EFFECT OF DIFFERENT MACRO-NUTRIENT COMBINATIONS ON GROWTH, YIELD AND FIBRE QUALITY OF COTTON (*Gossypium hirsutum* L.) IN MACHAKOS COUNTY, KENYA

ELIZABETH WAMBUI MAINA

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN AGRICULTURAL RESOURCE MANAGEMENT

DEPARTMENT OF PLANT SCIENCE AND CROP PROTECTION

FACULTY OF AGRICULTURE

UNIVERSITY OF NAIROBI

2023

DECLARATION

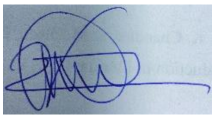
This thesis is my original work and has not been presented for the award of a degree in any other University.

Elizabeth Wambui Maina

Signature:  Date: 01/11/2023

This thesis has been submitted with our approval as university supervisors.

Dr. Onesmus M. Kitonyo
Department of plant science and crop protection
University of Nairobi

Signature: …………………… Date: ……02/11/2023………

Prof. George N. Karuku
Department of Land Resource Management and Agricultural Technology
University of Nairobi

Signature: …  …………. Date: 01/11/2023…………

DECLARATION OF ORIGINALITY

This form must be completed and signed for all works submitted to the University for examination.

Name of Student: Elizabeth Wambui Maina

Registration Number: A56/81630/2015

Faculty/School/Institute: Faculty of Agriculture

Department: Department of Plant Science and Crop Protection

Course name: Masters in Agricultural Resource Management

Title of the work: Effect of different combinations of N, P and K nutrients on growth, yield and fibre quality of cotton (*Gossypium hirsutum L.*)

Declaration

1. I understand what plagiarism is and I am aware of the University's policy in this regard

2. I declare that this project is my original work and has not been submitted elsewhere for examination, award of a degree or publication. Where other people's work or my own work has been used, this has properly been acknowledged and referenced in accordance with the University of Nairobi requirements.

3. I have not sought or used the services of any professional agencies to produce this work

4. I have not allowed, and shall not allow anyone to copy my work with the intention of passing it off as his/her own work

5. I understand that any false claim in respect of this work shall result in disciplinary action, in accordance with University Plagiarism Policy.

Signature Date: 01/11/2023

DEDICATION

To my dear husband Mr. Stephen Menu, my lovely children Reuel, Neriah and Nathanael, my parents and siblings for their unwavering support and motivation throughout the entire study.

ACKNOWLEDGEMENTS

First and foremost, praises and thanks to God for his grace and strength throught my study period.

I would like to express my deep and sincere gratitude to my supervisors Dr. Onesmus M. Kitonyo and Prof. George N. Karuku both from the University of Nairobi for their immense support. It was a great honour and previlidge to study under your guidance.

Special thanks go to the Machakos ATC management and Mr. Joshua Muia for giving out their farms for this study. I so much appreciate Onesmus Musau for his continued support in the field experimentation. I appreciate Harris Mwanzige and Dominic Obiero for their commitment and support in laboratory analysis.

I am extremely grateful to my dear husband, children, parents and siblings for their support and encouragement throughout my study period.

May God bless you all.

TABLE OF CONTENTS **Page**

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AE	Agronomic efficiency
AFA	Agriculture and Food Authority
ATC	Agricultural Training Centre
ATP	Adenosine Triphosphate
ANOVA	Analysis of variance
ASALs	Arid and Semi-arid lands
ASTM	American Society for Testing and Materials
+b	Yellowness
B	Boron
BGII	Bollgard II
Bt	Bacillus thuringiensis
°C	Degrees Celsius
cm	Centimeters
CODA	Cotton Development Authority
CO_2	Carbon dioxide
CU	Copper
DPS	Data Processing Software
E	East
F	Fertilizer
FAO	Food and Organization
g	Grams
g/tex	Grams per tex
GDP	Gross domestic product
GOK	Government of Kenya
GOT	Ginning out-turn
HCL	Hydrochloric Acid
HVI	High volume instrument
KARI	Kenya Agriculture Research Institute
KALRO	Kenya Agricultural and Livestock Research Organization
K_2O	Potassium oxide
L	Litre
LAI	Leaf area index
LCD	Liquid Crystal Display
LM	Lower midland
LSD	Least significant difference
LUI	Length Uniformity Index
m	Meters
Mg	Magnesium
ML	Mililitre
mm	Millimeters
M	Million
MT	Metric tonnes
ha	Hectare
MOP	Muriate of potash
NPK	Nitrogen, Phosphorus and Potassium
NUE	Nutrient use efficiency
P_2O_5	Phosphorous pentoxide
RATES	Regional Agricultural Trade Expansion Support Program

RCBD	Randomised complete block design
Rd	Degree of reflectance
RH	Relative Humidity
S	South
S	Sulphur
SSP	Single super phosphate
SE	Standard Error
SO_4	Sulphate
t/ha	Tonne per hectare
UHML	Upper Half Mean Length
USAID	United States Agency for International Development
V	Volume
W	Weight
WUE	Water use efficiency
Y	Yield
Zn	Zinc

GENERAL ABSTRACT

Cotton (*Gossypium hirsutum* L) requires large quantities of nitrogen (N), phosphorus (P) and potassium (K), and these nutrients are frequently limiting in cotton growing areas in Kenya. Nitrogen, P and K nutrition affects cotton growth, yield and lint quality but the peak demand for either nutrient is crop stage specific. As cotton successively goes through vegetative and reproductive growth, there is considerable shift in the relative demand among the macronutrients. It is only partially understood which among the combinations of N, P and K increases cotton growth and yield, as well as improves fibre quality. This study was carried out to investigate the effect of different combinations of N, P and K macro-nutrients on: (i) growth, yield of cotton, and (ii) water and nutrient use efficiency, and fibre quality of cotton. Experiments were conducted in Machakos County of southeastern Kenya at the Farmers' Training Centre in Machakos and in a farmer's field in Ndalani village. Treatments comprising two cotton varieties (conventional variety (HART 89M) and genetically modified variety (Bt-C571 BGII) and varying nutrient combinations of N, P, and K and unfertilized control were set out in a randomized complete block design with a split plot arrangement. Variety was assigned to the main plots while nutrient combinations formed the subplots. In the first objective, cotton growth and yield parameters were determined through the number of days taken to attain 50% branching, squaring, boll formation and boll opening, as well as the corresponding number of branches, squares and bolls per plant. Plant height and stem girth were measured during branching, flowering and at boll opening, whereas chlorophyll content was measured at branching and flowering. At harvesting, data on cotton yield and root length and angle were measured. In the second objective, water use efficiency (WUE), N, P, and K nutrient uptake, agronomic efficiency and fibre quality traits were measured. Generally, both cotton varieties grown in NP, NK, NPK, and $NPK_{Zn, S}$ fertilized soils matured earlier than those grown in soils fertilized with PK and in the unfertilized soils. Notably, cotton grown under NK, NP, NPK, $NPK_{Zn, S}$ nutrient combinations were significantly ($P \leq 0.05$) taller, thicker and greener than cotton grown in plots without N nutrient but fertilized with PK and unfertilized control. In addition, cotton grown in plots where N was combined with P and K produced larger biomass and yield compared with crops in treatments excluding N or unfertilized control. Similarly, cotton grown under N nutrient combinations had advanced uptake of N, P, and K compared with unfertilized crops. While the varieties did not differ in the majority of the measured quality traits, Bt-C571 BGII recorded higher strength and Rd than HART 89M, whereas HART 89M had higher +b. Compared with control, addition of nutrients did not affect maturation, fibre

attributes such as length uniformity index, upper half mean length, elongation and the number of short fibres. However, cotton grown in the soils fertilized with N nutrient had significantly ($P<0.05$) higher strength, micronaire, Rd and +b than those grown in unfertilized soils and PK plots. Overall, N nutrient combinations were observed to enhance maturity period, biomass, yield, WUE, uptake of N, P, and K, agronomic efficiency and fibre quality of cotton. This implies that the use of nitrogenous fertilisers guarantees efficient water and nutrients use consequently enhancing cotton growth, yield and fibre quality.

CHAPTER ONE: INTRODUCTION

1.1 Background information

Cotton (*Gossypium hirsutum* L.) is a main source of income for small-scale farmers in cotton growing countries in Africa (Duncan et al., 2003; Gerald, 2008), where more than two million rural households rely on cotton production for their livelihoods (Baffes, 2007). Cotton is produced in many countries but the leading producers are China, India, the United States, Pakistan, and Brazil (FAO, 2016). It is mainly cultivated for its fibres and seeds which serve as a source of raw materials for textile and feed, respectively (Constable and Bange, 2015). In Kenya, cotton is mainly grown in 24 Counties that are located in agro-ecological zones LM 3 and LM 4 (AFA, 2021; Wabule et al., 2006). Suitable ecological requirements for cotton are an altitude of 900-1,372 m, temperature 21-30 ^{o}C, 500-700 mm of well-distributed rainfall during the first four and a half months, and a wide range of soil types with an optimum pH of 6.2, according to the cotton growers' manual (2021).

Most soils do not provide sufficient nutrients for profitable production of seed cotton yield (McConnell et al., 1996). Nitrogen, P and K nutrients are greatly required by cotton (Rochester et al., 2007); therefore, an additional supply of N, P, and K nutrients is essential (Tucker, 1999; Khan et al., 2017). Poor soil fertility due to soil nutrient depravation, leaching and removal by plants Stewart et al. (2009) contributes to poor growth, low yield and consequently poor lint quality (Gitonga et al., 2011).

Nutrients are essential in the improvement of cotton growth (Borowski, 2001), maturity (Hutmacher et al., 2004), yield parameters and yield (Gerik et al., 1998), lint quality (Rochester et al., 2001), NUE (Fernie et al., 2020; Snyder et al., 2014) and WUE (Khan et al., 2017). According to Lewis (2000), cotton yield is improving considerably, as is the demand for high-quality cotton lint. To meet this demand, soil fertilization is imperative to restore the lost nutrents and improve growth, yield and lint quality (Stewart et al., 2009).

1.2 Statement of the problem

Over the years, cotton yield in Kenya has declined to about 0.57 t/ha against a yield potential of 2.5 t/ha under rain-fed conditions (Gitonga, et al., 2011). Yield potential is the yield of a crop variety when it is grown in its best adapted environs with satisfactory provision of water and nutrients, as well as with optimal exclusion of yield-restraining factors such as weeds, pests and diseases (Evans and Fisher, 1999). Despite limited reports, only about 23% of cotton farmers in Kenya use fertilizer (Gitonga et al., 2011). Studies have been done to show how nutrients influence cotton growth, yield and fibre quality. However, it is not known which among these macro nutrients is the most restrictive to cotton growth, yield and fibre quality. Further, it is also not known how these nutrients co-regulate each other on growth, yield and fibre quality of cotton.

1.3 Justification of the study

Cotton is a main contributor towards the growth of the manufacturing sector since it is the major source of raw materials for the industries AFA (2021) and Cotton grower's manual, (2021). However, the production is at 0.57 t/ha which is significantly low compared with the yield potential of 2.5 t/ha. In addition to water stress and pests, low yield of cotton is mainly influenced by poor soil fertility. Low fertility soils are not able to meet the substantial requirements for N, P, and K nutrients of cotton particularly during flowering and boll formation stages. Nutrients deficiency during these stages reduce seed cotton yield since bolls utilize high amounts of nutrients and may disrupt fibre development. This results to low seed cotton yield with low quality and consequently very low income which exacerbates the living standards of cotton farmers. Therefore, efficient supply and management of these nutrients to replenish the lost nutrients is a vital practice geared towards improving yield and fibre quality of cotton to alleviate poverty levels of cotton farmers.

This study therefore used different combinations of nitrogen, phosphorus, and potassium nutrients to establish their distinct contributions to the productivity of cotton in the area of study. The findings will be used to provide a guide on the best management practices of N, P, and K nutrients in order to improve cotton growth, yield and fibre quality. It will also provide information to smallholder farmers and stakeholders that will address the existing knowledge gap in cotton production and yield response to water requirements in the advent of climate change.

1.4 Objectives

The broad objective is to enhance yield and fibre quality of cotton crop through optimal combinations of nitrogen, phosphorous and potassium mineral fertilizer.

The study has the following specific objectives:

(i) To determine the effect of different combinations of N, P, and K nutrients on growth and yield of cotton

(ii) To determine the effect of different combinations of N, P, and K nutrients on fibre quality, water and nutrients use efficiency of two cotton varieties in Kenya

1.5 Hypotheses

(i) Use of different combinations of N, P, and K nutrients does not improve cotton growth, yield components and yield

(ii) Use of different combinations of N, P, and K nutrients does not improve fibre quality, water and nutrient use efficiency of cotton crop

CHAPTER TWO: LITERATURE REVIEW

2.1 Importance of cotton globally and in Kenya

Cotton is grown in dry areas as a cash crop in more than 30 countries (Riaz et al., 2013). Income generated from cotton farming and employment along its long value chain is essential since it contributes to food security, poverty reduction and wealth creation in marginalized areas (GOK, 2007; Ikiara and Ndirangu, 2002). It is also a main source of fibre that contributes about 40% of the global textile, feed Constable and Bange, (2015) and oil (Ali et al., 2019). Crops contribute significantly to the economy where industrial crops such as cotton, tea among others give upto 70% of agricultural exports (KNBS, 2020, MoAL&F, 2021). Nearby 80 percent of cotton is used in attire, 15 percent in home fittings and the remaining 5 percent mostly stands for non-woven uses, such as sieves and padding (FAO, 2023). However, cotton is among the industrial crops whose production is declining despite having a great potential and evident contribution to economic growth (MoAL&F, 2015; KNBS, 2020).

2.2 Cotton yield production

Statistics shows that the top cotton producing countries in the years 2014 and 2015 are China, India, the United States, Pakistan, and Brazil respectively (Statista, 2015). In Kenya, cotton yield has declined to about 0.57 t/ha against a yield potential of 2.5 t/ha under rain-fed conditions (Gitonga et al., 2011). Annual seed cotton production stands at 3060 MT against a national demand of 77,700 MT (AFA, 2021).

2.3 Constraints to cotton production in Kenya

The declining seed cotton yield is ascribed to numerous factors, such as drought Loka et al. (2011) and soil fertility depletion (Bationo et al., 2007; MoAL&F, 2021). Other factors are late planting, poor thinning, intercropping with the wrong crops such as maize and climbing beans, poor pest control practices, and use of ratoons, low quality inputs, inadequate use of modern technologies, pests and diseases among other factors (Wabule et al., 2006; MoAL&F, 2021). In addition, climate change affects cotton yield production due to changes in temperature and rainfall patterns (Parry et al., 2012; Kasimba, 2014). Parry et al. (2012), found out that yield may decline by 20% if temperatures increase only by 2.5 ºC. Kasimba (2014) concluded that climate change affects crop productivity due to low rainfall, high temperatures and sometimes very high rainfall, resulting in the outbreak of crop diseases.

Cotton is among the few crops that are able to grow in areas that receive inadequate rainfall due to its ability to tolerate heat and drought (Adhikari et al., 2015). This is because cotton has deep roots, which make it exhibit higher tolerance to drought Luo et al. (2016) as compared with other crops since deeper roots increase the capacity for more water extraction (Ludlow and Muchow, 1990). Further mild and initial stage droughts enhance the root length, therefore making the roots more adapted to drought stress by allowing the cotton plants to endure drought by retrieving water deeper in the soil profile (Luo et al., 2016). Other studies have also found that cotton roots are less affected by drought than the shoots (Pace et al., 1999).

Cotton roots can withstand drought, and Chastain et al. (2016) discovered that immature cotton leaves can continue to photosynthesise even when exposed to high temperatures (37 ^{o}C). In the early phases of its growth, the cotton plant might be able to live thanks to this. While cotton can withstand some drought, extreme droughts have the biggest an impact on its output. According to Loka et al. (2011), drought stress resulting from climate change interferes with the height of cotton, total dry weight, leaf area index, root and canopy development, yield and quality. The findings of Hejnák et al. (2015), who reported a drop in dry matter buildup, are comparable to those made here. This occurs because during droughts, some processes such as photosynthesis, water loss and stomatal function are affected (Kumar et al., 2001).

The two most significant environmental factors associated with climate change that have an impact on agricultural yields are extremely high temperatures and moisture stress. According to a number of studies (Bals et al., 2008; Chijioke et al., 2011; Parry et al., 2007; FAO, 2008), rising temperatures lead to increased evapotranspiration and low moisture levels, which significantly impair crop performance. According to studies by Reddy et al. (1999), Meredith (2005), and Pettigrew (2008), high temperatures have the following effects: a shorter maturity period for bolls, smaller bolls, fewer seeds per boll, short fibers, and poor and low yield. In his study, Gwimbi (2009) discovered that low rainfall and high temperatures were the main causes of poor cotton yields and that a drop in rainfall of 80% was equivalent to a drop in cotton production of 38%. Cotton is vulnerable to moisture stress during certain development phases, such as blooming and boll production, and insufficient rainfall during these times can significantly impair output (Ton, 2011).

The availability of plant nutrients further limits cotton yield because it needs high intakes of nutrients like N and K with daily intake rates of 0.04 t/ha/day, whereas micronutrient requirements can be easily satisfied with fertilizer application where appropriate (Rochester et al., 2007). Nitrogen, which plays a significant role in growth and seed cotton output, is one macronutrient that may be scarce in exhausted soils. Nitrogen usage in cotton cultivation enhances leaf area index and flowering when administered prior to the emergence of flowers (Borowski, 2001). According to Mullins and Burmester (2010), throughout the blooming and fruiting phases of cotton production, nutrient absorption rates are noticeably higher, and they start to decline as the bolls mature. Oosterhuis et al. (2008) state that there is a possibility that inconsistent nitrogen levels in the flower may result in poorer yield and unpredictable yields over time.

Excessive nitrogen treatment, contrary to common assumption, may result in excessive vegetative growth at the expense of reproductive development, delaying crop maturity and lowering seed cotton production (Perumai, 1999). Furthermore, nitrogen is a key component of biological substances, and its absence affects photosynthetic rate, crop growth rate, and crop source-sink relationship (Borowski, 2001). Furthermore, nitrogen reduces square, flower, and boll abscission (Gangaiah et al., 2013; Afzal et al., 2011).

Total N, P, and K intake is anticipated to occur during the boll setting phase, when they have a significant impact on cotton output and quality (Malik, 1995). Glen et al. (2007) discovered that nutritional inadequacies in cotton production cause squares and bolls to shed, resulting in reduced seed cotton output. Short fibers, weak fibers, poor uniformity index, colored fibers, and premature fibers are all caused by nutrient deficits (Rochester et al., 2001; El-Feky, 2010; Thaxton & El-Zik, 1994). The addition of N, P, and K nutrient combinations will thereby reduce soil degradation and increase the likelihood of profitable cotton crop production.

2.4 Growth and development of cotton

According to Peters et al. (2001) and Ikitoo (2011), cotton is a perennial crop that is mostly produced yearly, with the present types growing to a height of around 1.0 to 1.5 meters. Depending on the cultivar and environmental factors, the cotton crop matures in between 120 and 220 days, or 4 to 7 months (Ikitoo, 2011). The genus, variation, environmental factors, and management techniques like fertilizer and water supply all affect how long cotton takes to develop and how long each growth stage lasts (Ikitoo, 2011; Peeters et al., 2001).

2.5 Nutrients and cotton growth and yield

Long-term experiments have shown that continuous plowing of land reduces soil fertility, which leads to a low yield (Bekunda et al., 1997). According to Bationo et al. (2007), family farms with poor soil management methods are responsible for the declining soil fertility in sub-Saharan African nations. As a result of continuous cropping without replacing lost minerals, it has been shown that soil fertility has decreased over time in Kenya, with a net nutrient exhaustion rate of above 30 kg N/ha year (Smaling, 1993). These elements make it impossible for African nations to provide the desired output (Bationo and Waswa, 2011). The key limiting nutrients for crop yield are water levels, N, P_2O_5, and K_2O (Glass, 2003; Parry et al., 2005).

At least 0.2 t/ha of potassium and nitrogen are taken up. According to Bradow and Davidonis (2000) and Boquet and Moser (2003), plant growth and the growth stage are related to this high requirement for N and K. According to Mullins and Burmester (2010), the rate of nitrogen absorption in cotton production increases noticeably throughout the blooming and fruiting stages and decreases as the bolls mature. Boll formation uses a lot of K, with the seeds consuming a large portion of it (Usherwood, 2000), hence a N and K shortfall may prevent fiber production. According to Pettigrew's (1997, 1999) research, K has a role in nutrient and water intake, and its lack considerably reduces fruit output relative to vegetative development. In order to increase the stability of the soil aggregate, nutrients including nitrogen, phosphorus, and potassium are necessary (Green et al., 2010). Additionally, the application of N, P, and K promotes root growth, which boosts the efficiency of water and nutrients (Masunga et al., 2016; Penuelas et al., 2011). Lack of nitrogen and potassium in cotton also reduces output by reducing the development of the leaf surface and the plant's capacity to absorb CO_2, which leads to poor fiber quality (Bradow and Davidonis, 2000; Reddy et al., 2004). In cotton production systems where more yield is anticipated, N, P, and K nutrient management strategies are crucial (Gerik et al., 1998).

2.6 Nutrients and fibre quality.

Revenues generated from cotton cultivation are influenced by seed cotton yield and fibre quality. The range of fibre lengths is enormous, with fibre lengths of less than 12.7 mm being considered unsuitable for yarn production (Smith et al., 2010). The strength and quality of the cotton fibre products are determined by qualities such as short fibre content, length variability, fineness, strength, maturity, and uniformity index, among others, in the process of adding value to cotton (ASTM, 2005). These features also help to decrease processing waste (Smith et al., 2010). This study will primarily concentrate on the fibre length, micronaire, color (Rd and +b), strength, and uniformity index when it comes to fibre quality criteria. In the 20^{th} century, cotton crop breeding led to the development of longer fibres and higher bundle strengths (May, 1999). Since they reduce spinning waste and result in better yarn, uniform length, and distribution are desirable (Smith et al., 2010; Lawrence, 2003). According to Cai et al. (2011), the amount of short fibres in a cotton fibre is a crucial factor since it has a negative impact in the production of yarn.

Due to early fibres' poor dye absorption, high breakage, defect, and waste rates, cotton fibre maturity is also a crucial processing characteristic (Paudel et al., 2013). Since it can provide estimations for the yarn strength in spinning systems, micronaire (Fiber fineness and maturity) is significant (Jackowski et al., 2002). Finer fibres have a key role in boosting fibre interactions, which enhance yarn strength (Morton, 1993). The price paid for cotton per bale is significantly influenced by micronaire and length as well (Chakraborty and Etheridge, 1999).

Percy and Kohel (1999) assert that the fibre color of cotton is naturally cream-white. The two criteria that are used to characterize cotton's color are the degree of reflectance (Rd) and the amount of yellowness (+b). According to Rogers et al. (2005), the range of yellowness values is between 4% and 18% for darker cotton, whereas the range of brightness values is between 40% and 85% for brighter cotton. According to Raghavendra et al. (2004), the yellow hue depicts the degree of cotton coloring, while the reflectivity represents the cotton's brightness. Although cotton fibres are typically cream-white in color, variations can happen due to a number of factors, such as climatic conditions, soil type, storage conditions, insect discharges and molds, litter and dust particles, exposure to ultraviolet radiation, excessive heat, and harvesting and ginning processes (Raghavendra et al., 2004; Rogers et al., 2005). Cotton fibre can also be contaminated by weeds, cotton plant leaf fragments, boll husks, planting date, and genotype (Law et al., 2007; Porter et al., 1996). The most popular fibres are white, but dyed fibre is also utilized since there is an increasing amount of interest in using garments made from naturally colored fibres on a global scale (AFA, 2021). A cotton fibre's strength is regarded as 30 g/tex or above to be extremely strong; 26 to 28 g/tex is considered to be medium; 24 to 25 g/tex is considered to be intermediate; and 23 g/tex is considered to be weak. According to Cook's (2006) research, cotton breaks at a strength of around 3.0 to 4.9 g/denier and an elongation of roughly 8 to 10%.

According to Cassman et al. (1990), potassium is one of the main mineral nutrients that influence cotton performance. Pettigrew et al. (1996) came to the conclusion that inadequate K results in poor fibre quality in terms of strength, micronaire, lint production, and elongation. Compared to other crops, cotton is particularly sensitive to the availability of K and often displays signs of a deficit considerably early (Cassman et al., 1989). Numerous studies have shown that inadequate K has a negative effect on photosynthesis (Bednarz et al., 1998; Zhao et al., 2001; Pettigrew, 2003), leaf size, and total dry matter (Zhao et al., 2001). Low fibre output and quality are the effects of this (Pettigrew, 2003; Petigrew et al., 1996). Cotton performance has improved thanks to nutrient management (Howard et al., 1998; Adeli and Varco, 2002). According to Rochester et al. (2001) and USDA-NASS (2018), higher nitrogen fertilizer rates enhanced fibre length and strength but decreased micronaire. In their study, Bauer et al. (2000) also found that the crop that received no nitrogen had inferior fibre quality in various metrics, including fibre strength, uniformity, and length. Over the years, enhancing the ginning outcome has been a major goal of breeding (El-Feky, 2010; Thaxton & El-Zik, 1994). According to RATES (2003; World Bank, 2005), Kenya's cotton lint ginning outturn (GOT) is only approximately 33%, which is below the 40–42% GOT potential for Kenyan types and the average of roughly 36%–44%. Use of fertilizers to improve fibre quality is important in order to meet the need for high quality fibre (Lewis, 2000).

2.7 Cotton water and nutrient use efficiency

Mineral fertilizer like nitrogen, phosphorous and potassium improves soil aggregate stability, which further improves the soil water holding capability (Green et al., 2010). According to Masunga et al. (2016), this leads to appropriate root growth and supplies the energy for the roots to absorb water. Penuelas et al. (2011) claim that the availability of nutrients often influences plant response through enhanced plant performance, which enhances plant efficiency and water utilization. In their investigation, Wang et al. (2010) came to a conclusion that crop yield and nutrient usage efficiency may suffer in the long run if fertilizer supply does not keep up with crop nutrient demand.

Water resource is currently inadequate due to rising human consumption (Wu and Cosgrove, 2000). Concerns regarding the consumption of finite water resources have been raised as a result, which has rekindled interest in improving WUE (Tang et al., 2005; Tennakoon and Milroy, 2003). Application of nitrogen to plants under water shortage stress may improve cotton's ability to withstand and develop during droughts (Zhou and Derrick, 2012). Previous research shown that the usage of N fertilizer boosts the leaf area index, which enhances biomass, grain yield, and WUE under conditions of water constraint (Latiri-Souki et al., 1998; Conaty et al., 2015).

CHAPTER THREE: DETERMINATION OF THE EFFECT OF DIFFERENT COMBINATIONS OF N, P, AND K NUTRIENTS ON GROWTH AND YIELD OF COTTON

3.1 Abstract

Nitrogen, phosphorus and potassium nutrients are highly required by cotton (*Gossypium hirsutum* L.), especially during the blooming and boll production stages. However, it is not known which among these macro nutrients primarily restricts cotton growth and yield. Furthermore, it is unknown how these nutrients interact to influence growth and yield of cotton. Treatments comprising two cotton varieties (HART 89M and Bt-C571 BGII) and different nutrient combinations of N, P, and K and control were set out in a randomized complete block design with a split plot arrangement in two study sites in Machakos County. Number of days to 50% branching, squaring, boll formation and boll opening were determined as well as the corresponding number of branches, squares and bolls per plant. Plant height and stem girth were measured during branching, flowering and boll opening whereas the chlorophyll content was measured at branching and flowering. Data on root length and angle were measured during flowering and at physiological maturity while that of cotton yield t/ha was determined at harvesting. Generally, both cotton varieties grown in N nutrient fertilized soils matured earlier than those grown in unfertilized soils and soils fertilized with PK nutrient combinations. The two cultivars in both sites demonstrated a progressive increase in plant height, stem girth, and chlorophyll content across all treatments. Except for cotton grown in soils fertilized with PK nutrient combinations, cotton grown in NK, NP, NPK, and $NPK_{Zn,\ S}$ fertilized soils exhibited considerably greater ($P \leq 0.05$) plant height, stem girth, and leaf greenness than control. Additionally, compared with the unfertilized plot and the plot without a N nutrient, cotton cultivated in soils treated with N nutrient combinations generated more branches, squares, bolls, and yield. Furthermore, compared with control and soil fertilized with PK, NP, NK, NPK and $NPK_{Zn,\ S}$ combinations significantly affected the boll size and weight, and quantity of seeds per boll. In Machakos and Ndalani, respectively, the yield of cotton cultivated on soils fertilized with NP was greater (3.9 and 1.6 t/ha) than in control and PK. In comparison to control and N nutrient combinations, cotton roots in PK-fertilized soils were much longer ($P \leq 0.05$) in both kinds and locations. Considerably, N nutrients combinations influenced cotton growth and yield as a result supporting the hypothesis that N nutrient combinations can be used to speed up growth as well as increase seed cotton yield.

Key words: Cotton, nitrogen, phosphorus, potassium, growth, yield

3.1 Introduction

Cotton (*Gossypium hirsutum* L) is one of the industrial crops grown to produce raw materials for textile and feed. China, India, United States of America, Pakistan and Brazil are the top cotton producers (FAO, 2016). Small-scale farmers in Africa use cotton as a source of income, according to Gerald (2008) and Duncan et al. (2003). According to the Cotton Growers' Manual of 2021, ideal ecological conditions for cotton production include elevations between 0 and 1,372 m, temperatures between 21 and 30 ^oC, evenly distributed rainfall of 500 and 700 mm, and soil with a pH of 6.2. Given the variety of its agro-ecological zones, Kenya has the ability to increase cotton production to meet its 5, 513 MT annual lint demand (AFA, 2021).

Due to the fact that most soils do not provide sufficient nutrients for profitable production of seed cotton yield (McConnell et al., 1996), additional supply of N, P and K nutrients is essential (Khan et al., 2017). An extensive range of cotton indices, including plant size, boll retaining level, size and number of bolls per plant, are significantly shaped by an optimal nutrient supply (Rashidi et al., 2011; sawan et al., 2006). In addition, enhancement of seed and lint development entirely depends on adequate soil nutrient levels (Holden and Constable, 1994). Majority of researchers studied the use of N, P, and K nutrients and concluded that these nutrients had a significant influence on cotton output (Gill et al., 2000; Mullins & Burmester, 1990; Nawaz et al., 1996; Reddy et al., 2004; Seagull et al., 2000). According to Hutmacher et al. (2004) nutrients supply is a limiting factor in both dryland and irrigated cotton production systems.

Poor yield, which results from stunted growth and early senescence, is associated with N, P, and K nutritional deficiencies (Gill et al., 2000; Nawaz et al., 1996). Due to soil deterioration, leaching, or removal by plants, some nutrients are frequently insufficient or scarce in soils (Stewart et al., 2009). This necessitates frequent replenishment of the lost nutrients through fertilizer application to meet cotton high demand for nitrogen, phosphorus and potassium (Rochester et al., 2007). Nitrogen deficiency at the initial growth stages results to increased production of ethylene in cotton which encourages abscision of squares and flowers (Lege et al., 1997). This is so because nitrogen is essential for enhancing vegetative growth (Perumai, 1999). Additionally, nutritional deficiencies in cotton production results in decreased vegetative and reproductive growth Gerik et al. (1994) which consequently lowers seed cotton yield (Tewolde and Fernandez, 1997). On the other hand, it has been demonstrated that nitrogenous fertilizers can improve cotton production in terms of seed yield, growth rate, and fibre quality (Hutmacher et al., 2004).

Deficiencies in potassium have become more common even with supplemental fertilization (Oosterhuis et al., 2013). There are two types of potassium deficiencies whereby the first is full-season and severe Davis (1996) and the second is transient during boll fill with uncharacterized effects (Oosterhuis, 2002). Potassium majorly influences fibre growth, photosynthesis, osmotic regulation, and enzymatic activities (White and Karly, 2010). Cotton grown in soils with adequate potassium has increased water use efficiency (Pervez et al., 2004). This is because Phosphorus is responsible for growth and root development (Zhang et al., 1998). Zinc is involved in metabolic processes in plants such as membrane integrity, photosynthate mobilization and protein synthesis (Cakmak and Marschner,1988).

Soil fertilization is important considering excessive removal of nutrients in the soil by crops and soil degradation (Stewart et al., 2009). However, higher yield of cotton calls for appropriate and optimal nutrient application. Every nutrient has appropriate demands and functions by the crop hence, appropriate amounts need effective optimization (Rochester et al., 2007). On the other hand, the nitrogen amounts either in excess or inadequate have undesirable effects on cotton growth (Boquet and Breitenbeck, 2000; Howard et al., 2001). Therefore, this study is aimed at determining the influence of diverse nutrient combinations on growth and yield of two cotton varieties in Kenya. The outcomes of the study would be ideal in recommending fertilizer blends for optimal yield of cotton.

3.1.1 Materials and methods

3.1.2 Study sites

Field experiments were conducted in Machakos Agricultural Training Centre (ATC) farm and in Ndalani farmer's field in Ndalani ward both in Machakos County. ATC is located 1°32′12″S, 37°14′21″E at 1606 m above sea level. Ndalani farm is located at 1°06′21″S, 37°29′11″E at 1165 m above sea level. The sites receive unevenly distributed bimodal rainfall with March to May receiving the long rains and October to December the short rains. The mean annual rainfall range is between 500-1250mm (Jaetzold et al., 2009). The sites have luvisols soils and land use systems consist of livestock such as goats, cattle, chicken and cultivation of both cash and food crops like maize, sorghum and cotton (Jaetzold et al., 2009).

3.3.2 Treatments, experiment design and layout

Treatments were different combinations of inorganic nitrogen, phosphorous and potassium and two contrasting varieties of cotton. Treatments were laid out in a randomized complete block design with a split-plot arrangement and were replicated three times. Cotton varieties were the main plots whereas different nutrient regimes and control (no fertilization) were the subplots, Figure 3.1. Plots were separately fertilized with NP, NK, PK, NPK, and NPK, $_{Zn\ S}$ nutrient combinations. Nitrogen was applied at 150 kg N/ha (urea, 46% N), P at 50 kg P/ha (single super phosphate, 20% P), K at 100 kg K/ha (muriate of potash, 60% K) while Zn and S were sourced from zinc sulphate.

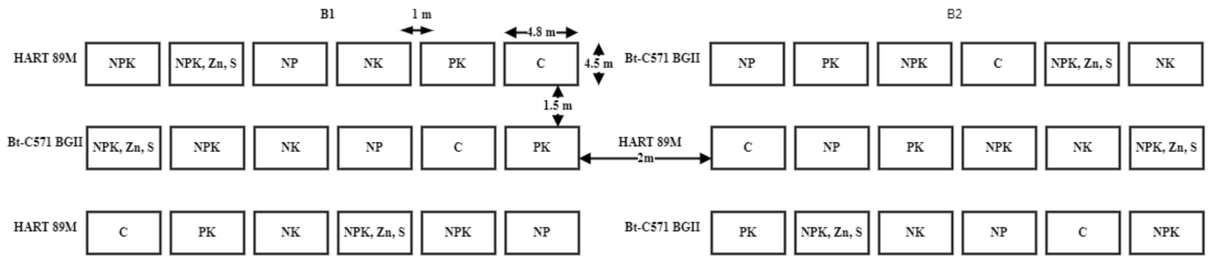


Figure 3.1. Treatment combinations and field layout

3.3.3 Experiment management

Land clearing and ploughing were done to remove all vegetation, followed by harrowing to achieve a medium tilth. Two main blocks were laid out with a spacing of 2 m apart, and the sub plots measured 4.8 m by 4.5 m, with a spacing of 1 metre apart and 1.5 metre in between the replicates. Sowing was done on twentieth day of October 2021, at a rate of 3 seeds per hole, 3 cm depth and a spacing of 90 cm by 60 cm. Thinning, gapping and weeding were done two weeks after emergence. Frequent scouting was done to monitor the occurrence of pests and diseases. Cotton stainers, aphids, weevils and bollworms were identified during the boll formation stage. Pests were controlled using Thunder®, a broad spectrum insecticide that combines two different active ingredients imidacloprid and beta-cyfluthrin, at a rate of 10 mL per 20 litres of water. There were no disease incidences during this study in both sites.

3.3.4 Soil sample collection and analysis

Soils were sampled by selecting 10 random points following a zigzag pattern and sampled using a 600 cm^3 auger at 30 cms depth. The soil samples from each site were mixed thoroughly and a composite sample was taken for analysis. Soils were air dried for about 48 hours and sieved using 2 mm sieve for pH, phosphorous, potassium, magnesium, zinc, boron, copper and sulphate and 0.5 mm sieve for the total nitrogen.

The sampled soils were analyzed for the pH, available P, Exchangeable K, Mg, Zn, B, Cu, SO_4 and total nitrogen. Total nitrogen was analyzed using Kjeldahl method (Bremner, 1996). Phosphorous, zinc, copper, sulphur, boron and magnesium was analyzed using Mehlich I method Mylavarapu et al. (2002) while exchangeable potassium was analyzed using the extraction method by 1 mL of ammonium acetate.

3.3.5 Data collection

3.3.6 Weather data and crop phenology

Daily minimum and maximum temperature (°C) and rainfall (mm) were obtained from the sites meteorological weather stations. Crop phenology was scored regularly but with particular emphasis on the number of days to 50% branching, squaring, boll formation and boll opening. Time to respective phenological stages was scored when 50% of the crop stand attained the specific growth stage.

3.3.7 Crop growth traits

Crop growth was tracked throughout the growing season by measuring plant height, stem girth, leaf greenness, root growth characteristics and biomass. Five plants per plot were randomly selected and tagged for repeated measurements. Measurements for the plant height were taken from the base to the terminal end of the plant at branching, flowering and maturity using a meter rule. Stem girth was determined at branching, flowering and maturity with the use of a vernier caliper at 5cm below the insertion of the first branch. At 50% branching and flowering, five uppermost fully expanded leaves were sampled per pant and leaf greenness determined using a SPAD meter.

Root length and root angle were evaluated using ImageJ software during flowering and at physiological maturity. Five plants were randomly sampled, uprooted, cleaned, placed on separate and well labelled clean A4 papers, and a ruler was placed at the bottom to give the calibrations. Images from the five sampled plants were taken using a camera for analysis. The software was optimized by taking clear images with a clear focus of the root image and avoiding surrounding objects. These five plants were later oven dried at 70 ^{o}C to measure biomass accumulation using a weighing balance machine.

3.3.8 Crop yield components

Number of squares, flowers and bolls were counted from formation stage and when fully formed to physiological maturity. Five bolls were randomly sampled and their size measured using a vernier caliper. Five fully opened bolls were harvested, seed cotton was oven dried at 70 ^{o}C and weighed using a weighing balance machine to measure the boll weight. Harvesting was done from an area of 3m by 3m of the plot and seed cotton yield was later determined through calculations, and expressed in t/ha.

3.3.9 Data analysis

Analysis of variance (ANOVA) was done to measure the sources of experimental variation for all the parameters using GenStat 15th Edition (Payne et al., 2011). Data was verified for regularity and complied to the needs of ANOVA. Residuals were checked for normal dispersal and there were no modifications to be made. Treatment means were compared and separated using Fisher's protected least significant difference (LSD) at 5% probability level.

3.4 Results

3.4.1 Weather conditions and crop growth stages

Rainfall trends during cotton growth stages are shown in Figure 3.2. Annual average rainfall for Machakos ATC was 440 mm while Ndalani received 503 mm. Temperature range was between 10 ^{o}C and 32.4 ^{o}C in both sites. In Machakos ATC, the two cotton varieties took an average of 46 days to branch, 61 days to form squares, 96 days to form bolls,170 days for bolls to open and 226 days to mature. In Ndalani, the two cotton varieties took 51 days to branch, 66 days to form squares, 89 days to form bolls, 157 days for bolls to open and 206 days to mature Tables 3.1, 3.2 and 3.3.

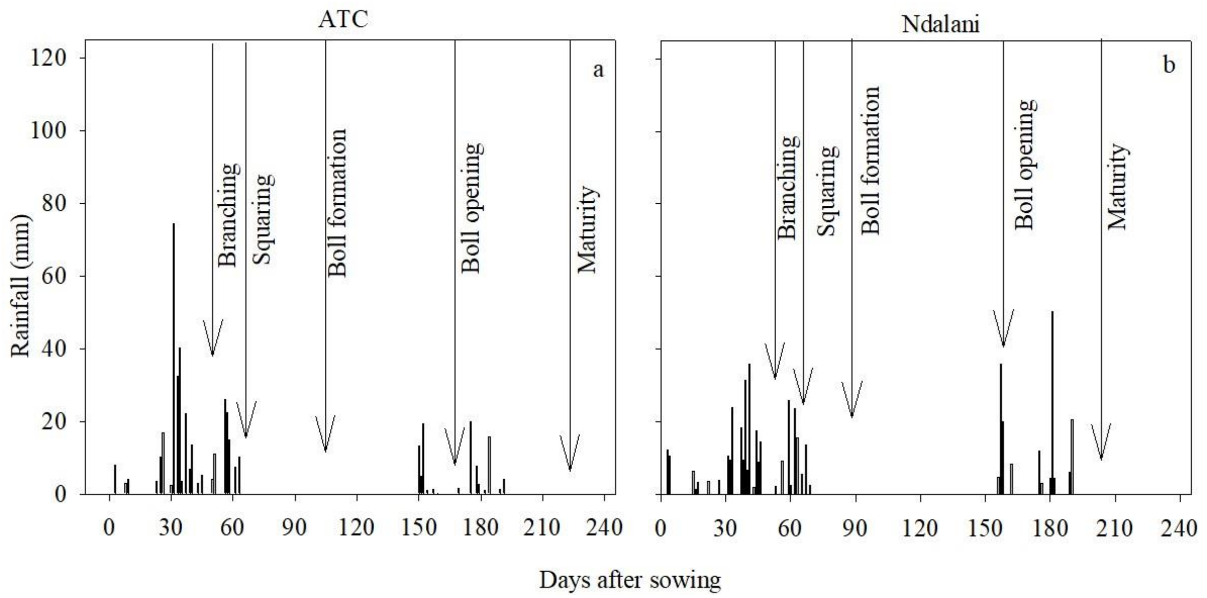


Figure 3.2 Daily rainfall (mm) and days to select phenological stages of cotton grown in Machakos ATC (a) and Ndalani farm (b)

3.4.2 Soil conditions

Results showed that % nitrogen was low, zinc and sulphur were deficient while potassium and phosphorus were sufficient in both sites Table 3.1. Percentage nitrogen was rated as low <0.2%, medium 0.21-0.5%, and high >0.5% while K (Mol (+)/Kg, as deficient < 0.2, Sufficient 0.2-1.5, and rich >1.5, SO4- (ppm) as deficient at 20 and sufficient 20-100, Zn (ppm) as deficient <5, sufficient >5.0 and P (ppm) as deficient 0.2, sufficient 20-80 and rich >80.

Table 3.1. Soil analysis results for Machakos Agriculture Training Center and a farmer's field in Ndalani, Machakos County

Soil sample test	pH	% N	K	SO_{4-} (S)	P	Zn
Machakos ATC	6.85	0.09	0.88	15.20	39.41	4.75
Ndalani farm	6.61	0.13	0.79	9.64	53.60	4.21

3.4.3 Effect of nutrient combinations on branching

The interactive effect of different nutrient groupings on the two cotton varieties is shown in Table 3.2. Crops grown in fertilized soils took significantly ($P \leq 0.05$) fewer days to 50% branching in HART 89M and Bt-C571 BGII cotton varieties than those in unfertilized soils in Machakos ATC and Ndalani. In both sites, different combinations of N, P and K nutrients had a significant effect on the time taken to attain 50% branching. The results showed that in Machakos ATC, $NPK_{Zn, S}$ took 43 days, NPK and NK 44 days, NP 45 days, PK 49 days while control 52 days to form branches. In Ndalani, $NPK_{Zn, S}$ took 49 days, NPK, NP and NK 50 days, PK 52 days and control took 53 days to form branches. Irrespective of variety, this shows that crops supplied with N nutrient combinations branched earlier compared with crops fertilized with PK combinations and unfertilized crops in both sites. Similarly, cotton in soils fertilized with N nutrient combinations had slightly more branches per plant than cotton grown in soils fertilized with PK and control. In Machakos ATC, NPK, $_{Zn, S}$ had 36 branches, NPK and NK 34, NP 33, PK and control 31 branches. In Ndalani, NP and NK had 27 branches, NPK and NPK, $_{Zn, S}$ 25, PK 24 while control had 22 branches. Generally, Bt-C571 BGII had slightly more branches per plant than HART 89M.

Table 3.2. Days to 50% branching and number of branches per plant of two cotton varieties grown under different nutrient combinations in Machakos Agriculture Training Center and a farmer's field in Ndalani, Machakos County

Nutrient combinations	Days to 50% branching			Branches per plant		
	HART	Bt	Mean	HART	Bt	Mean
Machakos ATC						
Control	52c	51c	52d	30a	32ab	31a
NP	45a	45a	45b	32ab	35ab	33b
NK	45a	44a	44ab	33ab	35ab	34b
PK	49a	48b	49c	30a	32ab	31a
NPK	44a	44a	44ab	33ab	35ab	34bc
NPK, $_{Zn\ S}$	42b	44a	43a	35ab	36b	36c
LSD	*1.67*		*1.15*	*5.6*		*1.5*
Ndalani farmer's field						
Control	53e	53de	53d	23a	22a	22a
NP	51cde	49ab	50ab	27a	26a	27a
NK	51cd	48ab	50ab	26a	27a	27a
PK	52de	52de	52cd	24a	24a	24a
NPK	50bc	50bc	50bc	26a	25a	25a
NPK, $_{Zn\ S}$	50bc	48a	49a	25a	26a	25a
LSD	*1.96*		*1.51*	*7.68*		*5.3*

Means in the same column not having a common letter are significantly different (P<0.05)

3.4.4 Effect of nutrient combinations on squaring

Table 3.3 presents the interaction between nutrient combinations and the two cotton varieties grown in Machakos ATC and Ndalani. Nutrient combinations exerted a significant difference in the number of days to 50% square formation and total number of squares in both varieties and sites. In Machakos ATC, NPK, $_{Zn, s}$ and NPK took 59 days, NP and NK 60 days, PK 64 days while control 66 days to square. In Ndalani, NPK, Zn, S took 48 days, NPK and NK 51 days, NP 52 days, PK 55 days and control 60 days. Notably, these results revealed that significantly fewer (P<0.05) days to 50% squaring were observed in cotton grown in N nutrient fertilized soils than those grown in soils fertilized with PK and control across sites. In

Machakos ATC, NK had 62 squares, NP 61, NPK, $_{Zn, S}$ and NPK had 59, PK had 49 while control had 45 squares. In Ndalani, NK had 31 squares, NP 29, NPK, $_{Zn, S}$ 28, NPK 27, PK 24, and control 18 squares. In addition, significant varietal differences were observed in the number of days to 50% squaring whereby Bt-C571 BGII took a shorter period than HART 89M across the two sites.

Table 3.3. Days to 50% squaring and the number of squares per plant of two cotton varieties grown under different nutrient combinations in Machakos Agricultural Training Centre and a farmer's field in Ndalani, Machakos County

Nutrient combinations	Days to 50% squaring			Squares per plant		
	HART	Bt	Mean	HART	Bt	Mean
Machakos ATC						
Control	73e	58b	66b	41a	50abc	45a
NP	65c	55a	60a	58abcd	64cd	61b
NK	65c	54a	60a	55abcd	67d	62b
PK	69d	59b	64b	47ab	52abcd	49a
NPK	64c	55a	59a	53abcd	65cd	59b
NPK, Zn S	64c	53a	59a	57abcd	62bcd	59b
LSD	*2.74*		*1.93*	*17.23*		*5.41*
Ndalani farmer's field						
Control	64e	56cd	60d	15a	21a	18a
NP	54bcd	51b	52bc	26a	32a	29bc
NK	55cd	46a	51ab	29a	33a	31c
PK	57d	52bc	55c	25a	22a	24ab
NPK	56cd	47a	51b	28a	25a	27bc
NPK, Zn S	52bc	44a	48a	25a	31a	28bc
LSD	*3.71*		*2.53*	*26.19*		*6.26*

Means in the same column not having a common letter are significantly different (P<0.05)

3.4.5 Effect of nutrient combinations on boll formation

Table 3.4 displays the interactive effect of varying nutrient blends on the two cotton varieties grown in Machakos ATC and Ndalani. In Machakos ATC, cotton grown in fertilized soils took significantly fewer (P≤0.05) days to reach 50% boll formation than those in control. Among the cotton grown in fertilized soils, the least days to 50% boll formation were from those incorporated with NPK, Zn S since it took 93 days while NPK took 94, NP and NK took 95, PK 99 while control took 102 days. In Ndalani, NPK, Zn S took 84 days, NPK and NP 88 days, NK 87, PK 91 and control 96 days to form bolls. Overall, HART 89M took slightly more days to 50% boll formation than Bt-C571 BGII in all the treatments. Further, in Machakos ATC, NPK, Zn, S, NPK and NK took 169 to 50% boll opening, NP 168 days, PK 171 and control 172 days. In Ndalani, NPK, Zn, S, NPK and NK took 156 days, NP 55 days, PK 158 and control 159 days to reach 50% boll opening. Markedly, number of days to 50 % boll opening was higher in N fertilized soils than in control and PK combinations. In Machakos ATC, NPK, Zn, s had 35 bolls, NK, 34, NPK and NP had 32, PK 28 while control had 22 bolls. In Ndalani, NK had 20 bolls, NP and NPK, Zn, S had 19 bolls, NPK 17, PK 15 and control had 11 bolls. These results show that bolls per plant were more in soils with N nutrient combinations compared with PK and control. Across the two sites, HART 89M took significantly more (P≤0.05) days to 50% boll opening than Bt-C571 BGII. On the contrary Bt-C571 BGII had slightly higher number of bolls per plant than HART 89M across the two sites.

Table 3.4. Days to 50% boll formation, opening and number of bolls per plant of two cotton varieties grown under different nutrient combinations in Machakos Agriculture Training Center and a farmer's field in Ndalani, Machakos County

Nutrient	Boll formation			Boll opening			Bolls/plant		
combinations	HART	Bt	Mean	HART	Bt	Mean	HART	Bt	Mean
Machakos ATC									
Control	108g	97d	102d	182b	162a	172a	21a	24ab	22a
NP	100e	90b	95b	178b	158a	168a	29bc	36def	32c
NK	100e	89ab	95b	178b	160a	169a	29bcd	39f	34c
PK	103f	94c	99c	179b	162a	171a	27abc	29bc	28b
NPK	99e	90b	94ab	178b	160a	169a	25ab	40f	32bc
NPK, Zn S	99e	88a	93a	178b	158a	169a	32cde	38ef	35c
LSD	*1.62*		*1.17*	*4.73*		*4.73*	*7.10*		*4.46*
Ndalani farmer's field									
Control	100f	92de	96d	168d	151bc	159c	8a	14a	11a
NP	91de	85bc	88b	165d	144a	155a	14a	23a	19b
NK	92de	82ab	87b	165d	148abc	156abc	16a	23a	20b
PK	93e	89cde	91c	164d	152c	158bc	15a	15a	15ab
NPK	93e	83ab	88b	164d	149bc	156abc	16a	18a	17b
NPK, Zn S	88cd	80a	84a	164d	147ab	156abc	14a	23a	19b
LSD	*4.41*		*2.49*	*4.53*		*3.07*	*18.06*		*4.76*

Means in the same column not having a common letter are significantly different ($P<0.05$)

3.4.6 Effect of nutrient combinations on plant height and stem girth

Table 3.5 shows the plant height of the two cotton varieties grown under two contrasting environments in Machakos county. Use of different nutrient combinations resulted into a significant increase (P≤0.05) in height of the two cotton varieties across growth stages and sites. In Machakos ATC, the height of the two cotton varieties progressively increased from branching to maturity. Overall, cotton plants in soils fertilized with NP, NK, NPK, and NPK, $_{Zn\ S}$ were significantly (P≤0.05) taller than those grown without N nutrient and in unfertilized soils across the growth stages. Similarly, in Ndalani, cotton plants in soils fertilized with N nutrient combinations were significantly (P≤0.05) taller than those grown in PK combinations and in unfertilized soils across the growth stages. Varietal differences were observed in height, whereby HART 89M was slightly taller than the Bt-C571 BGII across the growth stages.

Progressive increase in stem girth from branching to physiological maturity of the two cotton varieties is shown in Table 3.6. In Machakos County, cotton grown in soils fertilized with N nutrient combinations had a significantly thicker (P≤0.05) stem girth than cotton grown with PK combinations and control across all growth stages. Likewise, in Ndalani, cotton grown in soils fertilized without N nutrient and control had significantly thinner stem girth compared with N nutrient combinations. Notably, control and cotton grown in soils fertilized with PK had statistically similar stem girth across the growth stages and sites.

3.4.7 Effect of nutrient groupings on the leaf greenness

The interactive effect of different nutrient groups on leaf greenness of the two cotton varieties is displayed in Table 3.7. There was a progressive increase in leaf greenness of the two cotton varieties from branching to flowering in Machakos ATC and Ndalani. In Machakos ATC, all cotton grown in N nutrient fertilized soils were significantly greener (P≤0.05) than cotton grown in control and in soils fertilized with PK. Significant varietal differences were only recorded in PK combinations. In Ndalani, cotton grown in N nutrient combinations had significant diffrences in leaf greenness at branching. However, different combinations of NPK nutrients had statistically similar leaf greenness at flowering. Varietal differences were not recorded in Ndalani.

Table 3.5. Mean height (cm) of the two cotton varieties at branching, flowering and maturity grown under different nutrient combinations in Machakos Agricultural Training Center (ATC) and a farmer's field in Ndalani, Machakos County

Nutrient	Branching			Flowering			Maturity		
combinations	HART	Bt	Mean	HART	Bt	Mean	HART	Bt	Mean
Machakos ATC									
Control	35.0ab	38.8abc	36.9a	67.5a	75.0abc	71.2a	84.1abc	78.4a	81.2a
NP	47.8cde	48.4cde	48.1b	84.1cd	82.4cd	83.3b	96.7fgh	88.1cd	92.4b
NK	44.9bcde	50.0de	47.5b	77.6bcd	84.7d	81.2b	95.5efgh	89.4cde	92.4b
PK	33.5a	41.5abcd	37.5a	69.8ab	75.0abc	72.4a	85.5bcd	79.7ab	82.6a
NPK	50.4de	47.8cde	49.1b	80.8cd	84.4d	82.6b	97.9gh	90.9def	94.4b
NPK, $_{Zn\ S}$	45.2cde	52.3e	48.8b	83.9cd	85.5d	84.7b	100.7h	91.7defg	96.2b
LSD	*10.1*		5.95	*9.22*		4.58	*6.40*		4.95
Ndalani farmer's field									
Control	40.7a	43.7abc	42.2a	56.53ab	55.93ab	56.2ab	70.5a	65.9a	68.2a
NP	56.4e	53.3cde	54.8bc	71.2e	62.53bcde	65.1cd	96.6a	85.1a	90.9b
NK	58.1e	56.7e	57.4c	71.2e	58.93abcd	66.9d	92.1a	86.7a	89.4b
PK	41.2ab	44.0abc	42.6a	67.4cde	55.07ab	53.4a	80.3a	64.1a	72.2a
NPK	51.2bcde	45.8abcd	48.5ab	68.07de	63.8bcde	61.2bc	85.7a	85.7a	85.7b
NPK, $_{Zn\ S}$	55.9de	58.3e	57.1c	57.2abc	49.6a	65.9cd	93.7a	80.3a	87.0b
LSD	*10.51*		*6.59*	*10.81*		*5.24*	*41.91*		*8.52*

Means in the same column not having a common letter are significantly different (P<0.05).

Table 3.6. Mean stem girth (mm) at branching, flowering and maturity of two cotton varieties grown under different nutrient combinations in Machakos Agricultural training centre and a farmer's field in Ndalani, Machakos County

Nutrient combinations	Branching			Flowering			Maturity		
	HART	Bt	Mean	HART	Bt	Mean	HART	Bt	Mean
Machakos ATC									
Control	6.0a	6.7ab	6.4a	11.3bc	10.4ab	10.9a	13.1b	10.8a	11.9a
NP	7.9bcd	8.2bcd	8.0b	13.7d	11.5c	12.6b	16.8c	12.7b	14.8b
NK	7.5abcd	9.2d	8.3b	13.3d	12.0c	12.6b	15.9c	12.6b	14.2b
PK	9.0d	6.9abc	6.4a	11.7c	10.1a	10.9a	13.3b	11.0a	12.1a
NPK	8.1bcd	8.7cd	8.4b	13.4d	11.8c	12.6b	16.4c	13.0b	14.7b
NPK, $_{Zn\ S}$	7.6abcd	9.0d	8.3b	13.3d	11.9c	12.5b	16.5c	13.3b	14.9b
LSD	*1.84*		0.79	*1.08*		0.69	*1.10*		0.76
Ndalani farmer's field									
Control	6.8a	7.0a	6.9a	7.7abc	6.5a	7.1a	9.8abc	8.2a	9.0a
NP	10.1d	8.7bcd	9.4b	9.8bc	9.2abc	9.5b	13.2c	10.8abc	12.0c
NK	9.7d	9.3cd	9.5b	9.4abc	9.8bc	9.6b	12.2bc	11.9abc	12.1c
PK	7.9abc	7.3ab	7.6a	8.3abc	7.3ab	7.8a	9.8abc	8.6ab	9.2a
NPK	9.8d	8.4abcd	9.1b	9.5bc	8.9abc	9.2b	11.3abc	10.2abc	10.8b
NPK, $_{Zn\ S}$	9.8d	10.0d	9.9b	10.3c	9.4bc	9.8b	13.0c	11.7abc	12.4c
LSD	*1.68*		*1.06*	*2.89*		*1.04*	*3.88*		*1.13*

Means in the same column not having a common letter are significantly different (P<0.05).

Table 3.7. Leaf greenness (SPAD units) at branching and flowering of two cotton varieties grown under different nutrient combinations in Machakos Agriculture Training Center and a farmer's field in Ndalani, Machakos County

Nutrient combinations	Branching			Flowering		
	HART	Bt	Mean	HART	Bt	Mean
Machakos ATC						
Control	38.03a	41.93abc	39.98a	42.33a	42.93a	42.63a
NP	44.17cd	45.73cd	44.95bc	47.40c	48.80c	48.10b
NK	45.83cd	44.17bcd	45.00bc	46.77bc	47.83c	47.30b
PK	38.30a	43.63bcd	40.97a	43.37a	43.93ab	43.65a
NPK	47.20d	46.03cd	46.62c	48.50c	49.33c	48.92b
NPK, $_{Zn\ S}$	39.97ab	43.73bcd	41.85ab	48.17c	48.70c	48.43b
LSD	*4.22*		3.25	*3.37*		1.18
Ndalani Farmer's field						
Control	43.27a	43.50a	43.38a	48.13a	51.10a	49.62b
NP	47.10a	47.77a	47.43c	46.97a	53.10a	50.03b
NK	46.37a	46.30a	46.33bc	43.93a	51.83a	47.88b
PK	43.77a	45.83a	44.80ab	48.63a	50.10a	49.37b
NPK	47.07a	45.27a	47.32c	45.27a	51.23a	48.25b
NPK, $_{Zn\ S}$	45.67a	42.73a	45.95bc	42.73a	45.77a	44.25a
LSD	*7.07*		*1.88*	*13.03*		*3.04*

Means in the same column not having a common letter are significantly different (P<0.05)

3.4.8 Effect of nutrient combinations on the boll size, boll weight and number of seeds per boll

Table 3.8 shows the interactive effect of N, P and K nutrient combinations on boll size, weight and number of seeds per boll of the two cotton varieties grown in Machakos ATC and Ndalani. In Machakos ATC, cotton grown in soils fertilized with N nutrient combinations had larger bolls than control and cotton grown with PK combinations across the two cotton varieties. Equally, larger cotton bolls were recorded in cotton grown in soils fertilized with N nutrient combinations than in soils fertilized with PK combinations and in control in Ndalani. Notably, cotton bolls in Machakos ATC were larger for the two cotton varieties than those in Ndalani. Varietal differences in boll size were recorded and Bt-C571 BGII had larger bolls than HART 89M across all nutrient combinations and sites. In Machakos ATC, cotton bolls were significantly heavier ($P \leq 0.05$) for cotton grown with N nutrient than in control and in cotton grown without N nutrient. In Ndalani, cotton grown in soils fertilized with PK had smaller bolls which were statistically similar to control in both varieties. Markedly, Across the two cotton varieties, cotton in the fertilized soils had the heaviest bolls compared with cotton grown in PK combinations and in control. Significant varietal differences in boll weight were recorded in Machakos ATC where Bt-C571 BGII bolls were heavier compared with HART 89M bolls. In Machakos ATC, number of seeds per boll were more in N nutrient combinations than in the control and in PK combinations. A similar observation was made in Ndalani, where higher number of seeds per boll were recorded in soils fertilized with N nutrient combinations compared with the control and PK combinations.

Table 3.8. Boll size (mm), boll weight (g) and number of seeds per boll of two cotton varieties grown under different nutrient combinations in Machakos Agriculture Training Center and in a farmer's field in Ndalani, Machakos County

Nutrient	Boll size			Boll weight			Seeds/boll		
combinations	HART	Bt	Mean	HART	Bt	Mean	HART	Bt	Mean
Machakos ATC									
Control	33ab	35b	34a	5.0ab	5.8cde	5.4a	31a	31a	31a
NP	34b	36c	35b	6.0cde	6.3efg	6.1bc	34c	34c	34c
NK	34b	36c	35b	5.8cde	6.2def	6.0b	34c	34c	34c
PK	32a	35b	33a	4.9a	5.6bcd	5.3a	31a	32ab	31a
NPK	34b	37c	35b	5.5abc	6.9g	6.2bc	33bc	34c	34c
NPK, Zn S	33ab	37c	35b	5.9cde	6.8fg	6.3c	33bc	34c	33b
LSD	*1.45*		*0.88*	*0.62*		*0.32*	*1.3*		*0.9*
Ndalani farmer's field									
Control	28ab	27a	28a	3.8ab	3.6a	3.7a	31a	32ab	32a
NP	30abc	33c	31bc	4.4bc	4.6c	4.5bc	33ab	34b	33ab
NK	30abc	31abc	31bc	4.7c	4.6c	4.6c	32ab	33ab	33ab
PK	29abc	29abc	29ab	4.3bc	4.2bc	4.3b	32ab	33ab	32a
NPK	32c	32c	32c	4.4bc	4.6c	4.5bc	33ab	34b	34b
NPK, Zn S	31abc	31bc	31bc	4.5c	4.2bc	4.4bc	34b	34b	34b
LSD	*3.67*		*2.15*	*0.64*		*0.28*	*2.9*		*1.0*

Means in the same column not having a common letter are significantly different (P<0.05)

3.4.9 Effect of nutrient combinations on the root length and angle

Table 3.9 presents the interactive effect of different nutrient combinations on the root length and root angle of the two cotton varieties. Root length increased progressively from flowering to harvesting in all the treatments across the two cotton varieties. In Machakos ATC, cotton in fertilized soils had significantly longer ($P \leq 0.05$) root length across the two cotton varieties than in control at flowering. Both HART 89M and Bt-C571 BGII showed significantly longer ($P \leq 0.05$) root lengths in soil fertilized with PK at flowering and harvesting. In Ndalani, different nutrient combinations had significant effects on the root length of both varieties. Cotton grown in all fertilized soils had significantly longer ($P \leq 0.05$) root length across the two cotton varieties than in control. Prominently, cotton grown in soils fertilized with PK combinations had significantly longer roots at flowering and harvesting compared with cotton grown in other combinations and control. Soil nutrient combinations had a significant difference in root angles between HART 89M and Bt-C571 BGII in Machakos and Ndalani. In Machakos ATC, the control root angle was similar to cotton grown under fertilized soils except for Bt-C571 BGII grown under NPK fertilized soils. In Ndalani, the control root angle was similar to that of cotton grown under fertilized soils, except for Bt-C571 BGII grown under NK fertilized soils.

Table 3.9. Root length (cm) and root angle of two cotton varieties grown under different nutrient combinations in Machakos Agriculture Training Center and a farmer's field in Ndalani, Machakos County

Nutrient combinations	Root length						Root Angle		
	Flowering			Harvesting			Harvesting		
	HART	Bt	Mean	HART	Bt	Mean	HART	Bt	Mean
Machakos ATC									
Control	39a	38a	38a	62c	50a	56a	78ab	76ab	77ab
NP	41ab	44abc	43b	63cd	55b	59b	77ab	73a	75a
NK	40ab	46abc	43b	65cd	56b	60bc	73a	83bc	78ab
PK	50bc	54c	52c	69e	58b	67d	73a	74ab	74a
NPK	44abc	48abc	46b	66de	57b	62c	78ab	88c	83b
NPK, Zn S	45abc	46abc	45b	66de	58b	62c	83bc	83bc	83b
LSD	*10.2*		4.0	*3.4*		2.3	*9.8*		7.5
Ndalani farmer's field									
Control	47bc	37a	42a	52ab	48a	50a	73abc	66a	70a
NP	48bc	46bc	47ab	55bc	54bc	55bc	77abc	75abc	76ab
NK	46bc	48bc	47ab	52ab	55bc	53ab	80c	81c	80b
PK	53c	54c	54c	57bc	58c	58c	68ab	74abc	71a
NPK	48bc	52bc	50bc	57bc	57bc	57c	82c	68ab	75ab
NPK, Zn S	51bc	44ab	48b	55bc	54abc	54bc	79bc	78bc	78ab
LSD	*8.77*		5.05	*5.72*		3.44	*11.9*		8.8

Means in the same column not having a common letter are significantly different (P<0.05.)

3.4.10 Effect of nutrient combinations on total dry matter and ginning out-turn percentage

The interactive effects of diverse nutrient blends on total dry matter and the ginning-out turn % is shown in Table 3.10. In Machakos ATC, application of different combinations of N, P and K nutrients had a significant effect on the biomass. The total dry matter was higher for cotton grown in the plots that had N nutrient applied than in plots without N nutrient. Correspondingly, cotton grown in Ndalani using different N nutrient combinations had higher dry matter per unit area compared with cotton grown in PK combinations and in control. Similarly, different combinations of N, P and K nutrients had a significant ($P \leq 0.05$) effect on ginning out-turn percentage of the two cotton varieties in Machakos ATC. In this study, the application of N nutrient combinations negatively influenced the ginning out-turn %. The results showed that average ginning out-turn percentage was lower in soils fertilized with N nutrient combinations compared with the plot without N nutrient and the unfertilized control. In Ndalani, cotton grown in PK and control had a higher ginning out-turn percentage than cotton grown in N nutrient combinations. Varietal differences in biomass and ginning out-turn % were not recorded in the two sites

Table 3.10.Total dry matter (t/ha) and ginning out-turn percentage of two cotton varieties grown under different nutrient combinations in Machakos Agricultural Training Centre and a farmer's field in Ndalani, Machakos County

Nutrient combinations	Biomass t/ha						GOT %		
	Flowering			Harvesting			Harvesting		
	HART	Bt	Mean	HART	Bt	Mean	HART	Bt	Mean
Machakos ATC									
Control	1.14a	0.97a	1.05a	2.42a	1.97a	2.20a	41.47a	41.40a	41.43c
NP	0.23a	0.16ac	1.95b	4.52a	2.56b	3.54ab	38.80a	40.53a	39.67b
NK	1.63a	1.12ac	1.38a	4.26a	3.95a	4.11b	39.87a	41.67a	40.77c
PK	1.33a	1.15ac	1.24a	3.02a	1.83a	2.42a	40.33a	41.27a	40.80c
NPK	0.21a	1.91bc	2.02b	4.95a	4.48a	4.72b	39.27a	39.80a	39.53b
NPK, $_{Zn\ S}$	2.72a	1.77bc	2.24b	5.30a	4.34a	4.82b	39.00a	40.60a	39.80b
LSD	*0.90*		*0.50*	*1.76*		*1.35*	*14.11*		*1.04*
Ndalani farmer's field									
Control	0.51a	0.49a	0.50a	1.21a	1.11a	1.16a	43.90a	44.60a	44.25c
NP	1.04a	1.03a	1.03b	2.13a	1.56a	1.84b	42.10a	43.70a	42.90ab
NK	1.03a	1.08a	1.06b	2.11a	1.50a	1.81b	42.63a	45.07a	43.85bc
PK	0.62a	0.96a	0.79a	1.27a	1.11a	1.19a	43.00a	44.40a	43.70bc
NPK	0.89a	1.19a	1.04b	1.92a	1.67a	1.80b	42.13a	42.17a	42.15a
NPK, $_{Zn\ S}$	1.51a	1.03a	1.27b	2.12a	1.67a	1.90b	43.77a	43.77a	42.72ab
LSD	*1.11*		*0.26*	*1.61*		*0.46*	*10.27*		*1.23*

Means in the same column not having a common letter are significantly different (P<0.05.

3.4.11 Effect of nutrient combinations on seed cotton yield per hectare

The interactive effect of different nutrient groupings on seed cotton yield is shown in Table 3.11. In Machakos ATC, both cotton varieties grown in fertilized soils had significantly more ($P \leq 0.05$) yield than cotton grown in unfertilized soils. However, the two cotton varieties grown in soils fertilized with PK had the lowest yield which were statistically similar to those without fertilizer. Among cotton grown in fertilized soils, cotton grown with NP had the highest yield of 3.9 t/ha. Likewise, cotton grown in N nutrient combinations had higher yield than in PK combinations and control in Ndalani. Across all the treatments and sites, HART 89M had slightly higher yield than those in Bt-C571 BGII. Noticeably, yield obtained in Machakos ATC across all the treatments used was about twice that obtained in Ndalani.

Table 3.11. Seed cotton yield (t/ha) of two cotton varieties grown under different nutrient combinations in Machakos Agriculture Training Center and in a farmer's field in Ndalani, Machakos County

Nutrient combinations	HART	Bt	Mean
Machakos ATC			
Control	3.037abc	2.397a	2.717a
NP	4.353d	3.460bcd	3.907c
NK	3.680bcd	3.393abcd	3.537bc
PK	3.310abcd	2.630ab	2.970ab
NPK	4.013cd	3.500bcd	3.757c
NPK, Zn S	3.900cd	3.313abcd	3.607c
LSD	*1.0597*		*0.617*
Ndalani farmer's field			
Control	1.337a	1.407ab	1.372a
NP	1.583c	1.58bc	1.582c
NK	1.450abc	1.593c	1.522bc
PK	1.423abc	1.497abc	1.460ab
NPK	1.533bc	1.590c	1.562c
NPK, Zn S	1.507abc	1.593c	1.550c
LSD	*0.1746*		*0.0882*

Means in the same column not having a common letter are significantly different ($P<0.05$).

3.5 Discussion

3.5.1 Effect of nutrient combinations on crop phenology

The two cotton varieties showed significant ($P\leq0.05$) variations with respect to the number of days taken to attain 50% branching, squaring, flowering, boll formation, and overall maturity with the application of different nutrient combinations. Bt cotton took a significantly shorter period to reach maturity compared to HART 89M. This could probably mean that Bt cotton has a more vigorously growth with the application different nutrient combinations compared to HART 89M. Significant differences were recorded for the time taken to attain 50% squares and branches at ($P\leq0.05$). The PK combinations took 51 days and 60 days while the unfertilized plot took 53 days and 63 days to form 50% branches and squares respectively. On the other hand, N combinations (NP, NK, NPK, NPK, Zn S) took significantly fewer ($P\leq0.05$) days to reach maturity compared with control and cotton grown in soils fertilized with phosphorus and potassium. This is because nitrogen plays a key role as a single most important growth-limiting factor which influences growth rate, maturity, yield and fiber quality (Rashid et al., 2011; Khan et al., 2017). These results also agree with the findings of Reddy et al. (2007) and sawan et al. (2009) who observed that the use of nitrogen considerably increase cotton growth compared with the control. In addition, Brown (2002) and Khan et al. (2017) also found that nitrogen promotes and hastens vegetative growth. There was no effect on the interaction between the variety and the nutrient combinations.

3.5.2 Effect of nutrient combinations on growth parameters

Across the two sites, different combinations of N, P and K nutrients influenced the number of branches, biomass, leaf greenness, plant height, stem girth and boll size. Significant effects of different combinations of N, P, and K nutrients were observed on the total number of branches of the two cotton varieties. Branches per plant were significantly higher for cotton grown in soils fertilized with N nutrient combinations than for cotton grown without N nutrient and control. These results were in agreement with those of Dar and Anwar (2005), Khan and Dar (2006), and Kumbhar et al. (2008), who noticed that nitrogen application increased the total branches per plant. This could be as a result of nitrogen's ability to control growth Borowski, (2001).

Application of different combinations of N, P and K nutrients had a significant effect on the total dry matter production per unit area. The total dry matter was higher within the plots that had N nutrient application than in plots without N nutrient applied. This could be as a result of nitrogen being an important nutrient in the build up of plant dry matter and energy rich compounds, which control photosynthesis (Sawan et al., 2009). The findings are also similar to those of Perumai (1999), Fritschi et al. (2003), and Ibrahim et al. (2010), who observed that nitrogen application significantly increased above ground dry matter. There was a significant effect on the leaf greenness whereby the highest SPAD units were found in the plots that had N nutrient and lower in the plot without N nutrient and the unfertilized control. This means the leaf greenness (SPAD values) increased with nitrogen application. This could be due to better N nutrient uptake and utilization by cotton plants (Khan et al., 2001). These results agree with those of Boquet et al. (1999), who reported similar strong relationships between nitrogen and SPAD values.

Plant height was significantly influenced by the application of different combinations of N, P, and K nutrients. Plants were taller in the plots that had N nutrient combinations as compared with the plots without N nutrient and the negative control. Similarly, the nutrients combinations had highly significant effects on the stem girth. Plots with N nutrient combinations had significant wider stem girth as opposed to the plot without N nutrient and in PK combinations. Similar observations were also made for boll size, whereby bolls in the negative control and in

PK combinations were significantly smaller as opposed to those in N nutrient combinations. These results are in agreement with the findings of Kumbhar et al. (2008) and Dong et al. (2010), who found an increase in crop size as a result of N nutrient application. These results further revealed that N deficiency caused a reduction in the vegetative growth of the two cotton varieties, resulting in smaller bolls, shorter plants, thin plants, fewer shoots and less biomass. These results are further supported by Gerik et al. (1994), who noted that nitrogen deficits decreased vegetative and reproductive growth of cotton.

On the other hand, the root length of cotton was highly influenced by the application of different combinations of N, P, and K nutrient. The roots of cotton in the PK nutrient combinations were longer than the roots of cotton grown without P nutrient and in the unfertilized plots. This means that P fertilization increased the root length of cotton. These results agree with the findings of Brouder and Cassman (1994), who observed increased cotton root length as a result of P fertilization. The root angle was not influenced in any way by the application of different combinations of N, P, and K nutrients.

3.5.3 Effect of nutrient combinations on seed cotton yield parameters

Both the number of seeds per boll and yield of the two cotton varieties were significantly affected by the application of different combinations of N, P and K nutrients. The results revealed that cotton grown in unfertilized soils and in PK combinations had fewer seeds per boll compared with cotton grown in N nutrient combinations. Similarly, the plots that had N nutrient had higher yield (NP 2.7t/ha, NK 2.5t/ha, NPK 2.5t/ha, NPK +Zn +S 2.6 t/ha) than the plots without N nutrient which had PK 2.2t/ha and the unfertilized control 2.1t/ha. These results showed that N's absence significantly reduced seed cotton yield and number of seeds per boll. The findings are similar with those of Sawan et al. (2006) and Abdel-Malak et al. (1997), who recorded a significant increase in the seed cotton yield where nitrogen was applied and the lowest yield in the negative control. Dar and Khan (2005) and Khan and Dar (2006) who found more seeds per boll with the application of N nutrient.

Further, different combinations of N, P, and K nutrients had a significant ($P \leq 0.05$) effect on boll weight and ginning out-turn percentages of the two cotton varieties. In this study, the application of N nutrient combinations negatively influenced the ginning out-turn percentage. The results showed that average ginning out-turn percentage was NP 41.3, NK 42.29, NPK 40.84, NPK +Zn +S 41.26 which was lower compared with the plot without N nutrient PK 42.33 and the unfertilized control 42.84. These findings disagree with Hussain et al. (2000)

who reported that ginning out-turn percentage did not respond to N fertilization. Further, the application of N combinations positively affected the boll weight whereby, NP had 5.31g, NK 5.3g, NPK 5.34g, NPK +Zn +S 5.35g which is higher compared to boll weight of cotton grown without N nutrient (PK) (4.77g) and in unfertilized control (4.55g).

In addition, different combinations of N, P, and K nutrients significantly affected the number of squares and bolls per plant. The highest number of bolls were reported for cotton grown in soils fertilized with N nutrient combinations, NP 26, NK 27, NPK 25, NPK + Zn + S 27 and the lowest were reported in PK which had 22 and control 17 bolls per plant. These results agree with various researchers who found out that nitrogen increases weight and number of the bolls, and consequently the seed cotton yield Prakash and Prasad, (2000); Karthikeyan and Jayakumar, (2001&2002); Dar and Anwar, (2005); Sawan et al., 2006; Nadeem et al., 2010). Other researchers found that seed cotton weight per boll and seed cotton yield were affected by diverse doses of N (Rochester et al., 2001; Anjum et al., 2007; Kumbhar et al., 2008; Saleem et al., 2010). This could be as a result of N’s secondary effect on increasing boll weight (Gerik et al., 1998; Bouqet et al., 1993). These consequences also agree with the findings of Rashidi et al. (2011), who found an increase in number of squares, flowers, bolls per plant and consequently the yield due to cotton being more receptive to nitrogen uptake than other crops.

3.6 Conclusion

In the present study, it is evident that nutrients play a very important role in growth and yield of cotton. However, nitrogen was prevailing in hastening cotton growth and eventually guaranteeing early maturity. As well, nitrogen increased the number of branches, squares, number of bolls per plant, and subsequently the yield of cotton. Contrary, to established trends, nitrogen negatively influenced the ginning out-turn percentage of cotton. The ginning out-turn percentage reduced with the use of N nutrient and increased in the absence of N nutrient. Adherence to 150 kg N/ha, 50 kg P/ha and 100 kg K/ha nutrient levels will ensure positive interactions that will increase seed cotton yield and neutralize negative interactions which may interfere with growth and seed cotton yield.

CHAPTER FOUR: ESTABLISHMENT OF THE INFLUENCE OF DIFFERENT COMBINATIONS OF N, P, AND K NUTRIENTS ON WATER AND NUTRIENT USE EFFICIENCY AND FIBRE QUALITY OF COTTON

4.1 Abstract

Nutrient strain in cotton (*Gossypium hirsutum* L.) depresses yield and may interfere with fibre development and ultimately fibre quality. Production of cotton therefore requires soil fertilization since it has a high demand for nutrients, mainly during flowering and boll formation periods. This study determined the effect of different combinations of N, P, and K nutrients on water use efficiency (WUE), nutrient uptake, nutrient agronomic efficiency, and the fibre quality of cotton. Treatments comprising two cotton varieties (HART 89M and Bt-C571 BGII) and different combinations of N, P, and K nutrients and control were set out in a randomized complete block design (RCBD) with a split plot arrangement in two sites in Machakos County of Kenya. Measurements included WUE, N, P and K nutrient uptake and agronomic efficiency as well as fibre quality traits. Lint quality traits were maturity and length uniformity index, micronaire, strength, short fibre percentage, Rd and +b. Different combinations of N, P and K nutrients showed significant ($P<0.05$) effects on WUE compared with unfertilized control. However, among the nutrient combinations PK returned the lowest WUE of 6.75 kg/ha/mm and 2.90 kg/ha/mm, compared with NP which had the highest WUE of 8.88 kg/ha/mm and 3.17kg/ha/mm in Machakos ATC and Ndalani farm respectively. In both sites, cotton grown under NPK and NPK$_{Zn\ S}$ had a higher uptake of N, P and K compared with those grown in PK nutrient combinations while the other nutrient combinations were intermediate. The varieties did not differ in the majority of the measured quality traits but Bt-C571 BGII recorded higher strength and Rd than HART 89M. On the other hand, HART 89M had higher +b. There were no significant differences in maturity, length uniformity index, upper half mean length, elongation and short fibres. Cotton grown in soils fertilized with N nutrient combinations had higher strength than those in unfertilized soils and soils fertilized with PK nutrient combinations. In addition, cotton grown in fertilized soils had higher micronaire, Rd and +b than those grown in unfertilized soils. Overall, N nutrient combinations were observed to enhance WUE, uptake of N, P and K and quality of cotton. This indicates that the use of N nutrient combinations in cotton production will boost its water and nutrient use efficiency plus fibre quality.

Key words: Cotton, nitrogen, phosphorus, potassium, fibre quality, WUE, NUE

4.2 Introduction

Cotton (*Gossypium hirsutum* L) is a perennial crop cultivated majorly for its fibres and seeds which provide raw materials for textile and feed industries respectively Constable and Bange, (2015). In Kenya, cotton is mostly cultivated by small-scale farmers for income generation given its suitability in diverse agro ecological zones within an altitude range of 900-1,372m. According to Lewis (2000), cotton yield is improving considerably as well as the need for high-quality cotton fibre. As a result, cotton crop management practices for improvement of fibre quality and at the same time sustaining yield are the focus of research currently. Some of the important fibre quality parameters include Fibre length, strength, micronaire, Length uniformity index(LUI), colour among others (ASTM), 2005). Fibre length is a key quality parameter in textile processing since it governs the machine settings during spinning. Study findings by Cook (2006) shows that the length upland cotton is about 15 to 30 mm while that of the longer Sea Island cotton is 60 mm. Length uniformity index is the ratio of mean length to UHML length in percentage. Greater values of more than 85% LUI are considered very high, 83-85% is high, 80-82% is intermediary, 77-79% is low and below 77% is very low and unattractive (Lawrence, 2003).

The amount of reflectance (Rd) and yellowness (+b) are the two parameters that define cotton colour. The brightness range is between 40%, signifying the dark cotton, and 85%, which signifies lighter or brighter cotton, while yellowness value ranges between 4% and 18% (Rogers et al., 2005). Raghavendra et al. (2004) concluded that reflectance range shows the brightness and dullness of cotton sample while yellowness shows the extent of cotton pigmentation. Cotton fibres are cream-white in colour which may be a result of climatic situations, soil type, storage situations, pest secretions and molds, trash and dust particles, exposure to ultra violet radiation and high temperature Raghavendra et al. (2004) and harvesting and ginning processes (Rogers et al., 2005). In addition, cotton colour is influenced by planting date and genotype (Porter et al., 1996). Fibre fineness refers to quantity per unit length of a fibre and is measured in micronaire. Cotton fibres with a micronaire value of 3.7-4.2 are fine and superior quality while values that range between 4.3-4.9 are rough and inferior quality (Lawrence, 2003).

Previous studies have shown a significant improvement in cotton quality with the addition of organic or inorganic fertilizers (USDA-NASS, 2018). While most soils in sub-Saharan African are prone to soil degradation, little is done as mitigation to improve soil fertility. According to Stewart et al. (2009), soils often contain limited amounts of or lack certain nutrients either due to soil nutrients deprivation, leaching or removal by plants. In other instances, the availability of other macro- or micronutrients limits the availability of others for adsorption by the crops. Poor soil fertility has been reported to significantly affect cotton fibre quality. According to Gitonga et al. (2011), only a few farmers apply fertilizer and this contributes to either low yields or poor fibre quality of cotton.

In Kenya, demand for cotton stands at 200,000 bales annually (AFA 2021), and following the high demand for cotton to improve the textile industry, both quality and quantity are important. As a result, there is a major focus on improving soil fertility, nutrient use and water use efficiency of cotton. According to Rochester et al. (2007), cotton has a high demand for N, P, and K nutrients that require frequent replenishment through fertilizer application. Yin et al. (2011) concluded that there is little information available in the current literature on yield and lint quality responses of cotton to fertilization. This means that the effect of fertilizing the soil with macronutrients on the quality of cotton yields in Kenya remains unexplored. In addition, Fernie et al. (2020) established that nutrient supply increases crop yield and nutrient use efficiency (NUE).

Nutrient Use Efficiency is plant's ability to absorb, integrate and make use of the nutrients for optimal yield (Erisman et al., 2018). NUE is an important factor for fertilizer inputs in agricultural systems since it maintains the N balance without affecting the profit and atmosphere (McAllister et al., 2012). To improve NUE in crop production, efficient management of N nutrient is important (Snyder et al., 2014). Che et al. (2021) also found an increase in N uptake with N application. Further application of N fertilizer during flowering also improve NUE since cotton plants utilize N more efficiently for reproduction (Ali, 2015). Nutrient Agronomic Efficiency (AE) is an important indicator of nutrient management and is defined as nutrient accumulated in the above-ground part of the plant or the nutrients recovered within the entire crop growth (Wortmann et al., 2016). On the other hand, an understanding of water use efficiency (WUE) is essential for crop performance monitoring in semiarid areas where water is a limiting factor (Khan et al., 2017).

Water use efficiency is the proportion of yield to the amount of water consumed all through the entire crop growth (Waraich et al., 2008). Nitrogen use in cotton crop production particularly in water scarcity states is essential for enhancement of crop growth recovery from drought distress (Khan et al., 2017; Zhou and Derrick, 2012). Moreover, cotton can obtain water from soil water reserves to counterbalance the adverse consequences of water shortage during initial growth stages. This optimizes the dispersal of photosynthates amid roots and shoots to build up total dry matter with water intake and also improve the WUE (Khan et al., 2017). Water and nutrients uptake is related to root growth and dispersal (Masunga et al., 2016). However, water resource is regularly insufficient because of the rising human need (Wu and Cosgrove, 2000). This has raised alarm over the consumption of inadequate water resources resulting to attentiveness in improving WUE (Tennakoon and Milroy, 2003; Tang et al., 2005).

Production and retention of bolls are majorly affected by water stress and this lowers seed cotton yield (Yazar et al., 2002). Therefore, this study intended to explore the effects of N, P and K nutrient combinations on nutrient and water use efficiency and fibre quality of cotton. Information generated will be resourceful in guiding the production of cotton through appropriate nutrient management and their implications on the quality.

4.3 Materials and methods

Materials and methods are fully described in Chapter three. Here, a brief summary of sites, treatments, key measurements, and analytical procedures are provided.

4.3.1 Study sites

Field experiments were conducted in the Agricultural Training Centre (ATC) farm and in a farmer's field in Ndalani ward both in Machakos County. ATC is located 1º32′12″S, 37º14′21″E and at 1606 m above sea level. Ndalani farm is located at 1º06′21″S, 37º29′11″E and 1165 m above sea level.

4.3.2 Treatments, experiment design and layout

The treatments were different combinations of inorganic nitrogen, phosphorous and potassium and two contrasting varieties of cotton. Nitrogen was applied at 150 kg N/ha (urea, 46% N), P at 50 kg P/ha (single super phosphate, 20% P), K at 100 kg K/ha (muriate of potash, 60% K) while Zn and S were obtained from zinc sulphate (33%), each at the rate of 5kg/acre.

4.3.3 Experimental procedure

Land clearing and ploughing were done to remove all the vegetation, followed by harrowing to achieve a medium tilth. Thinning was done after germination and when the seedlings attained a height of 15cm. Extra and weak plants were uprooted by hand leaving 2 plants per hole. Gapping was done during the leaf development stage. Weeding was done during the second week after seedling emergence and during leaf development stage. This procedure was repeated after every 3 weeks. Frequent scouting was done to monitor the occurrence of pests and diseases.

4.3.4 Data collection

4.3.4.1 Fibre quality parameters

Maturity and length uniformity index, micronaire, upper half mean length, elongation, strength, short fibre percentage, reflectance and the yellowness of cotton lint were determined after the ginning process. The lint obtained after ginning was submitted for testing using the HVI machine at the National cotton classing and testing laboratory. HVI is a modular system, which measures several cotton fiber parameters which include length uniformity, total length, short fiber content, reflectance, color, elongation, strength, fineness and maturity (ASTM, 2005). Prior to the test, the lint was stored under the recommended temperatures due to its hygroscopic nature of which is likely to affect the fineness measurements (Rodgers et al., 2012).

4.3.4.2 Water Use Efficiency

Water use efficiency (WUE) was computed as a ratio between cotton yield and water use (Equation 4.1). Water use was calculated as the sum of soil moisture content at sowing and in-crop rainfall, minus soil moisture content at harvesting, and presented as kg/ha/mm.

$$WUE = \frac{\text{Seed cotton yield (kg)}}{\text{Water use (mm)}} \quad \text{.......... Equation 4.1}$$

4.3.4.3 Nutrient agronomic efficiency

Agronomic efficiency was computed as the variance between the yield with fertilizer (Y) and the yield without fertilizer (Yo) multiplied by the amount of fertilizer applied (F), as presented in Equation 4.2 (Dobermann, 2007).

$$AE = [Y - Yo]F \quad \text{...Equation 4.2}$$

4.3.4.4 Nutrient uptake

Nutrient uptake of the two varieties was determined using the analysis of the above ground matter of cotton at maturity. Three plants were sampled from every plot, cut above the ground, dried in an oven at 60 ºC and later submitted for analysis. Nitrogen percentage in plant sample was calculated as the ratio between the change in the volume of the titre HCl for the blank (a) and volume of the titre HCl for the sample (b), multiplied by 0.2 and final volume of digestion (V) times a hundred by one thousand multiplied by weight (w) of the shoot biomass and aliquot of the solution taken for analysis (al) Equation 4.3.

$$\% \text{ N in plant} = \frac{(a-b)\ 0.2 \times v\ 100}{1000 \times W \times al} \quad \text{...Equation 4.3}$$

The phosphorus percentage in plant sample was computed as the ratio between the amended concentration of P in the sample (c), the volume of the digest (v) and the dilution factor (f) by the weight of the shoot biomass (w) Equation 4.4.

$$\% \text{ p in plant} = \frac{C \times V \times F}{W} \quad \text{...Equation 4.4}$$

Potassium percentage in plant sample was calculated as the ratio between the difference in the concentration of potassium in the digest (a) and concentration of the blank digest (b) and dilution factor (f) multiplied by one hundred by one thousand multiplied by weight (w) of the shoot biomass times one thousand Equation 4.5.

$$\% \text{ K in plant} = \frac{(a-b) \times v \times F \times 100}{1000 \times W \times 1000} \quad \text{...Equation 4.5}$$

4.3.5 Data analysis

Data on all parameters were subjected to the analysis of variance (ANOVA) to measure the sources of experimental variation using GenStat 15th Edition (Payne et al., 2011). Data was verified for regularity and fulfilled the requirements of ANOVA. Residuals were checked for normal dispersion and there were no modifications to be made. Treatment means were compared and separated using Fisher's protected least significant difference (LSD) at 5% probability level.

4.4 Results

4.4.1 Effect of different nutrient combinations on maturity and length uniformity index.

Table 4.1 shows the influence of different combinations of N, P and K nutrients on maturity and length uniformity index of cotton grown in Machakos ATC and Ndalani. In Machakos ATC, different combinations of N, P, and K nutrients did not show significant differences in maturity and length uniformity index. Similarly, the two cotton varieties grown either in fertilized or unfertilized soils did not differ in maturity and length uniformity index.

In Ndalani, different combinations of N, P, and K nutrients did not show significant differences in maturity. However, significant differences were observed in length uniformity index where NPK combinations had the highest length uniformity index compared with other nutrient combinations. In both varieties, maturity was statistically similar either grown in fertilized or unfertilized soils.

Table 4.1. Mean maturity and length uniformity index of two cotton varieties grown under different nutrient combinations in Machakos Agricultural Training Centre and in a farmer's field in Ndalani, Machakos County

Nutrient combinations	Maturity			Length uniformity index		
	HART	Bt	Mean	HART	Bt	Mean
Machakos ATC						
Control	0.84a	0.84a	0.84a	83.70a	83.67a	83.68a
NP	0.84a	0.84a	0.84a	83.90a	84.93a	84.42a
NK	0.84a	0.85a	0.85a	84.53a	84.23a	84.38a
PK	0.85a	0.85a	0.85a	83.63a	84.57a	84.10a
NPK	0.85a	0.84a	0.84a	84.23a	84.37a	84.30a
NPK $_{Zn\ S}$	0.85a	0.85a	0.85a	83.17a	84.27a	83.72a
LSD	*0.023*		*0.013*	*1.956*		*1.493*
Ndalani farmer's field						
Control	0.83ab	0.82a	0.83a	80.63ab	80.50a	80.66a
NP	0.84b	0.82a	0.83a	80.81ab	81.81ab	81.30ab
NK	0.83ab	0.83ab	0.83a	80.50a	80.44a	80.40a
PK	0.83ab	0.82a	0.83a	80.91ab	80.62ab	80.80ab
NPK	0.83ab	0.82a	0.83a	81.22ab	82.31b	81.80b
NPK $_{Zn\ S}$	0.83ab	0.83ab	0.83a	80.40a	80.55a	80.51a
LSD	*0.015*		*0.007*	*1.72*		*1.21*

Means in the same column not having a common letter are significantly different (P<0.05)

4.4.2 Effect of different nutrient combinations on micronaire, upper half mean length and elongation.

Table 4.2 shows the interactive effect of different nutrient combinations and the two cotton varieties grown in Machakos ATC and Ndalani. In Machakos ATC, the two cotton varieties grown either in fertilized or unfertilized soils had micronaire, Upper Half Mean Length (UHML) and Elongation that varied between 4.01-4.63, 1.17-1.21 and 8.3-9.47, respectively. There were slightly higher micronaire and elongations in Bt-C571 BGII than in HART 89M. It was the UHML that was slightly higher in HART 89M than in Bt-C571 BGII variety. The two cotton varieties grown in soil fertilized with NK had significantly (P<0.05) higher micronaire than those grown in unfertilized soils. On the other hand, Bt-C571 BGII variety grown in soil fertilized with NPK had significantly (P<0.05) higher elongation than HART 89M grown in soil fertilized with PK.

In Ndalani, the application of different combinations of N, P, and K nutrients did not show any significance difference in micronaire, upper half mean length and elongation, of cotton either grown in fertilized or unfertilized soils. Variety HART 89M grown either in fertilized or unfertilized soils had slightly higher micronaire than Bt-C571 BGII. On the other hand, Bt-

C571 BGII grown in fertilized or unfertilized soils had slightly higher elongation than the HART 89M. Both varieties grown in soil fertilized with NP had the highest elongation than those grown in soil fertilized with NK and PK. Overall, cotton grown in soil fertilized with NP had the highest micronaire and elongation than other treatments.

Table 4.2. Mean micronaire, upper half mean length (UHML) and elongation of two cotton varieties grown under different nutrient combinations in Machakos Agricultural Training Centre and in a farmer's field in Ndalani, Machakos County

Nutrient combinations	Micronaire		Mean	UHML		Mean	Elongation		Mean
	HART	Bt		HART	Bt		HART	Bt	
Machakos ATC									
Control	4.09a	4.01a	4.05a	1.21a	1.19a	1.20a	9.00ab	9.13ab	9.07ab
NP	4.37a	4.43a	4.40ab	1.20a	1.18a	1.19a	8.87ab	9.17ab	9.02ab
NK	4.35a	4.63a	4.49b	1.19a	1.19a	1.19a	9.10ab	9.10ab	9.10ab
PK	4.35a	4.39a	4.37ab	1.17a	1.19a	1.18a	8.30a	8.77ab	8.53a
NPK	4.40a	4.50a	4.45ab	1.21a	1.17a	1.17a	9.00ab	9.47b	9.23b
NPK $_{Zn\ S}$	4.28a	4.53a	4.40ab	1.21a	1.17a	1.17a	8.40ab	9.00ab	8.70ab
LSD	*0.616*		*0.401*	*0.062*		*0.053*	*1.098*		*0.573*
Ndalani farmer's field									
Control	3.17a	2.86a	3.01a	1.05a	1.05a	1.05a	6.2a	6.5a	6.3a
NP	3.29a	2.84a	3.07a	1.03a	1.08a	1.05a	6.1a	6.9a	6.5a
NK	3.08a	3.02a	3.05a	1.05a	1.08a	1.07a	5.9a	6.4a	6.1a
PK	3.14a	2.79a	2.96a	1.05a	1.04a	1.05a	5.9a	6.4a	6.1a
NPK	3.16a	2.89a	3.02a	1.06a	1.09a	1.07a	6.4a	6.5a	6.4a
NPK $_{Zn\ S}$	3.18a	3.20a	3.19a	1.04a	1.01a	1.02a	6.0a	6.5a	6.2a
LSD	*0.886*		*0.23*	*0.08*		*0.059*	*2.26*		*0.46*

Means in the same column not having a common letter are significantly different (P<0.05)

4.4.3 Effect of different nutrient combinations on strength, short fibre percentage, reflectance and the yellowness of cotton.

Table 4.3 presents the effect of different nutrient combinations on strength, short fibres, reflectance and yellowness of cotton grown in Machakos ATC and Ndalani. In Machakos ATC, the two cotton varieties grown either in fertilized or unfertilized soils had significant differences in strength, Rd and +b but not in short fibres. The two cotton varieties grown in fertilized soils had significantly ($P<0.05$) higher strength than those grown in unfertilized soils and soil fertilized with PK. The HART 89M cotton variety grown in fertilized and unfertilized soils had higher strength than the Bt-C571 BGII. Cotton grown in all the soils had short fibres that varied between 6.07 and 7.10 per cent. Herein, cotton grown in unfertilized soils had slightly higher short fibres percentage than those grown in fertilized soils. The highest Rd were recorded in Bt-C571 BGII grown either in fertilized or unfertilized soils compared with HART 89M. The Bt-C571 BGII grown in soil fertilized with NP, NK, NPK and $NPK_{Zn}S$, all at par, had significantly ($P<0.05$) higher Rd. Cotton grown in unfertilized soils had significantly higher +b than those grown in fertilized soils. HART 89M grown in both fertilized and unfertilized soils had a higher +b than the Bt-C571 BGII.

In Ndalani, cotton grown in fertilized and unfertilized soils had significant differences in strength, Rd and +b. Cotton grown in fertilized soils had significantly ($P<0.05$) higher strength than those grown in unfertilized soil and soil fertilized with PK. HART 89M grown in soil fertilized with NPK had significantly ($P<0.05$) higher strength than Bt-C571 BGII grown in unfertilized soil. The two cotton varieties grown either in fertilized or unfertilized soils had no significant difference in short fibre percentage. The highest +b was recorded in HART 89M and while the highest Rd was recorded in Bt-C571 BGII.

Table 4.3. Mean Strength (g/tex), short fibres (%), reflectance (Rd) and yellowness (+b) of two cotton varieties grown under different nutrient combinations in Machakos Agricultural Training Centre and in a farmer's field in Ndalani, Machakos County

Nutrient combinations	Strength		Mean	Short fibres%		Mean	Rd		Mean	+ b		Mean
	HART	Bt		HART	Bt		HART	Bt		HART	Bt	
Machakos ATC												
Control	27.0abc	26.6a	27.1a	6.6a	7.1a	6.9a	74.9a	81.6ab	78.3a	9.7ab	8.2a	8.9b
NP	30.9gh	29.4defg	30.2b	6.6a	6.2a	6.4a	79.1a	82.9ab	81.0a	9.2ab	8.6a	8.9a
NK	30.1efg	28.8bcde	29.5b	6.5a	6.7a	6.6a	79.4a	83.0ab	81.2a	9.4ab	8.5a	9.0a
PK	28.4bcd	27.1ab	27.8a	6.6a	6.4a	6.5a	77.3a	81.9ab	79.6a	9.7ab	8.4a	9.0ab
NPK	30.6fgh	29.2cdef	29.9b	6.1a	6.6a	6.4a	79.1a	83.1ab	81.1a	9.5ab	8.4a	9.0ab
NPK $_{Zn\ S}$	31.7h	29.3cdefg	30.5b	6.3a	6.2a	6.3a	79.5a	83.0ab	82.2a	9.5a	8.8a	9.0a
LSD	*1.65*		*1.17*	*1.11*		*0.85*	*2.69*		*1.37*	*0.69*		*0.42*
Ndalani farmer's field												
Control	22.7ab	21.1a	21.9a	8.8a	8.7a	8.8a	76.5ab	79.6d	78a	10.6cd	9.7ab	10.2b
NP	26.5ab	26.0ab	26.2b	8.3a	8a	8.2a	76.9abc	80.7de	78.8abc	10.7cd	9.7ab	10.2b
NK	25.6ab	26.2ab	25.9b	8.2a	9.3a	8.8a	77.8bc	79.9de	78.8abc	10.6cd	9.6ab	10.1b
PK	23.1ab	22.1ab	22.7a	8.5a	8.7a	8.6a	78.0c	81.2e	79.6c	10.1bc	9.1a	9.6a
NPK	28.0b	24.5ab	26.2b	8.3a	8a	8.1a	76.2a	80.6de	78.4ab	10.9d	9.4ab	10.2b
NPK $_{Zn\ S}$	25.1ab	26.3ab	25.7b	8.8a	8.7a	8.7a	77.7bc	80.5de	79.1bc	10.7cd	9.7ab	10.2b
LSD	*5.94*		*2.33*	*1.89*		*0.76*	*1.36*		*0.9*	*0.71*		*0.49*

Means in the same column not having a common letter are significantly different ($P<0.05$).

4.4.4 Effect of different nutrient combinations on water use efficiency

Table 4.4 shows the effect of different nutrient combinations on water use efficiency of cotton grown in Machakos ATC and Ndalani farmer's field. Water use efficiency in ATC showed a significant difference between the two cotton varieties grown either in fertilized or unfertilized soils. The highest WUE was observed in HART 89M than the Bt-C571 BGII all grown either in fertilized or unfertilized soils. In both cotton varieties grown in soils fertilized with N nutrient combinations had significantly ($P<0.05$) higher WUE than those grown in unfertilized soil and in soils fertilized with PK nutrient combinations. This means that cotton grown in soils fertilized with N nutrient combinations had significantly ($P<0.05$) higher WUE than cotton grown in soils without N nutrient.

In Ndalani, WUE significantly differed in the two cotton varieties either grown in fertilized or unfertilized soils. The highest WUE was observed in Bt-C571 GBII and lowest in HART 89M in all soils. Apart from soil fertilized with PK nutrient combinations, all cotton grown in N nutrient fertilized soils had significantly ($P<0.05$) higher WUE than cotton grown in unfertilized soils.

Table 12.4. Effect of different nutrient combinations on WUE (kg/ha mm) of two cotton varieties grown in Machakos Agricultural Training Centre and in a farmer's field in Ndalani, Machakos County

Nutrient combinations	HART	Bt	Mean
Machakos ATC			
Control	6.90abc	5.45a	6.17a
NP	9.89d	7.86abcd	8.88c
NK	8.36bcd	7.71abcd	8.04bc
PK	7.52abcd	5.98ab	6.75ab
NPK	9.12cd	7.95bcd	8.54c
$NPK_{Zn\ S}$	8.86cd	7.53abcd	8.20c
LSD	*2.41*		*1.4*
Ndalani farmer's field			
Control	2.66a	2.81ab	2.73a
NP	3.19d	3.14bcd	3.17c
NK	2.88abcd	3.17d	3.03bc
PK	2.83abc	2.98abcd	2.9ab
NPK	3.05bcd	3.16cd	3.1c
$NPK_{Zn\ S}$	3bcd	3.17d	3.08c
LSD	*0.33*		*0.17*

Means in the same column not having a common letter are significantly different ($P<0.05$).

4.4.5 Effect of different nutrient combinations on agronomic efficiency

Table 4.5 highlights the effect of different nutrient combinations on agronomic efficiency of cotton grown in Machakos ATC and Ndalani. There was a significant difference in AE between the two cotton varieties grown in fertilized soils in Machakos. Cotton grown in soil fertilized with N nutrient combinations had significantly ($P<0.05$) higher AE than cotton grown in PK combinations and control. HART 89M had a higher AE than Bt-C571 BGII grown in fertilized soils. The least AE was observed in cotton grown in soil fertilized with PK. In Ndalani, the AE was lower than those recorded in ATC. However, cotton grown in soil fertilized with N nutrient combinations had significantly ($P<0.05$) higher AE than PK combinations and controls.

Table 4.5. Effect of different nutrient combinations on the agronomic efficiency (AE) of two cotton varieties grown in Machakos Agricultural Training Centre and in a farmer's field in Ndalani, Machakos County

Nutrient combinations	HART	Bt	Mean
Machakos ATC			
NP	6.58a	5.32a	5.95b
NK	2.57a	3.99a	3.28a
PK	2.11a	1.56a	1.83a
NPK	3.26a	3.68a	3.47ab
$NPK_{Zn\,S}$	2.88a	3.06a	2.97a
LSD	*6.368*		*2.58*
Ndalani farmer's field			
NP	1.23b	0.87ab	1.05b
NK	0.50a	0.75ab	0.60a
PK	0.49a	0.60a	0.54a
NPK	0.66ab	0.61a	0.63a
$NPK_{Zn\,S}$	0.57a	0.62a	0.59a
LSD	*0.6*		*0.41*

Means in the same column not having a common letter are significantly different ($P<0.05$).

4.4.6 Effect of different nutrient combinations on nitrogen, phosphorus and potassium uptake

Table 4.6 shows the influence of different combinations of N, P and K nutrients on uptake of N, P, and K nutrients of cotton grown in Machakos ATC and Ndalani. All cotton grown in fertilized soils except those grown in PK had significantly ($P<0.05$) higher uptake of % K. Likewise, cotton grown in the fertilized soils had significantly ($P<0.05$) higher uptake of % N than those grown in PK nutrient combinations. Significantly (P<0.05) higher uptake of % P was observed in cotton grown in soils fertilized with PK nutrient combinations than those grown in N nutrient combinations.

In Ndalani, cotton grown in soil fertilized with N nutrient combinations had significantly (P<0.05) higher uptake of % K than in soils fertilized with PK nutrient combinations. There was a slightly higher uptake of % K in Bt-C571 BGII than in HART 89M grown in both fertilized and unfertilized soils. Cotton grown in fertilized soils had significantly (P<0.05) higher uptake of % N than those grown in soils fertilized with PK nutrient combinations. The two cotton varieties grown either in fertilized or unfertilized soils had no significant difference in the uptake of % P.

Table 4.6. Effect of different nutrient combinations on the uptake of N, P and K nutrients of two cotton varieties grown in Machakos Agricultural Training Centre and in a farmer's field in Ndalani, Machakos County

Nutrient	% K			% N			% P		
combinations	HART	Bt	Mean	HART	Bt	Mean	HART	Bt	Mean
Machakos ATC									
Control	0.51a	0.58ab	0.55a	0.73a	0.72a	0.73a	0.1a	0.07a	0.08a
NP	0.72bc	0.65abc	0.68ab	1.49ab	1.52ab	1.51b	0.08a	0.09a	0.08a
NK	0.73bc	0.71bc	0.72b	1.57b	2.22b	1.90b	0.08a	0.07a	0.08a
PK	0.64abc	0.62abc	0.63ab	1.48ab	1.51ab	1.50b	0.14a	0.15a	0.15b
NPK	0.7bc	0.7bc	0.7b	2.07b	1.83b	1.95b	0.15a	0.12a	0.14ab
$NPK_{Zn\ S}$	0.67abc	0.76c	0.71b	1.69b	1.79b	1.74b	0.12a	0.11a	0.11ab
LSD	*0.16*		*0.13*	*0.82*		*0.63*	*0.08*		*0.06*
Ndalani farmer's field									
Control	0.58a	0.60a	0.59a	1.18ab	0.96a	1.07a	0.08a	0.08a	0.08a
NP	0.69a	0.68a	0.69b	1.64bc	1.58abc	1.61bc	0.15b	0.09ab	0.12a
NK	0.64a	0.71a	0.68b	2.02c	1.63bc	1.82c	0.11ab	0.08a	0.1a
PK	0.62a	0.63a	0.63a	1.17ab	1.41abc	1.29ab	0.11ab	0.09ab	0.1a
NPK	0.74a	0.67a	0.71b	1.27ab	1.77bc	1.52bc	0.11ab	0.11ab	0.11a
$NPK_{Zn\ S}$	0.69a	0.76a	0.73b	1.65bc	1.52abc	1.58bc	0.09ab	0.13ab	0.11a
LSD	*0.18*		*0.09*	*0.66*		*0.44*	*0.06*		*0.06*

Means in the same column not having a common letter are significantly different (P<0.05).

4.5 Discussion

4.5.1 Quality traits

Results showed that different combinations of N, P, and K nutrients had no significant influence on the maturity, length uniformity index, upper half mean length, elongation and short fibres. However, significant differences were found in strength, Rd, and +b. In Machakos ATC, the two cotton varieties grown either in fertilized or unfertilized soils had significant differences in strength, Rd and +b. Cotton grown in soils fertilized with N nutrient combinations had significantly ($P<0.05$) higher strength than those grown in unfertilized soils and soil fertilized with PK. Notably, HART 89M grown either in fertilized or unfertilized soils had higher strength than the Bt-C571 BGII cotton variety. Similarly, Bauer and Roof (2004) and Bauer et al. (2000) observed lower fiber strength in plots that did not receive nitrogen fertilization. Fritschi et al. (2003) found a significant and direct relationship between fiber strength and nitrogen, which further supports these findings. On the other hand, these results disagree with those of Boman and Westerman (1994), who found no relationship between fiber strength and nitrogen application.

Further, results showed significant varietal differences with HART 89M recording higher +b than Bt-C571 BGII. On the other hand, Bt-C571 BGII had a higher Rd than HART 89M. In addition, cotton grown in soil fertilized with N nutrient combinations had significantly ($P<0.05$) higher Rd than those in unfertilized soils and in PK combinations. Contrary, varying blends of N, P, and K nutrients did not significantly influence +b. The results are similar to those of Porter et al. (1996), who concluded that the colour of cotton sample is influenced by the genotype.

4.5.2 Water use efficiency

This study showed that the two cotton varieties grown in fertilized soils recorded the highest water use efficiency compared with those grown in unfertilized soils. Notably, cotton grown where N nutrient was applied had significantly ($P<0.05$) higher WUE compared with cotton grown without N nutrient and in control. This could be linked to the fact that N sustains crop growth and yield and its scarcity adversely affects physiological and biochemical activities in plants (Khan et al., 2014, 2017). These findings are in agreement with Latiri-Souki et al. (1998) and Conaty et al. (2015) that use of N nutrient increases WUE.

4.5.3 Nutrient uptake and Agronomic Efficiency (AE)

This study revealed that nutrient uptake and Nutrient Agronomic Efficiency of cotton were significantly affected by the application of different combinations of N, P, and K nutrients. In both sites, the highest agronomic efficiency was observed in N nutrient combinations, while the lowest was recorded in PK. These findings are in agreement with those of Ali (2015), who reported that N nutrient application results in higher nutrient agronomic efficiency. This could be attributed to the optimal supply of nitrogen that made cotton able to create a balance of its requirements of the nutrients, consequently promoting the nutrient agronomic efficiency (Quemada and Gabriel, 2016).

Similarly, the uptake of N, P, and K nutrients in N nutrient combinations was significantly ($P<0.05$) higher than in cotton grown in PK nutrient compositions and control. These results are in agreement with Chen et al., (2010), who also found greater total N uptake in N-applied cotton than in cotton without N application. Significant varietal differences were observed where HART 89M grown in soil fertilized with NK had significantly ($P<0.05$) higher uptake of % N than other treatments except for soil fertilized with NP and NPK $_{Zn\ S}$. However, Bt-C571 BGII grown in soil fertilized with NK and NPK had significantly ($P<0.05$) higher uptake of % N than those grown in unfertilized soils. The two cotton varieties grown either in fertilized or unfertilized soils had no significant difference in the uptake of % P. In HART 89M, significantly ($P<0.05$) higher uptake of % P was observed on cotton grown in soils fertilized with NP than cotton grown in unfertilized soils. A better nutrient agronomic efficiency could be as a result of varying genotypes where those with efficient nutrient acquisition tend to perform better than the inefficient ones. Similarly, Venugopalan and Pundarikakshudu (1998) observed that the desi cotton varieties had higher N and P utilization efficiency than the American Upland cotton.

4.6 Conclusion

In the present study, it is evident that nutrients play a very important role in nutrient and water use efficiency as well as lint quality. N nutrient combinations showed significant effects on fibre quality, which is a clear pointer that nitrogen is very helpful in enhancing WUE, NUE as well as fibre quality. Therefore, optimum nitrogen nutrition can be helpful in utilizing the available water and nutrients more efficiently and consequently improve fibre quality of cotton.

Further, different combinations of N nutrients will maintain high water uptake and enhance WUE in areas that receive very low rainfall of about 500 mm and below. Further studies, are required to explore on P and K nutrient combinations on cotton which were found to have low water and nutrient use efficiency, lint strength and colour.

CHAPTER FIVE: GENERAL DISCUSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 General discussion

Different combinations of N, P, and K nutrients had a significant effect on crop phenology, growth, yield components, yield and fibre quality of cotton. Cotton grown in the soils fertilized with N nutrient combinations attained maturity earlier than those grown in PK nutrient combinations and control. In adittion, significant ($P \leq 0.05$) varietal differences with respect to the number of days taken to attain 50% branching, squaring, boll formation and overall maturity with the application of different nutrient combinations were recorded. According to Khan et al. (2017), early maturity in cotton grown in N nutrient combinations could be attributed to the fact that nitrogen plays a major role as a single vital growth-limiting factor which influences growth period and maturity time of cotton.

Application of different combinations of N, P and K nutrients had a significant effect on the biomass production per unit area. Biomass was higher within the plots that had N nutrient application than in plots without N nutrient applied (Fritschi et al., 2003). This could be as a result of nitrogen being an important nutrient in the buildup of plant dry matter as well as many energy rich compounds which regulate photosynthesis (Sawan et al., 2009). There was a significant effect on the leaf greenness whereby the highest SPAD units were found in the plots that had N nutrient and lower in the plot without N nutrient and the unfertilized control (Boquet et al., 1999). Results further showed that N presence significantly increased seed cotton yield and quantity of seeds per boll (Sawan et al., 2006: Khan and Dar, 2006). This could be due to better assimilation and translocation of cotton plants with N nutrient (Khan et al., 2001). These consequences also agree with the findings of Rashidi et al. (2011), who found an increase in total squares, bolls per plant and consequently the yield due to cotton being more receptive to nitrogen uptake than other crops. The results showed that average ginning out-turn percentage decreased with N application and increased in absence. These findings disagree with Hussain et al. (2000) who reported that ginning out-turn percentage did not respond to N fertilization.

Cotton grown in soils fertilized with N nutrient combinations had significantly ($P<0.05$) higher strength and brighter cotton colour than those grown in unfertilized soils and soil fertilized with PK (Bauer and Roof, 2004). Notably, cotton grown where N nutrient was applied had significantly ($P<0.05$) higher WUE compared with cotton grown without N nutrient and in control (Latiri-Souki et al., 1998; Conaty et al., 2015). Similarly, the highest agronomic efficiency was observed in N nutrient combinations while the lowest was recorded in PK (Ali, 2015). Further, uptake of N, P, and K nutrients in N nutrient combinations was significantly ($P<0.05$) higher than in cotton grown in PK nutrient compositions and control (Chen et al., 2010).

Cotton varieties significantly varied in maturity period, fibre strength, colour, and N nutrient uptake with the application of different combinations of N, P, and K nutrients. Results revealed that HART 89M took long to mature, had strong fibres, yellow fibre colour (+b) and higher N uptake compared with Bt-C571 BGII, which matured early, had weak fibres, brighter colour (Rd) and lower N uptake. Similarly, Venugopalan and Pundarikakshudu (1998) observed varietal differences in response to fertilizer use. This can be attributed to the influence of the genotype of distinct cotton variety (Porter et al., 1996). This clearly shows how N nutrient influences maturity period, growth, yield, fibre quality, nutrient and water use efficiency of cotton.

5.2 Conclusions

Cotton grown in soils fertilized with N nutrient combinations took a significantly shorter span to reach maturity than cotton grown in unfertilized soils and in soils fertilized with PK nutrients combinations. In addition, cotton grown in N nutrient fertilized soils had intensified growth as indicated by taller plants, wider stem girth, longer roots, more branches, more squares, more bolls and consequently higher dry matter than cotton grown in control and in soils fertilized with PK. Irrespective of the variety, N nutrient fertilized soils had enhanced fibre quality strength, micronaire, Rd and +b. In addition, N nutrient fertilized soils were observed to enhance WUE, uptake of N, P and K and quality of cotton. Overall, exclusion of N reduced cotton growth, yield, fibre quality, and water and nutrient use efficiency.

5.3 General recommendations

1. Nitrogen presented to be the most limiting nutrient to cotton growth, yield and fibre quality, thus nitrogen should be included in nutrient fertilizer combinations.
2. Economically optimal combinations of N, P and K macronutrients that maximize cotton growth, yield and fibre quality need to be established

3. Matching of the optimal proportions of N, P and K nutrient combinations to different growth stages of cotton need to be fine-tuned
4. Micro-nutrients that complement in N, P and K macro-nutrients need to be investigated and optimal rates of application recommended

REFERENCES

Abdel-Malak, K.I., F.E. Radwan and S.I. Baslious. 1997. Effect of row width, hill spacing and nitrogen levels on seed cotton yield of Giza 83 cotton cultivar. Egypt. Journal of Agriculture Research, 75, 743–752.

Adeli, A., Varco, J.J. 2002. Potassium management effects on cotton yield, nutrition, and soil potassium level. Journal of Plant Nutrition, 25, 2229–2242.

Adhikari, U., Nejadhashemi, A. P. & Woznicki, S. A. 2015. Climate change and eastern Africa: a review of impact on major crops. Food and Energy Security, 4, 110–132.

Agriculture and Food Authority. 2021. The current status of cotton crop report presented on 11th October 2021 during a public participation and sensitization forum on Fibre Crops Bill, 2021.

Ali, N. 2015. Nitrogen utilization features in cotton crop. American Journal of Plant Sciences, 6, 987-1002.

Ali, M. A., Farooq, J., Batool, A., Zahoor, A., Azeem, F., Mahmood. 2019. Cotton production in Pakistan. Cotton Production, 249–276.

American Standard Testing Method (ASTM). 2005. International Standard Test Methods for Measurement of Physical Properties of Cotton Fibers by High Volume Instruments.

Afzal, M.N.; Ahmad, F.; Ahmad, S.; Akhtar, M.; Atif, R. 2011. Effect of sowing dates, plant spacing and nitrogen application on growth and productivity on cotton crop. International Journal of science Engineering Research, 2, 1–6.

Anjum, F.H., A. Tanveer, R. Ahmad, A. Ali, M.A. Nadeem and M. Tahir. 2007. Response of cotton (*Gossypium hirsutum*) to split application of nitrogen and weed control methods. The Indian Journal of Agriculture Science, 77 (4), 224-229.

Baffes, J. 2007. Distortions to Cotton Sector Incentives in West and Central Africa", Agricultural Distortions Working Paper 50, World Bank 2007.

Bals, C., Harmeling, S., & Windfuhr, M. 2008. Climate change, food security and the right to adequate food. Diakonisches Werk der Evangelischen Kirche in Deutschland. Stuttgrat: German watch.

Bauer, P. J., Frederick, J. R., Bradow, J. M., Sadler, E. J., and Evans, D. E. 2000. Canopy photosynthesis and fibre properties of normal and late-planted cotton. Agronomy Journal, 92, 518–523.

Bednarz, C.W., Oosterhuis, D.M., Evans, R.D., 1998. Leaf photosynthesis and carbon isotope discrimination of cotton in response to potassium deficiency. Environmental and Experimental Botany, 39, 131–139.

Bationo, A. and Waswa, B. S. 2011. New challenges and opportunities for integrated soil fertility management in Africa. In Innovation as Key to the Green Revolution in Africa,1, 1-3.

Bationo, A., Waswa, B., Kihara, J., & Kimetu, J. 2007. Advances in integrated soil fertility management in sub Saharan Africa: challenges and opportunities. Nutrient Cycling in Agroecosystems, 1-2.

Bauer, P.J., Frederick, J.R., Bradow, J.M., Sadler, E.J., Evans, D.E., 2000. Canopy photosynthesis and fiber properties of normal- and late-planted cotton. Agronomy Journal, 92, 518–523.

Bauer PJ, Roof ME. 2004. Nitrogen, aldicarb, and cover crop effects on cotton yield and fiber properties. Agronomy Journal, 96, 369-376.

Bekunda, M. A., Bationo, A., & Ssali, H. 1997. Soil fertility management in Africa: A review of selected research trials. Replenishing soil fertility in Africa, 51, 63-79.

Brandow, J., & Davidonis, G. 2000. Quantification of Fibre Quality and the Cotton Production-Processing Interface. Journal of Cotton Science, 4, 34-64.

Bremner, J.M. 1996. Nitrogen Total. In: Sparks, D.L., Ed., Methods of Soil Analysis Part 3: Chemical Methods, SSSA Book Series 5, Soil Science Society of America, Madison, Wisconsin, 1085-1122.

Borowski, E. 2001. The effect of nitrogenous compounds on the growth, photosynthesis and phosphorus uptake of sunflowers. Annales Universitatis Mariae Curie-Sklodowska. Section EEE, Horticultural, 9, 23-31.

Boquet, D.J.; Holman, E.M.; Brown, R.E.A.; Thomas, W.J.; Coco, A.B. 1999. Use of a chlorophyll meter to determine cover crop, rotation and N rate effect on crop N status. Proceedings 2, 1269–1271.

Boquet, D.J., E.B. Moser, and G.A. Breitenbeck. 1993. Nitrogen effects on boll production of field-grown cotton. Agronomy Journal, 85, 34–39.

Boquet, D. J., & Breitenbeck, G. A. 2000. Nitrogen rate effect on partitioning of nitrogen and dry matter by cotton. Crop Science, 40 (6), 1685-1693.

Boquet, D. J., & Moser, E. B. 2003. Boll retention and boll size among intrasympodial fruiting sites in cotton. Crop Science, 43 (1), 195-201.

Bowman, R.K., and R.L. Westerman. 1994. Nitrogen and mepiquat chloride effects on the production of nonrank, irrigated, short season cotton. Journal of Production Agriculture, 7, 70–75.

Brouder S M and Cassman K G. 1994. Cotton root and shoot response to localized supply of nitrate, phosphate and potassium: Split-pot studies with nutrient solution and vermiculitic soil. Plant Soil, 161, 179–193

Cai, Y., Cui, X., Rodgers, J., Thibodeaux, D., Martin, V., Watson, M. and Pang, S. 2011. An investigation on different parameters used for characterizing short cotton fibers. Textile Journal, 81, 239-246.

Çakmak, İ., & Marschner, H. 1988. Zinc-dependent changes in ESR signals, NADPH oxidase and plasma membrane permeability in cotton roots. Physiologia Plantarum, 73 (1), 182-186.

Cassman, K.G., Kerby, T.A., Roberts, B.A., Bryant, D.C., Brouder, S.M. 1989. Differential response of two cotton cultivars to fertilizer and soil potassium. Agronomy Journal, 81, 870–876.

Cassman, K. G., Kerby, T. A., Roberts, B. A., Bryant, D. C., & Higashi, S. L. 1990. Potassium nutrition effects on lint yield and fiber quality of Acala cotton. Crop Science, 30 (3), 672-677.

Chastain, D.R., Snider, J.L., Choinski, J.S., Collins, G.D., Perry, C.D., Whitaker, J., Grey, T.L. 2016. Leaf ontogeny strongly influences photosynthetic tolerance to drought and high temperature in *Gossypium hirsutum* L. Journal of Plant Physiology, 199, 18–28.

Chakraborty K. and D. Etheridge. 1999. Cotton quality price differentials from textile mills' perspective: an update. Production of the Beltwide Cotton Conference, 1, 256-259.

Chen, B. L., Yang, H. K., Song, W. C., Liu, C. Y., Xu, J., Zhao, W. Q. 2016. Effect of nitrogen fertilization rate on soil alkalihydrolyzable nitrogen, subtending leaf nitrogen concentration, fiber yield, and quality of cotton. Crop Journal, 4, 323–330.

Chijioke, O. B., Haile, M., & Waschkeit, C. 2011. Implications of climate change on 196 crop yield and food accessibility in Sub-Saharan Africa. Interdisciplinary Term Paper. Bonn: University of Bonn.

Cook G. J. 2006. Hand Book of Textile Science. Abington Hall: Wood Head Publishing Ltd, 46.

Cotton growers' manual. 2021. Agriculture and Food Authority, Fibre Crops Directorate manual on cotton production.

Chen, W., Hou, Z., Wu, L., Liang, Y., and Wei, C. 2010. Effects of salinity and nitrogen on cotton growth in arid environment. Plant Soil, 326, 61–73.

Conaty, W. C., Mahan, J. R., Neilsen, J. E., Tan, D. K. Y., Yeates, S. J., and Sutton, B. G. 2015. The relationship between cotton canopy temperature and yield, fibre quality and water-use efficiency. Field Crops Resesearch, 183, 329–341.

Constable, G. A., & Bange, M. P. 2015. The yield potential of cotton (*Gossypium hirsutum* L.). Field Crops Research, 182, 98-106.

Dar, J.S. and B. Khan. 2004. Yield variations of CIM-499, CIM-511 and CIM-707 cotton varieties as affected by different nitrogen levels. Journal of Life Social Science, 3, 178-181.

Dar, J.S. and M. M. Anwar. 2005. Response of varying levels of nitrogen on growth of different inbred lines of cotton. Journal of Agriculture & Social Science, 1, 48-49.

Davis, J. G. 1996. Provision of mid-season potassium requirements in cotton with slow release potassium applied pre-plant. Journal of Plant Nutrition, 19, 1– 14.

Dobermann, A. 2007. Nutrient use efficiency measurement and management. In “IFA International Workshop on Fertilizer Best Management Practices”, Brussels, Belgium, 1-28.

Dong, H.Z., Kong, X.Q., Li, W.J., Tang, W., Zhang, D.M., 2010. Effects of plant density and nitrogen and potassium fertilization on cotton yield and uptake of major nutrients in two fields with varying fertility. Field Crops Res. 119, 106–113.

Duncan, A., Macmillan, H., & Simutanyi, N. 2003. Drivers of pro-poor change: an overview. Oxford: Department of Policy Management. Retrieved September, 8, 2010.

El-Feky H.E-D.H. 2010. Motes percentage and ginning outturn as affected with cultivar and location. Agriculture Science. 1, (1), 44-50.

Erisman, J. W., Leach, A., Bleeker, A., Atwell, B., Cattaneo, L., and Galloway, J. 2018. An integrated approach to a nitrogen use efficiency (NUE) indicator for the food production–consumption chain. Sustainability, 10 (4), 925.

Evans, L. T., and R. A. Fischer. 1999. Yield potential: Its definition, measurement, and significance. Crop Science, 39 (6), 1544–51.

Fernie, A. R., Bachem, C. W., Helariutta, Y., Neuhaus, H. E., Prat, S., Ruan, Y. L., et al. 2020. Synchronization of developmental, molecular and metabolic aspects of source–sink interactions. Nature Plants, 6, 55–66. doi: 10.1038/s41477-020-0590-x

Food and Agriculture Organization. 2008. Soaring food prices: facts, perspectives, impacts and actions required. Rome: FAO.

Food and Agriculture Organization & FCRN (Food Climate Research Network). 2016. Plates, pyramids, planet. Developments in national healthy and sustainable dietary guidelines: a state of play assessment. Rome and Oxford.

Food and Agriculture Organization. 2023, https://www.fao.org/,markets-and-trade/commmodities/en/

Fritischi, F. B., A. R. Bruce, R. L. Travis, D. W. Rains and R. B. Hutmacher. 2003. Response of irrigated Acala and Pima cotton to nitrogen fertilization: Growth, dry matter partitioning and yield. Agronomy journal, 95, 133-146.

Gangaiah, B.; Ahlawat, I.P.S.; Babu, M. 2013. Response of nitrogen fertilization on Bt and non-Bt cotton (*Gossypium hirsutum*) hybrids. SAARC Journal of Agriculture, 11, 121–132.

Gerald, E. 2008. Comparative analysis of organization and performance of African cotton sectors: Quality and marketing of cotton lint in Africa. Africa Region Working Paper Series No. 121.

Gerik TJ, Jackson BS, Stockle CO, Rosenthal WD. 1994. Plant nitrogen status and boll load of cotton. Agronomy Journal 86, 514-518.

Gerik, T. J., Oosterhuis, D. M., & Torbert, H. A. 1998. Managing cotton nitrogen. Advanced Agronony, 64, 115-147.

Gitonga, W., Macharia, J. M. K., Mungai, A., Muthoni, L., Gitunu, A.M., Muriithi, A. 2011. Improving cotton production efficiency in small-scale farming systems of Kenya through better vertical integration of the supply chain. Baseline survey. Annual report 2011. KARI Mwea.

Gill KH, Sherazi SJA, Iqbal J, Ramzan M, Shaheen MH, Ali ZS. 2000. Soil fertility investigations on farmers' fields in Punjab", Soil Fertility Research Institute, Department of Agriculture, Government of Punjab, Lahore, Pakistan, 133- 135.

Glass, A. D. M. 2003. Nitrogen use efficiency of crop plants: Physiological constraints upon nitrogen absorption. CRC. Critical Reviews in Plant Sciences, 22, 453-470.

Glen, L. R., Craig, W. B., Philip, H. J. and Steve, M. B. 2007. Cotton growth and development. Cooperative Extension, University of Georgia. Online: Pubs.caes.uga. edu/caespubs/pubcd/B1252. Htm. 25/6/2009

Government of Kenya. 2007. The Kenya Vision 2030; A Competitive and Prosperous Kenya. Ministry of National Planning and Development. Government Printer, Nairobi.

Gwimbi P. 2009. Cotton Farmers' Vulnerability to Climate Change in Gokwe District (Zimbabwe): Impact and Influencing Factors. JAMBA: J. Disaster Risk Study, 2 (2).

Hejnák, V., Tatar, Ö., Atasoy, G.D., Martinková, J., Çelen, A.E., Hnilička, F. and Skalický, M. 2015. Growth and photosynthesis of Upland and Pima cotton: response to drought and heat stress. Plant Soil Environment. 61, 507–514.

Holden, J. and Constable, G. 1994. Phosphorus nutrition for cotton- Research review. In: CRC – Newsletter, Volume 1, 4.

Howard, D.D., Gwathmey, C.O., Roberts, R.K., Lessman, G.M. 1998. Potassium fertilization of cotton produced on a low K soil with contrasting tillage systems. Production Agriculture journal, 11, 74–79.

Howard, D. D., Gwathmey, C. O., Essington, M. E., Roberts, R. K., & Mullen, M. D. 2001. Nitrogen fertilization of no-till cotton on loess-derived soils. Agronomy Journal, 93 (1), 157-163.

Hussain SZ, Faird S, Anwar M, Gill MI, Baugh MD. 2000. Effect of plant density and nitrogen on the yield of seed cottonvariety CIM-443. Sarhad Journal of Agriculture, 16, 143-147.

Hutmacher RB, Travis RL, Rains DW, Vargas RN, Roberts BA, Weir BL, Wright SD, Munk DS, Marsh BH, Keeley, MP, Fritschi FB, Munier DJ, Nichols RL, Delgado R. 2004. Response of recent Acala cotton cultivars to variable nitrogen rates in the San Joaquin Valley of California. Agronomy Journal 96, 48-62.

Ibrahim, M.A.S., K.E. Ahmed, S. Osman, El Tahir, S. Ali and A.A. Hamada. 2010. Response of new cotton varieties to nitrogen fertilization in Sudan Gezira. African Journal of Agriculture Research, 5, 1213-1219.

Ikiara M. & Ndirangu K. 2002. Developing a Revival Strategy for the Kenyan Cotton Textile Industry: A Value Chain Approach. Kenya Institute for Public Policy Research and Analysis (KIPPRA). Nairobi, Kenya.

Ikitoo E.C. 2011. *Gossypium hirsutum* L. Available at: < http://database.prota.org/search. htm> [Accessed 25 February 2016].

Jackowski, T., B. Chylewska, and D. Cyniak. 2002. Influence of the spinning process parameters on strength characteristics of cotton yarns. Fibers and Textile. 116, 27-31.

Jaetzold, R. and Schmidt H. 2009. Farm Management Handbook of Kenya. Vol. II/C Kenya. Natural Condition and Farm Management Information. Ministry of Agriculture and German Agricultural Team (GTZ), Nairobi.

Johnson, R., Vishwakarma, K., Hossen, M. S., Kumar, V., Shackira, A. M., Puthur, J. T., et al. (2022). Potassium in plants: Growth regulation, signaling, and environmental stress tolerance. Plant Physiol. Biochem. 172, 56–69. doi: 10.1016/j.plaphy.2022.01.001

Karthikeyan, P.K., and R. Jayakumar. 2001. Nitrogen and chlormequat chloride on cotton cultivar. p. 806-807. In W.J. Horst et al. (ed.) Plant nutrition: food security and sustainability of agro-ecosystems through basic and applied research. International Plant Nutrition Colloq., 14th, Hannover, Germany. 27 July - 3 Aug. 2001. Kluwer Academic Publishers, Dordrecht, Netherlands.

Karthikeyan, P.K. and R. Jayakumar. 2002. Nitrogen and chlormequat chloride on cotton cultivar. Plant Nut. Developments in Plant and Soil Sciences, 92, Symposium, 10, 806-807.

Kasimba, Rosemary, 2014. "Impacts of climate change on crop production practices among small holder farmers in Guruve district, Zimbabwe."

Khan A, Tan DKY, Afridi MZ. 2017. Nitrogen fertility and abiotic stresses management in cotton crop: a review. Environmental Science Pollution Research, 24 (17), 14551–66.

Khan, B. and J.S. Dar. 2006. Response of cotton (*Gossypium hirsutum* L.) cultivars to different levels of nitrogen. Journal of science research, 17, 257-261.

Khan, N., K.B. Marwat, G. Hassan, F. Ullah, S. Batool, K. Makhdoom, W. Ahmad and H.U. Khan. 2005. Genetic variations and heretiblity for cotton seed, fiber and oil traits in *Gossypium hirsutum* L. Pakistan Journal of Botany, 42 (1), 615-625.

Khan, M.B.; Hussain, N.; Asif, M. 2001. Growth and yield of cotton as influenced by various nitrogen levels and plant population. International Journal of Agriculture Biology, 3, 5–7.

KNBS. 2020. Economic Survey. Nairobi, Kenya: Kenya National Bureau of Statistics, Government of Kenya.

Kumar, B., Pandey, D.M., Goswami, C.L. and Jain, S. 2001. Effect of growth regulators on photosynthesis, transpiration and related parameters in water stressed cotton. Biology. Plantarum, 44, 475–478.

Kumbhar, A.M., U.A. Buriro, S. Junejo, F.C. Oad, G.H. Jamro, B.A. Kumbhar and S.A. Kumbhar. 2008. Impact of different nitrogen levels on cotton growth, yield and Nuptake planted in legume rotation. Pakistan Journal of Botany, 40, 767-778.

Latiri-Souki, K., Nortcliff, S., and Lawlor, D. W. 1998. Nitrogen fertilizer can increase dry matter, grain production and radiation and water use efficiencies for durum wheat under semi-arid conditions. Europeen Journal of Agronomy, 9, 21–34. doi: 10.1016/S1161-0301(98)00022-7

Law, L., Onumah, G., Braine, C., Muzoora, L. and Butterworth, R. 2007. Cotton Quality Assurance in Uganda: Training Manual, 21-22.

Lawrence, C.A. (2003) Fundamental of Spun Yarn Technology. Woodhead Publishing Ltd., Cambridge. http://dx.doi.org/10.1201/9780203009581

Lege, K.E., J.T. Cothren and P.W. Morgan. 1997. Nitrogen fertility and leaf age effects on ethylene production of cotton in a controlled environment. Journal Plant Growth Regulation, 22, 23-28.

Lewis, H. 2000. Cotton yield and quality—yesterday, today and tomorrow. In 2000 EFS® 1 Systems Conference Presentations. Available at http://www.cottoninc.com/ (verified 22 Oct. 2010). Cotton Inc., Cary, NC, 137– 145.

Loka, D.M., Derrick, M., Oosterhuis, D.M. and Ritchie, G.L. 2011. Water-deficit stress in cotton in Stress Physiology in Cotton (Oosterhuis D.M., eds). The Cotton Foundation Book Series. National Cotton Council of America, 37–72.

Ludlow, M.M. and R.C. Muchow. (1990). A critical evaluation of traits for improving crop yields in water-limited environments: Advances in Agronomy 43,107-153.

Luo, H.H., Zhang, Y.L. and Zhang, W.F. 2016. Effects of water stress and rewatering on photosynthesis, root activity, and yield of cotton with drip irrigation under mulch. Photosynthetica, 54, 65–73.

Malik, M.N. 1995. Nutrient Management of Cotton. Trainers Manual, Workshop on Training of Trainers in Cotton IPM. FAO/FAP, CCRI, Multan, Pakistan, 6-13

Masunga, R. H., Uzokwe, V. N., Mlay, P. D., Odeh, I., Singh, A., Buchan, D., & De Neve, S. 2016. Nitrogen mineralization dynamics of different valuable organic amendments commonly used in agriculture. Applied Soil Ecology, 101, 185-193.

May, O L. 1999. Genetic variation in fiber quality. Cotton Fibers: Developmental Biology, Quality Improvement, and Textile Processing, Basra, A. S. (Ed.) Food Products Press, Binghamton, New York.

Meredith, W. R. Jr. 2005. Changes in yield and quality due to genetics and climatic factors. 2001. EFS System Conference Proceedings. Appendix 1. Greenville, SC June 9 – 11, 2003.

McAllister, C. H., Beatty, P. H., and Good, A. G. 2012. Engineering nitrogen use efficient crop plants: The current status. Plant Biotechnology Journal, 10, 1011–1025.

McConnell JS, Baker WH, Frizzell BS. 1996. Distribution of residual nitrate-nitrogen in long-term fertilization studies of an Alfsol cropped to cotton. Journal of Environment Quality, 25 (6), 1389–94.

Ministry of Agriculture Livestock and fisheries. 2015. Annual Report done by the Ministry of Agriculture Livestock and Fisheries in Nairobi.

Morton, W., J. Hearle, and C. Text. 1993. Physical properties of textiles. The Textile Institute. Manchester, United Kingdom, 4, 82-2001.

Mullins, G. L., & Burmester, C. H. 2010. Relation of growth and development to mineral nutrition. Physiology of cotton. Netherlands: Springer, 97-105.

Mullins GL, Burmester CH. 1990. Dry matter, nitrogen, phosphorus and potassium accumulation by four cotton cultivars. Agronomy Journal 82, 729- 736.

Mwangi, J. N., Mugendi, D. N. and O'Neill, K. M. 1998. Crop yield response to incorporation of leaf prunings in sole and alley cropping systems. East Africa Agricultural Journal 62, 209–218.

Mylavarapu, RS; Sanchez, JF; Nguyen, JH; Bartos, JM. 2002. Evaluation of Mehlich-1 and Mehlich-3 extraction procedures for plant nutrients in acid mineral soils of Florida, 33, 807-820.

Nadeem, M.A., A. Ali, M. Tahir, M. Naeem, A.R. Chadhar and S. Ahmad. 2010. Effect of nitrogen levels and plant spacing on growth and yield of cotton. Pakistan Journal Life Social Science, 8, 121-124.

Nawaz M, Malik MNA, Chaudhry FI, Makhdum MI. 1996. Investigation on phosphorus availability and seed cotton yield in silt loam soils. Journal of Animal and Plant Sciences 6, 21- 23.

Oosterhuis, D.M. and D.D. Howard. 2008. Programmed release nitrogen and potassium fertilizers for cotton production. African Journal of Agricultural Science 3, 68-73.

Oosterhuis, D. M. 2002. Potassium management of cotton. In N. S. Pasricha & S. K. Bansal (Eds.), Potassium for sustainable crop production, 331– 346.

Oosterhuis, D. M., Loka, D. A., & Raper, T. B. 2013. Potassium and stress alleviation: Physiological functions and management of cotton. Journal of Plant Nutrition and Soil Science, 176, 331– 343.

Pace, P. F., H. T. Cralle., S. H. El-Halawany., J. T. Cothren, and S. A. Senseman. 1999. Drought-induced changes in shoot and root growth of young cotton plants: Journal of Cotton science, 3,183-187.

Parry, M. A. J., Flexas, J., & Medrano, H. 2005. Prospects for crop production under drought: research priorities and future directions. Annals of applied biology, 147 (3), 211-226.

Parry et al. 2012; Hayes, C. 2007. Climate change, water in Kenya, http://www.trocaire.org/sites/trocaire/files/resources/edu/kenya-climate-change-water-post-primary.pdf

Parry J., Echeverria D., Dekens J. and Maitima J. 2012. Climate Risks, Vulnerability and Governance in Kenya: A Review. Climate Risk Management Report. Nairobi: UNDP.

Paudel, D. R., Hequet, E. F. and Abidi, N. 2013. Evaluation of cotton fiber maturity measurements. Industrial Crops and Products, 45, 435–441.

Payne RW. 2011. The Guide to GenStat 15th Edition, Part 2 – Statistics. VSN international, Hemel Hempstead.

Peeters M.-C., Van Langenhove L., Louwagie J., Waterkeyn L. & Mergeai G. 2001. Fibre crops: Cotton – *Gossypium hirsutum* L. In: Raemaekers R.H. (eds.), Crop Production in Tropical Africa, 10, 1041-1070.

Peñuelas, J., Canadell, J. G., & Ogaya, R. 2011. Increased water-use efficiency during the 20th century did not translate into enhanced tree growth. Global Ecology and Biogeography, 20 (4), 597-608.

Percy, RG and Kohel RJ. 1999. Qualitative genetics. In Smith CW and Cothren JT (eds.) Cotton: Origin, history, technology, and production. John Wiley and Sons, New York, 319-360.

Pervez, H., Ashraf, M., & Makhdum, M. I. 2004. Influence of potassium nutrition on gas exchange characteristics and water relations in cotton (*Gossypium hirsutum* L.). Photosynthetica, 42, 251-255.

Pettigrew, W. T., & Meredith Jr, W. R. 1997. Dry matter production, nutrient uptake, and growth of cotton as affected by potassium fertilization. Journal of Plant Nutrition, 20 (4-5), 531-548.

Perumai, N. K. 1999. Effect of different nitrogen levels on morpho-physiological characters and yield in rainfed cotton, Journal of Plant Physiology, 4, 65–67.

Pettigrew, W. T., J. J. Heitholt and W. R. Meredith, Jr. 1996. Genotypic interactions with potassium and nitrogen in cotton of varied maturity. Agronomy Journal, 88 (1), 89–93.

Pettigrew, W.T. 2003. Relationships between insufficient potassium and crop maturity in cotton. Agronomy journal, 95, 1323–1329.

Porter PM, Sullivan MJ, Harvey LH. 1996. Cotton cultivar response to planting date on the southeastern coastal plain. Journal of production agriculture, 9 (2), 223–7.

Prakash, R. and M. Prasad. 2000. Effect of nitrogen, chlormequat chloride and farmyard manure applied to cotton (*Gossypium hirsutum*) and their residual effect on succeeding wheat (*Triticum aestivum*) crop. Indian Journal of Agronomy, 45, 263-268.

Quemada, M., and Gabriel, J. L. 2016. Approaches for increasing nitrogen and water use efficiency simultaneously. Global Food Security, 9, 29-35.

Raghavendra, R., Hegde, A. D Atul Dahiya, M.G. Kamath, Xiao.G and Praveen K.J. 2004. Cotton Fibers, 1-15.

Rashidi, M.; Gholami, M. 2011. Response of yield and yield components of cotton to different rates of nitrogen fertilizer. Journal of Plant Science, 4, 22–25.

Rashidi M, Gholami M. 2011. Nitrogen and boron effects on yield and quality of cotton (*Gossypium hirsutum* L.). International Research Journal of Agricultural Science and Soil Science, 1, 118-125.

Regional Agricultural Trade Expansion Support Program [RATES]. 2003. Cotton-Textile and Apparel Value Chain report for Kenya. The RATES Center, Nairobi, Kenya.

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. Agronomy journal, 96, 1148-1157.

Riaz, M., Farooq, J., Sakhawat, G., Mahmood, A., Sadiq, M. and Yaseen, M. 2013. Genotypic variability for root/shoot parameters under water stress in some advanced lines of cotton (*Gossypium hirsutum* L.). Genetic and Molecular Research, 12, 552–561.

Rochester, I. J., M. B. Peoples, and G. A. Constable. 2001. Estimation of the N fertilizer requirement of cotton grown after legume crops. Field Crops Research, 70, 43–53.

Rochester, I. J. 2007. Nutrient uptake and export from an Australian cotton field. Nutrient cycling in Agroecosystems, 77 (3), 213-223.

Rogers, D. D. 2005. Engineering and Ginning: The Effect of Harvesting Procedures on Fibre and Yarn Quality of Ultra-Narrow-Row Cotton. Journal of Cotton Science, 9, 25-23.

Rodgers J., C. Delhom, C. Fortier, and D.P. Thibodeaux. 2012a. Rapid measurement of cotton fiber maturity and fineness by image analysis microscopy using the Cotton scope. Texture Research Journal 82 (3), 259-271.

Rodgers J., C. Delhom, D. Hinchliffe, H.J. Kim, and X. Cui. 2012b. Rapid measurement for cotton breeders of maturity and fineness from developing and mature fibers. Textile Research Journal, 84 (14), 1439- 1451.

Saleem, M.F., M.F. Bilal, M. Awais, M.Q. Shahid and S.A. Anjum. 2010. Effect of nitrogen on seed cotton yield and fiber qualities of cotton (*Gossypium hirsutum* L.) Cultivars Journal of Animal & plant science, 20, 23-27.

Sawan, Z. M., A. H. Fahmy and S. E. Yousef. 2009. Direct and residual effect of nitrogen fertilization, foliar application of potassium and plant growth retardant on Egyptian cotton growth, seed yield, seed viability and seed vigor. Acta Ecological Sinica, 29, 116-123.

Sawan, Z. M., M. H. Mahmoud and A. H. El-Guibali. 2006. Response of yield, yield components, and fiber properties of Egyptian cotton (*Gossypium barbadense* L.) to 209 nitrogen fertilization and foliar-applied potassium and mepiquat chloride. Journal of cotton science, 10, 224–234.

Smaling, E. M. A. 1993. Soil nutrient depletion in Sub-Saharan Africa. In the Role of Plant Nutrients for Sustainable Food Crop Production in Sub- Saharan Africa, 47–6.

Smith, C. W., Braden, C. A. and Hequet, E. F. 2010. Genetic analysis of fiber length uniformity in upland cotton. Crop Science, 50 (2), 567-573.

Statista. 2015. http://www.statista.com/statistics/263055/cotton-production-worldwide-by-top-countries/.

Seagull RW, Oliveri V, Murphy K, Binder A, Kothari S. 2000. Cotton fiber growth and development 2. Changes in cell wall diameter and wall birefringence. Journal of Cotton Science, 4, 97-104.

Stewart, C. E., Paustian, K., Conant, R. T., Plante, A. F., & Six, J. 2009. Soil carbon saturation: Implications for measurable carbon pool dynamics in long-term incubations. Soil Biology and Biochemistry, 41 (2), 357-366.

Snyder, C. S., Davidson, E. A., Smith, P., and Venterea, R. T. 2014. Agriculture: Sustainable crop and animal production to help mitigate nitrous oxide emissions. Current Opinion on Environmental Sustainability, 9, 46–54.

Tang, L., Li, Y., Zhang, J. 2005. Physiological and yield responses of cotton under partial root zone irrigation. Field Crops Research, 94, 214–223.

Tennakoon, S.B., Milroy, S.P. 2003. Crop water use and water use efficiency on irrigated farms in Australia. Agricultural Water Management, 61, 179–194.

Tewolde H, Fernandez CJ.1997. Vegetative and reproductive dry weight inhibition in nitrogen and phosphorus deficient Pima cotton. Journal of Plant Nutrition, 20, 219-232.

Thaxton P.M. & El-Zik K.M. 1994. Development of MAR cotton germplasm with morphological mutant traits. In: G.A. Constable and N.W. Forrester (Eds.), Production World Cotton Research Conference, 244-250.

Ton, P. 2011. Cotton and climate change: impacts and options to mitigate and adapt. International Trade Center, Geneva, Switzerland 4,34.

Tucker MR. 1999. Essential plant nutrients: their presence in North Carolina soils and role in plant nutrition. North Carolina, US: Department of Agriculture and Consumer Services, Agronomic Division, 9.

United states department of Agriculture.2018. National Agriculture statistics service (NASS) reports for the year 2018.

Usherwood, N. R. 2000. The influence of potassium on cotton quality. Agri-Briefs, Agronomic News, (8).

Venugopalan MV, Pundarikakshudu R. 1998. Long term effects of nutrient management and cropping system on cotton yield and soil fertility in rainfed vertisols. Nutr. Cycling Agroecosystems, 55, 159-164.

Wabule, M. N., Ngigi, R., Ngari, B. M., Kimani, A. W. and Macharia, J. M. K. 2006. Recommendations for growing cotton in Kenya. Kenya Agricultural Research Institute.

Waraich, E. A., Ahmad, R. and Ahmad, S. S. 2008. Water use efficiency and yield performance of wheat (*Triticum aestivum* L.) under different levels of irrigation and nitrogen. Caderno de Pesquisa série Biologia, 20,22–34.

Wang, Y., Wang, E., Wang, D., Huang, S., Ma, Y., Smith, C.J., Wang, L., 2010. Crop productivity and nutrient use efficiency as affected by long-term fertilization in North China Plain. Nutrient cycle. Agro ecosystems, 86, 105-11.

World Bank. 2005. Kenya Growth and Competitiveness. Report No. 31387-KE, retrievedhttps://openknowledge.worldbank.org/bitstream/handle/10986/8505/313870KE.pdf?sequence=1

Wortmann, C. S., Shapiro, C. A., & Schmer, M. R. 2016. Residue harvest effects on irrigated, no-till corn yield and nitrogen response. Agronomy Journal, 108, 384– 390.

White, P. J., & Karley, A. J. 2010. Potassium. In R. Hell & R. Mendel (Eds.), Cell biology of metals and nutrients, 199– 224.

Wu, Y., and Cosgrove, D. J. 2000. Adaptation of roots to low water potentials by changes in cell wall extensibility and cell wall proteins. Journal of Experimental Botany, 51, 1543–1553.

Yazar, A., Sezen, S. M., & Sesveren, S. 2002. LEPA and trickle irrigation of cotton in the Southeast Anatolia Project (GAP) area in Turkey. Agricultural Water Management, 54 (3), 189-203.

Yin X, Gwathmey O, Main C, Johnson A. 2011. Effects of sulfur application rates and foliar zinc fertilization on cotton lint yields and quality. Agronomy Journal, 103, 1794-1803.

Zhao, D., Oosterhuis, D.M., Bednarz, C.W. 2001. Influence of potassium deficiency on photosynthesis, chlorophyll content, and chloroplast ultrastructure of cotton plants. Photosynthetica 39, 103–109.

Zhou, Z. G., and Derrick, M. O. 2012. Physiological mechanism of nitrogen mediating cotton seedlings growth under water-stress conditions. Journal of Plant Science, 3, 721–730.