	Syria	50, 100, 150, 200 & 250	Stelometer & Pressley	Small but insignificant differences in fibre strength as measured by stelometer and elongation as measured by pressley with increased N application levels	Janat (2008)
2003–2004	Adana	Turkey	0, 80 & 160	HVI	No significant differences in fibre strength and elongation with increased N application levels	Gormus (2005)
2001–2004	Stoneville, Mississippi	US	112 in four different application methods	Stelometer	No significant differences in fibre strength and elongation with increased N application levels	Pettigew and Adamczyk (2006)
2005	Nanjing, Jiangsu	China	0, 240 & 480	HVI	Significant increase in strength up to 240 kg·ha^{-1} with a significant decrease above 240 kg·ha^{-1}	Zhao et al. (2012)
2005	Xuzhou, Jiangsu	China	0, 240 & 480	HVI	Significant increase in strength up to 240 kg·ha^{-1} with a significant decrease above 240 kg·ha^{-1}	Zhao et al. (2012)
2005–2006	Multan, Punjab	Pakistan	0, 50, 100 & 150	HVI	No significant differences in fibre strength or elongation with increased N application levels	Afzal et al. (2018)

Table 2 (continued)

Year	Location	Country	N levels in kg·ha^{-1}	Instrument	Remarks	References
2006	Faisalabad, Punjab	Pakistan	0, 60, 120 & 180	HVI	No significant differences in fibre strength or elongation with increased N application levels	Saleem et al. (2010)
2007	Anyang, Henan	China	0, 240 & 480	HVI	Significant increase in strength up to 240 kg·ha^{-1} with a significant decrease above 240 kg·ha^{-1}	Zhao et al. (2012)
2009–2012	Stoneville, Mississippi	US	0, 56 & 112	HVI	Significant increase in fibre strength with increased N application levels	Pettigew (2012) and Pettigew and Zeng (2014)
2008–2010	Varamin, Tehran	Iran	200, 300, 350 & 400	HVI	No significant differences in fibre strength with no clear trend for elongation with increased N application levels	Madani and Oveysi (2015)
2008–2010	Gorgan, Golestan	Iran	200, 300, 350 & 400	HVI	No significant differences in fibre strength with no clear trend for elongation with increased N application levels	Madani and Oveysi (2015)
2009–2010	Varamin, Tehran	Iran	0, 100, 200 & 300	HVI	No significant differences in fibre strength with increased N application levels	Rashidi and Gholami (2011), Hossein et al. (2014) and Seilsepour and Rashidi (2011)
2009	Mississippi, Louisiana	US	0 & 100	HVI	Small but significant decrease in fibre strength with increased N application levels	Lokhande and Reddy (2015)
2010–2011	Adana	Turkey	0, 60, 120, 180 & 240	HVI	Significant increase in fibre strength with increased N application levels	Gormus et al. (2016a)
2011	Torreón, Coahuila	Mexico	0, 50, 100 & 150	Unknown	No significant differences in fibre strength with increased N application levels	Hernandes-Cruz et al. (2015)

Table 2 (continued)

Year	Location	Country	N levels in kg·ha^{-1}	Instrument	Remarks	References
2011–2012	Yellow River Delta, Hebei	China	0, 120, 240 & 480	HVI	Significant increase in fibre strength with increased N application levels. There was, however, no effect on elongation	Chen et al. (2019)
2012–2013	Primavera do Leste, Mato Grosso	Brazil	70, 140 & 210	HVI	No clear trend with increased N application levels	Echer et al. (2020)
2012–2013	Chapadão do Sul, Mato Grosso do Sul	Brazil	0, 40, 80, 120 &160	HVI	No significant differences in fibre strength or elongation with increased N application levels	Leal et al. (2020)
2012–2013	Adana	Turkey	0, 60, 120, 180 & 240	HVI	Significant increase in fibre strength with increased N application levels	Gormus and El Sagagh (2016b)
2013	Stoneville, Mississippi	US	0, 39, 67, 101, 135 & 168	HVI	No significant differences in fibre strength with increased N application levels	Sui et al. (2017)
2014	Stoneville, Mississippi	US	0, 56, 112, 168 & 224	HVI	Significant increase in fibre strength with 56 kg·ha^{-1} with no further changes in fibre strength	Sui et al. (2017)
2013–2014	New Delhi	India	100, 125, 150 & 175	Pressley 0 gauge	Significant decrease in fibre strength with increased N application levels	Verna et al. (2017)
2016–2018	Suffolk, Virginia	US	0, 45, 90, 135 & 180	HVI	No significant differences in fibre strength with increased N application levels	McClanahan et al. (2020)
2016–2017	Lewiston-Woodside, North Carolina	US	0, 45, 90, 135 & 180	HVI	No significant differences in fibre strength with increased N application levels	McClanahan et al. (2020)
2018	Yale, Virginia	US	0, 45, 90, 135 & 180	HVI	No significant differences in fibre strength with increased N application levels	McClanahan et al. (2020)
Unknown	Giza[a]	Egypt	107 & 161	Stelometer with 3.2 mm gauge	No significant differences in fibre strength with increased N application levels	Sawan et al. (1997)

[a] Pima

[b] Ultra narrow row

Table 3 Effect of N level on micronaire

Year	Location	Country	N levels in kg·ha^{-1}	Instrument	Remarks	References
1944–1946	Rocky Mount, North Carolina	US	11,39 & 67	Arealometer	No significant differences in fineness with increased N application levels	Nelson (1949)
1951–1960	Brawley, California	US	0, 107, 214 & 321	Micronaire	Increase in micronaire with increased N application levels	Bennett et al. (1967)
1956–1962	Thorsby, Alabama	US	0, 107, 214 & 321	Micronaire	No significant differences in micronaire with increased N application levels	Bennett et al. (1967)
1959–1960	Brawley, California	US	0, 107, 214 & 321	Micronaire	No clear trend with increased N application levels	MacKenzie and Schaik (1963)
1961–1963	Magnum, Oklahoma	US	0, 44, 67, 90 & 112	Micronaire	No clear trend with increased N application levels	Murray et al. (1965)
1961–1963	Altus, Oklahoma	US	0, 44, 67, 90 & 112	Micronaire	No clear trend with increased N application levels	Murray et al. (1965)
1961–1963	Unknown	US	0, 28, 54, 80, 120, 134, 161 & 187	Arealometer	No clear trend with increased N application levels	Perkins and Douglas (1965)
1963–1965	Yuma, Arizona	US	84 & 224	Unknown	No clear trend with increased N application levels	Jackson and Tilt (1968)
1965–1980	Eight locations	Greece	0, 60, 50, 100, 120, 150,180 & 200	Micronaire	No clear trend with increased N application levels	Setatou and Simonis (1994, 1995)
1967	Fresno County, California	US	56, 105, 224, 343 & 392	Micronaire	No significant differences in micronaire with increased N application levels	Grimes et al. (1969a; b)
1967	Kern County, California	US	0, 41, 140, 239 & 280	Micronaire	No significant differences in micronaire with increased N application levels	Grimes et al. (1969a; b)
1972–1973	Kimberley, Western Australia	Australia	34, 112, 168 & 225	Micronaire	Significant reduction in micronaire with increased N application levels	Hearn (1976)
1973–1974	Unknown[b]	US	0, 45 & 90	Micronaire	Although not significant a clear reduction in micronaire with increased N application levels	Koli and Morrill (1976a)

Table 3 (continued)

Year	Location	Country	N levels in kg·ha^{-1}	Instrument	Remarks	References
1972–1983	Altus, Oklahoma	US	0, 44, 90& 135	Micronaire	In less than ideal conditions (e.g., short seasons, excessive rain in the fall, low temperatures), high N application levels tended to delay maturity, resulting in more immature fibres and reduced micronaire. While in the opposite (e.g., under the opposite conditions from those listed above), fibres tend to be more mature and thus increased micronaire. However, as these micronaire results were within the base grade (3.5 to 4.9) and hence resulted in no discounts, the differences were of little practical importance	Boman et al. (1997) and Fritschi et al. (2003)
1974	Narrabri, New South Wales	Australia	0, 40, 80 &160	Arealometer	No significant differences in micronaire with increased N application levels	Constable and Hearn (1981)
1975–1978	Narrabri, New South Wales	Australia	0, 50, 100 & 150	Arealometer	No significant differences in micronaire with increased N application levels	Constable and Hearn (1981)
1984–1986	Altus, Oklahoma	US	0, 56, 112 & 224	HVI	No significant differences in micronaire with increased N application levels	Boman and Westerman (1994)
1989–2004	Altus, Oklahoma	US	0, 45, 90, 135, 180 & 225	HVI	No significant differences in micronaire with increased N application levels	Girma et al. (2007)
1991–1992	Stoneville, Mississippi	US	112 & 150	Arealometer	No significant differences in micronaire with increased N application levels	Pettigew et al. (1996)
1991–1992	Lakhasti	India	0, 40, 80 & 120	Unknown	No clear trend with increased N application levels	Chand et al. (1997)
1991–1992	Uvalde, Texas[a]	US	0, 67, 135, 202 & 269	HVI	Small but significant decrease in micronaire with increased N application levels	Tewolde and Fernandez (2003)

Table 3 (continued)

Year	Location	Country	N levels in kg·ha^{-1}	Instrument	Remarks	References
1992–1996	Mississippi Delta	US	101, 135, 168 & 202	HVI	Significant reduction in micronaire with increased N application levels	Ebelhar et al. (1996)
1995–1998	Hama	Syria	0, 60, 120, 180 & 240	Unknown	Small decrease in micronaire with increased N application levels	Janat and Somi (2002)
1996–1998	Florence, South Carolina	US	0, 78 & 112	HVI	Small but significant increase in micronaire with increased N application levels	Bauer and Roof (2004)
1997–2000	Winnsboro, Louisiana[b]	US	90, 112, 134 & 157	HVI	No significant differences in micronaire with increased N application levels	Boquet (2005)
1998–2000	San Joaquin Valley, California	US	56, 112, 168 & 224	HVI	No clear trend with increased N application levels	Fritschi et al. (2003)
1999	Thrall, Texas[b]	US	0, 56, 112 & 224	HVI	No significant differences in micronaire with increased N application levels	McFarland et al. (1999)
1999–2000	Mississippi	US	Small scale trial with control and 20% at first flower & 0% at first flower	Micronaire	No clear trend with increased N application levels	Read et al. (2006)
1999–2000	Fresno, California[a]	US	56, 112, 168 & 224	HVI	Small but significant decrease in micronaire, in all likelihood due to delay in maturity, with increased N application levels	Fritschi et al. (2003)
1999–2000	Giza[a]	Egypt	95 & 143	Micronaire	Small but significant increase in micronaire with increased N application levels	Sawan et al. (2006)
2001–2002	Unknown	Syria	50, 100, 150, 200 & 250	Unknown	No clear trend with increased N application levels	Janat (2008)
2003–2004	Adana	Turkey	0, 80 & 160	HVI	No clear trend with increased N application levels	Gormus (2005)
2001–2004	Stoneville, Mississippi	US	112 in four different application methods	Arealometer	No significant differences in micronaire with increased N application levels	Pettigew and Adamczyk (2006)

Table 3 (continued)

Year	Location	Country	N levels in kg·ha^{-1}	Instrument	Remarks	References
2005	Nanjing, Jiangsu	China	0, 240 & 480	HVI	Small but significant reduction in micronaire with increased N application levels	Zhao et al. (2012)
2005	Xuzhou, Jiangsu	China	0, 240 & 480	HVI	Small but significant reduction in micronaire with increased N application levels	Zhao et al. (2012)
2005–2006	Multan, Punjab	Pakistan	0, 50, 100 & 150	HVI	No significant differences in micronaire with increased N application levels	Afzal et al. (2018)
2006	Faisalabad, Punjab	Pakistan	0, 60, 120 & 180	HVI	No clear trend with increased N application levels	Saleem et al. (2010)
2007	Anyang, Henan	China	0, 240 & 480	HVI	Small but significant reduction in micronaire with increased N application levels	Zhao et al. (2012)
2009–2012	Stoneville, Mississippi	US	0, 56 & 112	HVI	Significant reduction in micronaire with increased N application levels	Pettigew (2012) and Pettigew and Zeng (2014)
2008–2010	Varamin, Tehran	Iran	200, 300, 350 & 400	HVI	No clear trend with increased N application levels	Madani and Oveysi (2015)
2008–2010	Gorgan, Golestan	Iran	200, 300, 350 & 400	HVI	No clear trend with increased N application levels	Madani and Oveysi (2015)
2009–2010	Varamin, Tehran	Iran	0, 100, 200 & 300	HVI	Slight increase in micronaire with increased N application levels	Rashidi and Gholami (2011), Hossein et al. (2014), and Seilsepour and Rashidi (2011)
2009	Mississippi State University	US	0 & 100	HVI	Slight but significant decrease in micronaire due to reduced maturity with increased N application levels	Lokhande and Reddy (2015)
2010–2011	Adana	Turkey	0, 60, 120, 180 & 240	HVI	Significant increase in micronaire up to 180 kg·ha^{-1} with a significant decrease above 180 kg·ha^{-1}	Gormus et al. (2016a)

Table 3 (continued)

Year	Location	Country	N levels in kg·ha^{-1}	Instrument	Remarks	References
2012–2013	Adana	Turkey	0, 60, 120, 180 & 240	HVI	No significant differences in micronaire with increased N application levels	Gormus and El Sagagh (2016b)
2011	Torreón, Coahuila	Mexico	0, 50, 100, & 150	Unknown	No significant differences in micronaire with increased N application levels	Hernandes-Cruz et al. (2015)
2011–2012	Yellow River Delta, Hebei	China	0, 120, 240 & 480	HVI	Significant increase in micronaire up to 240 kg·ha^{-1} with a significant decrease above 240 kg·ha^{-1}	Chen et al. (2019)
2012–2013	Primavera do Leste, Mato Grosso	Brazil	70, 140 & 210	HVI	Significant reduction in micronaire with increased N application levels	Echer et al. (2020)
2012–2013	Chapadão do Sul, Mato Grosso do Sul	Brazil	0, 40, 80, 120 & 160	HVI	Significant decrease in micronaire with increased N application levels	Leal et al. (2020)
2013	Stoneville, Mississippi	US	0, 39, 67, 101, 135 & 168	HVI	No clear trend with increased N application levels	Sui et al. (2017)
2014	Stoneville, Mississippi	US	0, 56, 112, 168 & 224	HVI	Significant reduction in micronaire with increased N application levels	Sui et al. (2017)
2013–2014	New Delhi	India	100, 125, 150 & 175	Micronaire	No clear trend with increased N application levels	Verna et al. (2017)
2016–2018	Suffolk, Virginia	US	0, 45, 90, 135 & 180	HVI	Small decrease in micronaire with increased N application levels	McClanahan et al. (2020)
2016–2017	Lewiston-Woodside, North Carolina	US	0, 45, 90, 135 & 180	HVI	Small decrease in micronaire with increased N application levels	McClanahan et al. (2020)
2018	Yale, Virginia	US	0, 45, 90, 135 & 180	HVI	No clear trend with increased N application levels	McClanahan et al. (2020)
Unknown	Giza[a]	Egypt	107 & 161	Micronaire	Slight increase in micronaire with increased N application levels	Sawan et al. (1997)

[a] Pima

[b] Ultra narrow row

Table 4 Effect of N level on maturity In the pdf the Year is in 2 rows instead of 1 as in all other tables. Also first entry is skewed to the left in the pdf

Year	Location	Country	N levels in kg·ha^{-1}	Instrument	Remarks	References
1956–1957	Thorsby, Alabama	US	0, 67, 134 & 270	Unknown	Significant delay in maturity with increased N application levels	Scarsbrook et al. (1959)
1995–1998	Hama	Syria	0, 60, 120, 180 & 240	Unknown	No significant differences in maturity with increased N application levels	Janat and Somi (2002)
2001–2002	Unknown	Syria	50, 100, 150, 200 & 250	Unknown	No clear trend with increased N application levels	Janat (2008)
2001–2004	Stoneville, Mississippi	US	112 in four different application methods	Calculated	No significant differences in maturity and perimeter	Pettigew and Adamczyk (2006)
2005–2006	Multan, Punjab	Pakistan	0, 50, 100 & 150	HVI	No significant differences in maturity index or micronaire with increased N application levels	Afzal et al. (2018)
2007–2008	Multan, Punjab	Pakistan	0, 60, 110 & 160	HVI	No clear trend with increased N application levels	Ali (2011)
2009–2012	Stoneville, Mississippi	US	0, 56 & 112	AFIS	Significant reduction in maturity and fineness with increased N application levels	Pettigew and Zeng (2014)
2012–2013	Chapadão do Sul, Mato Grosso do Sul	Brazil	0, 40, 80, 120 & 160	HVI	Significant decrease in maturity with increased N application levels	Leal et al. (2020)
2011–2012	Yellow River Delta, Hebei	China	0, 120, 240 & 480	Taicang Electron Apparatus	Significant increase in maturity up to 240 kg·ha^{-1} with a significant decrease above 240 kg·ha^{-1}	Chen et al. (2019)
2012–2013	Primavera do Leste, Mato Grosso	Brazil	70, 140 & 210	HVI	Significant reduction in maturity with increased N application levels	Echer et al. (2020)

Table 5 Effect of N level on colour

Year	Location	Country	N levels in kg· ha^{-1}	Instrument	Remarks	References
1984–1986	Altus, Oklahoma	US	0, 56, 112 & 224	HVI	Fibres becoming less bright, due to a reduction in reflectance (Rd) and an increase in yellowness (+b), with increased N application rates	Boman and Westerman (1994)
1991–1992	Uvalde, Texas[a]	US	0, 67, 135, 202 & 269	HVI	Significant decrease in reflectance (Rd) and an increase in yellowness (+b), with increased N application rates	Tewolde and Fernandez (2003)
1992–1996	Mississippi Delta	US	101, 135, 168 & 202	HVI	Fibres becoming significantly less bright, due to a reduction in reflectance (Rd) and an increase in yellowness (+b), with increased N application rates	Ebelhar et al. (1996)
1996–1998	Florence, South Carolina	US	0, 78 & 112	HVI	Significant increase in yellowness (+b), with increased N application rates	Bauer and Roof (2004)
2005–2006	Multan, Punjab	Pakistan	0, 50, 100 & 150	HVI	No significant differences in either Rd or+b with increased N application levels	Afzal et al. (2018)
2009–2012	Stoneville, Mississippi	US	0, 56 & 112	HVI	Significant increase in yellowness (+b), with increased N application rates	Pettigew and Zeng (2014)
2013	Stoneville, Mississippi	US	0, 39, 67, 101, 135 & 168	HVI	Significant decrease in reflectance (Rd) and an increase in yellowness (+b), with increased N application rates	Sui et al. (2017)
2014	Stoneville, Mississippi	US	0, 56, 112, 168 & 224	HVI	Significant decrease in reflectance (Rd) and an increase in yellowness (+b), with increased N application rates	Sui et al. (2017)

[a] Pima

[b] Ultra narrow row

on colour and that they were all measured by HVI. The results clearly show that N application negatively affects colour, decreasing Rd and increasing+b, thereby negatively affecting the colour grade. It has been stated that fibre colour is directly linked to the growth environment (Bradow and Davidonis 2000; Meredith 1994) as well as planting date and genotype (Porter et al. 1996) and harvesting practices (Munshi and Sundaram 1985). The Ordered Logit model mentioned earlier also showed that the application of N can adversely affect colour in terms of+b (Zhao et al. 2010). Certainly, the application of N results in increased vegetative growth, rank growth and denser canopies, resulting in an reduction in light intensity and increased insect attractiveness and secretions. The use of growth regulators, defoliation, harvesting and increased trash due to leaves caught in the canopy can all result in the fibre becoming less bright, more dull, grey or yellow. This often encourages gins to aggressively clean the fibre to achieve base grade or a higher grade and subsequently a better price for the cotton grower (van Doorn 1986). Certainly, anecdotal information from Australia suggests that in general lint turn out has been below expectation for a number of years (Buster 2019b, 2020).

Lint turn out

From Table 6 it is clear that in general, increased N application levels negatively affected lint turn out. However, a small number of studies, which were mainly small scale trials, where seed cotton was hand harvested and, with no or little information, on ginning was in all likelihood also hand ginned, found that lint turn out increased with increased N application levels (Gadhiya et al. 2009; MacKenzie and Schaik 1963; Gormus 2005; Gormus et al. 2016a; Verna et al. 2017). Some studies found no clear trend mainly due to the fact that the results for lint turn out varied over the years that the studies were conducted

Table 6 Effect of N level on lint turn out

Year	Location	Country	N levels in kg·ha^{-1}	Remarks	References
1944–1946	Rocky Mount, North Carolina	US	11,39 & 67	Significant reduction in lint turn out with increased N application levels	Nelson (1949)
1951–1960	Brawley, California	US	0, 107, 214 & 321	No consistent trend for both lint and seed turn out with increased N application levels	Bennett et al. (1967)
1956–1962	Thorsby, Alabama	US	0, 107, 214 & 321	Significant reduction in lint turn out with increased N application levels and corresponding increase in seed turn out	Bennett et al. (1967)
1959–1960	Brawley, California	US	0, 107, 214 & 321	General increase in lint and seed turn out with increased N application levels	MacKenzie and Schaik (1963)
1956–1957	Thorsby, Alabama	US	0, 67, 134 & 270	Significant reduction in lint turn out with increased N application levels and corresponding increase in seed turn out	Scarsbrook et al. (1959)
1961–1963	Unknown	US	0, 28, 54, 80, 120, 134, 161 & 187	Significant reduction in lint turn out with increased N application levels	Perkins and Douglas (1965)
1963–1965	Yuma, Arizona	US	84 & 224	No clear trend in lint turn out with increased N application levels	Jackson and Tilt (1968)
1965–1980	Eight locations	Greece	0, 60, 50, 100, 120, 150, 180 & 200	Significant reduction in lint turn out with increased N application levels	Setatou and Simonis (1994, 1995)
1972–1983	Altus, Oklahoma	US	0, 44, 90& 135	Significant reduction in lint turn out with increased N application levels	Boman et al. (1997)
1982–1983	Morena, Madhya Pradesh	India	0, 40, 80 & 120	No significant effect on lint or seed turn out with increased N application levels	Shrivastava and Singh (1988)
1991–1992	Stoneville, Mississippi	US	112 & 150	No significant effect on lint or seed turn out with increased N application levels	Pettigew et al. (1996)
1991–1992	Lakhasti	India	0, 40, 80 & 120	Significant reduction in lint turn out with increased N application levels with corresponding increase in seed weight	Chand et al. (1997)
1998–2000	San Joaquin Valley, California	US	56, 112, 168 & 224	Significant reduction in lint turn out with increased N application levels	Fritschi et al. (2003)
1999–2000	Fresno, California[a]	US	56, 112, 168 & 224	Significant reduction in lint turn out with increased N application levels	Fritschi et al. (2003)
1999–2000	Giza[a]	Egypt	95 & 143	Significant reduction in lint turn out with increased N application levels	Sawan et al. (2006)
1996	Portageville, Missouri	US	45, 90 & 135	Significant reduction in lint turn out with increased N application levels	Phipps et al. (1996)
2001–2002	Unknown	Syria	50, 100, 150, 200 & 250	Slight but significant reduction in lint turn out with increased N application levels	Janat (2008)
1998–2000	San Joaquin Valley, California	US	56, 112, 168 & 224	Significant reduction in lint turn out with increased N application levels	Fritschi et al. (2003)
2003–2004	Adana	Turkey	0, 80 & 160	Although not significant lint turn out increased with increased N application levels	Gormus (2005)
2005–2006	Khedbhrahma, Gujarat	India	160, 200 & 240	Although not significant lint turn out increased with increased N application levels	Gadhiya et al. (2009)

Table 6 (continued)

Year	Location	Country	N levels in kg·ha^{-1}	Remarks	References
2006	Faisalabad, Punjab	Pakistan	0, 60, 120 & 180	Significant increase in lint turn out up to 120 kg·ha^{-1} with a decrease in lint turn out at 180 kg·ha^{-1}	Saleem et al. (2010)
2007–2008	Multan, Punjab	Pakistan	0, 60, 110 & 160	No significant effect on lint turn out with increased N application levels	Ali (2011)
2006–2013	Narrabri, NSW	Australia	0, 50, 100, 150, 200, 250, 300 & 350	Significant reduction in lint turn out with increased N application levels and corresponding increase in seed turn out	Rochester and Constable (2020)
2010–2011	Adana	Turkey	0, 60, 120, 180 & 240	Significant increase in lint turn out up to 180 kg·ha^{-1} with a significant decrease in lint turn out above 180 kg·ha^{-1}	Gormus et al. (2016a)
2011	Torreón, Coahuila	Mexico	0, 50, 100 & 150	Reduction in lint turn and seed turn out with increased N application levels	Hernandes-Cruz et al. (2015)
2011–2012	Yellow River Delta, Hebei	China	0, 120, 240 & 480	Significant increase in lint turn out up to 240 kg·ha^{-1} with a decrease in lint turn out at 480 kg·ha^{-1}	Chen et al. (2019)
2012–2013	Primavera do Leste, Mato Grosso	Brazil	70, 140 & 210	Significant reduction in lint turn out with increased N application levels	Echer et al. (2020)
2012–2013	Adana	Turkey	0, 60, 120, 180 & 240	Significant increase in lint turn out up to 120 kg·ha^{-1} with a significant decrease in lint turn out above 120 kg·ha^{-1}	Gormus and El Sagagh (2016b)
2013–2014	New Delhi	India	100, 125, 150 & 175	Significant increase in lint turn out with increased N application levels	Verna et al. (2017)
Unknown	Giza[a]	Egypt	107 & 161	Small but not significant decrease in lint turn out with increased N application levels with significant increase in seed index	Sawan et al. (1997)

[a] Pima

[b] Ultra narrow row

Table 7 Effect of N level on stickiness

Year	Location	Country	N levels in kg· ha^{-1}	Sucking Pest	Remarks	References
Unknown	Greenhouse	US	Low, Medium & High	Silver whitefly	Whiteflies in a high N environment matured earlier and as a consequence also started to produce honeydew earlier	Blua and Toscano (1994)
1992–1994	Chillicothe, Texas	US	0, 29, 55 & 79	Aphid	Increased N application levels and late planting resulted in an increase in aphid population	Slosser et al. (1997)
1997	Shafter, California	US	0 & 145	Aphid	Increased N application levels resulted in significantly increase in aphid population, which were less susceptible to insecticides	Cisneros and Godfrey (1998)
1997	Kern County, California	US	57 & 227	Aphid	Increased N application levels resulted in significantly increase in aphid population	Cisneros and Godfrey (2001a)
1998	Kern County, California	US	57, 136 & 227	Aphid	Increased N application levels resulted in significantly increase in aphid population	Cisneros and Godfrey (2001a)
1998	Multiple sites in California	US	0, 45, 89, 134 & 178	Aphid	Increased N application levels resulted in significantly increase in aphid population	Godfrey et al. (1999)
1998	Riverside, California	US	0, 112,168 & 224	Silver whitefly	Increased N application levels resulted in significantly increased densities of both adult and immature whiteflies with increased honeydew production	Bi et al. (2000, 2001)
1999	Riverside, California	US	0, 112,168 & 224	Silver whitefly	Increased N application levels significantly increased the number of adult whiteflies on both early and late planted cotton. This may reduce photosynthetic rates	Bi et al. (2005a; b)
1999	Multiple sites in California	US	0,45, 89,134 & 178	Aphid	Increased N application levels resulted in significantly increase in aphid population	Godfrey (2000)
2000	Kern County, California	US	0, 45, 89,134,178 & 223	Aphid	Increased N level alters the cotton aphid at the individual level stimulating the aphid fecundity and hastening the insect development to the reproductive stages. This may promote higher aphid populations in cotton	Cisneros and Godfrey (2001b)
2004	Vehari, Punjab	Pakistan	50,100,150 & 200	Jassid	Increased N application levels resulted in significantly increase in jassid population	Ahmed et al. (2007)

Table 7 (continued)

Year	Location	Country	N levels in kg· ha^{-1}	Sucking Pest	Remarks	References
2004	Vehari, Punjab	Pakistan	50,100,150 & 200	Whitefly	Increased N application levels resulted in significantly increase in whitefly population	Ahmed et al. (2007)
2004	Vehari, Punjab	Pakistan	50,100,150 & 200	Thrips	No clear trend with increased N application levels	Ahmed et al. (2007)
2013	Lam, Guntur	India	0, 120, 150, 180, 225, 280, 350 & 440	Aphid	Significant increase in aphid population above 120 kg·ha^{-1}	Anusha et al. (2017)
2013	Lam, Guntur	India	0, 120, 150, 180, 225, 280, 350 & 440	Leaf hopper	Significant increase in leaf hopper population above 120 kg·ha^{-1}	Anusha et al. (2017)
2016–2018	Halfa, Algadidah	Sudan	44, 88 & 131	Whitefly	Increased N application levels resulted in significantly increase in whitefly population	Fadlelmawla et al. (2021b)
2016–2018	Halfa, Algadidah	Sudan	44, 88 & 131	Jassid	Increased N application levels resulted in significantly increase in jassid population	Fadlelmawla et al. (2021b)
2016–2018	Halfa, Algadidah	Sudan	44, 88 & 131	Mealybug	No clear trend with increased N application levels	Fadlelmawla et al. (2021b)
2018	Halfa, Algadidah	Sudan	44, 88 & 131	Whitefly	No significant changes in aphid population with increased N application levels	Fadlelmawla et al. (2021b)

(Bennett et al. 1967; Jackson and Tilt 1968). The decrease in lint turn out corresponded with an increase in seed turn out, largely due to an increase in seed weight. Anecdotal information gathered from the gins in Australia over four years suggests that the percentage of seed and the weight of seed per lint bale (227 kg) has been steadily increasing, which resulted in a decrease in lint turn out.

Stickiness

Cotton stickiness, when it occurs, can present a major problem, in terms of textile processing performance and cost and product quality. The main problem related to cotton stickiness is that of the sticky deposit, or residue. The most common and problematic causes of stickiness are those due to excess sugars related to insect secretions, notably that from aphids (*Aphis Gosypii* Glov.) and whitefly (*Bemesia Tabaci* Genn.), referred to as honeydew. This deposit adheres to any machine part or surface encountered by the cotton along the processing pipeline, causing an accumulation of fibres (and even dust or grit) during the ginning and spinning processes, but can also cause issues during cotton classification, with deposits on the combs used in HVI instruments, resulting in incorrect and inaccurate fibre measurements. In addition, a black sooty mould can also grow on honeydew, darkening the lint and adversely affecting grade (van der Sluijs and Hunter 2017).

From Table 7 it is clear that increased N application levels result in increased populations of aphids and whitefly. N also increased their and other pests resistance to standard insecticides, resulting in increased applications and the use of more harmful products (Godfrey et al. 2000b; Fadlelmawla et al. 2021a; Andrews et al. 2000).

Conclusion

The observed effects of N application levels on fibre quality are rather varied and often inconsistent. This was specifically the case for fibre length and length uniformity, strength and micronaire. This was unsurprising as length and strength are primarily genetic traits with micronaire primarily attributed to weather and management. Of course, the range of different test methods and instruments and at times no indication of the test method and instrument could have contributed to these differences. On the other hand, fiber colour, lint turn out and sticky cotton were greatly influenced by the N application level. The colour of the fibre becoming less bright and duller, with a reduction in lint turn out and increased susceptibility and insect attractiveness with increased N application levels.

There is no doubt that N plays a significant role in the production of cotton. However, the excess application above NUE has no economical benefit and could impact on fibre quality.

It is proposed that further assessment of N application levels on fibre quality will need to be performed to clarify the effects of N application levels on the various fibre quality parameters.

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