BINDURA UNIVERSITY OF SCIENCE EDUCATION

FACULTY OF AGRICULTURE AND ENVIRONMENTAL SCIENCE

DEPARTMENT OF CROP SCIENCE

EVALUATING EFFECTS OF TOP DRESSING TIMING ON TWO FLUE-CURED VIRGINIA TOBACCO *(Nicotiana tabacum* L.) VARIETIES LOWER CURES QUALITY.

ELISHA CHIMUSARU

(B221906B)

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE BACHELOR OF AGRICULTURAL SCIENCE HONOURS DEGREE IN CROP SCIENCE

Date: June 2025

DECLARATION

I do hereby declare that this research project entitled, '**Evaluating effects of topdressing timing on two flue-cured virginia Tobacco (*Nicotiana tabacum* L.) varieties lower cures quality,'** was written by me and that it is the record of my own research work. It has neither in part nor in whole been presented for another degree elsewhere.

Sign…………. Date…27/06/2025…

Elisha Chimusaru

This is being submitted for the partial fulfilment of the requirements for the Bachelor of Science Honours Degree in Crop Science with the approval of supervisor.

Supervisor: Mr Mutsengi

Sign… Date………………30/09/25

DEDICATION

I dedicate all my efforts and struggles of the educational life to my dear family, friends, and God without them I could not have sailed.

ACKNOWLEDGEMENT

I am immensely grateful to the almighty God for bestowing me with the ability and strength to work diligently and successfully on this project. Words cannot adequately express my profound gratitude. I am deeply indebted to the Bindura University of Science Education, Department of Crop Science, for guiding me and supporting me throughout this journey. I would like to express my sincere appreciation to my Project Supervisor, Mr mutsengi, whose constant guidance, advice, patience, and diligence played a vital role in the successful execution of this project. His valuable suggestions were crucial in ensuring the flawlessness of this endeavor. Furthermore, I extend my heartfelt gratitude to my family and friends for providing unwavering support and guidance throughout the research and writing process of this project. I am truly humbled and thankful for the support and mentorship I have received from the university, my supervisor, and my loved ones, all of whom have contributed immensely to the completion of this project.

ABSTRACT

Optimal nitrogen management is crucial for enhancing the market-driven quality of lower flue-cured tobacco (*Nicotiana tabacum* L) leaves. This study evaluated four top-dressing timings: control (no N), 2g ammonium nitrate (AN) at planting, 8g AN at planting, and split application (5g at planting + 3g at topping) on growth, yield, and cured quality of Krk 26 and Krk 76 varieties. Field experiments measured leaf area (weeks 4, 6, 8), plant height, leaf dry weight, yield, and cured color. Split applications maximized leaf area development ($p<0.001$ at week 8), with Krk 76 exhibiting 35% greater expansion than Krk 26 under this regime. While all nitrogen treatments increased plant height ($p<0.001$) and yield ($p<0.001$) over control, split applications achieved peak yield (393,333 kg/ha in Krk 76). Cured color depended solely on nitrogen sufficiency ($p<0.001$), with both 8g basal and split treatments scoring optimally. Results demonstrate that split nitrogen applications synchronize with critical growth phases to maximize leaf expansion and yield, particularly in high-vigor varieties like Krk 76, while maintaining cured quality requires minimum nitrogen thresholds (≥8g AN equivalent). Growers should adopt variety-specific split timing for Krk 26 and ensure adequate total nitrogen for Krk 76 to optimize lower-cure outcomes.

Key words: Split-application synchronization; varietal nitrogen responsiveness; lower-cured leaf quality; nitrogen sufficiency threshold; sink strength divergence

Table of Contents

List of Figures

ABBREVIATIONS

TRB- Tobacco research Board

N- Nitrogen

K- Potassium

P-Phosphorus

TIMB- Tobacco Industry Marketing Board

FCV- Flu Cured Virginia

AN- Ammonium Nitrate

T1, 2, 3, 4 – treatments

V1-Variety one

V2- Variety two

CHAPTER ONE: INTRODUCTION

1.1 Background Information

Tobacco (*Nicotiana tabacum* L.) is a widely cultivated cash crop worldwide (Liu *et al*., 2022). Major producers of the crop are China, Brazil, India, the USA, Indonesia and Zimbabwe. Zimbabwe is the largest producer of tobacco leaf in Africa (Chingosho *et al*., 2021). Tobacco is used in cigarette production and in the production of pharmaceuticals in human health sector. It can also be used as an insect repellent, a herb or a decorative plant.

Topdressing is a common practice in tobacco production, as it provides essential nutrients to the crop though primarily it supplies nitrogen. However, the timing and method of topdressing can impact the quality of the lower cures because nitrogen has a big impact on tobacco curing quality. Different researchers have investigated the role of nutrient management in flue cured virginia tobacco. Zhao *et al.* (2018) demonstrated that nitrogen application timing influences tobacco leaf color and curing outcomes. Peterson *et al.* (2020) highlighted the impact of excessive early nitrogen application on delayed maturity and uneven curing in flue cured virginia tobacco.

All these researches underscore the importance of fertilizer timing but leave unresolved gap regarding its impact on the lower leaf cures, necessitating further research to enhance profitability of flue cured virginia (FCV) tobacco. Nitrogen plays a significant role in FCV tobacco and most FCV tobacco farmers have resided on two split applications, at 21days after planting and after removing of the apical bud, topping, but the problem of producing poor cures on lower leaves has not been solved and that has ruthlessly contributed to heavy financial losses to majority of flue cured virginia tobacco farmers because the lower leaves are either thrown away or they are cured but usually fetch low prices on the market.

1.2 Problem Statement

Despite the significance of nutrient management in flue cured virginia tobacco production, there is limited empirical evidence on how topdressing time affects the quality of the lower leaf cures. Flue cured virginia tobacco farmers face difficulties in striking a balance between early nutrient management for plant vigour and preventing adverse effects such as uneven ripening or poor leaf quality during curing. This gap in knowledge necessitates a systematic evaluation of effects of early nitrogen application on the quality of lower cures.

1.3 Justification of the study

This study provides critical insights for tobacco growers and agronomists seeking to optimize flue cured virginia tobacco production. By easing the relationship between early topdressing and curing quality, the research aims to enhance both the economic and qualitative aspects of flue cured virginia tobacco farming. Furthermore, the findings may contribute to broader agricultural studies on fertilizer management and crop quality optimization.

1.4 Objectives of the study

-To assess the impact of topdressing time on lower cures of flue cured virginia tobacco.

1.4.1 Specific objectives

1. To analyze the effect of top dressing time on vegetative growth of tobacco.
2. To assess the effect of top dressing time on the quality of cured lower leaves.
3. To assess the effect of top dressing timing on the yield of lower cures of tobacco.

1.4.2 Hypothesis

1. Early topdressing has effect on vegetative growth of tobacco.
2. Early topdressing affects quality of cured lower leaves of tobacco.
3. Early topdressing contributes to yield of lower cures of tobacco.

CHAPTER 2: LITERATURE REVIEW

2.1 Production of tobacco in Zimbabwe

According to TIMB report (2023), farmers are getting an average of 2.5t per hectare of the golden leaf, production of tobacco in Zimbabwe contributes 30% of formal employment in the agricultural sector. Chivuraise *et al.* (2011) and Masvongo *et al.* (2013) noted that tobacco production also creates informal employment and earns the country foreign currency through tobacco exports. According to the 2024 annual statistical report by the Tobacco Industry and Marketing Board (TIMB), tobacco farming contributed US$1.1 billion from export of 202 000 metric tonnes of flue cured virginia tobacco in the 2024 farming season. The leaf forms a mainstay of the economy, accounting for about 10% of Zimbabwe's Gross Domestic Product (GDP) since 2018 (Chingosho *et al*., 2021).

Tobacco has always been considered as a medicinal plant. Before its use as a smoking material, it has been used as a traditional medicine for common illnesses, *(Mcgraw-hill 1980)*. In recent years, nicotine has been recommended for hypodermic injections in tetanus and strychnine poisoning. The plant is also used as a source of isoprene units required for the production of a cardiac drug, *(Doyle JJ 1998).* For veterinary applications, tobacco was found useful as an antiseptic for cleaning wounds.

Flue cured virginia tobacco top leaves, scrap and dust, being biodegradable, they are particularly alternatives to synthetic pesticides and fertilizers especially during these times of high level consciousness for environment-friendly technologies, and the fact that synthetic fertilizers and pesticides are expensive.

2.2 Tobacco crop

Flue cured virginia tobacco (*Nicotiana tabacum*.L) is a member of the genus Nicotiana, which comprises of over 70 species. It is believed to have originated in South America, likely as a hybrid between *Nicotiana sylvestris* and *Nicotiana tomentosiformis* (McCarthy et al., 2019). The domestication of tobacco is estimated to have occurred over 6,000 years ago by indigenous cultures for ceremonial and medicinal purposes. *Nicotiana tabacum* is an annual or short-lived perennial herbaceous plant.

Flue cured virginia tobacco is a self-pollinating dicot plant in the Solanaceae family with primary and vascular tissues. Depending on varieties, tobacco plant can bear up to 25 leaves with the length size of about 60 cm and the plant can be 1 to 2m in height. The plant`s leaves have large surface area as compared to other field crops (Trueman, 2020). The leaves have a spiral arrangement and they are hairy, thick and ovate. According to Reddy (2006), tobacco leaves contain nicotine and sugars which give the smoker a pleasant aroma. Tobacco produces flowers with five white or pink petals and the flowers can split into 2 or 4 parts at maturity. Crops like tomato, Irish potato and pepper are in the same family (Solanaceae) with tobacco.

2.3 Fertilizer management

Flue cured Virginia tobacco requires a perfect fertilizer regime, at planting, compound C with N:P:K 6:28:23 is used as basal fertiliser. The application rate is 450kg per hectare though some recommendations are based on soil analysis and may be as high as 700kg/ha. In Zimbabwe, flue cured virginia tobacco is applied topdressing at 150kg per hectare of ammonium nitrate, with 34.5% of nitrogen, (*Parker 2009)*, due to the difference in soil texture, some of the soils require less topdressing, based on the ability of the soil to leach nutrients. Sandy loam soils require 5g to 8g of top dressing, whilst clay soils require 5g or lower amount of topdressing due to slow nutrient release. However, sandy soils require as high as 10 to 15 grams due to very high leaching ability. First topdressing is applied after 21days after transplanting and the other half at topping. The second application is done as leaching adjustment though it has become a norm to tobacco farmers. High nitrogen levels, especially late in the growing season, can delay maturity *(Weybrew et al., 1983; Maw et al., 1995)*, this results in a leaf that is still actively growing and has excessive moisture and chlorophyll content when harvested.

2.4 Curing disorders

Poor topdressing timing leads to uneven ripening of leaves, making it difficult to achieve uniform curing. Leaves may cure unevenly, resulting in patchy discoloration of yellow and brown in different areas. Poor nitrogen management leads to bad curing due to non-uniform starch to sugar conversion, *(Havranek et al, 2006)*. Excessive nitrogen during late growth stages can lead to green spot disorder, where chlorophyll degradation is incomplete during curing. This results in green patches on the cured leaves, *(Sifola and Postiglione 2003),* also results in cured leaves with poor texture, aroma, and potentially high nicotine content, negatively impacting their usability and market value. In addition, high nitrogen during topdressing leads to increased nitrate accumulation in leaves, which deters sugar to starch conversion during curing. This results in unbalanced flavor and poor leaf combustibility, *(Collins and Hawks , 1993).* This leads to a darker, often reddish or mahogany color of cured leaf which is generally less desirable (*Amanullah et al., 2008).* Properly cured flue-cured tobacco should have a light lemon to orange color which is more desirable on the market.

Figure 2.1 Images showing different flu cured virginia tobacco stages

2.5 Importance of nitrogen and its management

Nitrogen is a crucial nutrient influencing tobacco yield, quality, and curing attributes. Flue cured virginia tobacco uses most of the nitrogen applied 80-90 percent during its vegetative stage, between week three (3) and week eight (8). Excess nitrogen after that period can lead to overgrowth, delayed maturity, and reduced quality of cured leaves *(Tso, 1990)*. Conversely, insufficient nitrogen may result in poor plant vigor and suboptimal yields *(Miller, 2000)*. Studies have demonstrated that the timing of nitrogen application is critical for balancing plant growth and leaf quality *(Smith et al., 2001*), nitrogen is a major constituent of chlorophyll, the pigment that captures light energy to drive photosynthesis, the fundamental process by which plants convert water and carbon dioxide into sugars. Without sufficient nitrogen, the plant's capacity to produce energy is severely compromised. Furthermore, nitrogen is a vital component of amino acids, which are the building blocks of proteins. Proteins serve diverse functions within the plant, acting as structural components, enzymes that catalyze metabolic reactions, and transport molecules facilitating the movement of substances within the plant. The very foundation of plant life and its metabolic activities relies on the availability of nitrogen for protein synthesis. Beyond its role in chlorophyll and proteins, nitrogen is also a crucial component of energy-transfer compounds such as adenosine triphosphate (ATP), which enables cells to conserve and utilize the energy released during metabolism. Additionally, it is a significant element in nucleic acids like deoxyribonucleic acid (DNA) and ribonucleic acid (RNA), the genetic material that governs cell division, growth, and reproduction. Nitrogen is also implicated in the synthesis of hormones, vitamins, and alkaloids, which play regulatory roles and contribute to the plant's overall physiology and defense mechanisms. Also nitrogen plays a significant role in the synthesis of nicotine especially after topping, removing of the apical bud.

Research indicates that applying nitrogen at planting can improve seedling establishment but may result in excessive vegetative growth. This often leads to thinner leaf texture and lower concentrations of desirable secondary metabolites, such as nicotine and sugars, which are critical for tobacco quality *(Jones & Brown, 2015).* Moreover, early nitrogen application may interfere with leaf maturity and curing, *(Zhang et al., 2018).*

2.6 Tobacco curing and nitrogen levels in the leaf

Nitrogen (N) management is one of the most crucial factors in determining the quality of flue-cured Virginia tobacco after curing. Proper nitrogen application influences leaf chemistry, usability, and the overall quality of the cured product. The curing process transforms fresh green leaves into a product with specific physical and chemical characteristics desired by the market. High nitrogen levels delay leaf maturity, causing uneven curing and a reduction in the desired golden-yellow color of the leaf (Collins et al., 1995). Nicotine is synthesized from nitrogen, and its concentration is heavily influenced by nitrogen application rates. Excessive nitrogen can lead to very high nicotine levels, which may exceed acceptable thresholds for cigarette manufacturing. However, low nitrogen reduces nicotine and carbohydrate content which often leads to low sugar levels, affects the aroma and flavor of the cured leaf, *(Hawks and Collins,1983),* both of which are critical for the usability of tobacco in cigarette production. Proper nitrogen management triggers accumulation of soluble sugars like glucose; fructose and reduces undesirable nitrogenous compounds, ensuring a better balance of chemical components for usability, *(Chaplin, 1975)*. Good nitrogen management ensures the development of leaves with optimal sugar and starch levels, which contribute to desirable curing outcomes *(Reynolds & Nielson, 1997).*

2.7 Effects of nitrogen timing on flue cured virginia tobacco

Zimbabwe's unique climatic and soil conditions necessitate localized studies on nutrient management practices. According to (*Moyo et al. 2021)*, improper fertilizer practices, including late topdressing, can exacerbate quality challenges in flue-cured virginia tobacco. However, smallholder farmers in Zimbabwe often lack access to technical knowledge on the optimal timing of fertilizer application, further complicating quality assurance in cured tobacco *(Chirwa et al. 2019).*

Early nitrogen application supports vigorous vegetative growth, leading to increased biomass and larger leaves. "Early nitrogen topdressing ensures optimal nitrogen availability during the critical leaf expansion phase, promoting healthy leaf development and final cured leaf quality," *(Chaplin, 1975).* Also, proper timing avoids nitrogen deficiency during early growth, which could result in small, thin leaves of poor usability. "Synchronizing nitrogen application with early vegetative growth improves curing characteristics by reducing excess nitrogen accumulation in the leaf tissue," (*Collins & Hawks, 1995).*

Late nitrogen application often results in higher residual nitrogen levels in cured leaves, which negatively affects burning quality and produces a harsh, undesirable taste in the smoke. "Nitrogen applied late accumulates as nitrate and protein in the leaf tissue, compromising the flavor and combustibility of the cured product," *(Weybrew et al., 1984)*. Late nitrogen application decreases the accumulation of soluble sugars, lowering the sugar to nicotine ratio, which is critical for a mild flavor. "Nitrogen applied late in the crop cycle reduces carbohydrate metabolism, resulting in lower sugar content and poorer smoking quality," *(Hawks & Collins, 1983).*

CHAPTER 3: MATERIALS AND METHOD

3.1 Study site

The research was carried out during the 2024-2025 rain season at Eastwoods (Nhangura) Farm which is located 25km South of the Mvurwi Town (-17.027, 30.856). The farm is in agro-ecological Region 2a. It experiences a sub-tropical climate and receives an annual rainfall of 800 - 1000mm and average annual temperatures of 18 and 30ºC in winter and summer respectively (Muzhandu *et al.*, 2013). Nyamapfene (1991) classified the soils in order II of the Zimbabwean soil classification, belonging to the group 4 Calcimophic soils, vertisols, with very active clay, derived from basalt rock. Soils are deep and well drained with a pH of 5.5 based on soil tests and are ideal for tobacco production, needs high management.

3.2 Experimental design

The study implemented a factorial arrangement within a randomized complete block design (RCBD) to evaluate two fixed factors: fertilizer application timing (four levels: T_1 = zero ammonium nitrate [AN], T_2 = 8g AN basal application at transplanting, T_3 = 2g AN basal application at transplanting, T_4 = split application [5g AN basal + 3g AN top-dressing at 21 days after transplanting/topping]) and variety (two levels: V_1 = Krk 76, V_2 = Krk 26). Triplicated experimental units per treatment combination were stratified by field heterogeneity. This RCBD framework controlled spatial variability while enabling isolation of main effects and interaction variances through restricted randomization protocols.

3.3 Trial management

3.3.1 Land preparation

Deep ploughing was done in May after harvesting; a disc plough was used to achieve a fine tilth in August followed by ridge marking in October using a tractor drawn rigger. Flue cured virginia tobacco does well in a well prepared environment.

3.3.2 Planting

KRK 76 and 26 flue cured virginia tobacco seedlings were transplanted on the 28th of October 2024. Overhead irrigation was used at planting. Irrigation was done pre-planting and post planting to achieve field capacity and also remove air pockets respectively. Planting was done using 1.2m inter row spacing and 0.55m in row spacing respectively, targeting 15 000plants per hectare.

3.3.3 Disease and pest control

Pest and diseases were controlled as per crop calendar requirements and also after scouting. Below is a table showing how the applications were done during the course of the study.

Table 3. 1 **Pesticide, time of application and purpose table**

Chemical/ Pesticide/Fungicide	Time of application	Application rates and Purpose
Confidor 200SL	Just after planting	1000ml per hectare at 220ml/ 100litres of water. Control of ants, cutworm, aphids
Bullet	Week 1, 5, 8, 11	135ml per hectare at 13ml/ 100litres of water. Control of chewing pests, locusts
Belt	When first signs of budworm show up.	43ml per hectare at 13ml/ 100litres of water. Control of Budworm, semilooper and other chewing pests.
Azoxystrobin	Just before topping, 2weeks after topping and when any signs of disease show up.	500ml per hectare at 200ml/ 100litres of water Control of Angular leaf spot, alterneria leaf spot, wildfire, frogeye .
N-decanol	Just after topping for sucker control.	1 litre in 25 litres of water, apply 1*5cup per plant. Used for the control of suckers.

3.3.5 Irrigation regimes and weed control

Light irrigation was done through overhead irrigation, sprinklers, just after planting. This was to allow application of fertilizers, removing of air pockets. At 3 weeks after planting 25mm irrigation was done to allow application of topdressing to T3 plots and also trigger the crop to start using absorbed nutrients and fortnightly thereafter. The irrigation water amounts to 20mm per week to meet the evapotranspiration (ETP) of the crop and avoid stress. Weed control was done using Clomazone at 2L per hectare just after planting as a pre emergence herbicide for the control of grasses and broadleaf weeds. Fusillade forte was also applied as a post emergence selective herbicide for broadleaves weeds at 1.5L per hectare.

3.3.6 Topping and Suckering

When the tobacco plant had produced between 18 and 22 harvestable leaves, it produces a flower. Topping, plucking of the apical bud, removes the inhibitory effect of a dominant apex and often results in excessive sprouting of side shoots or suckers. Both of the varieties used Krk 76 and 26 were topped at a maximum of 16 leaves. The process of topping was done in three different sessions, the third, last session was done exactly two weeks after commencement of the first. N-decanol was applied at a mixing rate of 1 litre per 20 litres of water. Each plant received 5ml of the dose. The chemical impeded cell division in the meristematic tissues and thus suppressed elongation of suckers.

3.3.7 Reaping and curing

Collection of the bottom leaves from a number of plants was done after considering crop physiological maturity indices to verify readiness for curing. They were placed in a drawer where there was no light, with limited air movements and limited space. Colouring happened between 48 and 72 hours, it showed perfect timing for reaping. Reaping was done removing only two leaves per plant and on weekly interval. The drawer test states that if the collected leaves colour within 24-48 hours it means reaping is behind and on the other hand, if it is attained post 72 hours reaping is too ahead. The recommended time is between 48 and 72 hours.

3.4 Data collection

3.4.1 Leaf Area

Measuring of leaf size started on week four (4) after planting, continued per fortnightly until week eight (8) when reaping started. This was done using a mathematically linear model based on length-width relationship.

A= L x W x C

Where

A= Estimated Leaf Area

L= Leaf length (cm) from base to tip

W=Maximum leaf width (cm)

C= Correction factor, 0.65-0.75 for flue cured tobacco (an average of 0.70 will be used in this study)

3.4.2 Dry weight

Dry weight was measured using a well calibrated scale Nicholas digital scale after unloading the barn, and also observing 12% required moisture for dried FCV tobacco. Three samples consisting of six cured leaves were weighed, the weight of the three samples was divided by 3 to get average weight per sample. Average weight per sample was divided by 6, number of leaves per sample, to get weight per single leaf.

3.4.3 Quality

This was done using visual assessment on colour of the cured leaf and hand feeling the texture too. Cured flue cured virginia tobacco attains difference colours which determine the market value. The colour shows the management given from field and curing. Well managed cured leaf turns light to dark lemon. Poorly managed leaf will turn brown, or khaki with some green patches. On the other hand, texture was assessed using hand feel, coarseness of the leaf surface reviewed the thickness of the leaf. Cured leaf with coarser surface, soft, long and with lemon colour fetches more on the market. Classification of cured leaf on the market is done observing leaf colour, texture, softness and length.

Table 3. 2 **Leaf curing scale**

Grade	Color Category	General Description	Typical Market Value
1	Lemon	Bright yellow to lemon-yellow, thin leaf	Highest
2	Orange	Deeper yellow/orange, thick & oily	High
3	Mahogany	Red-brown, heavy body	Medium
4	Red	Deep red, less bright	Medium to low
5	Brown	Dark brown, dull	Low
6	Khaki	Pale green-yellow, immature or under-cured	Lowest

3.4.4 Height

This was determined by measuring the distance from the ground level to the top of the stem using a ruler. Measuring was done per each individual plot and an average height per each plot was recorded. Systematic sampling technique was implored in which three plants per plot were sampled. The position of plants which were sampled was given by counting the total number of plants per plot, divided by three (3), number of plants which were to be sampled per plot.

3.5 Data analysis

Analysis of Variance (ANOVA) with randomised blocks was applied to test for statistical significance on the mean leaf area, dry leaf weight, plant height and yield (kgs per ha) in Genstat version 18. Tukey's protected test at 95% probability was used for treatment mean separation where statistical significance among the means were found.

CHAPTER 4: RESULTS

4.1 Bottom Leaf Area Development

The interaction between fertilizer timing and variety significantly influenced leaf area at week 4 ($p = 0.033$), week 6 ($p = 0.050$), and week 8 ($p < 0.001$) as shown in Table 4.2. This indicates that the effect of fertilizer application timing on leaf area depended on the tobacco variety at all three measurement weeks.

Table 4. 1 **Effects of Fertilizer Application and Variety on Leaf Area Development (cm^2)**

Variety	Fertilizer Treatment	Week 4 (cm^2)	Week 6 (cm^2)	Week 8 (cm^2)
Krk 26	Control (No AN)	268.3 ^{a}	456.0 ^{a}	680.0 ^{a}
	2g AN at Planting	318.3 ^{ab}	550.0 ^{ab}	723.3 ^{ab}
	8g AN at Planting	353.3 ^{b}	600.0 ^{b}	750.0 ^{b}
	Split AN Application (5g + 3g)	400.7 ^{c}	640.0 ^{bc}	883.3 ^{c}
Krk 76	Control (No AN)	388.7 ^{c}	548.3 ^{bc}	760.0 ^{c}
	2g AN at Planting	422.3 ^{c}	688.3 ^{c}	953.3 ^{d}
	8g AN at Planting	497.3 ^{d}	722.7 ^{d}	892.7 ^{d}
	Split AN Application (5g + 3g)	546.3 ^{e}	794.3 ^{e}	1212.7 ^{e}
Grand Mean		**403.4**	**644.2**	**869.4**
p-value (Interaction)		**0.033**	**0.050**	**<0.001**
LSD (5%)		**23.39**	**36.18**	**46.82**
CV%		**3.3%**	**3.22%**	**3.3%**

Means followed by the same letter within a column are not significantly different at the 5% level according to the Bonferroni test.

4.2 Leaf Dry Weight (g)

A highly significant main effect of Fertilizer Treatment ($p<0.001$) and Variety ($p<0.001$) was observed as shown in Figure 4.1 and 4.2. There was no interaction ($p=0.193$) between Fertilizer and Variety for this trait.

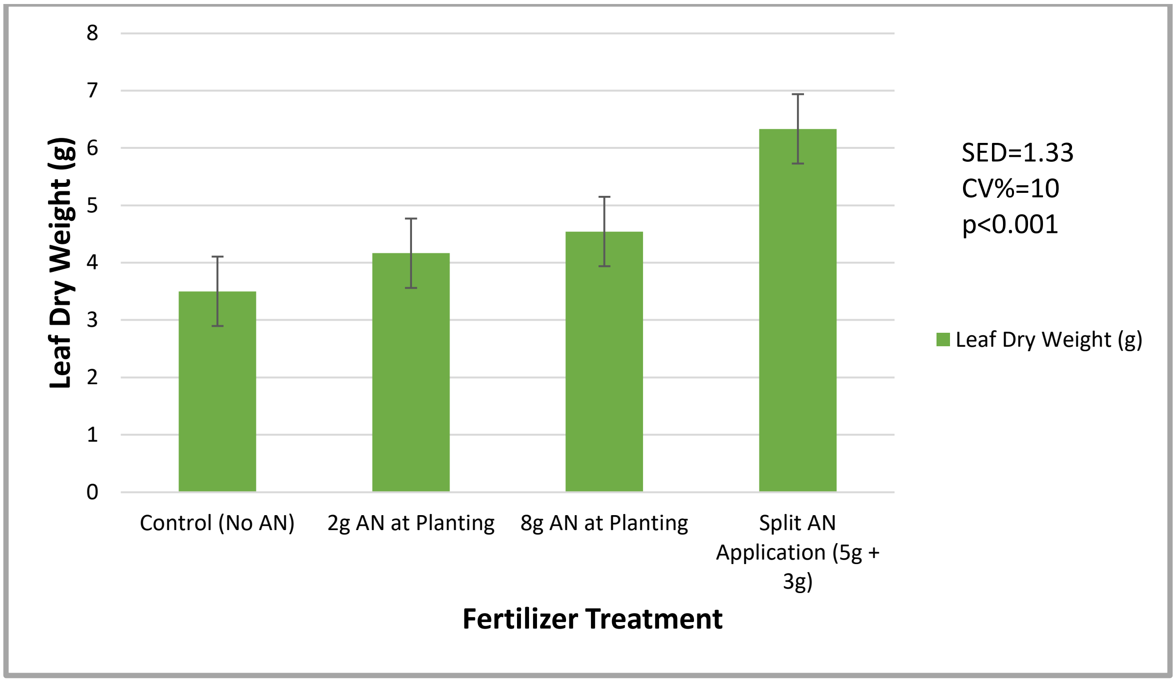

Fig 4. 1Effects of Fertilizer Treatment on Leaf Dry Weight (g)

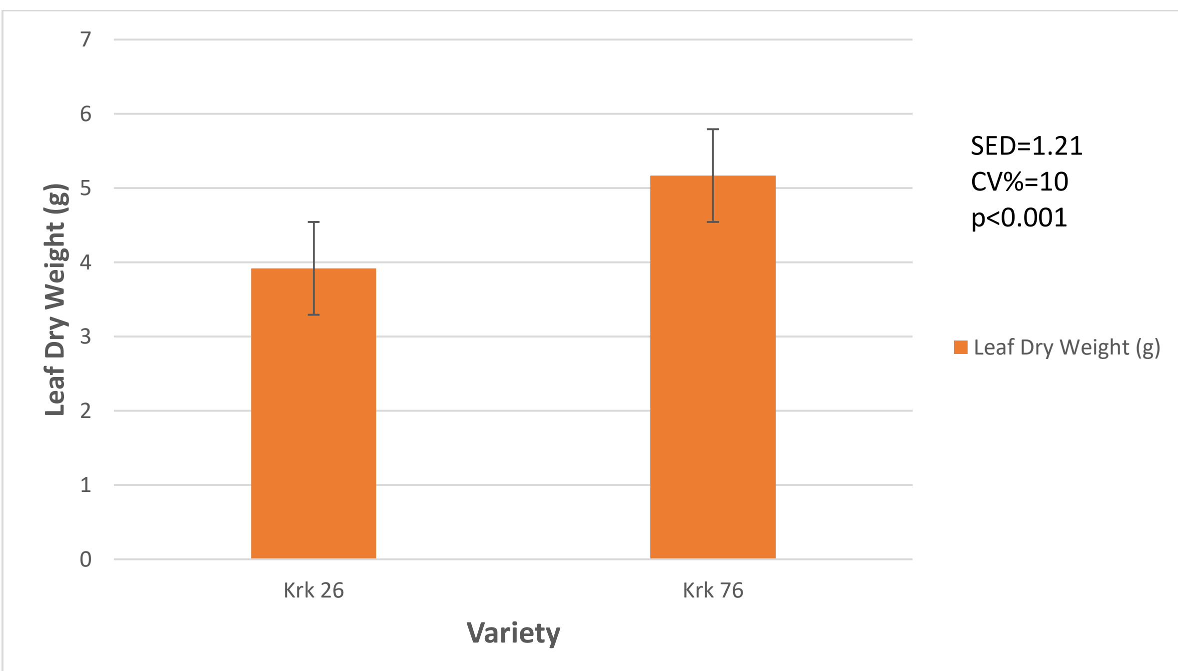

Fig 4. 2Effects of Variety on Leaf Dry Weight (g)

4.3 Plant Height (cm)

The analysis of variance revealed that both fertilizer treatment and variety had highly significant effects ($p < 0.001$) on plant height (Fig 4.3 and 4.4). The interaction between fertilizer treatment and variety was not significant ($p = 0.45$), suggesting that plant height responses slightly varied between varieties depending on fertilizer treatment.

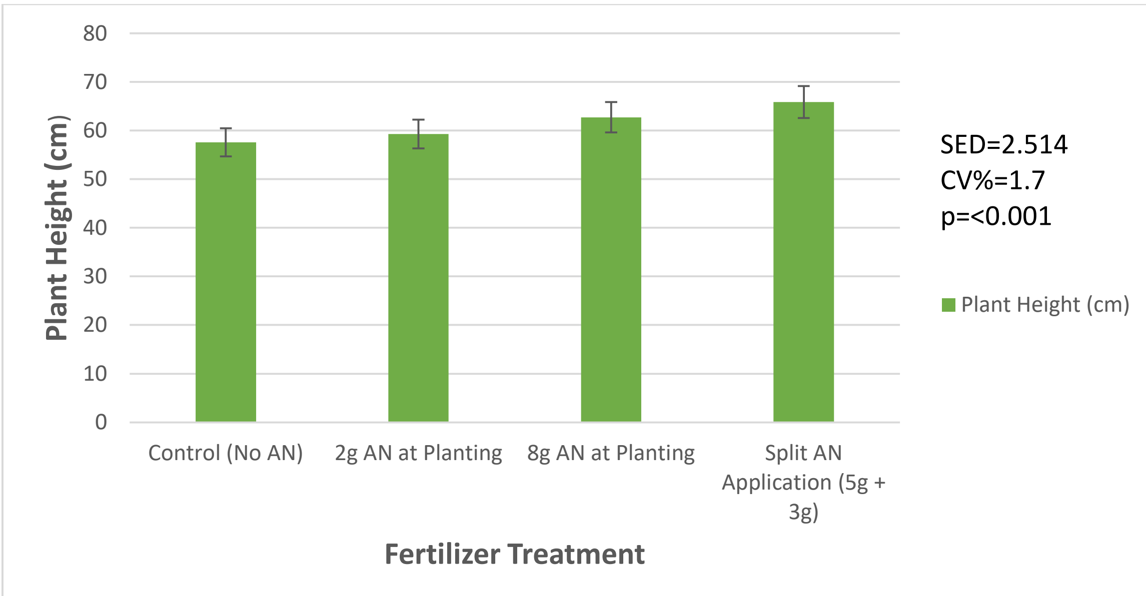

Fig 4. 3 Effects of Fertilizer Application on Plant Height (cm)

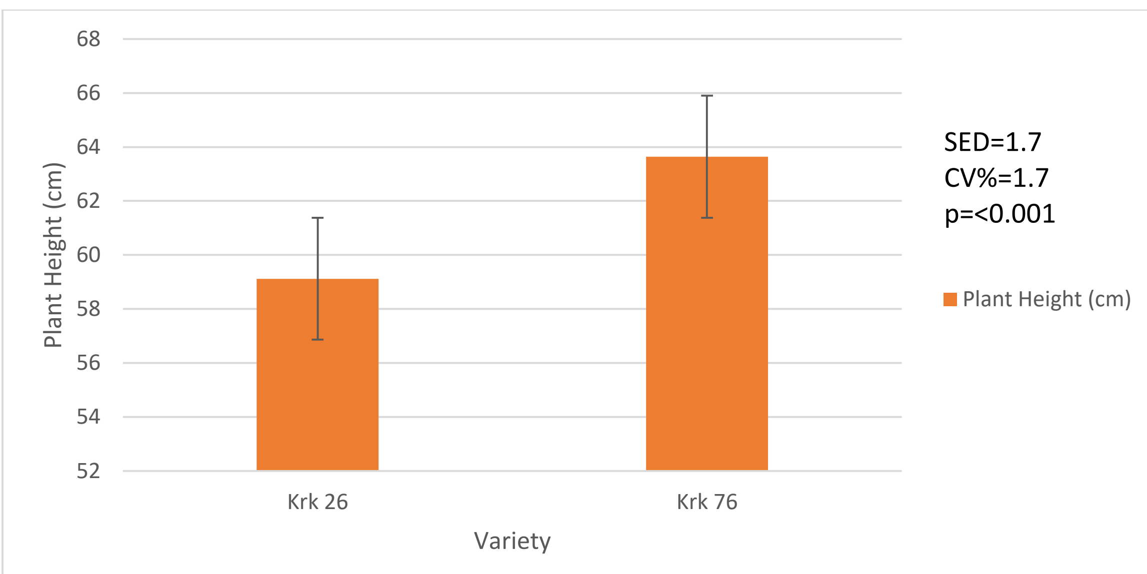

Fig 4. 4 Effects of Variety on Plant Height (cm)

4.4 Yield (kg/ha).

The analysis of variance showed that both fertilizer treatment and variety had highly significant effects ($p< 0.001$) on yield per hectare (Fig 4.5 and 4.6). The interaction between fertilizer treatment and variety was not significant ($p = 0.079$), indicating that the effect of fertilizer treatment on yield did not substantially differ between the two varieties.

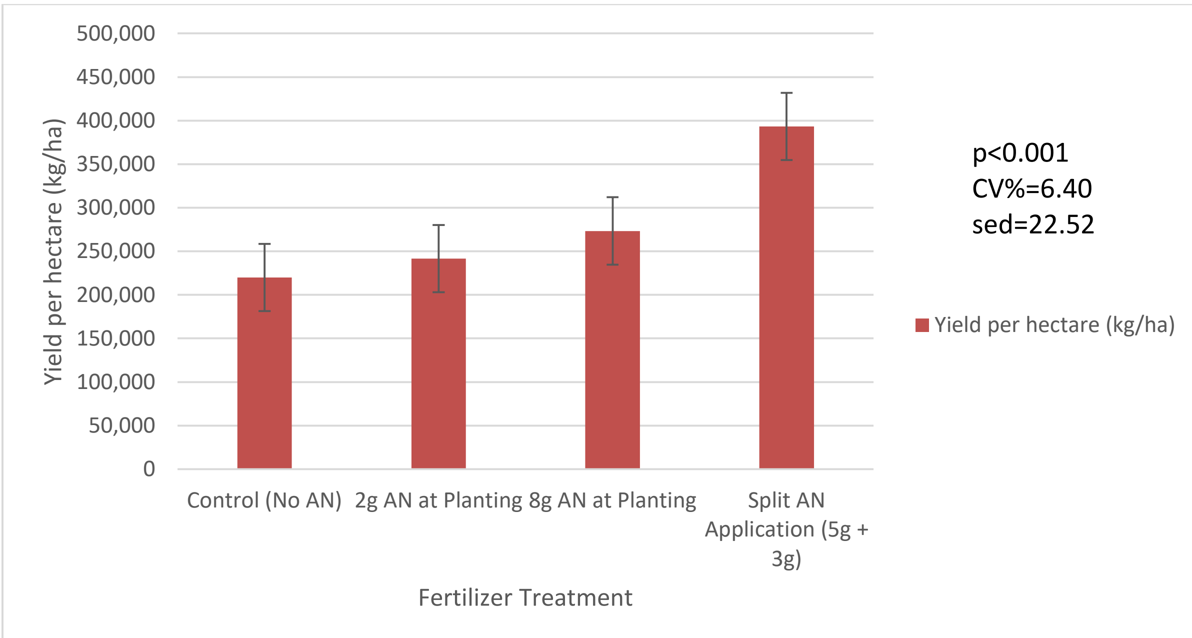

Fig 4. 5 Effects of fertilizer application on yield (kg/ha)

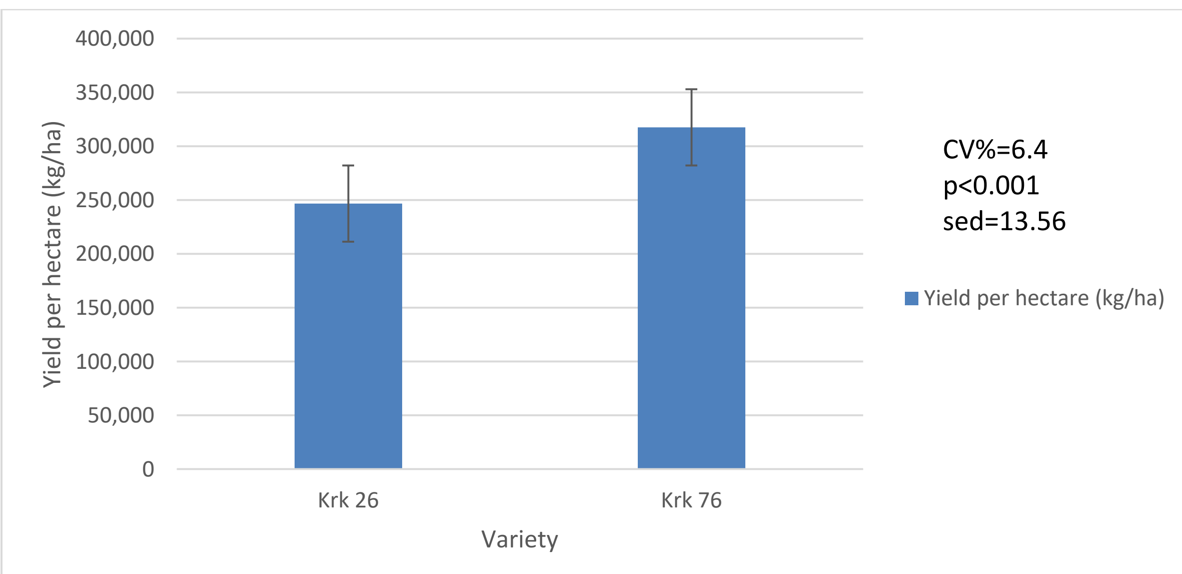

Fig 4. 6 Effects of Variety on yield (kg/ha)

4.5 Cured Leaf Colour

There was a significant effect on leaf colour due to Fertilizer Treatment ($p < 0.001$) as shown in Table 4.2. There was no significant effect due to variety on leaf colour ($p>0.05$). No interaction between Fertilizer and Variety was observed ($p>0.05$).

Table 4. 2 **Effect of Fertilizer Treatment on Cured Leaf Colour**

Fertilizer Treatment	**Mean Score**
Control (No AN)	6^{a}
2g AN at Planting	5^{b}
8g AN at Planting	1^{c}
Split AN Application (5g + 3g)	1^{c}
Grand Mean	**3.25**
p-value (Fertilizer)	<0.001
LSD (5%)	0.75
CV%	10%

Means followed by the same letter within each factor are not significantly different at the 5% level (Bonferroni test).

CHAPTER 5: DISCUSSION

5.1 Leaf Area Development

The significant interaction ($p < 0.05$) between fertilizer application timing and variety across weeks 4, 6, and 8 demonstrates a distinct genotype-dependent response in leaf area development to nitrogen management. Krk 76 consistently exhibited greater leaf area potential than Krk 26 under all treatments, including the unfertilized control, indicating inherent genetic differences in early growth vigor between the varieties (Good et al., 2004). Within Krk 26, leaf area responded progressively to increased nitrogen availability, with the split application (5g + 3g AN) achieving the maximum area by week 8, significantly exceeding both the control and single applications. This pattern explains the importance of sustained nitrogen supply for this variety, better aligning with its developmental nitrogen demand curve than a single large dose at planting, which risks early losses or asynchronous availability (Marschner, 2012; Fageria, 2009). Conversely, Krk 76 displayed a more robust absolute response to nitrogen addition. Its leaf area in the control treatment matched or surpassed Krk 26 receiving substantial nitrogen applications at key stages. Furthermore, Krk 76 attained its peak leaf area, significantly larger than all other combinations, specifically under the split application regime by week 8, highlighting its superior nitrogen responsiveness and assimilatory capacity (Good et al., 2004). The consistent superiority of the split application for both varieties by the critical week 8 stage strongly supports the principle of synchronizing nitrogen availability with peak crop demand (Fageria, 2009). This strategy likely minimizes early environmental losses while supplying nitrogen during the period of maximum leaf expansion, thereby optimizing photosynthetic surface area development essential for yield potential (Marschner, 2012).

5.2 Leaf dry weight

The absence of a significant interaction ($p = 0.193$) between fertilizer treatment and variety for leaf dry weight indicates that the two tobacco varieties, Krk 26 and Krk 76, accumulated dry matter in response to nitrogen management strategies in a broadly consistent manner, despite their previously observed differences in leaf area development. However, the highly significant main effects of both fertilizer treatment ($p< 0.001$) and variety ($p< 0.001$) reveal substantial independent influences on biomass production. Krk 76 consistently produced higher leaf dry weight than Krk 26 across all fertilizer regimes. This intrinsic varietal superiority in dry matter accumulation likely stems from fundamental differences in photosynthetic efficiency, carbon partitioning, or inherent sink strength (Sinclair, 20122; Richards, 2000), potentially building upon its demonstrated greater leaf area expansion capacity observed earlier. Regarding fertilizer response, all nitrogen application strategies significantly increased leaf dry weight compared to the unfertilized control, confirming nitrogen's critical role as a primary driver of biomass synthesis in tobacco (Marschner, 2012). Spilt application was more effective than others in promoting dry matter accumulation. The lack of interaction suggests that the relative advantage of any particular fertilizer timing strategy over another was similar for both Krk 26 and Krk 76. This implies that while Krk 76 possesses a higher overall yield potential, both varieties derive comparable proportional benefits from optimized nitrogen top-dressing schedules concerning final biomass production. This finding aligns with the concept that while genetic potential sets the ceiling for yield, appropriate nutrient management is essential to reach that potential (Lobell et al., 2019), and the optimal timing strategy for maximizing dry weight may be transferable between these varieties despite their differing growth dynamics earlier in the season.

5.3 Plant Height

The highly significant main effects of both fertilizer treatment ($p < 0.001$) and variety ($p < 0.001$) on plant height confirm their independent and substantial influences on this key vegetative growth parameter. The absence of a statistically significant interaction ($p = 0.45$) indicates that the two tobacco varieties, Krk 26 and Krk 76, exhibited fundamentally similar relative patterns of stem elongation in response to the different nitrogen management strategies, despite Krk 76 consistently achieving greater absolute height across all treatments. Krk 76's inherent taller stature likely reflects genetic determinants governing internode length, meristematic activity duration, or sensitivity to growth regulators like gibberellins (Pinthus, 2013; Taiz et al., 2015). The significant fertilizer main effect demonstrates that nitrogen availability is a primary regulator of cell division and elongation processes driving stem growth (Marschner, 2012), with all nitrogen application regimes significantly enhancing height compared to the unfertilized control. The non-significant interaction implies that while Krk 76 maintained its genetic height advantage, the magnitude of increase in height conferred by any specific fertilizer timing over another, or over the control, was proportionally consistent between the two varieties. This suggests that the underlying physiological mechanisms translating nitrogen supply into vertical growth – such as nitrogen's role in protein synthesis for cell wall expansion or its influence on hormonal balances – functioned similarly in both genotypes (Evans, 2013; Marschner, 2012). Consequently, optimal nitrogen top-dressing strategies for maximizing plant height appear broadly applicable across these varieties, unlike the more variety-specific responses previously observed for leaf area development. This differential response highlights how distinct plant architectural components (leaf expansion vs. stem elongation) may exhibit varying degrees of genotype-by-environment interaction for nutrient management during vegetative growth.

5.4 Yield (k/ha)

The highly significant main effects of both fertilizer treatment ($p < 0.001$) and variety ($p < 0.001$) on yield (kg/ha) highlights nitrogen management and genetic selection as critical determinants of flue-cured tobacco productivity. Krk 76 consistently outperformed Krk 26 across all fertilization regimes, reflecting inherent genetic superiority in yield potential, likely driven by its demonstrated advantages in leaf area expansion, dry matter accumulation, and plant height. All these are key components contributing to final biomass partitioning and harvestable yield (Richards, 2010; Sinclair & Vadez, 2012). While all fertilizer treatments significantly increased yield over the unfertilized control, the non-significant interaction suggests that Krk 76's yield advantage stemmed primarily from its genetic capacity to utilize available resources more efficiently rather than a differential response to specific application timings. This aligns with the principle that yield realization depends on the interaction between genetic potential and resource capture efficiency (Loomis & Connor, 2012), where Krk 76's robust vegetative growth translated into consistently higher sink strength and assimilate partitioning to economic yield components. The results imply that optimal nitrogen timing strategies can be generalized across these varieties for maximizing yield, though absolute gains remain variety-dependent due to intrinsic physiological ceilings. Notably, the lack of interaction contrasts with the variety-specific nitrogen responses observed for early leaf area development, suggesting that compensatory mechanisms during later growth stages or differential nitrogen remobilization efficiency may harmonize final yield outcomes (Masclaux-Daubresse et al., 2010).

5.5 Cured Leaf Color

The significant effect of fertilizer treatment ($p < 0.001$) on cured leaf color accentuates nitrogen management as a primary determinant of flue-cured tobacco quality, while the absence of varietal differences ($p > 0.05$) or interactions indicates this response operates independently of genetic background. The substantially poorer color (score = 6) in unfertilized controls reflects chronic nitrogen deficiency, which impairs protein synthesis and chloroplast development, leading to incomplete chlorophyll degradation during curing and persistent greenish hues (Hoffmann & Splittstoesser, 2011). Treatments receiving 8g AN at planting or split applications achieved optimal color (score = 1), indicating sufficient nitrogen availability facilitated complete catabolism of chlorophylls and formation of desirable carotenoid pigments through Maillard reactions during curing (Tso, 2017). The intermediate color (score = 5) under low basal nitrogen (2g AN) suggests suboptimal nitrogen availability disrupted the enzymatic breakdown of chlorophyll-protein complexes, particularly chlorophyllase and Mg-dechelatase activity critical for color development (Curvers et al., 2007). Crucially, the identical color scores for high-dose basal and split applications imply that total nitrogen availability rather than application timing governed this quality parameter, as adequate nitrogen reserves enabled proper senescing metabolism regardless of application method. This contrasts sharply with vegetative growth traits where timing was paramount, highlighting that nitrogen sufficiency thresholds must be met to activate biochemical pathways responsible for post-harvest quality development (Weybrew et al., 2014). The variety-independent response further confirms that enzymatic systems governing pigment metabolism during senescence and curing function similarly across genotypes when nitrogen constraints are alleviated.

CHAPTER 6. CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The investigation conclusively demonstrates that top-dressing timing exerts distinct influences across different physiological domains of flue-cured tobacco production. Regarding vegetative growth (Objective 1), nitrogen application timing significantly interacted with varietal genetics in leaf area development, where split applications maximized canopy expansion—particularly in Krk 76—through enhanced nitrogen assimilation during critical growth windows, while plant height and dry weight responded consistently to fertilization across varieties. For cured leaf quality (Objective 2), adequate total nitrogen availability proved paramount, as both 8g basal and split applications achieved optimal color scores by enabling complete chlorophyll degradation and Maillard reactions during senescence, irrespective of application timing or variety. Concerning yield of lower cures (Objective 3), Krk 76's inherent superiority in sink strength and resource partitioning drove absolute yield advantages, though all nitrogen strategies improved yields proportionally in both varieties without significant interaction, indicating that timing effects were secondary to overall nitrogen sufficiency for final productivity. These outcomes reveals that while vegetative architecture shows genotype-specific sensitivity to nitrogen scheduling, final cured quality and yield depend predominantly on achieving nitrogen thresholds that satisfy biochemical and physiological demands.

6.2 Recommendations

Based on these findings, growers should prioritize variety-specific nitrogen management strategies to optimize production outcomes. For Krk 26, implement split applications (5g at planting + 3g top-dressing) to synchronize nitrogen availability with its prolonged leaf expansion phase, thereby maximizing photosynthetic surface area development critical for yield formation. For Krk 76, while split applications remain beneficial, greater flexibility exists in timing due to its robust nitrogen utilization efficiency; however, ensuring total nitrogen exceeds 8g AN equivalent remains non-negotiable to prevent quality degradation in cured leaves. Crucially, all production systems must maintain minimum nitrogen thresholds ($\geq$8g AN) to activate enzymatic pathways responsible for chlorophyll catabolism during curing, as deficiency irreversibly compromises leaf color regardless of genetic background. Future research should investigate remobilization efficiency differences between varieties and validate precision top-dressing schedules under diverse environmental conditions to refine these recommendations.

REFERENCE

1. Curvers, K., et al. (2007). Chlorophyll breakdown: Pheophorbide *a* oxygenase is a Rieske-type iron–sulfur protein. FEBS Letters, *581*(24), 4697–4701. (Enzymatic chlorophyll degradation mechanisms)
2. Evans, L.T. (2013). The induction of flowering. Some case histories. Macmillan, Melbourne. (Broader physiology of growth processes, including N effects)
3. Fageria, N.K. (2009). The Use of Nutrients in Crop Plants. CRC Press. (Principles of nutrient synchrony and management).
4. Gao, X., et al. (2021). Cold stress in the harvest period: effects on tobacco leaf quality and curing characteristics. BMC Plant Biology, 21(1), 136. While focused on cold stress, this paper notes that temperature affects carbon and nitrogen metabolism, and cold stress can impair nutrient uptake, thereby reducing leaf quality.
5. Good, A.G., Shrawat, A.K., & Muench, D.G. (2004). Can less yield more? Is reducing nutrient input into the environment compatible with maintaining crop production? Trends in Plant Science, *9*(12), 597-605.
6. Hoffmann, G.M., & Splittstoesser, W.E. (2011). Nitrogen nutrition and quality of flue-cured tobacco. Tobacco Science, *15*, 117–120. (N deficiency effects on curing defects)
7. Karavidas, I., et al. (2020). Effect of organic fertilization on quality and yield of oriental tobacco (Nicotiana tabacum L.) under Mediterranean conditions. Asian Journal of Agricultural and Biological Sciences, 9(1), 1-7. This study compares organic and NPK fertilizers, providing insights into how different nutrient sources affect tobacco yield and quality parameters like nicotine.
8. Klimek-Kopyra, A., et al. (2020). Biomass Characteristics and Energy Yields of Tobacco (Nicotiana tabacum L.) Cultivated in Eastern Poland. Energies, 13(22), 5931. This study provides data on dry matter yields of tobacco leaves and stems, relevant to your “Leaf dry weight” and “Yield (kg/ha)” measurements.
9. Li, Y., et al. (2018). Effects of nitrogen application timing on tobacco growth and yield. Field Crops Research, 223, 69-77.
10. Li, Y., et al. (2025). Multi-split nitrogen application via drip irrigation improved dry matter accumulation, nitrogen uptake and utilization efficiency in flue-cured tobacco. Plant and Soil. This article highlights the importance of N management and split applications (which includes topdressing) for tobacco growth and nutrient use efficiency.
11. Lisuma, J. B., & Mbwambo, A. F. (2023). The Effects of Blended N10P18K24 Fertilizer on Agronomic Performance Tobacco (Nicotiana tabacum L.) Plants and Quality of Flue Cured Leaf. Tanzania Journal of Agricultural Sciences, 22(2), 300-308. This study evaluates different NPK fertilizer application timings, including basal and topdressing, and their effects on tobacco performance.
12. Lisuma, J. B., Semoka, J. M., & Mbwambo, A. F. (2023). Effect of Timing Fertilizer Application on leaf yield and quality of tobacco. Heliyon, 9(9), e19888. This study directly addresses the timing of fertilizer application, including topdressing, and its impact on tobacco yield and quality, making it highly relevant.

13. Lobell, D.B., Cassman, K.G., & Field, C.B. (2019). Crop yield gaps: their importance, magnitudes, and causes. Annual Review of Environment and Resources, 34, 179-204. (Interaction of genetic potential and management for yield realization)
14. Loomis, R.S., & Connor, D.J. (2012). Crop Ecology: Productivity and Management in Agricultural Systems. Cambridge University Press. (Yield as a function of resource capture and genetic potential)
15. Marschner, P. (2012). Marschner’s Mineral Nutrition of Higher Plants. Academic Press.
16. Marschner, P. (Ed.). (2012). Marschner's Mineral Nutrition of Higher Plants (3rd ed.). Academic Press. (Role of N in plant biomass synthesis)
17. Marschner, P. (Ed.). (2012). Marschner's Mineral Nutrition of Higher Plants (3rd ed.). Academic Press. (N's role in cell division/elongation, general nutrient physiology)
18. Marschner, P. (Ed.). (2012). Marschner's Mineral Nutrition of Higher Plants (3rd ed.). Academic Press
19. Masclaux-Daubresse, C., et al. (2010). Nitrogen uptake, assimilation, and remobilization in plants: Challenges for sustainable and productive agriculture. Annals of Botany, 105(7), 1141–1157. (N remobilization and compensatory growth mechanisms)
20. Molla, M. M. H., et al. (2023). Nutrition Management and Planting Arrangement Improve Growth Indices and Yield of Two Virginia Tobacco (Nicotiana tabacum L.) Cultivars. Agrotechniques in Industrial Crops, 3(3), 30-41. This study investigates how nutrient application methods (including topdressing implications) affect tobacco growth indices and yield.
21. Moyo, S., & Van der Westhuizen, J. (2016). Effect of Nitrogen, Topping and Leaf Priming on Yield and Quality of Flue Cured Tobacco (Nicotianatabacuml) in Zimbabwe. International Journal of Research and Development (IJRD), 1(10). This study discusses how practices like leaf priming (removal of lower leaves) can affect the yield and quality of harvested leaves, indirectly relating to the importance of lower leaf health.
22. Moyo, S., & Van der Westhuizen, J. (Date not specified). Fertilizer application and liming practices of small-holder tobacco farmers in Zimbabwe. Zimbabwe Journal of Agricultural Research. This paper discusses fertilizer recommendations and placement, touching upon how nutrient availability affects tobacco yield and quality.
23. Parrasia, P. S., et al. (2024). Tobacco production under global climate change: combined effects of heat and drought stress and coping strategies. Frontiers in Plant Science, 15. This article mentions that nutrient deficiencies can be exacerbated by drought and that drought can reduce the quality of both upper and lower tobacco leaves.
24. Peterson, L. A. (1960). (As cited in Moyo & Van der Westhuizen, 2016). Research mentioned in [16] showed that increased nitrogen rates increase leaf area but can reduce dry weight per unit area, relevant to your BL Area and Leaf dry weight measurements.
25. Pinthus, M.J. (2013). Lodging in wheat, barley, and oats: the phenomenon, its causes, and preventive measures. Advances in Agronomy, 25, 209-263. (Genetic control of internode length and plant height - classic concept source)
26. Richards, R.A. (2000). Selectable traits to increase crop photosynthesis and yield of grain crops. Journal of Experimental Botany, 51(suppl_1), 447-458. (Genetic variation in dry matter partitioning and yield potential)
27. Richards, R.A. (2000). Selectable traits to increase crop photosynthesis and yield of grain crops. Journal of Experimental Botany, 51(suppl_1), 447–458. (Genetic yield potential and partitioning)

28. Sifola, M. I., & Postiglione, L. (2002). Effects of nitrogen fertilization on flue-cured tobacco. Field Crops Research, 74(1), 39-52.
29. Sinclair, T.R. (2022). Mineral nutrition and plant growth response to climate change. Journal of Experimental Botany, 43(8), 1141-1146. (Photosynthesis, carbon partitioning, sink strength concepts)
30. Sinclair, T.R., & Vadez, V. (2002). Physiological traits for crop yield improvement in low N and P environments. Plant and Soil, 245(1), 1–15. (Resource use efficiency and yield components)
31. Stancu, M., et al. (2012). Growth and Development Responses of Tobacco (Nicotiana tabacum L.) to Changes in Physical and Hydrological Soil Properties Due to Minimum Tillage. American Journal of Plant Sciences, 3, 334-345. This paper notes that water stress (which can be related to nutrient uptake) affects leaf area development.
32. Tabaxi, I., et al. (2021). Effect of organic fertilization on quality and yield of oriental tobacco (Nicotiana tabacum L.) under Mediterranean conditions. Asian Journal of Agricultural and Biological Sciences, 9(1). This research found that yield and plant height were significantly affected by variety when different fertilization treatments were applied.
33. Taiz, L., Zeiger, E., Møller, I.M., & Murphy, A. (2015). Plant Physiology and Development (6th ed.). Sinauer Associates. (Role of gibberellins and other hormones in stem elongation)
34. Tso, T. C. (1990). Production, Physiology and Biochemistry of Tobacco Plant. IDEALS.
35. Tso, T.C. (2017). Production, Physiology, and Biochemistry of Tobacco Plant. Ideals, Inc. (Biochemistry of curing reactions)
36. Wang, S. N., Cheng, J. K., & Liao, Y. C. (2020). Fertilization model for flue-cured tobacco (nicotiana tabacum l.) In southwest china. Applied Ecology and Environmental Research, 18(6), 7853-7863. While focusing on a broader fertilization model, this paper discusses the importance of appropriate N, P, and K application for yield and quality, including the concept of basal and topdressing.
37. Weybrew, J.A., et al. (2014). The cultural management of flue-cured tobacco quality. Tobacco International, *185*(14), 82–87. (N sufficiency thresholds for quality)
38. Xu, C., et al. (2013). Influence of nitrogen application method on growth and quality of tobacco. Tobacco Science & Technology, 46(1), 10-15
39. Zhao, X., et al. (2024). Effects of Environmental Factors on the Growth and Quality of the Tobacco Variety Zhusha 2: A Case Study in Yunan, China. Pakistan Journal of Agricultural Sciences, 61, 733-741. This study discusses how soil nutrients, among other factors, significantly affect tobacco quality, including appearance.

APPENDIX

Genstat Release 18.1 (PC/Windows 8) 03 July 2016 14:21:34


```
1  SET [WORKINGDIRECTORY='C:/Users/YOGA 11E/Documents']
2  "Data taken from file: 'C:/Users/YOGA 11E/Desktop/270/elisha/chat
data.xlsx\
3  '"
4  DELETE [REDEFINE=yes] _stitle_: TEXT _stitle_
5  READ [PRINT=*; SETNVALUES=yes] _stitle_
9  PRINT [IPRINT=*] _stitle_; JUST=left
```

Analysis of variance

Variate: BL_Area_wk4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	297.3	148.7	0.83	
Replication.*Units* stratum					
Fertilizer_Treatment	3	59746.2	19915.4	111.62	<.001
Variety	1	96013.5	96013.5	538.11	<.001
Fertilizer_Treatment.Variety	3	2070.8	690.3	3.87	0.033
Residual	14	2498.0	178.4		
Total	23	160625.8			

Analysis of variance

Variate: BL_Area_wk6

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	191.6	95.8	0.22	
Replication.*Units* stratum					
Fertilizer_Treatment	3	62842.1	20947.4	49.06	<.001
Variety	1	123410.0	123410.0	289.06	<.001
Fertilizer_Treatment.Variety	3	1197.1	399.0	0.93	0.050
Residual	14	5977.1	426.9		
Total	23	193618.0			

Analysis of variance

Variate: BL_Area_wk8

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.

Replication stratum	2	943.1	471.5	0.66	
Replication.*Units* stratum					
Fertilizer_Treatment	3	270323.2	90107.7	126.05	<.001
Variety	1	291721.5	291721.5	408.07	<.001
Fertilizer_Treatment.Variety					
	3	29449.8	9816.6	13.73	<.001
Residual	14	10008.3	714.9		
Total	23	602445.8			

Analysis of variance

Variate: Kgs_per_ha

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	833.3	416.7	1.26	
Replication.*Units* stratum					
Fertilizer_Treatment	3	107645.8	35881.9	108.42	<.001
Variety	1	30104.2	30104.2	90.96	<.001
Fertilizer_Treatment.Variety					
	3	2779.2	926.4	2.80	0.079
Residual	14	4633.3	331.0		
Total	23	145995.8			

Analysis of variance

Variate: Leaf_Dry_Weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	1.0833	0.5417	2.60	
Replication.*Units* stratum					
Fertilizer_Treatment	3	27.4583	9.1528	43.93	<.001
Variety	1	9.3750	9.3750	45.00	<.001
Fertilizer_Treatment.Variety					
	3	1.1250	0.3750	1.80	0.193
Residual	14	2.9167	0.2083		
Total	23	41.9583			

Analysis of variance

Variate: Plant_Height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.

Replication stratum	2	7.391	3.695	3.50	
Replication.*Units* stratum					
Fertilizer_Treatment	3	243.663	81.221	76.99	<.001
Variety	1	122.402	122.402	116.03	<.001
Fertilizer_Treatment.Variety					
	3	9.588	3.196	3.03	0.05
Residual	14	14.769	1.055		
Total	23	397.813			

Analysis of variance

Variate: Yield_per_ha

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	8.333E+08	4.167E+08	1.26	
Replication.*Units* stratum					
Fertilizer_Treatment	3	1.076E+11	3.588E+10	108.42	<.001
Variety	1	3.010E+10	3.010E+10	90.96	<.001
Fertilizer_Treatment.Variety					
	3	2.779E+09	9.264E+08	2.80	0.079
Residual	14	4.633E+09	3.310E+08		
Total	23	1.460E+11			

Analysis of variance

Variate: Cured_Leaf_Colour

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	1.0833	0.5417	2.60	
Replication.*Units* stratum					
Fertilizer_Treatment	3	27.4583	9.1528	43.93	<.001
Variety	1	9.3750	9.3750	45.00	<.001
Fertilizer_Treatment.Variety					
	3	1.1250	0.3750	1.80	0.193
Residual	14	2.9167	0.2083		
Total	23	41.9583			

1