AFRICA UNIVERSITY

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A COMPARATIVE EVALUATION OF THE EFFICACY AND ECONOMIC ANALYSIS OF COATED AND NON-COATED NITROGEN APPLICATION IN MAIZE (*Zea mays* L.) AT SEED-CO RESEARCH STATION IN ZIMBABWE.

BY

O'BRIAN KUPETA

A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF PHILOSOPHY IN CROP PRODUCTION IN THE COLLEGE OF HEALTH, AGRICULTURE NATURAL SCIENCES

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Abstract

Maize (*Zea mays* L.) top-dressing in both smallholder and commercial production in Zimbabwe is carried out using uncoated nitrogen (N). A study was conducted for two consecutive seasons in 2015/2016 and 2016/2017 at Seed-Co's Rattray Arnold Research Station and Stapleford Research Centre, Zimbabwe to determine the comparative performance on maize grain yield and nitrogen use efficiency of Polymer coated urea fertilisers against conventional ammonium nitrate (AN) and plain white urea fertilisers. The study also looked at the loss of fertiliser nitrogen via volatilisation and economic advantages of each top-dressing source of nitrogen to maize cropping in Zimbabwe. The top-dressing treatments were; zero N, 69 N kg/ha and 138 N kg/ha. A volatilisation experiment in the lab was carried out using AN Plain white urea, Agrotain coated urea, and NBPT coated urea. The field experiment was laid out as a randomised complete block design (RCBD) and was a 6 x 2 x 2 factorial experiment involving 3 factors. The growth attributes measured were, plant height, stem diameter, number of leaves, chlorophyll content, number of days to 50% tasselling, grain yield, and nitrogen use efficiency (NUE). The results showed that there was no significant difference ($p>0.05$) in Grain Yield (GY) and NUE between zero N top-dressed plots, half rate (69 kg N/ha) and full rate (138 kg N/ha) top-dressed plots. This was attributed to high inherent nitrogen levels in the soil and not to the type of top-dressing fertiliser. Source of N was found to have no effect on chlorophyll levels in the leaf. Nitrogen losses through leaching from the same five top-dressing nitrogen sources were observed to be insignificant ($p>0.05$) and with no impact on both maize grain yield and NUE across soil depths of 15cm, 30cm and 45cm. The observed low leaching was attributed to high organic matter levels in the soil. Late top-dressing of N was observed to result in higher levels of residual N in the soil at the end of the season. This explains that maize plants also provided a sink for the applied mineral nitrogen and when it is missed during peak demand, there is higher residual N in the soil at the end of the season. Nitrogen volatilisation experiment results from the five top-dressing sources were ranked as follows in ascending order: NBPT urea< Black Urea® < White urea < Agrotain green/red urea < Ammonium nitrate. From the volatilisation experiment it was deduced that coated N delays the rate of N loss by volatilisation. A survey conducted to assess the adoption and cost effectiveness of coated nitrogen fertilisers on the market revealed that lack of product knowledge and related information on the new technologies is leading to very slow adoption and uptake of controlled release/stabilised N fertilisers. Maize farmers need more product information to adopt coated nitrogen fertilisers.

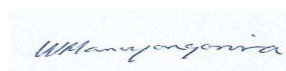
Key words: Maize, Volatilisation, Leaching, Nitrogen Use Efficiency

Declaration Page

I declare that this dissertation is original except where sources have been cited and acknowledged. The work has never been submitted, nor will it ever be submitted at other university for the award of a degree.

O'BRIAN T. KUPETA (29/6/2020)

Student's Full Name Student's Signature (Date)



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Dedication

To my mother, my late father Charles Kupeta, my wife, my children Unotida, Christian and Ariel. I love you very much.

List of Acronyms and Abbreviations

A.N	Ammonium Nitrate
AAPFCO	Association of American Plant and Food Control
AGU	Agrotain green urea
ATC	nine-1,2,4-triazole
BU	Black urea
CAN	Calcium ammonium nitrate
CCF	Common Compound Fertiliser
CFU	Commercial Farmers' Union
CRF	Controlled Release Fertiliser
DAP	Di-ammonium phosphate
DCD	Dicyandiamide
DMPP	3,4-dimethylpyrazol phosphate
EEF	Enhanced Efficiency Fertiliser
EONR	Economically optimum nitrogen rate
GY	Grain yield
LAN	Limestone ammonium nitrate

N	Nitrogen
NBPT	N-(n-butyl) thiophosphoric triamide
NR	Nitrogen Recovery
NUE	Nitrogen Use Efficiency
NXU	Agrotain red urea
PCU	Polymer coated urea
Ppm	Parts per million
RARS	Rattray Arnold Research Station
ROI	Return on Investment
SPAD	Soil Plant Analysis Development
SRC	Stapleford Research Centre
UAN	Urea Ammonium Nitrate
V_0	Zero leaf stage
V_6	Sixth veinal leaf stage
WU	White urea
ZSAES	Zimbabwe Sugar Association Experiment Station

Definition of Key Terms

Nitrogen Use Efficiency (NUE): As a concept, NUE is expressed as a ratio of output (total plant N, grain N, biomass yield, and grain yield) and input (total N, soil N or N-fertilizer applied). For crops, NUE has been defined as the grain yield per unit of nitrogen available from the soil, including nitrogen fertilizer.

Controlled release or Stabilised fertiliser: These technologies include application of some type of additive within the fertilizer formulation or sometimes the application is added as a coating. Such fertilizers are often referred to as 'Enhanced Efficiency Fertilisers' (EEFs) (Hunter & Mark, 2014). The Association of American Plant Food Control Officials (AAPFCO) defines EEFs as products with characteristics that allow increased fertiliser uptake and therefore reduce potential nutrient losses, leaching or run-off when compared to an appropriate reference fertiliser that does not contain additives (AAPFCO, 2012). The AAPFCO further breaks down EEFs into two distinct subcategories (1) Stabilised fertilisers and (2) Controlled or Slow release fertiliser (Hunter & Mark, 2014).

1. **Stabilised fertilisers**: These are fertilizers that reduce the transformation rate of fertiliser compound(s), extending the time of nutrient availability to the plant by a variety of mechanisms relative to its un-amended form.

2. **Controlled or Slow release fertilisers**: These are products that convert and/or release plant available nutrients at a slower rate relative to a 'reference-soluble' product (AAPFCO, 2012), (Hunter & Mark, 2014).

Nitrogen stabilisers: A term used to refer to either Urease inhibitors or Nitrification inhibitors. Nitrogen stabilisers work by suppressing nitrification of NH_4^+ nitrogen to NO_3^- nitrogen, urease activity, or both (Bouwman *et al.*, 2002).

Polymer coated urea (PCU): The premise of PCU is that the polymer coating allows moisture through to dissolve the urea but delays the movement of the dissolved urea solution back out to the soil solution and thus delays the contact of the urea component with urease enzyme (Nielsen, 2006)

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CHAPTER 1 INTRODUCTION

1.1 Introduction

Nitrogen (N) is one of the macro nutrients needed for crop production. It is the major nutrient that the farmer can control. The timing of N application as well as the amount (application rate) is integral in crop production. Nitrogen is very mobile in the soil system and the root zone such that most planting/basal fertilizers used in Zimbabwe have low N concentration to avoid leaching/volatilisation before peak crop demand. Timing of nitrogen application is highly dependent on the crop under cultivation. For instance, the major application of N in tobacco will be through top dressing from 3-4 weeks post transplanting or 4 to 6 weeks post emergence in crops such as maize or ratoon sugar cane.

1.2 Background to the study

Maize (*Zea mays* L.) is a member of the family Poaceae and the world's third cereal crop after wheat and rice. Its production can be traced back 7000 years in Mexico (Mangeisdorf, MacNeish & Galinat, 1964). Maize has a wide range of uses that include human food, industrial processed food production of starch, and used as a forage to feed animals. Maize has many varieties with different maturity periods and a wide range of tolerance to different environmental conditions (Purseglove, 1972). The standard recommendation in Zimbabwe is to plant maize with 400kg/ha of compound fertilizer which contains 7%N-14%P_2O_5-7%K_2O or 200kg/ha of compound fertilizer which contains 14%N–28%P_2O_5-14%K_2O. This gives 28kg of N/ha at planting versus a total seasonal requirement of 170kg N/ha. A top dressing of 400kg/ha ammonium nitrate is then applied in two equal splits at

4 weeks post emergence and at 8 weeks post emergence. These two applications add on 138kg of nitrogen/ha. The total N applied is 166 kg N/ha. The maize crop requires most of its N from the 'grand growth' phase to flowering and even up to senescence (van Antwerpen *et al*., 2013).

Split application of N should theoretically result in increased N efficiency and reduced nitrate losses because of greater synchronization between time of application and crop uptake. Evidence in the literature to support this concept is mixed, for example Baker & Melvin, (1994) reported losses of Nitrate-N to be higher for split application compared to a pre-plant application with continuous corn. Any surface applied ammonia and ammonia-based N fertilizer, including manure, can lose nitrogen (N) to the atmosphere via ammonia volatilization (Jones *et al*., 2013). Currently in Zimbabwe, due to changing weather patterns, dry land maize production is giving very low yields because farmers are failing to top dress maize at the right time with the right fertilizer and at optimum rates due to lack of effective rain/moisture. There are also other factors that influence availability of N to the crop such as soil pH, soil moisture content, soil temperature, and source/form of N (Mengel, 2013).

New technologies and continuous research in agronomy/crop nutrition have come up with coatings of nitrogen and or phosphorus to control the discharge of the element or to arrest volatilization and leaching (Mengel, 2013).

1.3. Statement of the Problem

The national average maize yield in Zimbabwe was 0. 8t/ha against an average yield potential of 8t/ha in the 2013/14 season (The Zimbabwe Mid Term Monetary Policy of 2014). This is supported by the data collected by the Agriculture & Food

Security Monitoring System which is implemented by the National Early Warning Unit with support from FAO (2011). Generally, it has been observed that in maize production, all factors being equal, the source of nitrogen, timing and application rates/ha have a significant impact on yield. In the maize sector currently, ammonium nitrate (34.5%N) followed by white urea (46%N) are the two commonly used sources of nitrogen. Dryland farmers rely on natural rain hence have no adequate moisture to follow up nitrogen applications to arrest related losses from volatilisation, this results in failure to apply N on time. Efficient nitrogen management is arguably the most challenging aspect of tropical small holder agriculture in sub-Saharan Africa including Zimbabwe (Chikowo *et al.*, 2004a; Giller, 1997) In the case of sugarcane, the splitting of urea applications is compounded by unavailability of irrigation water to incorporate the nitrogen before it volatilises (Nyathi & Chinorumba, 2011). Split application of N should theoretically result in increased N efficiency and reduced nitrate losses because of greater synchronization between time of application and crop uptake. Evidence in the literature to support this concept is mixed, however. Baker & Melvin, (1994) reported losses of Nitrate-N to be higher for split application compared to a pre-plant application with continuous corn. Coated urea is now being marketed in Zimbabwe by fertilizer manufacturers and suppliers. Unfortunately, however, there is limited information on the effectiveness of these coated nitrogen sources in Zimbabwean soils and climate for both commercial and smallholder farmers. Coated urea's efficiency, cost effectiveness and rates of applications for optimum yields have not been assessed in Zimbabwe. On the other hand, market uptake of these coated urea fertilizers remains low and no information is available on why the uptake is low.

1.4. Research Objectives

The objective of this study was to compare the efficacy and cost effectiveness of varying levels of coated nitrogen and application timing on maize yield.

Specific Objectives:

1. Investigate the efficacy and cost effectiveness of varying levels of coated urea application as a maize top-dressing fertiliser.
2. Compare the extent of volatilisation and leaching of different forms of coated nitrogen fertilizers compared to ammonium nitrate
3. Establish the market's perception on coated nitrogen for top dressing maize.
4. Determine the effect of timing application of different quantities of coated nitrogen top-dressing sources on soil mineral N availability, NUE and maize yield.

1.5. Research Questions

1. What is the cost effectiveness and production impact of coated nitrogen in dry land maize production?
2. Is coated nitrogen less susceptible to volatilisation and or leaching (N losses) than ammonium nitrate?
3. What is the market perception on coated nitrogen fertilisers in Zimbabwe when compared to ammonium nitrate?
4. What is the impact of coated nitrogen application timing on maize yield, NUE and residual N?

1.6 Hypotheses /Assumptions

$$H_0: \mu_A = \mu_B = \mu_C = \mu_D = \mu_E$$

H_1: at least one mean grain yield is different, where μ_A = mean grain yield using Ammonium nitrate, μ_B = mean grain yield using Black urea, μ_C = mean grain yield using Agrotain green urea, μ_D = mean grain yield using plain white urea, μ_E = mean grain yield using Agrotain red urea.

H_2: There are more nitrogen losses from ammonium nitrate via volatilisation

H_3: Factors such as lack of information, price, availability, influence by others, predict farmer perception and attitude towards adoption of coated nitrogen fertilisers

H_4: Top dressing application timing and quantity applied is significant in determining NUE, grain yield and residual mineral N.

1.7 Significance of the study

Controllable factors for crop nitrogen management are those management practices that crop producers use to improve yield and profitability of their enterprise. Split application of N should theoretically result in increased N efficiency and reduced nitrate losses because of greater synchronization between time of application and crop uptake. Time of N application, N fertiliser product, and nitrification inhibitors play a significant role in minimising nitrate loss, especially under wetter and warmer fall, winter and spring conditions (Dinnes *et al*., 2002). Nitrogen timing research results have produced variable results. The effect on yield of N application timing has been widely studied for decades. Common types of nitrogen timing studies include pre-plant vs. split between pre-plant and side dress, and different types of N fertilizers applied at various timings. Other studies also tested N application timing, multiple rates of N, and different proportions of total N applied at various times. These earlier studies showed a wide range of results that varied according to the weather conditions encountered during the study. For this reason, understanding the relationship between N supply, weather conditions, and maize needs was more important to developing successful N management strategies than research results per se. This also meant results obtained in a different environment should be applied with caution as local weather conditions have a bearing in nitrogen use efficiency. Nyamangara *et al*., (2003), documented that most studies on N leaching from soils amended with manure and or inorganic fertilisers have focused on humid temperate regions as was cited by Beckwith *et al*., (1998); Thomson *et al*., (1993); Unwin, (1986). Few quantitative measurements of N leaching have been made in tropical and sub-tropical regions of Africa (Arora & Juo, 1982; Omoti *et al*., 1983; Wong *et al*., 1987). It is for this reason that this research was conceived to try and develop local information under local conditions that can be used to bridge this knowledge gap.

The study investigated the efficacy and cost effectiveness of five different top-dressing nitrogen sources including the conventional ammonium nitrate (34.5% N). The outcome of this study helped commercial and smallholder farmers, government policy makers, agro-based firms currently in contract farming and those who contemplated starting maize production, to select cost effective sources of nitrogen for top dressing maize in Zimbabwe for increased maize yields at identified optimum rates and timing of application. The study helped us understand the performance of Efficiency Enhanced Fertiliser (EEF) sources of nitrogen in maize production under both irrigated and dry land conditions. The study made us understand why adoption of coated nitrogen by the Zimbabwean market was slow, and how it was perceived by the maize growers.

Generally, it was observed that farmers were failing to improve maize crop yield levels at viable costs due to factors such as low fertility soils, unstable high leaching nitrogen fertilizers, fluctuant weather patterns (climate change) and lack of financial outlay.

1.8 Delimitation of the study

The study was contextualised within the framework of the cost of fertiliser inputs for viable maize production using Zimbabwe as the point of reference. The study excluded other sources of nitrogen such as organic/animal manure and foliar fertilisers. The study did not look at the inflationary trends and impacts of economic policies on supply and demand of fertilizers in the country. As such its scope fell within the agronomy and marketing field, especially technical understanding of new technologies and product adoption by farmers. The key variables of the study were agronomic understanding of products for grain yield improvement, consumer/farmer product awareness, and factors considered by farmers when purchasing new technologies. The research was conducted for a period of three years i.e. between 2015 and 2018 at Rattray Arnold Research station in Zimbabwe; a developing and transitional economy. Zimbabwe has undergone major agrarian reforms and economic transformation since 2000 that has seen the agriculture sector not only dwindling in performance but lagging in new technologies. Agriculture - the backbone of the Zimbabwean economy has of late witnessed a surge in imported products/technologies since the land reforms of 2000 and the introduction of the multi-currency system in 2009, but information scarcity is still high on the targeted consumers of these imported products/technologies for realisation of their full benefit. As such it was a relevant sector to carry out this research study.

1.9 Limitations of the Study

It would have been ideal to survey the entire maize producing districts in the country on the options of top-dressing fertilisers available to the farmers, but the researcher encountered constraints on time, distance, cost, sensitivity and access of information, high work volume hence resorted to work with easily reachable farmers close to Harare. This gave a small sample size. This implies that the generalisation of the study findings is only limited to the category of coated granular urea among various forms of stabilised nitrogen sources. Nitrification inhibitors were not considered part of the present study sample. These limitations provide space for further research on stabilised nitrogen as a top-dressing option for maize farmers in Zimbabwe. It is assumed that this study, as a new research, remains experimental at best; localisation and agronomic practice preclude the generalisability of the findings to some extent, and thus, it needs to be evaluated by further confirmatory studies across a wider region.

CHAPTER 2 REVIEW OF RELATED LITERATURE

2.1. Introduction

There is increasing public pressure to reduce the environmental impacts of agricultural production. One key challenge to producers is to manage their crop production systems to minimize losses of nitrogen to the air or water, while achieving crop yield and quality goals. Zebarth, *et al*., (2009) reported that many strategies have been developed in recent years to meet this challenge. These include development of new tools to measure crop N status to refine in-season fertilizer N management, development of new soil N tests to improve prediction of soil N supply, development of new N fertilizer products with release patterns more closely matched to crop N uptake patterns, and development of site-specific N management strategies. One of the most effective means of improving the efficiency of N use in agricultural crop production is to match the supply of N to the crop N demand in both space and time (Zebarth & Rosen, 2007).

Plants have a fundamental dependence on inorganic nitrogen and 85–90 million metric tonnes of nitrogenous fertilizers are added to the soil worldwide annually (Good *et al*., 2004). Nitrogen is the nutrient that most frequently limits yield and plays an important role in quality of forage crops. It is almost deficient in most soils of Africa and most of the tropics (Jules, 1974). Urea was also the first organic compound ever synthesised. In 1828, Friedrich Wöhler synthesised urea from inorganic compounds (lead cyanate and ammonium hydroxide). This was a landmark achievement: Wöhler bridged the gap between the living and non-living worlds. He didn't receive a Nobel Prize for his discovery though, because the Nobel Prize did not exist at that time. Today, urea is synthesised in vast quantities:

it is used to make plastics and as a cheap nitrogenous fertiliser (Science in School, 2008).

In 1935 Urea (46-0-0), was first introduced to crop husbandry and is now the primary source of dry nitrogen fertiliser in most parts of the world due to its relatively high nitrogen content, ease of handling and cost-effective price (Jones *et al*, 2005). Ammonium Nitrate (34.5-0-0) may be superior in some situations to urea but due to high costs of production, it is no longer readily available in Zimbabwe compared to urea. Fortunately, decades of experience and research suggest that urea and fluids containing urea are effective substitutes of ammonium nitrate when managed properly. Widespread acceptance of urea was delayed in part due to its greater potential N loss via ammonia volatilisation (conversion from dissolved ammonia to ammonium gas). While all top-dressing ammonia and ammonium-based N fertilisers can volatilise, the potential is greatest with urea and fluids containing urea such as Urea Ammonium Nitrate (UAN: 28-0-0 or 32-0-0) (Jones & Jacobson, 2005). This is because urea and its intermediate product Ammonium carbonate ($NH_4CO_3NH_4$) are not stable as shown in the equation below.

[$(NH_4)_2CO_3 + H_2O \rightarrow 2NH_2 + H_2O + CO_2$ and $2NH_2 \rightarrow 2NH_4OH \rightarrow NH_3\ (gas) + H_2O$]. Optimising the use efficiency of N derived from different quality organic and inorganic fertilisers on sandy soils with less than 100g clay kg^{-1} is a major challenge for small holder farmers in southern Africa (Mtambanengwe & Mapfumo, 2005). With reduced availability of ammonium nitrate and increased reliance on urea, recent increases in N prices, and increasing environmental concern over atmospheric ammonia emissions, it should prove helpful to review conditions that affect ammonia volatilization and recommend ways to use urea effectively in maize cropping.

2.2. Crop response to Nitrogen

Positive crop response to nitrogen fertilizers has been reported by Koul (1997), Omer (1998), Gasim (2001) and Sawi (1993). Nitrogen use efficiency (NUE) varies from one situation to another due to variability of crop health (plant stresses) and the magnitude of N loss potential is influenced primarily by weather conditions and soil type (Nielsen, 2006). Sharma (1973) observed that addition of nitrogen fertilizer increased plant height. Increase in plant height resulted in an increase in leaf number per plant as reported by Akintoye (1996). Gasim (2001) indicated that the increase in plant height with nitrogen fertilizer is because nitrogen promotes plant growth, increases the number of internodes and length of the internodes which results in progressive increase in plant height. Chandler (1969), Turkhede & Rajendra (1978) & Koul (1997) reported similar results. Nitrogen fertilization increased number of leaves per plant and leaf area (El Noeman *et al*., 1990; Gasim, 2001). John & Warren (1967) noted that the addition of nitrogen increased stem diameter. Koul (1997) recorded that nitrogen application resulted in greater values of plant height, leaf area, number of leaves and stem diameter of fodder maize, fresh and dry forage yield were also increased due to addition of nitrogen. Leaf to stem ratio was found also to be increased by nitrogen (Duncan, 1980). These findings are in full agreement with that of Gasim (2001) who reported that the increase in leaf to stem ratio with nitrogen application is probably due to the increase in number of leaves and leaf area under nitrogen treatments, producing more and heavy leaves. The uptake of nitrogen by maize is low during early development and increases at tasselling. Although only relatively small amounts of fertilizers are required during the very early stages of plant growth, high concentration of nutrients in the root zone at that time are beneficial in promoting early growth (Ritchie *et al*., 1993). Gasim (2001) observed that nitrogen fertilization accelerated the time to reach 50% tasselling, promoted the fresh and dry forage weight. Salem & Ali (1979) found that nitrogen application increased the number of ears per plant, ear height, number of days to mid-silking and protein content, and decreased the number of barren stalks.

Grain protein content was increased by nitrogen (Warren *et al*., 1975; Gangwar & Kalra, 1988). Increased protein content in maize straw was obtained with increased dose of nitrogen (Rai, 1965). Tripathi *et al*. (1979) found that application of nitrogen gave a significant additional increase in crude protein contents of forage oats. Kalifa *et al*., (1981) studied the effect of nitrogen, given as ammonium nitrate, on an open-pollinated variety of corn. His results indicated that ammonium nitrate fertilizer increased the number of days to mid- tasselling, mid-silking and shelling percentage. Singh *et al*., (1986) found that the maize yield, content and uptake of nitrogen in grain and stover were highest with nitrogen applied as urea in two split dressings. Sawi (1993) and Omara (1989) observed that nitrogen had significant effects on chemical composition of leaves, plant height, leaves, internodes number per plant at early stages. Gasim (2001) observed that nitrogen also significantly affected final seed yield and some yield components such as number and weight of cobs/m^2 and weight of seeds per cob, also significantly affected straw yield. In addition, nitrogen had significant effect on seed protein content and seed and leaf P content. Gasim (2001) found that the addition of nitrogen increased forage fresh and dry yield, also increased percentage of crude protein in leaf stem.

2.3. Leaf Nitrogen Measurement

Optical techniques are not effective in estimating leaf N concentration directly; however, they are effective in estimating leaf chlorophyll concentration (Botha *et al*., 2006). Leaf N and chlorophyll concentrations are frequently well correlated within an individual crop species, for example in wheat (Vouillot *et al*., 1998), corn (Ercoli *et al*., 1993) and potatoes (Vos & Bom 1993). The most commonly used optical approach is the SPAD-502 chlorophyll meter. Minolta Corporation, Japan (1991). This hand-held device measures light transmittance in the red (650 nm, chlorophyll absorption) and near-infrared (960 nm) spectrum. Strong correlations between leaf chlorophyll concentrations and SPAD values have been obtained for a range of crops including wheat, potatoes and corn (Olfs *et al*., 2005). SPAD meter readings are well correlated to yield response of potato (Minotti *et al*., 1994) and cereal (Peltonen *et al*., 1995) crops.

2.4. Forms of soil nitrogen losses and urea management

Rainfall, sunshine, and temperature all influence the rate of volatilisation of surface-applied urea-based products (Nielsen, 2006). Kissel, *et al*., (1988) reported that when urea hydrolysis occurs at or near the soil surface, ammonia is lost into the air via volatilization (*Eqn. 3*). If ammonia volatilises at or near the planted seeds, they may not germinate or, if it is near seedlings, may prove to be toxic. It has been estimated that 50–70 % of the nitrogen provided to the soil is lost (Hodge *et al*., 2000).

Chen *et al*, (2008) reported that fertiliser nitrogen use in Australia has increased from 35 Gg N in 1961 to 972 Gg N in 2002, and most of the nitrogen is used for growing cereals. However, the nitrogen is not used efficiently, and wheat plants, for example, assimilated only 41% of the nitrogen applied. This review confirms that the efficiency of fertiliser nitrogen can be improved through management practices which increase the crop's ability to compete with loss processes. However, the results of the review suggest that management practices alone will not prevent all losses (e.g. by denitrification), and it may be necessary to use enhanced efficiency fertilisers, such as controlled release products, and urease and nitrification inhibitors, to obtain a marked improvement in efficiency. Some of these products (e.g. nitrification inhibitors) when used in Australian agriculture have increased yield or reduced nitrogen loss in irrigated wheat, maize and cotton, and flooded rice. The potential role of enhanced efficiency fertilisers (EEFs) to increase yield through efficient use of N by maize in smallholder production in Zimbabwe will be a breakthrough in the local agriculture sector. Nitrogen fertilizers in general move rapidly across the soil profile for losses to be prevented. Leaching is the main loss pathway (Nye & Tinker, 1977).

The risk of volatilisation loss is greatest with high-residue cropping systems, warm sunny days after application, and surface soil pH levels greater than 7.0, volatilisation risk is also high on lighter textured soils with low buffer capacity (Nielsen, 2006). Volatilisation of the ammonia gas can result in N losses of as much as 5% of the available nitrate nitrogen per day. Soils at greatest risk to denitrification N loss are those that are naturally heavy and poorly drained, plus fields with significant levels of soil compaction that restricts natural drainage (Nielsen, 2006). Reduction in nitrogen loss is achieved by supplementing the supply of N from soil with the appropriate rate and form of fertilizer N, at the right time, and at the right location. While the concept is simple, this is difficult to achieve in practice due to substantial variation in both crop N demand and in soil N supply across years and among and within fields. The loss of ammonia from the crop system is also affected by the crop canopy interaction with ammonia being absorbed by plants foliage (Denmead *et al.*, 1976; Denmead *et al.,* 2008) and respiration which can increase the concentration of carbon dioxide in the soil pH during the night (Fleechard *et al.*, 2007) and dew formation on the crop canopy combine to reduce ammonia losses during the night. These effects result in a strong diurnal pattern of NH_3^+ volatilisation with high losses during the day and low losses at night. Drury *et al*., 2007 revealed that Crop N demand and N supply interact with environmental conditions in determining N losses. Producers commonly fertilise assuming a good crop yield will be obtained. However, when climatic extremes limit crop yield (e.g., drought, excess water, heat stress, wind damage), crop N uptake can be reduced, and excess N remains in the soil at the end of the cropping season. Excess soil N in combination with wet conditions in the fall to spring periods can result in higher nitrate leaching and/or denitrification losses. Insufficient fertilizer N application will result in loss of crop yield or quality, whereas excessive fertilizer N application greatly increases the risk of N losses (Zebarth & Rosen 2007). For Zimbabwe at least 70% of total arable land is covered by the highly weathered sandy soils (Anderson *et. al*., 1993), with low physical protection of soil organic carbon. The risk of nitrate leaching to groundwater (Houles *et al*., 2004) and of nitrous oxide emissions (Chantigny *et al*., 1998; Zebarth *et al*., 2008a) increases rapidly as fertilizer N rate is increased above the optimum application rate. Chikowo *et al*., (2004a) noted that high-quality biomass from improved fallow systems showed early season nitrate -N leaching losses exceeding 20mg NO_3^- -N kg^{-1} soil within 9 weeks of maize growth on sandy soil in Zimbabwe.

The relationship between volatilisation from the soil and quantity of N containing fertiliser added has been studied under various conditions and for many soils. In certain cases, the quantity of NH_3^+ (gas) lost increased with higher application levels but the proportion of the added N volatilised remained constant. Some researchers reported an increase in this proportion while others found a decrease, although the total quantity of NH_3^+ (gas) that volatilises increased with higher application levels (Nelson, 1982, Fenn & Hossner, 1985). Mtambanegwe & Mapfumo, (2005) found that most of the N released was lost through leaching as evidenced by the progressive movement of NO_3^- - N bulges beyond maize rooting depth following major rainfall events. In some cases, excessive fertilizer N application may also result in loss of crop yield, for example due to increased lodging in wheat (Bundy & Andraski 2005), or reduced crop quality, for example due to reduced tuber specific gravity in potatoes (Zebarth & Rosen, 2007). Further increases in fertilizer rates are unlikely to be effective at increasing crop yields, as the use efficiency of fertilizer N sharply declines at higher application rates (Tilman *et al*., 2002). In addition, crop N demand also has economic implications. It is possible to estimate the fertilizer N rate that results in maximum biological yield, but also the N rate that results in maximum net return to the producer

(Zebarth *et al*. 1991), commonly referred to as the economically optimum N rate (EONR). With conventional fertilizers, only 50% of the available nitrogen is taken up by plants. These losses occur through volatilization and leaching, processes that are tough to control. The overall NUE in cereals production systems worldwide is estimated to be 33 percent (Raun & Johnson, 1999). NUE is low due to numerous loss pathways that include gaseous losses to the atmosphere via volatilisation, as well as denitrification, leaching and run off.

Kamukondiwa & Bergstrom, (1994) documented that in Zimbabwe nitrogen leaching losses of up to 39kg N ha^{-1} have been observed on sandy soils. Other studies (Hagmann, 1994; Vogel *et al.*, 1994) also on sandy soils in Zimbabwe revealed that most of the nitrogen fertiliser (up to 54% of applied N) was leached out of the top 0.5m of top soil when heavy rains followed N fertiliser application. Nielsen, (2006) documented that urea-based nitrogen fertiliser products are susceptible to volatilisation losses of N if surface-applied and not incorporated. Urease enzymes in the soil and plant residues convert the urea component to free ammonia gas. If this conversion occurs at the soil surface and is accompanied by warm sunny days, as much as 15-20% of the urea-based N volatilise within a week after application. The document further explains that if a half-inch or more of rain occurs within the first 24 hours after surface application, the risk of subsequent volatilisation also drops to essentially zero. If the urea product is injected or mechanically incorporated after application, the risk of volatilisation is essentially zero. According to Bishop *et al*., (2008), the loss of applied fertiliser nitrogen from urea applied via ammonia volatilisation has received significant attention over recent years in the Australian and New Zealand pastoral and arable sectors, with the active marketing of urease inhibitor (NBPT) as a nitrogen loss mitigation strategy. Connell *et al*., (1979) carried out an additional experiment comparing the effects of various fertilizer rates and placements using a Foster sandy loam soil. Nitrogen losses from the surface and 1 %-inch-deep urea applications were measured as volatilized ammonia and compared at rates of 100, 200, and 300 pounds of actual nitrogen per acre. Urea was surface-applied to soils at field capacity with a low relative humidity air stream passing over the soil surface. Throughout the course of this experiment the low-humidity air flow was drying the soils. Remoistening was done periodically to restore the soils to field capacity moisture level. Both soils were remoistened at 18 and 33 days following the application of urea.

Experiments on the Foster sandy loam soil compared volatilization losses for surface versus 1 %-inch-deep urea applications. At the highest application rate, fertilizer placement 1% inches deep resulted in a 23-fold decrease in the percentage of nitrogen lost when compared with surface application. When fertilizer was placed at the lower application rates (100 and 200 pounds N), the 1 %-inch-deep placement resulted in an even greater reduction in percent of nitrogen lost. After urea is applied to the soil surface it absorbs water, hydrolyses to ammonium carbonate, and ammonia is free to volatilize into the atmosphere. Patterns of loss for the two soils were notably different, largely because of differing soil characteristics. Most of the volatilization loss sustained by Foster sandy loam soil occurred within one week of fertilizer application. Rewetting the soil at 18 and 33 days had little or no effect on loss Connell *et al*., (1979).

When fertilizer is incorporated, ammonia is contained by the soil, captured in the soil solution, and can be bound to soil colloids as ammonium ions before loss to the atmosphere can occur. Fertilization rate influences the amount of ammonia loss: greater loss with increased fertilization can be anticipated. In addition, as fertilization rate increases the actual percentage of nitrogen lost also increases. When fertilization was increased from 200 to 300 pounds N/acre, the percentage of applied nitrogen lost nearly doubled from 19 percent to 36 percent. This increase may be the result of higher ammonia concentration: soil is unable to adsorb and hold high concentrations of ammonia as efficiently as it does lower concentrations. Wet-dry soil cycles proved to be most important with respect to ammonia volatilization losses. Foster sandy loam soil and Hanford loamy sand were used to investigate different soil responses to rewetting and resulting loss Connell *et al*., (1979).

2.5. Nitrogen Stabilizers/Inhibitors and their performance.

Chemical compounds can be added to urea fertilisers to inhibit transformation of N or to stabilise the urea not to transform (Jones *et al.*, 1995). Urease inhibitors are one class of compounds that prevent the conversion of urea to NH_4^+ (Eqn. 1) below.

Urea *Urease enzyme*

$$CO(NH_2)_2 + H^+ + 2H_2O \xrightarrow{\text{Urease enzyme}} 2NH_4^+ + HCO_3^-$$

Inhibitors/stabilisers can delay the hydrolysis of urea for 2-10 weeks (Jones *et al*., 1995). Urea can be encapsulated in various coatings or treated with chemical stabilisers to inhibit transformations that results in N losses. The oldest and most common coating is elemental Sulphur. Once applied, soil bacteria oxidise the Sulphur coating, allowing the granule to dissolve and undergo hydrolysis (Jones *et al*., 1995). The application of nitrification inhibitors together with ammonium-based fertilizers is proposed as a potent method to decrease nitrous oxide (N_2O)

emission while promoting yield and nitrogen use efficiency in fertilized agricultural fields. Liu, *et al*., (2013) researched on the effects of 5 nitrification inhibitors by monitoring year-round measurements of N_2O fluxes and observed that the urea + dicyandiamide (DCD) and urea + 3,4-dimethylpyrazol-phosphate (DMPP) treatments decreased the annual emissions by 35% and 38 %, respectively. The cumulative N_2O emissions were calculated to be 4.49±0.21, 2.93±0.06 and 2.78± 0.16 $kgNha^{-1}yr^{-1}$ for the Urea, DCD and DMPP treatments, respectively. The application of nitrification inhibitors increased the soil inorganic nitrogen and dissolved organic carbon availability and shifted the main soil inorganic nitrogen form from nitrate to ammonium (Liu, *et al*., 2013). The variations in soil temperature, moisture and inorganic nitrogen content regulated the seasonal fluctuation of N_2O emissions.

Majumdar *et al*., (2000); Zaman *et al*., (2009); Cui *et al.*, (2011); Moir *et al*., (2012) documented that there are a variety of new management practices and technologies that can promote N use efficiency and alleviate environmental pollution. One of the mitigation technologies that has proved to be highly effective in reducing fertilizer N losses and increasing N use efficiency and yield in a few cropping systems is the application of nitrification inhibitors. Nitrification inhibitors can delay the microbial oxidation of NH_4^+ to nitrite (N_2O^-) for a certain period (several weeks or months) by depressing the activities of *Nitrosomonas* species in the soil $2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 2H_2O + 4H^+$ (*Eqn.7*) and are therefore very effective at blocking microbial nitrification and subsequent denitrification (Weiske *et al*., 2001; Zerulla *et al*., 2001). Hundreds of nitrification inhibitors are known, but only a few so far have gained commercial importance for practical use, such as dicyandiamide (DCD) and 3,4-dimethylpyrazol-phosphate (DMPP). The application of DCD and DMPP together with NH_4^+ based fertilizers, cow urine or cattle slurry has demonstrated efficiency in reducing the N losses in forms of nitrous oxide (N_2O) emission and NO_3^- leaching while increasing the yield and use efficiency of fertilizer N in croplands and grasslands (Weiske *et al*., 2001; Majumdar *et al.*, 2000; Zaman *et al*., 2009; Cui *et al*., 2011; Di & Cameron, 2012; Moir *et al*., 2012; Pfab *et al*., 2012).

N-Lock helps keep nitrogen in the ammonium (NH_4^+) form for a longer period by inhibiting the bacteria that convert ammonium to nitrite (NO_2^-). As ammonium is positively charged it is attracted to the negatively charged soil particles, and hence is not washed out of the rooting zone. Nitrite (NO_2^-) and nitrate (NO_3^-) however are negatively charged and can be easily washed down the soil profile away from the roots of the crop (*Eqn. 7* and *Eqn. 8*).

$2\ NH_4^+ + 3\ O_2 \rightarrow 2\ NO_2^- + 2\ H_2O + 4\ H^+$ and $2\ NO_2^- + O_2 \rightarrow 2\ NO_3^-$. Therefore, N-Lock keeps more nitrogen in the rooting zone for longer, which means that crops can optimise their yield potential. The Dow Chemical Company (1995 – 2016).

“BASF has researched significantly to solve drawbacks of urease inhibitors and came up with Limus® which has two active ingredients and a longer shelf life (Pasda *et al*., 2016). Limus® Urease Inhibitor improves efficiency and flexibility in grower's nitrogen management programs to reduce nitrogen losses from volatilization of urea fertilizers, supports optimal nitrogen availability and use efficiency, blocks the activity of a broader variety of urease enzymes - about 40 percent more effective than urease inhibitors with a single active ingredient. It improves the environmental footprint of urea-containing fertilizers and reduces ammonia losses significantly by up to 95 percent (Pasda *et al*., 2016).

Vizura® Nitrification Inhibitor researched by BASF improves nitrogen use efficiency of liquid manure from livestock and biogas plant, which is a major method of fertilizing crops in many regions worldwide. Uses the well-established active ingredient DMPP (3,4-dimethylpyrazole phosphate) and reduces N_2O emissions by 50 percent on average and/or nitrate losses 47 percent on average, depending on soil and weather conditions. Vizura® **s**afeguards against nitrogen loss from nitrate leaching and nitrous oxide emissions, makes nitrogen available when needed by the crop and enhances the reliability of liquid manure, resulting in yield increase of 7 percent on average. It allows for earlier application, reducing working peaks and risk of soil compaction. It offers potential savings from reduced mineral fertilizer application while increasing nitrogen use efficiency (Pasda *et al*., 2016).

Nielsen, (2006), noted that a nitrogen fertiliser technology common to the turf industry is slowly making inroads to field crop production: Polymer Coated Urea (PCU). The premise of PCU is that the polymer coating allows moisture through to dissolve the urea but delays the movement of the dissolved urea solution back out to the soil solution and thus delays the contact of the urea component with urease enzyme.

(Advanced Nutrients), researched Black Fertilizers™. The Black urea coating is an organic complex specifically manufactured to contain a unique ratio of oxidative functional groups and cofactors of biological oxidation. These include – humic acid, fulvic acid, ulmic acid, amino acids, melanins, peptides, polysaccharides, vitamins and rare earth.

Black Fertilizers™: are granular fertilizers coated in organic carbon and other biological stimulants that increase the microbial activity around the fertiliser granule increasing fertiliser use efficiency. Black Fertilizers™: are coated in diverse organic carbons and other catalysts not only humic acid. Humic acid alone cannot provide an economic return to farmers as global research has shown. Black Fertilizers™: should not be described as "slow release", the availability of nitrogen, phosphorus and potassium are better "controlled" by the manipulation of biological activity and supported with chemical and energy processes. The manufacturer argues that, Black Fertilisers™: can be spread (Black Urea) and left on top of the ground without incorporation for extended periods. It is difficult to put an exact time on this as there are many variables that affect it, such as soil moisture, pH, temperature etc. However, applications 4-6 weeks prior to rainfall have been done and the crop results were still very good. (Advanced Nutrients).

Black Fertilisers™: can be stored for extended periods as they have long shelf life. They should be stored and handled in the same manner as normal fertilisers. Black Fertilisers™: the coating is a catalyst that works with natural soil cycles, as such it best performs in low fertility soils where biological activity is low. Generally, soils of less than 2% organic carbon (or where carbon is not bio-available) and low in nutrients will produce the best economic results. Soils with a lower cation exchange capacity (nutrient holding capacity) will further enhance results. Black Urea® is a marked improvement on previous technology (urease inhibitors, nitrification inhibitors, polymers, etc.) by increasing microbial activity and exchange capacity around the nitrogen/fertiliser granule, resulting in the nitrogen being held in the cation and organic forms longer, and reducing exposure to losses and improving nitrogen uptake. It is the combined effect of these, and possibly other unknown elements, that improve the overall utilisation of applied nitrogen and produce higher and more efficient rates of plant growth with less energy (fertiliser, fuel). (Advanced Nutrients).

2.6 Chemical reactions

Urea *Urease enzyme*

$CO(NH_2)_2 + H^+ + 2H_2O \rightarrow 2NH_4^+ + HCO_3^-$ Eqn.1a (Hydrolysis)

$HCO_3^- + H^+ \leftrightarrow CO_2 + H_2O$ Eqn. 1b

$NH_4^+ \rightarrow NH_3(d) + H^+$ Eqn. 2

$NH_3(d) \leftrightarrow NH_3(gas)$ Eqn. 3 (Volatilization)

$CO(NH_2)_2 + Ca^{2+} - soil + 2H_2O \rightarrow 2NH_4^+ - soil + CaCO_3$ Eqn.4 (Hydrolysis with exchangeable Ca)

Note: In the above equations, NH_3(d) = dissolved ammonia; Ca^{2+}- soil = exchangeable Ca^{2+}

Ammonium containing fertilizers will react with $CaCO_3$ in soil to form $(NH_4)_2CO_3$ and calcium precipitates. The $(NH_4)_2CO_3$ formed is unstable and decomposes as follows:

$(NH_4)_2CO_3 + H_2O \rightarrow 2NH_2 + H_2O + CO_2$ Eqn. 5

$2NH_2 \rightarrow 2NH_4OH \rightarrow NH_3\ (gas) + H_2O$ Eqn.6 (Volatilisation)

$NH_4NO_3 \rightarrow NH_4^+ + NO_3^-$ Eqn. 10

Nitrification:

Two step reactions that occur together:

- 1st step catalysed by *Nitrosomonas*

$2\ NH_4^+ + 3\ O_2 \rightarrow 2\ NO_2^- + 2\ H_2O + 4\ H^+$ Eqn. 7

- 2^{nd} step catalysed by *Nitrobacter*

$2\ NO_2^- + O_2 \rightarrow 2\ NO_3^-$ Eqn. 8

Note: Optimal $pH_{(CaCl2)}$ is between 6.6-8.0. If pH < 6.0 → rate is slowed,

if pH < 4.5 → reaction is inhibited.

Denitrification:

$2NO_3^- \rightarrow 2NO_2^- \rightarrow N_2O \rightarrow N_{2(g)}$ Eqn. 9

Note: Denitrification bacteria prefer elemental O_2 but under inadequate soil aeration/water logging, high soil temperatures or high soil pH, they can use NO_2^- and NO_3^- as sources of their oxygen (O_2) (Jones *et al*., 1995).

2.7. The economic benefit of using coated nitrogen

Hirel *et al*., (2007) noted that lowering fertilizer input and breeding plants with better nitrogen use efficiency (NUE) are some of the main goals of research on plant nutrition. Nitrogen stabilizers on average increased maize yields by 370kg/ha and held an average positive return on investment of $39.88/ha. Instinct, a stabilizer product that does not offer any volatilization protection, offered yield gains of 232kg/ha, which was 138kg/ha lower than the average yields of stabilizers that did offer volatilization protection. This is interesting, as we might be able to assume some yield contributions from volatilization versus denitrification. Four-year data evaluating Nutrisphere-N and Agrotain Plus has shown an average corn yield increase of 653kg/ha with net returns of over $79/ha. (BECK'S Practical Farm Research, 2014) The annual maize yield, above ground biomass and nitrogen uptake by above ground plants increased by 8.5–9.1 %,8.6–9.7% and 10.9–13.2%, respectively, for the DCD and DMPP treatments compared with the standard white Urea treatment. The results demonstrate the roles the nitrification inhibitors play in enhancing yield and nitrogen use efficiency and reducing N_2O emission from the wheat-maize cropping system (Liu *et al*., 2013). The Dow Chemical Company has researched that the amount of nitrogen in the root zone of the soil plays a key role in delivering maximum yields at harvest. Current RB209 gives N Max of 150 kg for maize – this is not enough for modern varieties/husbandry methods. Maize requires more than 50 % of nitrogen post flowering. Up to 60 kg nitrogen can be lost pre-flowering. Applying late nitrogen is difficult without crop damage/specialist equipment. The Dow Chemical Company (1995 – 2016). Figure 2.7.1 below shows that the amount of nitrogen in the root zone of the soil of variable texture plays a key role in delivering maximum yields at harvest.

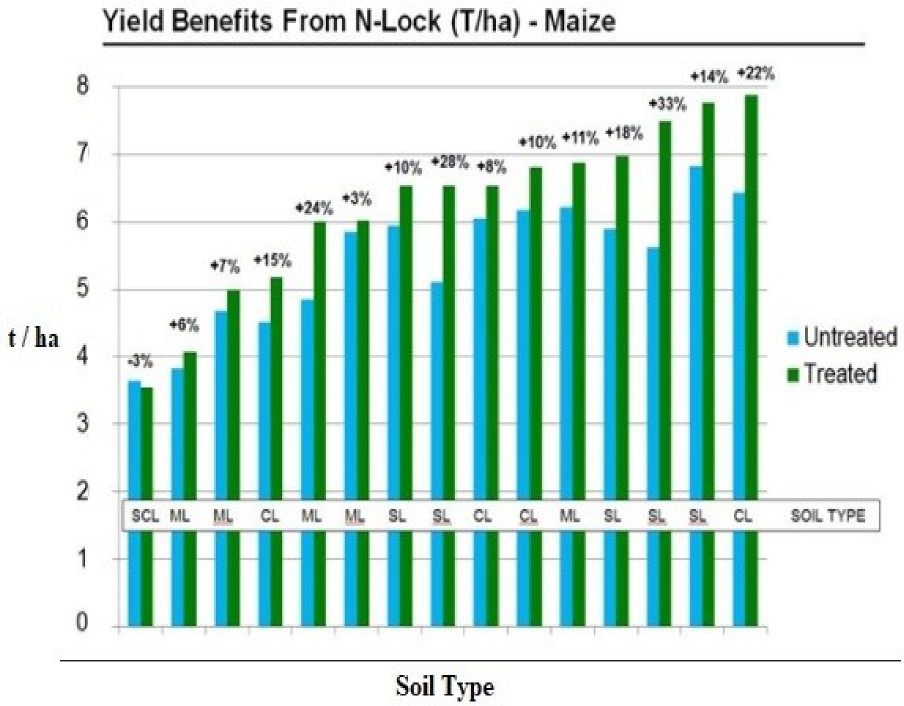

Figure 2.7. 1: Yield benefits from N-Lock. (http://uk.dowagro.com/products/n-lock/)

Farmers are constantly seeking new ways to produce more with less input and therefore be able to supply the increasing demand for food and feed. Fertilizers have become an essential resource to help achieve that. Based on the pot trials in South Africa by Janse van Vuuren *et al.*, (2014), at least 10-20% and 30-50% less Black urea needs to be applied on limed and acid soils, respectively compared to plain white urea. This has a huge financial implication for the farmer. The inhibitor limited ammonium oxidation prevented nitrogen loss by denitrification for 75 days, increased N accumulation by the wheat plants, increased grain N and resulted in a 46% greater recovery of applied nitrogen in the plant-soil system at harvest (Freney, *et al.*, 1992).

BLACK UREA® application in concert with sustainable farming practices such as incorporation, split application and irrigation management improve profits on low fertility soils as revealed on tables 2.4.1 and 2.4.2 below. Unlike the uncoated sources of N, it is suitable for pre-sowing, top/side dressing and water running typical to granular and soluble fertilisers Advanced Nutrients, (2004).

Research by Advanced Nutrients (2004) in Australia found that Black Urea does not only give a higher grain yield in sorghum but also an increase in net return as shown in table 2.7.1 below.

Table 2.7.1: Comparison of normal plain urea and Black Urea® on Net Return in Sorghum.

	Yield	Protein level	Increase in Net Return
Control (No	5.9	8.3 %	$ 0

fertiliser)	t/ha		
72kg/ha Urea	6.5 t/ha	9.5 %	$63
50kg/ha Black Urea®	6.82 t/ha	11.6 %	$117
80kg/ha Black Urea®	6.99 t/ha	11.8 %	$126

Another research in a wheat crop by Advanced Nutrients, (2004), found that Black Urea gave a higher grain yield per dollar invested, higher grain yield and lower cost/ha. Table 2.7.2 below shows that Black Urea® delivered an increase in the overall yield economics of over 40% compared to plain white urea.

Table 2.7.*2*: Grain yield economics between plain urea and Black Urea® on Wheat

	Cost per Ha	Yield	Yield per $
Urea	$28	4.23 t/ha	151 kg
Black Urea®	$23	4.89 t/ha	212 kg

(Advanced Nutrients) researched that in dry land systems and on exhausted soils the volume of Black Urea® can be reduced 15-35% to achieve the usual yields and quality.

2.8. Coated urea research in Zimbabwe

Several organisations have locally done various research trials on the technology but unfortunately did not publish their findings on the products. Only Agriculture Research Trust (ART) Farm has published their findings on coated urea and coated DAP. The Zimbabwe Sugar Association Experiment Station has published only their preliminary findings on Black DAP and Black urea and not yet on their final findings.

Research work in the summer of 2009 carried out by the Agriculture Research Trust (ART) Farm (Harare), Nutrichem (Zimbabwe) and Profert Holdings (South Africa) revealed that: The broad trend across the trial showed Black Urea® consistently out yielding uncoated standard white urea across all application rates and even at significantly lower application rates. The lower application rates yielded the same or similar as higher rates suggesting a strong indication that the usual application rates are probably too high in the first instance. The superior results came with the lowest of the Black Urea® rates, with Black DAP, though only when averaged over the three sites. Individual farm management would produce greater overall result as each farm had a different reduction in application rate producing the best result.

- At Chiweshe, the treatment of Black Urea® (220kg/ha) with Black DAP (145kgs/ha) produced the best economic result with fertiliser N+P Cost per ha of $29 per tonne of grain produced.
- At Musana the best result was a treatment of Black Urea® (270kgs/ha) with Black DAP (145kgs/ha) which produced a tonne of grain with $49/ha of fertiliser.
- At Zvimba results produced a tonne of grain with $46/ha worth of fertiliser with the Black Urea® (220kgs/ha) and uncoated DAP (145kgs/ha).
- By comparison, the usual practice of uncoated Urea (420kgs/ha) produced a tonne of grain at Chiweshe ($38/ha), Musana ($80/ha), Zvimba ($74/ha)".

ART Farm also found that: By using a coated Phosphorus source, there was a definite and strong trend of increased yield where Black DAP was used in replacement of un-coated DAP. A yield increase occurred across all farms, in all replications, at all application rates. Improvements in yield varied from 8.5% to 12% amongst different N rates, over the total trial treatment area, average yield increased almost 10% where Black DAP was used. (https://advancednutrients.com.au/black-urea-1)

Nyati & Chinorumba, (2011) revealed that Zimbabwe Sugar Association Experiment Station (ZSAES) research trials on black Urea gave the following findings:

Out of the four trials planted, two have been harvested one at Hippo Valley Farm 26 and the other at Mwenezana. Although data show some slight differences, there were no statistically significant differences between fertiliser treatments at Farm 26 in Hippo Valley.

Table 2.8.1 below shows the comparison of sugarcane yield t/ha of plant crop sugarcane after fertilising with Ammonium Nitrate, standard white Urea, and Black Urea® sources of nitrogen at Farm 26 in Hippo Valley Mill Group in 2010. All treatments were treated with equal amounts of Phosphate and Potassium fertilisers.

Table 2.8.1 below shows that coated Black Urea® gave the highest cane yield at three different fertiliser rates at a trial held at ZAES in Chiredzi, Zimbabwe.

Table 2.8. 1: Cane yield comparison between Ammonium Nitrate, standard white Urea, and Black Urea® sources of nitrogen.

	120Kg N ha^{-1}	**100 Kg N ha^{-1}**	**60 Kg N ha^{-1}**
A. N	165.7	162.5	205.2
UREA	154.1	161.8	164.9
BLACK UREA®	177.8	173.3	214.3
Mean cane yield [t/ha]	165.8	165.9	194.8

Table 2.8.2 below shows that plain white urea gave the least cane yield levels amongst other sources of top-dressing N.

Table 2.8. 2: Table 2.8.2. Comparison of cane yield from different sources of N.

	Cane yield [t/ha]
A.N versus **Urea**	177.8 vs 160.3
A.N versus **Black Urea®**	177.8 vs 188.4
A.N versus **DAP**	177.8 vs 190.5
DAP versus **SSP**	181.6 vs 198.4
Cropped versus **none-cropped, A.N applied**	177.8 vs 0
Cropped versus **none-cropped, Urea applied**	160 vs 0
Urea versus **Black Urea®**	160.3 vs 188.4

All none DAP treatments received equal amounts of Phosphate and Potassium fertilisers.

2.9. Summary

This chapter reviewed on literature from various global research works and publications on the topics of crop response to nitrogen, leaf nitrogen measurement, soil nitrogen loss and urea management, nitrogen stabilisers and their performance. The chapter also looked at research by various scientists looking at the cost and economics of using different types of nitrogen options for top dressing crops. Reviewed literature generally indicates that under low humidity and wet-dry soil-moisture cycling, substantial nitrogen losses do occur from sandy soils. However, under high humidity and high soil-moisture conditions, surface-applied nitrogen losses may be less than ***5*** percent. More efficient application of fertilizer nitrogen can be achieved provided good management practices are followed. On alkaline or sandy soils, nitrogen loss will be minimized if fertilizer is incorporated rather than left on the soil surface. Incorporation can be accomplished by shanking the fertilizer or by discing following application. Earlier research showed that application rate data illustrate that the rate or concentration of N fertilizer will affect the percentage of nitrogen loss. When N fertilizer is left on the soil surface, a larger percentage of fertilizer loss may occur if fertilizer is concentrated in bands rather than evenly distributed over the entire soil surface. Very sandy soils may experience ammonia volatilization losses of nitrogen even after a surface-applied fertilizer has been watered in. To effectively minimize nitrogen losses from high-pH sandy soils it is best to incorporate the fertilizer. Through various modern technologies, urea can be encapsulated in various coatings or treated with chemical stabilisers to inhibit transformations that results in N losses. The application of nitrification inhibitors has been researched as a potent method to decrease nitrous oxide (N_2O) emission while promoting grain yield and nitrogen use efficiency in fertilized agricultural fields.

CHAPTER 3 METHODOLOGY

3.1. Introduction

The nature of the research problem dictates the methodology. The research objectives, questions, and hypotheses were the key aspects of the research problem. The purpose of the methodology was to show the stages, procedures, processes, and approaches for collecting and analysing data in this research.

3.2. Research sites

The field study was carried out at two research sites of Seed Co namely (1) Rattray Arnold Research station (RARS) (17º40'47.06"S 31º12'44.87"E, Altitude 1300 m) in Arcturus, Mashonaland East province, Zimbabwe, 37 km north east of Harare.
(2) Stapleford Research Centre (SRC) (17º42'54"S 30º54'22.14"E, Altitude 1466 m) situated in Stapleford, Mashonaland West province, Zimbabwe, 23 km from Harare. Rattray Arnold Research station received supplementary irrigation while Stapleford was under dryland production. The third site was off station at Glenara estate (17°41ˈ07ˈS 30°59ˈ47ˈE, Altitude 1473 m) in Mashonaland Central province and was dryland. The research was carried out during the 2015/2016 and 2016/2017 farming seasons. All research sites are in agro-ecological region 2b (Munowenyu & Murray, 1990). Agro-zonation in Zimbabwe is defined in terms of mean annual rainfall during a unimodal season ranging October to May (Vincent & Thomas, 1960). All sites receive mean annual rainfall of 700-900 mm. The soils at the trial sites at SRC and Glenara estate are Luvisols. F.A.O legend, (1988) derived from dolerite intrusions and mafic parent material (Nyamapfene, 1988). These soils are moderately leached (Nyamapfene, 1987). At Rattray Arnold research station, the soils for the research block are predominantly granitic Haplic Lixisols. FAO legend, (1988). These are highly leached moderately fertile soils (Thompson &

Parves, 1978), (Nyamapfene, 1987). Two of the used sites (SRC & Glenara) had been under maize and (RARS) had soya beans in the preceding season.

3.3a. Experimental treatments

The trial was a 6 x 2 x 2 factorial experiment involving 3 factors: 6 top dressing nitrogen types (AN, Black Urea, White Urea, Agrotain red urea, Agrotain green urea and No top dressing), two top dressing nitrogen fertiliser rates (R_0 = 138N kg/ha and R_1= 68N kg/ha) and 2 fertiliser timings (all top dressing nitrogen fertilizer at planting (T_0) and half top dressing nitrogen at planting and half at 6 leaves (T_1). The above three factors were combined factorially to give 24 treatments. The treatments were replicated three times. The experiment was laid out as a randomised complete block design (RCBD). Randomisation was done using the Random number generator on internet (www.stattrek.com/statistics/random-number-generator.aspx).

The 3 replications resulted to a total of 72 experimental plots. The field layout in figure 3.3.1.1 below shows how the treatments were coded and the respective factors.

Factors:

Below is table 3.2.1 showing how the fertiliser treatments were coded and the presentation of the factors for the experiment.

Table 3.2 1: Experiment factors and codes

Top dressing Nitrogen type	**Code**	**Top dressing rate**		**Top dressing timing**	
		R_0	**R_1**	**T_0**	**T_1**
Ammonium nitrate (A.N) 34,5% N	A	138N kg/ha	68N kg/ha	At V0	At V0 and V6
White Urea (46% N)	W	138N kg/ha	68N kg/ha	At V0	At V0 and V6
Agrotain Red Urea (46% N)	X	138N kg/ha	68N kg/ha	At V0	At V0 and V6
Black Urea (46% N)	B	138N kg/ha	68N kg/ha	At V0	At V0 and V6
Agrotain Green Urea (46% N)	G	138N kg/ha	68N kg/ha	At V0	At V0 and V6
No top-dressing N (0% N)	Z	138N kg/ha	68N kg/ha	At V0	At V0 and V6

Top dressing Nitrogen rates

R_0 = Full rate (138N kg/ha) at planting

R_1 = Half rate (68N/kg/ha) at planting and half rate (68N/kg/ha) at 6 leaves

Top dressing application timing

T_0 = All top-dressing nitrogen fertilizer applied at planting

T_1 = Split timing**:** Half top-dressing nitrogen at planting (V0) and half at 6 leaves (V6)

Treatments:

The table 3.2.2.2 below shows that each treatment was replicated three times in the lay out.

Table 3.2 2: Top dressing treatments layout:

Treatment No.	**Treatment**	**Treatment No.**	**Treatment**	**Treatment No.**	**Treatment**
1	ZR_0T_0	9	BR_0T_0	17	XR_0T_0
2	ZR_0T_1	10	BR_0T_1	18	XR_0T_1
3	ZR_1T_0	11	BR_1T_0	19	XR_1T_0
4	ZR_1T_1	12	BR_1T_1	20	XR_1T_1
5	AR_0T_0	13	WR_0T_0	21	GR_0T_0
6	AR_0T_1	14	WR_0T_1	22	GR_0T_1
7	AR_1T_0	15	WR_1T_0	23	GR_1T_0
8	AR_1T_1	16	WR_1T_1	24	GR_1T_1

3.3b. Field layout

The field layout at Rattray Arnold Research Station (RARS) farm in Arcturus

The field treatment plots as shown in Appendix 1 had three replications with unique randomisation in each replication. Plots were 3.25m x 4.25m and blocks were separated by a 1m wide free space/ pathway between replications.

3.4. Soil sampling and Analysis

Pre-planting soil sampling and analyses was carried out at the research blocks to understand the initial fertility status of the soil. In the second year, new fields were used across all research sites with pre -planting soil sampling and analysis carried out. The trials were re-randomised in each case. In each field, five samples (0-20cm) were extracted from each rep before the start of the experiment using a simple random method with a soil auger. The five samples from each rep were bulked to form a composite sample, so that three samples were collected per field plot and sent to the laboratory. During the season, soil sampling was carried out from each plot to determine the nitrogen status. Soil samples were collected from 0-15cm (top soil), 15-30cm (sub-soil) and 30-45cm (sub-soil) depths for each plot. Another set of samples, at the three depths, was collected at the end of the season, after harvesting, to check for residual N. Soil texture analysis was carried out using the Finger 'Feel' method. Phosphate was analysed using the Mehlich III method, exchangeable cations were extracted using 1.0M Ammonium Acetate at pH 5.8, trace elements were extracted using 0.05M EDTA at pH 7. Soil pH was analysed using the 0.01M Calcium Chloride method. Plant analysis for N was done using the Micro Kjedahl method. Soil mineral nitrogen was analysed using the KCl method.

3.5. Planting

At planting a basal fertiliser Double 'D' (14 N-28 P_2O_5-14 K_2O) was applied at a uniform rate of 250kg/ha giving the following levels of nutrition 35kg/ha N, 70kg/ha P_2O_5 and 35 kg/ha K_2O. All other management procedures were as per standard farmer practice. Early maturity maize variety SC403 was used in both years to avoid inconsistencies in factors like yield which come from varietal differences and more to it, the El Nino drought had been predicted in the first season. Maize was planted at all sites, with the first effective rains, with in-row spacing of 0.25m and an inter-row spacing of 0.85m leading to a maize plant population of 45 000-55 000 plants/ha at all sites. At each site, all the 72 plots were uniformly planted on the same day and fertiliser applications were done as planned. Relative chlorophyll (SPAD) content at 53 days and 80 days was measured in maize leaves using the SPAD-502 chlorophyll meter (Konica Minolta Sensing Corp., Japan). The chlorophyll (SPAD) content meter readings were recorded from ear leaves from 10 plants in each plot then averaged. Crop variables that were measured included plant height at 30, 60, 90 days, stem diameter at 30 and 60 days, number of leaves at 30 and 60 days, number of days to 50% tasselling, chlorophyll content at 60 and 90 days, final grain yield and economic returns per unit of N were investigated in the study.

3.6. Laboratory measurements of ammonia volatilization from five nitrogen-top dressing fertilizers.

The investigation was undertaken to compare five N top-dressing fertilizers with respect to their susceptibility to NH_3 volatilization and to determine the effect of nitrogen coating on NH_3 volatilization. The aim was to minimize NH_3 losses from surface-applied nitrogen top dressing fertilizers in the field by selecting the least volatilizing fertilizer top dressing. The apparatus and procedure were as follows:

Materials:

2 transparent plastic Pots/ Petri dishes

200g soil for each pot

4ml water for each pot

Ammonium nitrate 34.5%N (6.6g/2.3units N) using a rate of 103.5N/ha (300kg/ha A.N) Controlled Release Urea 46%N (5g/2.3units N) using a rate of 103.5N/ha (225kg/ha)

Plain Urea 46% (5g/2.3units N) using a rate of 103.5N/ha (225kg/ha)

Spritzer with water (one spray is equivalent to one milli-litre [1ml])

Insulation tape

Cup number 5 Fertilizer cups

Sensitive Scale

Method

1. Place 200g soil in each pot and moisten the soil approximately to field capacity with distilled water using a spritzer.
2. Weigh the fertiliser to be applied for each pot and spread evenly on the soil surface in each pot.
3. Carefully break both tips of the glass tube to allow gas movement.

4. Close the pot lid and tightly seal it with insulation tape around the brim.
5. Leave the treated moist samples in sealed pots inside the room for at least an hour before taking them outside the room to an open space clear of any shed.
6. Observe ammonia gas released as the colorimetric indicator changes from yellow to blue and compare measurements and time taken for each fertilizer to reach the 100ppm point.
7. Stop recordings when all samples have colour indication to the desired mark on the calorimetric glass indicator.

3.7. The Questionnaire

A semi-structured questionnaire was designed so that the respondents had a space to elaborate on their views or simply ticked where no clarification was sought. Forty copies of questionnaires were distributed to commercial maize farmers and twenty were sent to communal maize farmers. Farmers were selected based on maize production output over years in their locations. The respondents were served with the semi-structured questionnaires from June 2016 and were advised to fill them in during their own spare time within the next three months from which the completed copies were collected by the researcher. Those who were emailed the questionnaires were required to email back completed copies within 3 months. Merit of written questionnaires was that they gave respondents a greater feeling of anonymity and therefore encouraged open responses to sensitive questions.

3.7.1. Questionnaire data collection procedure

After the initial design of the data collection instrument, the questionnaire was subjected to a 'test survey'. This involved identifying 15 commercial farmers who were asked to complete the questionnaire. The information gathered was then used to refine and perfect the questionnaire instrument before the final data collection exercise. The issues raised were mainly interpretation of technical words and statements, length of questionnaires, scale of response on closed questions and the apparent repetition on some questions. Sixty copies of the final questionnaire were administered to the farmers through the help of local agriculture extension workers in each zone that had target farmers with experience with the types of top-dressing nitrogen in question. Extension workers were first taught on how to explain the instrument to the farmers without providing answers so that the farmer is free to answer with his/her clear mind. Some farmers returned completed instrument well before the stipulated 3 months of answering. The researcher collected the completed questionnaires directly from a few farmers with his easy access but most of them came back through the same extensionist who helped issuing it in the first place.

3.8. Data Presentation and Analysis Procedure

Before detailed statistical analysis, the recorded maize data was tested for normality, autocorrelation and homoscedasticity. ANOVA was carried out using CropStat R7.2.2015.3. to assess the effects treatments, rates, and timing on the model crop maize. All analyses were conducted at the 5% level of significance. Data analysis involved systematically searching and arranging the questionnaires and other materials that the researcher had accumulated to increase his understanding of the study. The questionnaires went through a physical inspection process. This involved physically flipping through the pages of each questionnaire. This was done to ensure that all the pages were intact and if they were all fully completed. The observations on those that were incomplete were considered.

3.9 Summary

The chapter focused on research methodology. The appropriate research philosophy and design were identified for this study. Soil sampling issues were discussed and the appropriate sample size for the study was determined. The chapter went on to identify appropriate data collection methods for the study. The development of the research design and research instrument was done. The chapter examined data analysis procedures and the appropriate ones were identified.

CHAPTER 4 DATA PRESENTATION, ANALYSIS AND INTERPRETATION

4.1. Introduction

Soil analysis was very important as it exposes the hidden mechanics and physical/chemical characteristics of a soil. In this case it revealed that soil organic matter content influenced some results that came out from the analyzed research date. The rainfall pattern over the two years of research was unique as it comprised of two swings at opposite ends. This had its own effects on the research finds. The search findings showed that the soils had adequate inherent N resulting in insignificant variations in both grain yield and NUE across the treatments including the control. The soil analysis results show that all reps had sand clay loam soils with soil pH ranging between 4.4 to 4.6 on a Calcium Chloride scale. All the three soil samples were acidic, high in Initial mineral nitrogen and reported good organic matter/carbon levels. Appendix 2 shows the soil analysis reports.

In 2015/16, the season started with effective planting rains early in the first week of November. As the season progressed, this turned out to be a drought season with the El Nino effect causing poor rainfall distribution across the season. The rainfall peaked in the months of December, January and February as shown in the figures

4.2.1 and 4.2.2 but the quantity of the moisture was far from being adequate for the maize crop at critical physiological development stages. The 2016/17 season was totally the opposite with high rainfall despite effective planting rains commencing slightly late in the last week of November compared to the preceding season. This was well above the long-term seasonal average of 700-900mm for the two sites. January 2017 was the wettest month recording 576mm of rain at SRC and 533mm at RARS compared to same period in 2016 which recorded 134mm at SRC and 84mm of rain at RARS. In the 2016/17 season weekly evaporation rates which were routinely measured at the study sites, were small compared to weekly rainfall during the study period and the crop was therefore not affected by moisture stress in this entire second cropping season.

Figure 4.2.1 below shows that SRC received more rainfall across all months in the 2016-17 season than in the 2015-16 season with the highest rainfall being received in January 2017.

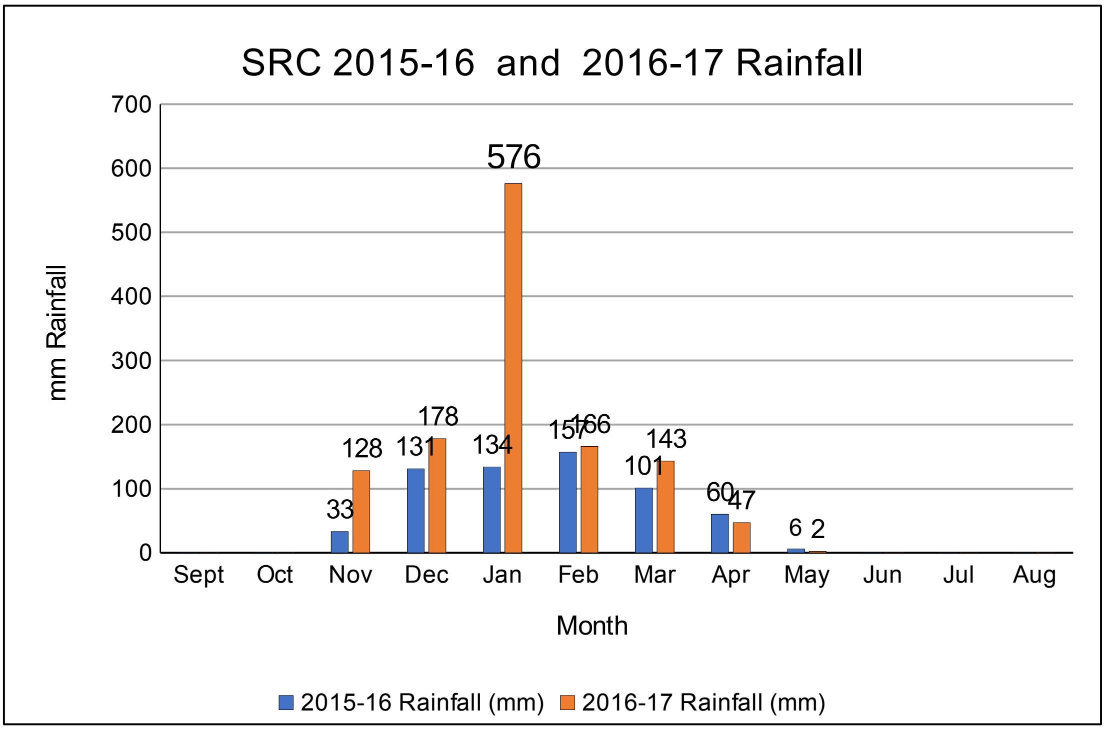

Figure 4.2. 1: SRC 2015-16 and 2016-17 rainfall.

Figure 4.2.2 below shows that in the 2016-17 season RARS received more rainfall than in the preceding 2015-16 season only in the months of November, December, January, March and May with the highest rainfall being received in January 2017.

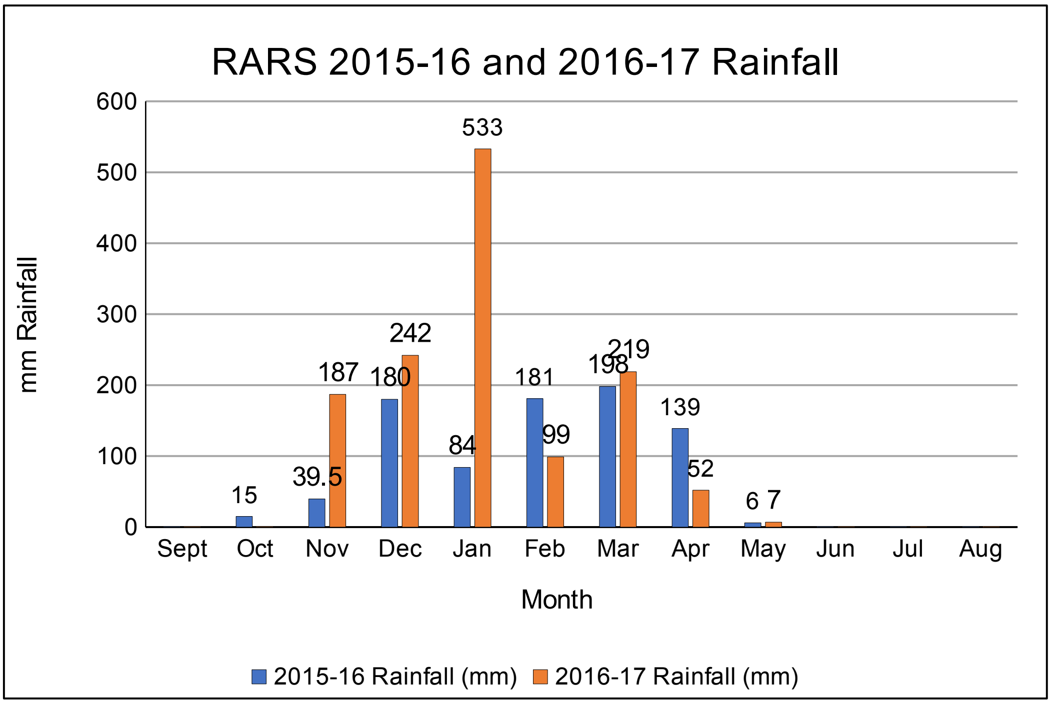

Figure 4.2.2: RARS 2015-16 and 2016-17 rainfall

Figure 4.2.3 below shows that in the 2016-17 season Glenara farm site had a rainfall season concentrated on the five months of November, December, January, February and March.

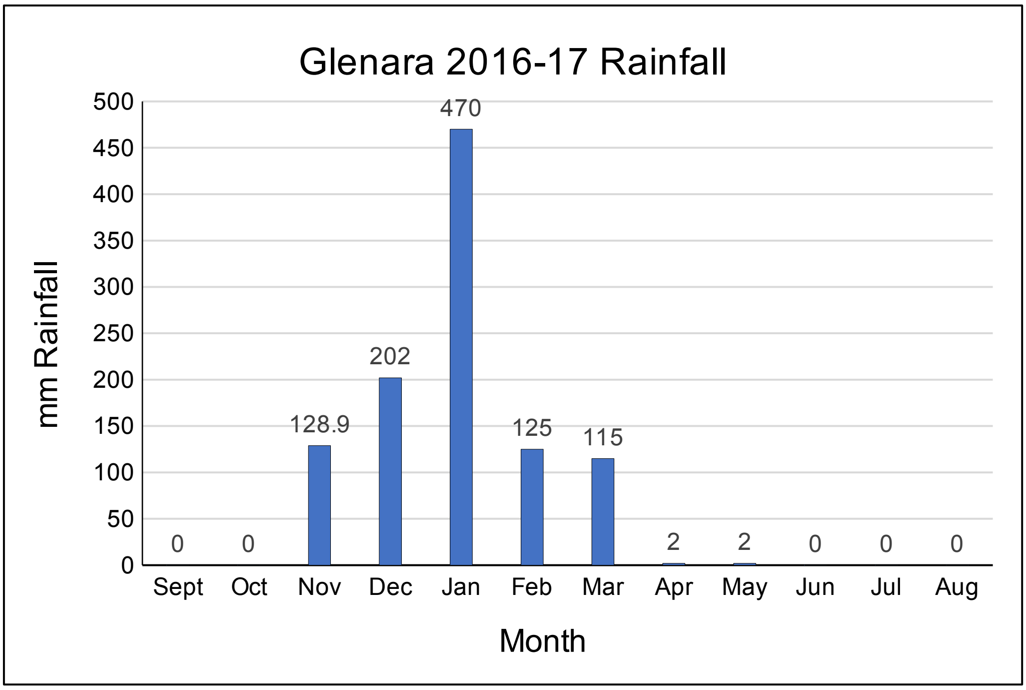

Figure 4.2. 3: Glenara Farm site 2016-17 rainfall.

4.2. Data Presentation and Analysis

4.2.1 The efficacy and cost effectiveness of varying levels of coated urea application as a maize top-dressing fertiliser

Table 4.2.1.1 below shows that there is no significant difference in grain yield (GY) and NUE between a full fertiliser rate and a half fertiliser rate.

Table 4.2.1 1: Two sample t-tests for Grain yield and Nitrogen use efficiency

	Probability	df	t	Confidence interval of difference in means	Standard error of difference
Grain yield	0.694	286	0.39	(-0.4445, 0.6674)	0.111
Nitrogen use efficiency	0.694			(-2.570, 3.858)	1.633

A two-sample t-test was conducted with null hypothesis that mean of grain yield with

full nitrogen top dressing recommendation rate (138 kg N/ha) is equal to mean of grain yield with half nitrogen top dressing recommended rate (69 kg N/ha). Results in Table 4.2.1.1 show no significant difference between the mean grain yield from full top-dressing recommended nitrogen rate and that from half the rate.

Figure 4.2.1.1 below shows that there is no significant grain yield difference between a full fertiliser rate and a half fertiliser rate.

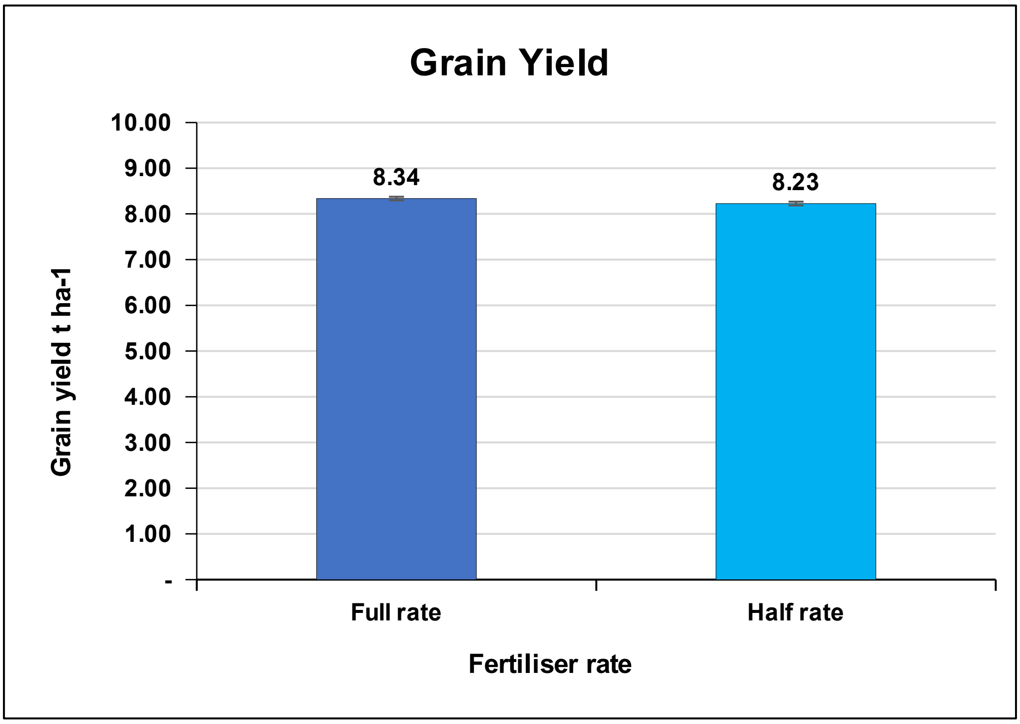

Figure 4.2.1. 1: Grain yield by fertiliser rate

Table 4.2.1.2 below shows that there is no significant difference in grain yield associated to the type of N source.

Table 4.2.1 2: One-way Analysis of variance for Grain yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Exp_Site stratum	1	328.302	328.302	70.57	
Nitrogen types	5	8.263	1.653	0.36	0.879
Residual	281	1307.243	4.652		
Total		287	1643.808		

Fig 4.2.1.2 shows the effect of different nitrogen fertilizer types on maize grain yield. The type of nitrogen fertilizer used had no significant difference (at 0.05%) on grain yield. While the maize yields (t/ha) in plots where AN, Black Urea and Agrotain Red were applied were higher than the yield for Agrotain green, White urea and the Control (Fig 4.2.1.2), the differences were not statistically different.

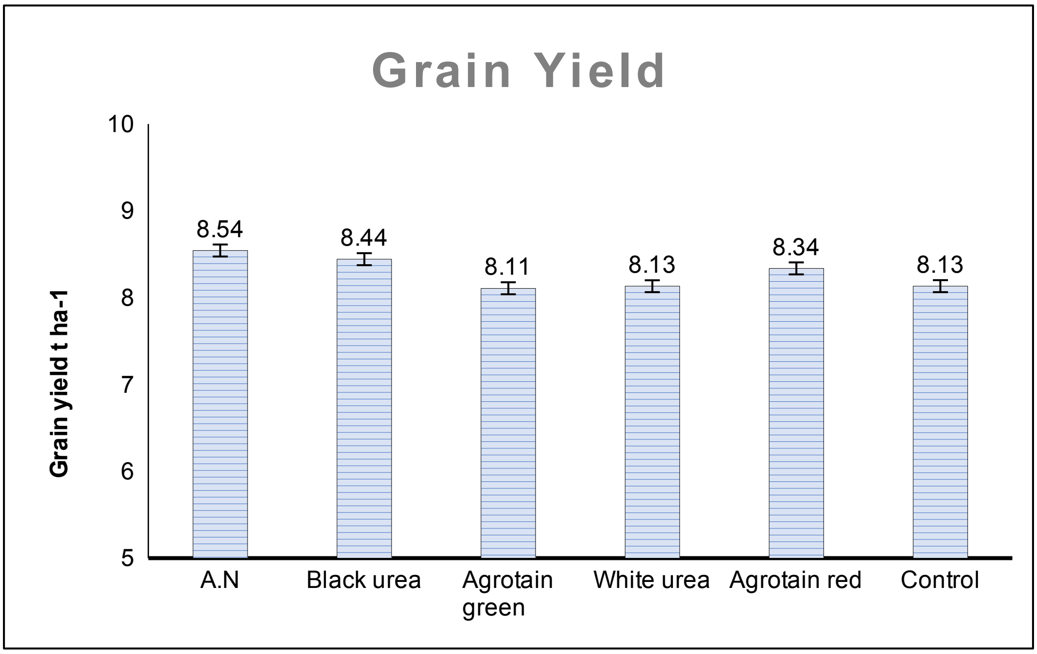

Figure 4.2.1. 2: Effect of different nitrogen fertilizer types on maize grain yield in tons/ha

Table 4.2.1.3 below shows that there is no significant difference in NUE related to full rate of N and half rate of N applied.

Table 4.2.1 3: One-way Analysis of variance for Nitrogen use efficiency.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Exp_Site stratum	1	10969.3	10969.3	70.57	
Treatment	5	276.1	55.2	0.36	0.879
Residual	281	43678.2	155.4		
Total		287	54923.6		

A two-sample t-test was conducted with null hypothesis - the mean of Nitrogen use efficiency with Full rate is equal to mean of nitrogen use efficiency with Half rate. Results showed that Test statistic t = 0.39 on 286 d.f. and Probability = 0.694. This means we are not able to reject the null hypothesis and therefore we conclude that there is no significant difference between the Nitrogen use efficiency means of Full rate and Half rate. This means there is no significant difference in nitrogen use efficiency between the full nitrogen fertilizer top dressing recommendation of 138 kg N/Ha and the half nitrogen fertilizer top dressing recommendation of 69 kg N/ha. Fig 4.2.1.3 below explains that there was no significant difference in Nitrogen use efficiency means for Full fertiliser rate and Half fertiliser rate.

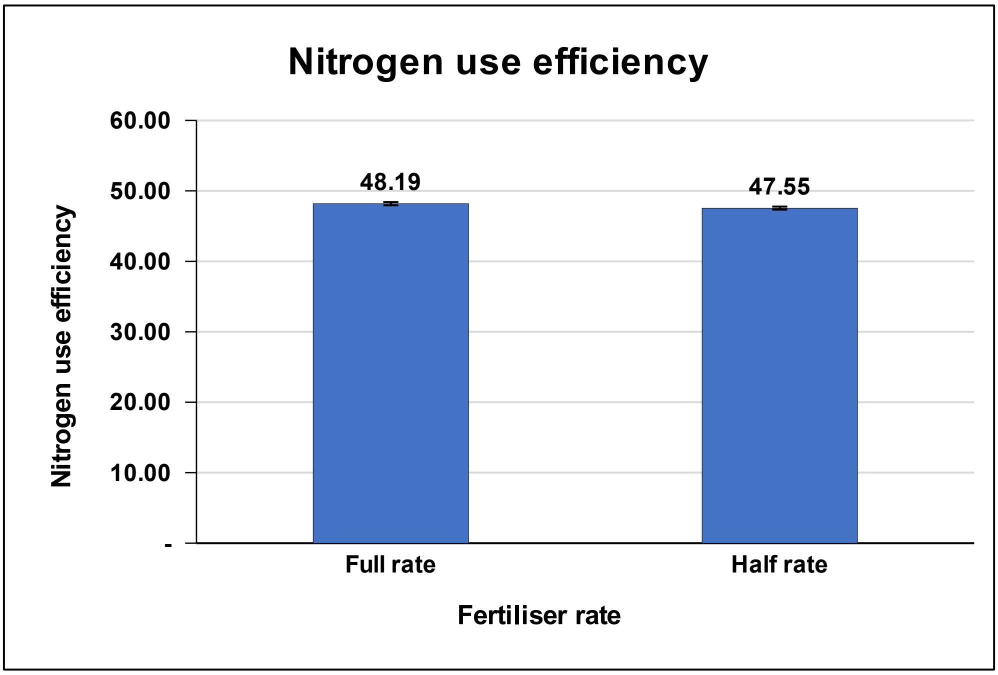

Figure 4.2.1. 3: Nitrogen Use efficiency by fertiliser rate

Fig 4.2.1.4 below shows that the type of nitrogen fertilizer used had no significant difference (at 0.05%) on NUE.

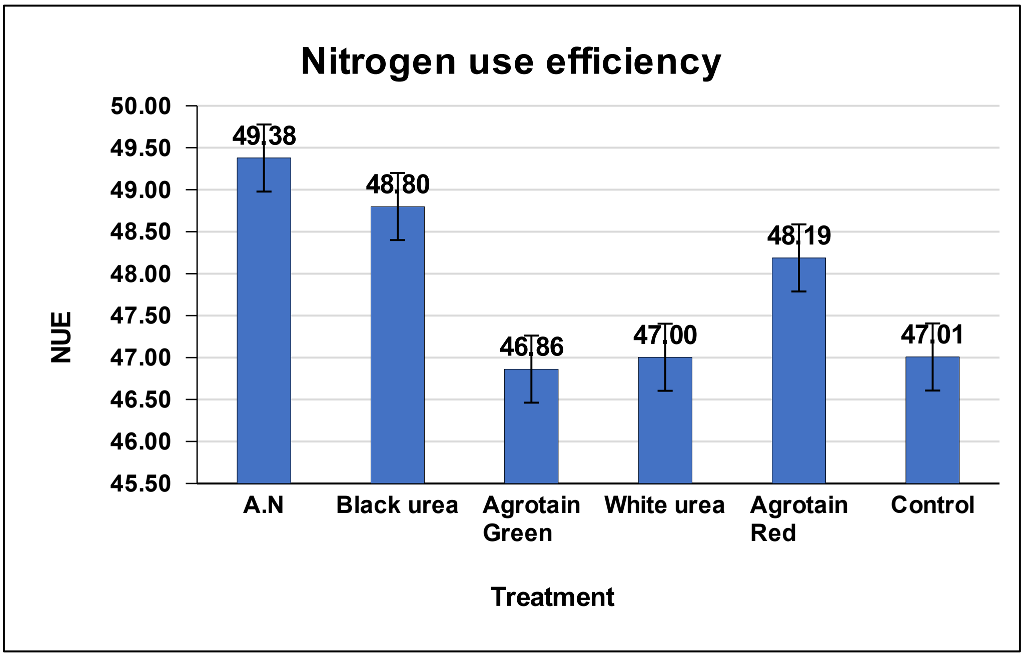

Figure 4.2.1. 4: NUE of the 5 different nitrogen types used in the experiments.

Fig 4.2.1.4 shows the effect of 5 different nitrogen top dressing fertilizers on maize nitrogen use efficiency (NUE). The type of nitrogen fertilizer used had no significant difference (at 0.05%) on NUE. While the NUE in plots where AN, Black Urea and Agrotain Red were applied, were higher than the NUE for Agrotain green, White urea and the Control (Fig 4.2.1.4), even though the differences were not statistically different.

Figure 4.2.1.5 below reveals that split top dressing application of A.N, White urea and Agrotain Red urea had significant interaction with NUE with the second split top-dressing application leading to higher NUE. Both first top dressing split, and second top dressing split treatment timings resulted in above average maize NUE in all seasons.

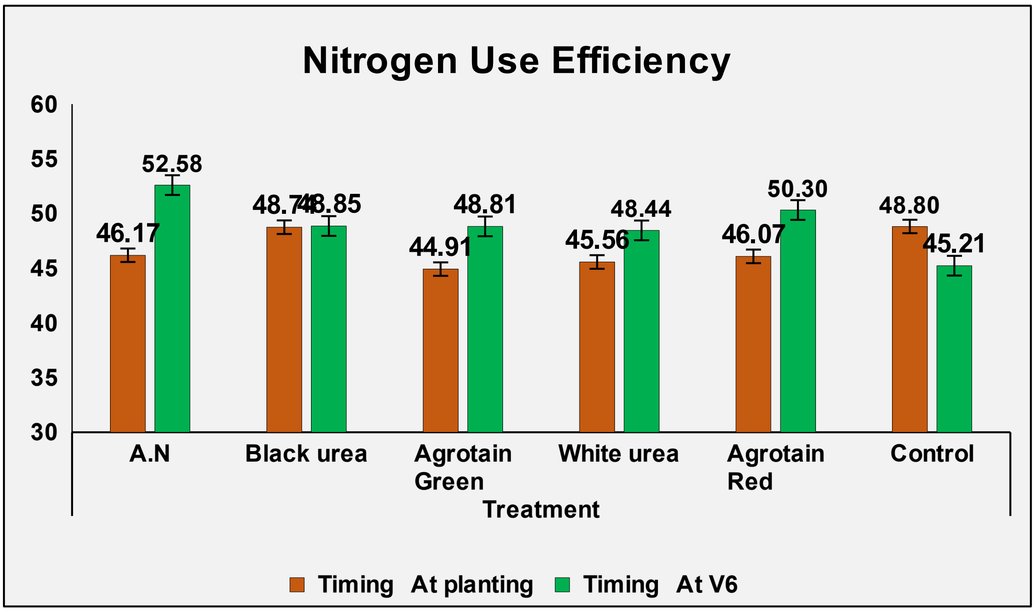

Figure 4.2.1.5: The effect of fertiliser type and timing on Nitrogen Use Efficiency.

Table 4.2.1.4 below show that there was no significant difference between the different nitrogen top dressing fertilizer types on Chlorophyll (SPAD) content in the plant leaves.

Table 4.2.1 4: Two-way Analysis of variance for Chlorophyll-one

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Exp_Site stratum	1	1570.21	1570.21	94.18	
Treatment (Nitrogen type)	5	170.89	34.18	2.05	0.076
Timing	1	0.91	0.91	0.05	0.816
Treatment x Timing	5	26.83	5.37	0.32	0.899
Residual	131	2183.99	16.67		
Total		143	3952.83		

The results also show that chlorophyll content is not affected by top dressing fertilizer timing of application. The interaction between type of nitrogen fertilizer applied and timing of application of the fertilizer had no significant effect on chlorophyll (SPAD) content. At 10% significance level, the nitrogen fertilizer type had a significant effect on chlorophyll content.

Fisher's protected least significant difference test

Table 4.2.1.5 below shows the multiple comparison tests results using the Fisher's protected least significant difference test.

Table 4.2.1 5: Grouping of means

Treatment	Mean	Group
Plain white urea	57.90	a
Control	59.21	ab
Agrotain Green urea	59.78	bc
Black urea	60.47	bc

Agrotain Red urea	60.72	bc
A. N	61.18	c

The Table 4.2.15 shows that White urea and Control treatments had the least chlorophyll-one means. Black urea, Agrotain green urea, Agrotain red urea and the Control treatments have the same chlorophyll-one means. Chlorophyll-one means (recorded at 53 days post emergence) of A.N, Black urea, Agrotain green urea and Agrotain red urea treatments were not significantly different but were significantly higher than those of the other nitrogen types. Chlorophyll-one means for AN, Agrotain Red, Black Urea and Agrotain green were 3%, 2.5%, 2%, and 1% higher respectively than that of the control. The Figure 4.2.1.6 below shows that the average Chlorophyll-one means for the 6 treatments were not significantly different.

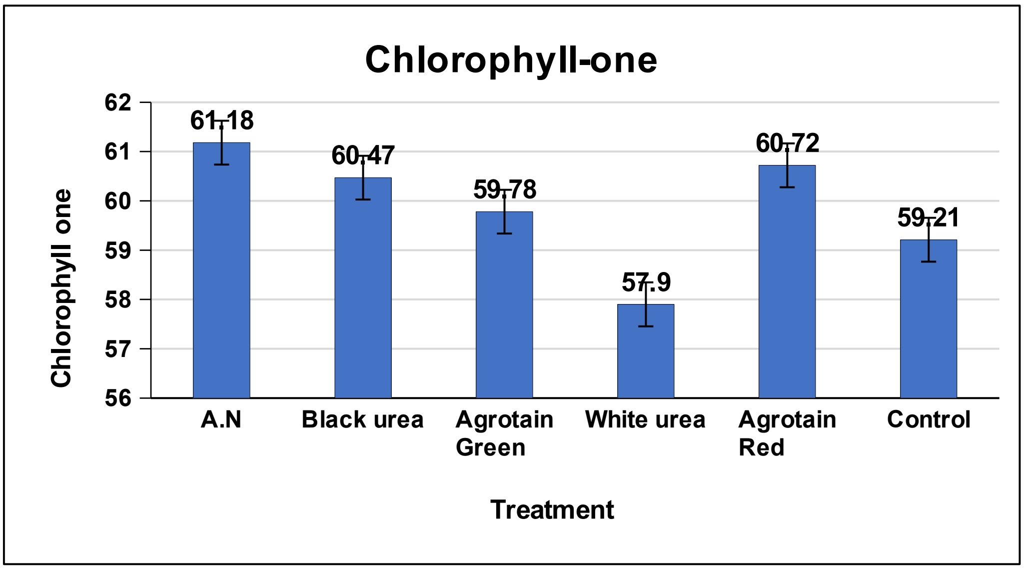

Figure 4.2.16: Chlorophyll-one means by Nitrogen Fertilizer type treatment.

Table 4.2.16 shows that leaf chlorophyll was not influenced by nitrogen fertilizer, and timing of fertiliser application.

Table 4.2.16: Two-way Analysis of variance for Chlorophyll-Two

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Exp_Site stratum	1	2259.71	2259.71	28.23	
Treatment	5	340.24	68.05	0.85	0.515
Timing	1	21.80	21.80	0.27	0.602
Treatment * Timing	5	56.65	11.33	0.14	0.982
Residual	275	22013.05	80.05		
Total	287	24691.46			

Table 4.2.1.6 shows a two-way Analysis of variance for chlorophyll-two (recorded at 80 days post emergence). The results show that type of nitrogen fertilizer, and timing of application did not affect the chlorophyll-two. The nitrogen fertilizer type times timing interaction also did not significantly affect chlorophyll- two.

4.3.2 Comparison of the extent of volatilisation and leaching of different forms of coated nitrogen fertilizers.

Figure 4.3.2.1 below shows that A.N volatilised fastest while NBPT urea volatilised slowest.

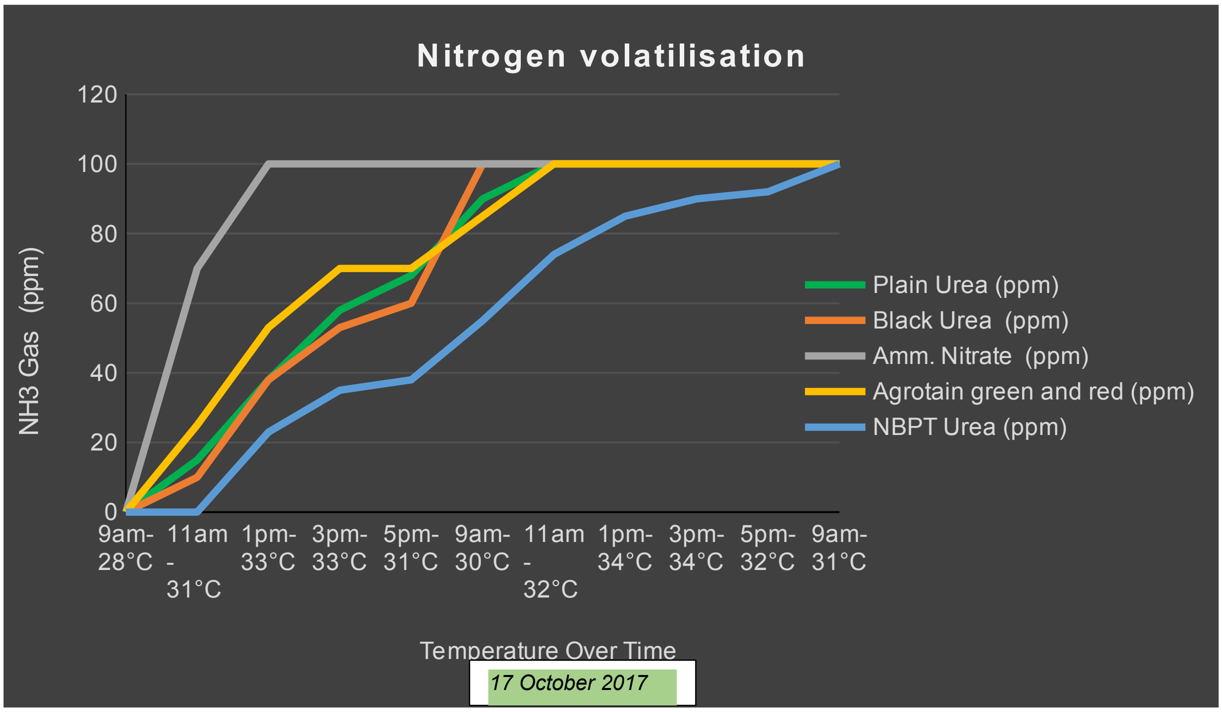

Figure 4.3.2. 1: Nitrogen volatilisation from different nitrogen sources over time.

To calculate ammonia gas losses due to volatilisation, it was assumed that under the experimental conditions, negligible microbial fixation of nitrogen and nitrification could take place. The results reported here were extracted from data for one soil type and other uniform environmental conditions such as similar pH and moisture levels. Through a period of 3 days, NH_3^+ gas losses were directly determined, and ammonia gas was lost from all the fertilisers under all treatments. Figure 4.3.2.1 above, shows the extend of nitrogen volatilisation from five different nitrogen sources (Plain urea, Black urea, Ammonium nitrate, Agrotain green and red urea and Arborite-NBPT Urea) over time and varying temperature. There was an increase in volatilisation of the treatments till they all reached an optimum value of 100ppm. Ammonium nitrate had the highest rate of volatilisation followed by Black urea, Agrotain urea and Plain urea then Arborite-NBPT Urea respectively. All treatments showed significant volatilisation trends between 0900-1100 hours and 1100-1300 hours when temperatures was increasing by 3 degrees and by 2 degrees on both day one and day two respectively. After 1300 hours temperature became static, hence the trends became less inclined and flatter with time as volatilisations reached their maximum 100ppm mark. At 1700 hours temperature was decreasing. The observed volatilisation trends can be ranked as follows from the slowest to the fastest: NBPT < Black Urea® < White urea < Agrotain urea< Ammonium nitrate.

Table 4.3.2.1 below reveals that within the 15cm depth there was a significant difference in the amount of nitrogen lost for the different nitrogen sources.

Table 4.3.2.1: One-way Analysis of variance for Mid-season – 15 cm depth N losses

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Exp_Site stratum	1	381.06	381.06	10.96	
Treatment	5	379.40	75.88	2.18	0.05
Residual	281	9769.00	34.77		
Total		287	10529.46		

Table 4.3.2.2 below shows that there was no significant difference in losses of nitrogen from the different nitrogen sources at 30cm soil depth in the mid-season.

Table 4.3.2.2: One-way Analysis of variance for: Mid-season – 30cm depth N losses

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Exp_Site stratum	1	2298.9	2298.9	6.46	
Treatment	5	2432.5	486.5	1.37	0.24
Residual	281	100035.8	356.0		
Total		287	104767.2		

Table 4.3.2.3 below shows that there was no significant difference in losses of nitrogen from the different nitrogen sources at 45cm soil depth in the mid-season.

Table 4.3.2.3: One-way Analysis of variance for Mid-season – 45cm depth N losses

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Exp_Site stratum	1	1166.40	1166.40	29.21	
Treatment	5	354.23	70.85	1.77	0.12
Residual	281	11221.45	39.93		
Total	287	12742.09			

According to Table 4.3.2.2 and 4.3.2.3, there was no significant difference in losses of nitrogen from the different nitrogen sources at 30cm and 45cm in the mid-season. The graphs 4.3.2.2 and 4.3.2.3 below shows the comparison of nitrogen losses of each of the 6 treatments with respect to the depth (15cm, 30cm and 45cm) within the mid-season and at the end of the season respectively.

Figure 4.3.2.2 below shows that mid-season N loses from the different top-dressing N fertilisers were not significantly different across soil depth ranging from 15cm – 45cm.

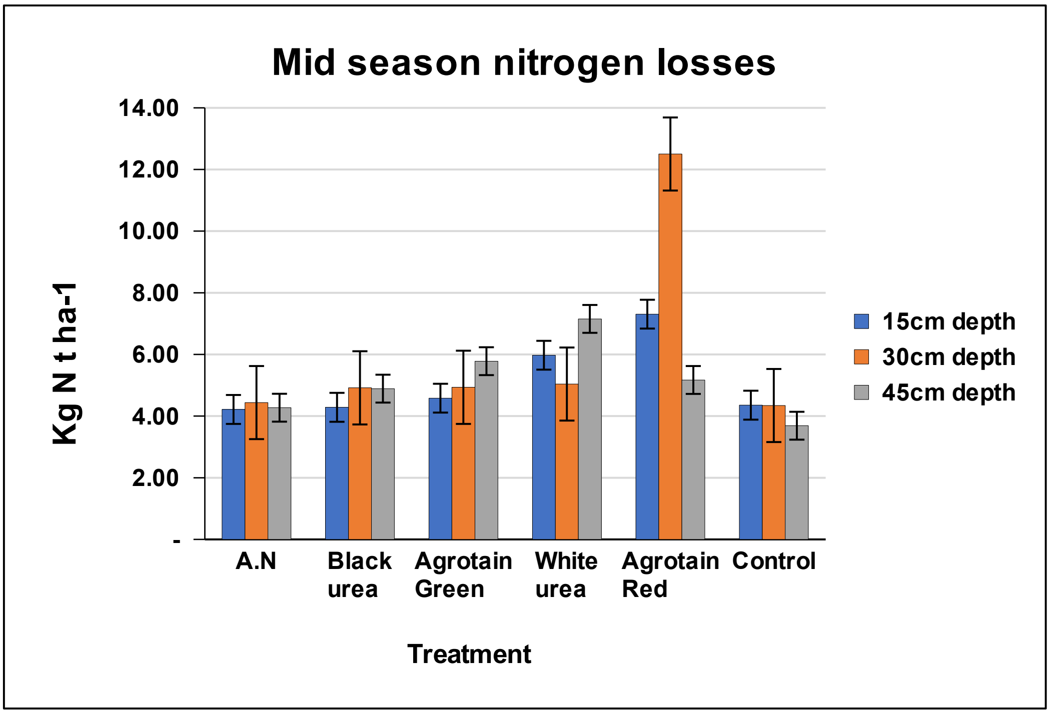

Figure 4.3.2. 2: Mid-season soil N in 15cm, 30cm and 45cm soil depth

Figure 4.3.2.3 below shows that residual N levels within the 30cm and 45cm soil depth are not significantly different and are not influenced by treatment.

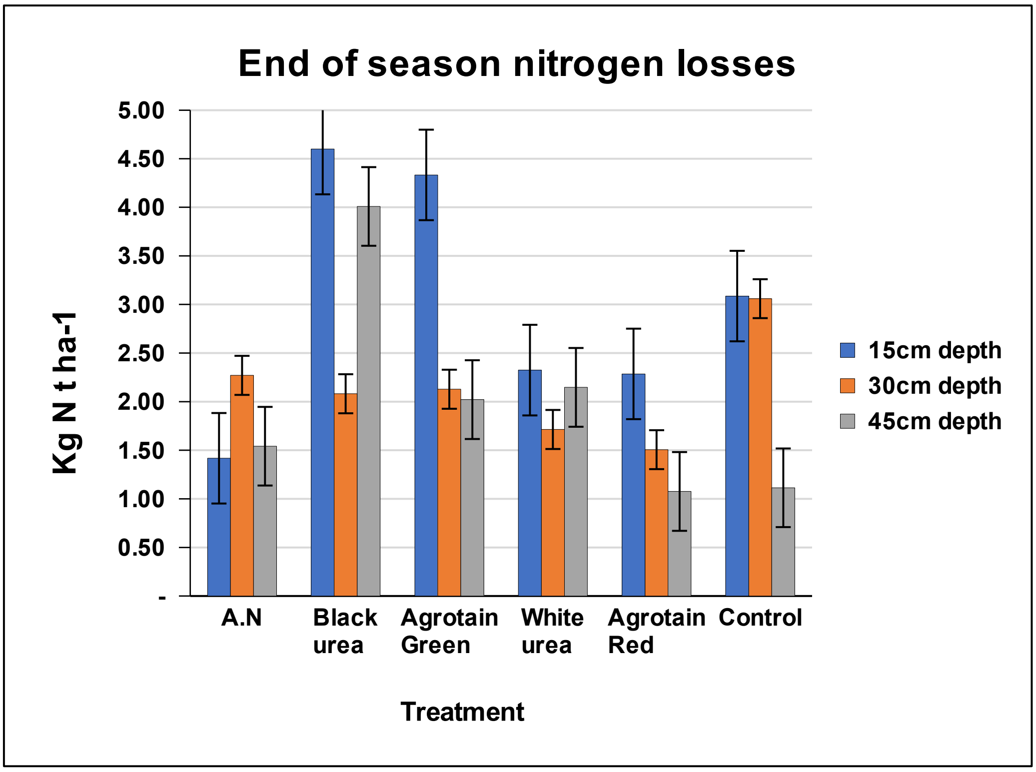

Figure 4.3.2.3: End of season soil N in 15cm, 30cm and 45cm soil depth

Table 4.3.2.4 below shows that late season residual N levels in the 15cm are not significantly different due to treatment.

Table 4.3.2.4: One-way Analysis of variance for Late season – 15cm depth Nitrogen losses

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	5	93.75	18.75	1.03	0.405
Residual	66	1196.71	18.13		
Total		71	1290.46		

Table 4.3.2.5 below shows that late season residual N levels in the 30cm are not significantly different due to treatment.

Table 4.3.2.5: One-way Analysis of variance for Late season – 30cm depth Nitrogen losses

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	5	17.401	3.480	0.62	0.682
Residual	66	368.365	5.581		
Total	71	385.767			

Table 4.3.2.6 below shows that late season residual N levels in the 45cm are not significantly different due to treatment.

Table 4.3.2.6: One-way Analysis of variance for Late season – 45cm depth Nitrogen losses

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	5	70.859	14.172	1.65	0.159
Residual	66	566.928	8.590		
Total	71	637.787			

Tables 4.3.2.4, 4.3.2.5 and 4.3.2.6 above shows a one-way Analysis of variance for late-season nitrogen losses. According to the analysis, probability = 0.405, 0.682 and 0.159 respectively, for treatment, which are all greater than 0.05, means that treatment is not significant in determining the nitrogen losses at either 15cm, 30cm or 45cm depth in the late-season.

4.3.3. Market perception on coated nitrogen for top dressing maize

A random survey was carried out to establish the above objective.

Characteristics of respondents.

Randomly chosen 60 maize farmers with experience with using coated nitrogen fertilisers were given the questionnaire instrument, since coated fertilisers are not yet commonly used in Zimbabwe. Out of the 60 farmers who were given the questionnaire, only 48 successfully completed and returned the instrument. The rate of response was therefore 80%. From the 48 respondents, only 8 (16.67%) were communal farmers while the rest (83.33%) were A2 commercial farmers. These 8 communal farmers have been using coated fertiliser for 2 years in maize and were both introduced to it by a non-governmental donor organisation. All the A2 commercial farmers had been farming since 2003 and had 4 years of using coated N fertiliser through contractors. Therefore 100% of the farmers were introduced to coated N by sponsors.

Table 4.3.3.1. below shows that farmers in Zimbabwe have experience with use of top-dressing fertiliser.

Table 4.3.3.1: Survey of farmers' experience with top dressing fertiliser

Years of experience with using top dressing fertilizer	**Number of farmers**
0 – 5 years	4
6 - 10 years	12
11 – 15 years	9
16 years and above	23

The survey revealed that 91.7% of farmers had experience with using top dressing fertilisers for over 6 years and it is a cultural practice to use top dressing fertiliser. Affordability was cited as the major constraint to those not using top dressing fertiliser unless it is given for free under government free inputs scheme.

Table 4.3.3.2. below shows that traditional ammonium nitrate is the most preferred top-dressing fertiliser.

Table 4.3.3.2: Survey of farmers' top-dressing fertiliser preferences

Most preferred type of top-dressing fertiliser	**Number of farmers**
Plain White urea	11
Ammonium Nitrate	21
Agrotain (Nitrex Red Urea/Green urea/Kyno Plus)	0
Black urea	16
Arborite-NBPT urea	0

Ammonium nitrate 34.5% N is the most preferred option at 46.7%, followed by Black urea at 35.5% then White urea at 24.4%. NBPT and Agrotain urea are very scarce on the market and surveyed farmers know very little on these options.

Table 4.3.3.3 below shows that farmers need more information on use of fertilisers.

Table 4.3.3.2: Farmer knowledge needs related to use of coated/non-coated N sources

Area of need	**Number of farmers**
Understanding of top-dressing fertiliser types	8
Crop fertiliser requirements	4
Fertiliser prices and costs	12
Fertiliser application rates and timing	24

It was observed that inadequate information was still very high on crop fertiliser application rates and timing and this was the major hindrance to optimal use of nitrogen fertilisers. Farmers also want help on understanding the cost of top-dressing options for effective budgeting and optimal timing. The table 4.3.3.4 below shows that lack of product information is leading to slow adoption of coated fertilisers by maize farmers.

Table 4.3.3.4: Survey on adoption of coated fertilisers

Causes of slow adoption of coated fertilisers	**Number of**

	farmers
Lack of cash	6
Difficult to find from local shops/suppliers	12
It is expensive	0
Lack of product information	30

Since the advent of coated fertilisers on the market a few years ago, it was observed that 62.5% of farmers lack product information to inspire them use such fertilisers. One quarter of the farmers surveyed complained that the products are difficult to find in local retail shops unless you procure them via contractors. Table 4.3.3.5 below shows that ammonium nitrate is an expensive source of top-dressing N compared to N from urea sources.

Table 4.3.3.5: Top dressing fertiliser cost/ha

	R.A.R.S Arcturus Farm				
Top dressing fertiliser type	Kg/ha	Cost/ha	Kg N/ha	N Cost/unit	Cost/MT
Ammonium Nitrate 34.5% N	400	$224	138	$1.62	$560
White Urea 46% N	300	$135	138	$0.98	$450
NitreX Urea 46% N	300	$145.5	138	$1.05	$485
Black Urea 45% N	300	$142.5	138	$1.03	$475
Agrotain Green Urea 46% N	300	$144	138	$1.04	$480
No Top dressing	0	0	0	0	---

The nitrogen cost analysis for the top-dressing options in table 4.3.3.5 clearly shows that ammonium nitrate 34.5% is more expensive (at $1,62/N) to the farmer than the urea options (at average $1.025/N).

Value generation via grain yield increase

The table 4.3.3.6 below explains the contribution of coated urea as a source of N to yield increase and the overall Return On Investment.

Table 4.3.3.6 : Coated nitrogen fertiliser – Return on investment (ROI) model from a farmer's perspective.

Revenue field crops [(1)]	$/ha	2000	2000	4000	4000	4800	4800
Yield increase [(a)]		3%	5%	3%	5%	3%	5%
Added value [(b)]	**$/ha**	**60** [(1 x a)]	**100**	**120**	**200**	**144**	**240**
Coated urea cost [(c)]	$/t	480	480	480	480	480	480
Total urea used/ha [(d)]	t/ha	0.25	0.25	0.25	0.25	0.25	0.25
Cost /ha [(e)]	$/ha	120	120	120	120	120	120
Net benefit/ha [(f)]		**-60** [(b – e)]	**-20**	**0**	**80**	**24**	**120**
ROI [(g)]		**0.5** [(b / e)]	**0.83**	**1.00**	**1.67**	**1.20**	**2.00**

Return on investment (ROI) significantly increases at 5% yield increase.

4.3.4 The effect of timing application of different quantities of coated nitrogen top-dressing sources on soil mineral N availability and maize yield.

Table 4.3.4.1: Two-way Analysis of variance for Grain Yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Exp_Site stratum	1	328.302	328.302	70.92	
Treatment	5	8.263	1.653	0.36	0.878
Timing	1	11.632	11.632	2.51	0.114
Treatment * Timing	5	22.622	4.524	0.98	0.432
Residual	275	1272.989	4.629		
Total		287	1643.808		

Table 4.3.4.1 shows a two-way Analysis of variance for grain yield. The analysis shows that there was no significant difference in grain yield between the different nitrogen fertilizer types. The results also show that fertilizer timing of application is not significant in determining grain yield. The interaction between type of nitrogen fertilizer applied and timing of application of the fertilizer had no significant effect on grain yield.

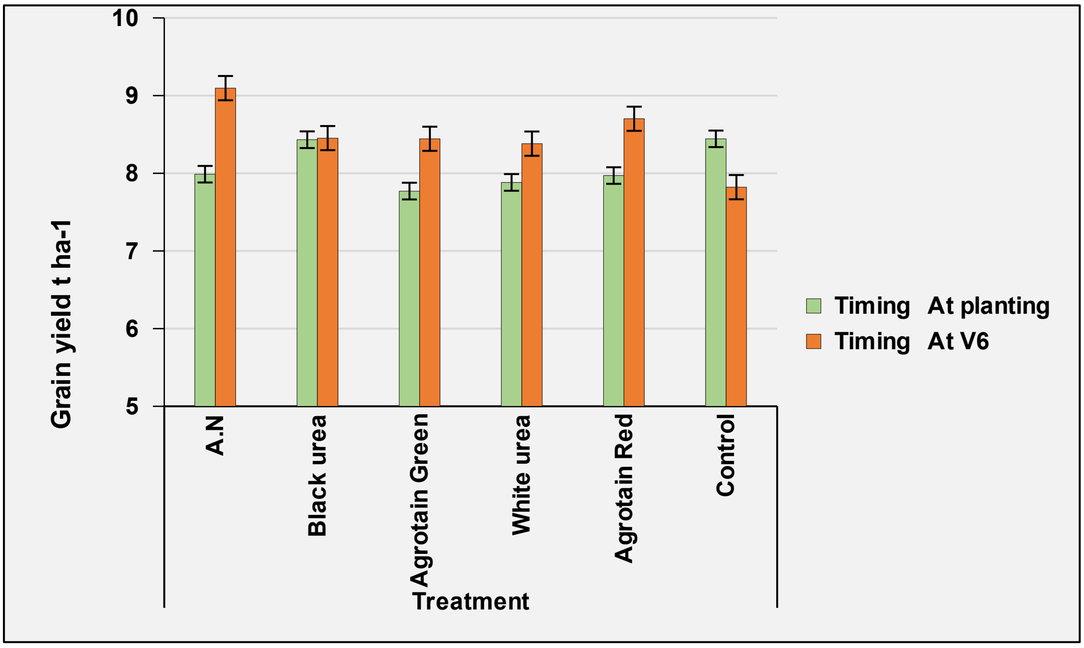

Figure 4.3.4.1: Grain yield by Treatment and Timing

Table 4.3.4.2: Two-way Analysis of variance for Nitrogen use efficiency

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Exp_Site stratum	1	10969.3	10969.3	70.92	
Treatment	5	276.1	55.2	0.36	0.878
Timing	1	388.7	388.7	2.51	0.114
Treatment * Timing	5	755.9	151.2	0.98	0.432
Residual	275	42533.6	154.7		
Total	287	54923.6			

Table 4.3.4.2 shows a Two-way Analysis of variance for Nitrogen Use Efficiency (NUE). There was no significant difference in NUE between the different nitrogen fertilizer types. The results also show that fertilizer timing of application is not significant in determining NUE. The interaction between type of nitrogen fertilizer applied and timing of application of the fertilizer had no significant effect on NUE.

The graph below shows the average Nitrogen use efficiency mean for the interaction of treatment and timing.

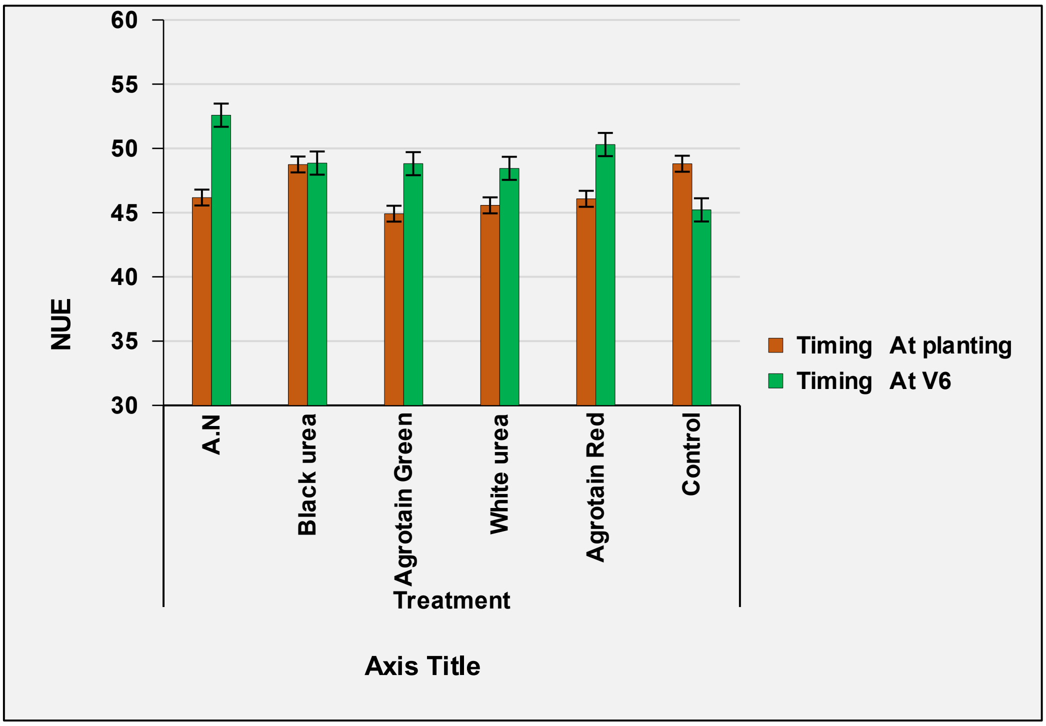

Figure 4.3.4.2: Nitrogen Use efficiency by Treatment and Timing.

The results in figure 4.3.4.3, show that there is a linear relationship between grain yield and available soil mineral nitrogen at the end of the season Y = -0.0708X + 8.4169. The maize yields were higher from the soils where late season mineral nitrogen was reported to be lower.

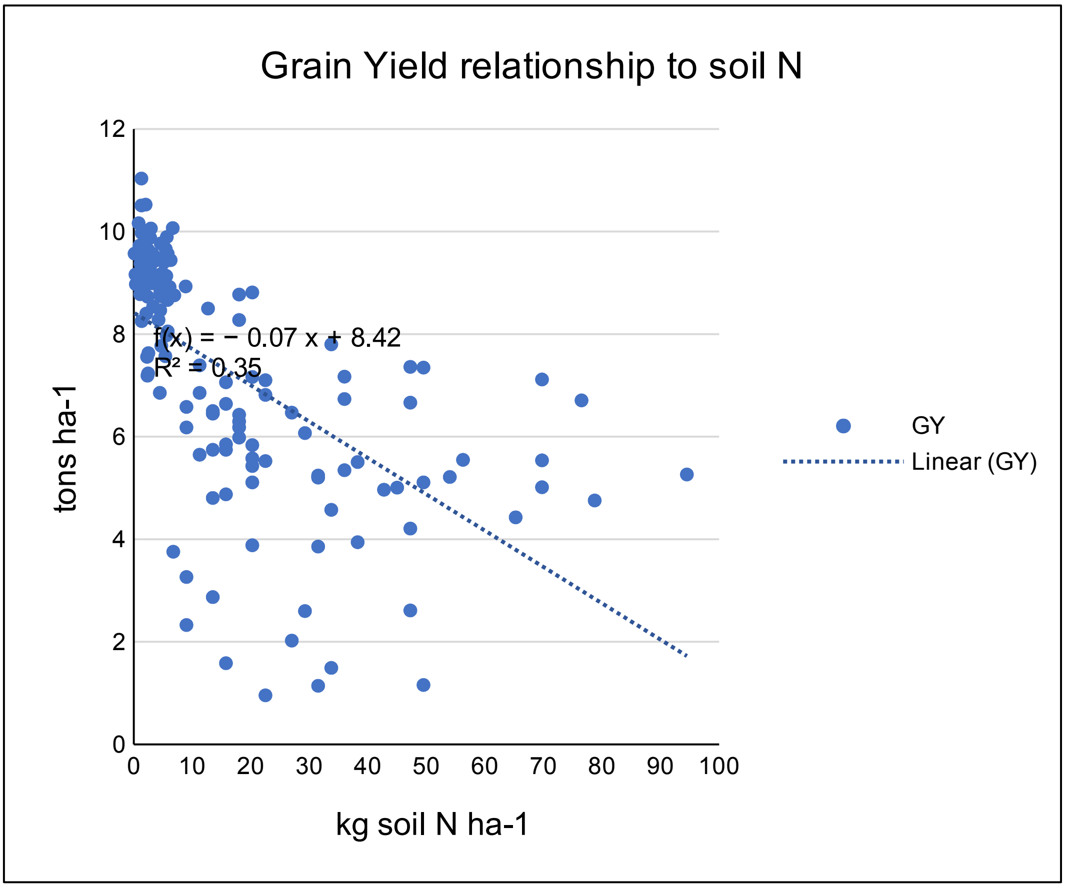

Figure 4.3.4.3: Linear relationship between grain yield and available mineral N in the soil.

4.4. Discussion and Interpretation

4.4.1 Seasonal Rainfall

The experiments were carried out in two different extreme seasons in terms of rainfall pattern. In both seasons, the start of the rain season and the rainfall distribution dictated the timing of the crop management practices. The El Nino weather phenomenon was very dominant in the 2015/16 season. In the dry 2015/16 season, the yields were comparatively low to the 2016/17 season yields and this was attributed to the low-quality rainfall season.

4.4.2 The efficacy and cost effectiveness of varying levels of coated urea application as a maize top-dressing fertiliser on grain yield

This objective in the study was to show the efficacy and cost effectiveness of varying levels of coated urea application as a maize top-dressing fertiliser on grain yield.

At both research sites and at the third additional site at Glenara, it was observed that there was no significant difference in GY and NUE between zero top-dressed plots, half rate (69kg N/ha) and full rate (138kg N/Ha) top dressed plots. Also, the type of top-dressing fertiliser used at different rates did not affect GY and NUE. This is in contrast with research findings quoted elsewhere where productivity of maize significantly increased ($P<0.01$) with increase in ammonium nitrate N rate (Mapanda *et al*., 2011). The lack of significant difference may be coming from several soil and ambient factors such as soil texture, soil organic matter content, inherent soil mineral N status, rainfall/moisture in the season affecting optimum N uptake by the crop. Initial soil analysis results before planting (tables 4.3.1 – 4.3.4) indicates very low (N<15ppm) to low (15ppm-25ppm) residual nitrogen levels in the soil system. This was not adequate for the maize crop without additional N application through basal fertiliser and N top dressing. Local research recommends that after incubation mineral N <15ppm, is Very low, mineral N 15ppm – 25ppm is Low; mineral N 25ppm – 40ppm is Medium; mineral N > 40ppm is High (Guide to the meaning of Soil analysis - Chemistry and Soil Research Institute, Ministry of Lands, Agriculture and Rural Resettlement- Zimbabwe (unpublished)). The initial soil analysis reports for the 2 seasons prior to planting also reported high organic matter content in the tillage layer at SRC (4.08%; 4.16%; 4.12%; 3.34%; 3.11%) but low to medium levels of soil organic matter at RARS (0.99%; 1.15%; 1.08%, 2.57%; 2.98%; 2.69%). The practice at these sites is that maize stover from the last crop is disced in during land preparation 2-3 months before the onset of planting rains and this fresh stubble may have played a part in releasing more N to the soil. The reported high organic matter in the soil at SRC is suspected to have resulted in the soil being able to mineralize and release N to the soil and therefore resulting in the plots (including no N top-dressed plots) having enough N leading to an indifferent high GY. Agrotain- green had the lowest GY and NUE (figs. 4.4.1.2 and 4.4.1.5). This is attributed to the higher volatilization characteristic of this top-dressing N fertiliser soon after application revealed in figure 4.4.2.1. The plots where this fertiliser was applied might have had substantial N volatilisation losses in the first period soon after top dressing and this effect has been confirmed by the low NUE and GY resultantly. Grain yields from the El Nino affected season of 2015-2016 were still satisfactory even though rain received at RARS was just below average (622mm against 700mm average) and just above average at SRC (842mm against 700mm average). The lack of response to N application on all the treatments above could be because of the high nitrogen release from organic matter. This was corroborated by the very high organic matter content in the soil. Because of this high N release, the nitrogen from the fertilizer did not significantly affect yield. Trends from the control treatment on yield are not agreeable to the findings by Zebarth & Rosen, (2007) that insufficient fertilizer N application will result in loss of crop yield.

Chlorophyll (SPAD) values at both growth stages irrespective of treatment or rate, showed no significant statistical difference across treatments as reported in figure 4.4.1.6 above. Table 4.4.1.6 shows that there was no significant interaction ($P \geq 0.05$) between chlorophyll (SPAD) values and treatment, rate, timing of top dressing and treatment x timing. This was contrary to research by Bullock & Anderson (1998) and Janos (2010) who reported that chlorophyll (SPAD) values at R1 growth stage significantly increased with increase in N application rate. High N levels in the soil from organic matter decomposition are suspected to have resulted in the observed very high chlorophyll (SPAD) values averaging 57.9-62.1 in the two seasons at both sites. Nitrogen is part of the enzyme associated with chlorophyll synthesis (Chapman & Barreto, 1997) and increasing N application is normally associated with increased N content and chlorophyll content in maize (Pandey et al., 2000; Rambo et al., 2010). In the case of this experiment the additional N fertilizer did not affect chlorophyll content since the soil already had adequate N from organic matter release. This confirms high N availability in the soil system for the maize as the recorded values averages mentioned above were well above global norms for maize at 35 (Ercoli et al., 1993). This was congruent to findings by (Liu & Wiatrak, 2012). The observation that yields were higher from the soils where late season mineral nitrogen was reported to be lower in the soil (Fig.4.4.4.3) means that there was equally efficient use of the inherent nitrogen and the resultant high yields across the 6 different treatment scenarios. Research needs to be carried out to establish if there was any other factor that caused lack of marginal response to the applied N apart from the suggested N release from organic matter. Nielsen (2006), noted that the use of agronomic crop production practices that help ensure the development of a vigorous healthy crop will also increase the probability of a high NUE. Important decisions under the farmer's control include variety selection, planting date, seeding rate, soil fertility in general, pest management and tillage practices. This researcher further indicated that NUE is primarily influenced by two factors. One is the health of the 'photosynthetic factory' (the corn crop). A healthy vigorous crop represents a 'factory' operating at maximum efficiency and one that uses all its available resources efficiently. The second factor that influences NUE is the frequency and severity of N loss opportunities within the nitrogen cycle. All NUE recordings in this research are above expected minimum for maize which stands at 35. The observed NUE were within the 25-80% range reported elsewhere (Nyamangara *et al*., 2003; Bergstrom, 1987; Kamukondiwa & Bergstrom, 1994; Korenkov *et al*., 1975; Jokela & Randell, 1997). This is congruent with the research that overall NUE in cereals production systems worldwide is estimated to be 33 percent (Raun & Johnson, 1999).

4.4.3 Comparison of the extent of volatilisation and leaching of different forms of nitrogen top-dressing fertilizers

The objective of the study was to compare the extent of nitrogen losses via volatilisation and leaching across different types of coated and non-coated nitrogen topdressing fertilisers.

Laboratory experiments on volatilisation losses of NH_3 gas from the five NH_4^+ based top dressing fertilisers namely plain White urea (WU) 46% N, coated Black Urea® (BU) 45.5% N, Agrotain coated Nitrex Red/Green urea -(Aborite U) 46% N, N-(n-butyl) thiophosphoric triamide (NBPT) coated urea 46% N, and ordinary Ammonium Nitrate (A.N) 34.5% N were carried out. There was an increase in volatilisation of the treatments till they all reached an optimum value of 100ppm over time and varying temperature. Figure 4.4.2.1 shows that the volatilisation trend of A.N was a graph that reached the 100ppm mark in just 4 hours' time making it significantly different from the graph of NBPT coated urea whose volatilisation characteristic was slowest starting with a flat graph along the horizontal axis or nil volatilisation in the first half day and increased slowly over 2 days to reach the 100ppm mark. Kissel, *et al*., (1988) reported that when urea hydrolysis occurs at or near the soil surface, ammonia is lost in to the air via volatilization NH_4^+ *(d)*$\leftrightarrow$$NH_3$ *(gas) (Eqn.2).* The above result shows that NBPT fertilizer N coating reduces losses of nitrogen as NH_3 gas in high temperature and moist environments. The less nitrogen is lost, the more nitrogen you have in the soil for improved plant growth and yield potential. The following factors are known to influence ammonia volatilization in soils: soil moisture, temperature, pH, naturally-occurring free lime in the soil, ground cover, wind, soil clay, %, humidity, and fertiliser type, and other factors (Schwenke, *et al*., 2008, 2009). In this experiment the following factors are suspected to have influenced ammonia volatilization: soil moisture, 'micro-zone pH' of the region surrounding the fertiliser granule where the reaction was occurring, temperature, and fertiliser type. High soil or ambient temperature cause higher rates of $NH_{3(g)}$ volatilization because they increase soil concentrations of $NH_{3(g)}$ dissolved in soil water ($NH_{3(d)}$). Liu, *et al*., 2013 observed that ammonia gas loss increases greatly when environment temperature is over 15 degrees Celsius. At temperatures below 7 degrees Celsius, $NH_{3(g)}$ loss is limited. This explains why the trends in the experiment show increasing volatilisation with increasing day temperature that ranged from 28 – 34 degrees Celsius (Fig. 4.3.2.1). This is one reason why applying urea during periods with forecasted cool temperatures is recommended to reduce volatilization, especially on high pH soils. Other reasons are that urea hydrolysis rates are higher at higher temperatures, and $NH_{3(g)}$, like all gases, is more volatile at higher temperatures (Jones *et al.*, 1995). However, pH near a urea granule or fluid droplet can be substantially higher than the surrounding soil because urea hydrolysis raises pH by removing hydrogen ions (H^+) from the soil solution and produces bicarbonate (*Eqn. 1*) which raises pH around the reaction zone (Hunter & Mark, 2013). Volatilization of top-dressed urea increases linearly as soil water content increases, until the soil reaches saturation. Conversely, volatilization decreases dramatically as urea is moved below the soil surface, either through incorporation or movement by rainfall (Jones *et al*., (1995). High moisture conditions common during early to mid-summer in Zimbabwe can increase volatilisation risk of surface applied urea. Hydrolysis approaches zero when the soil is dry as the conversion requires water. Wet soil dissolves fertiliser but does not move N into the soil, Schwenke, *et al.,* (2008). Volatilisation of A.N is likely to have been accelerated by the applied water and high temperature that led to quick hydrolysis and dissociation of $NH_4.NO_3$. Ammonium nitrate is a highly soluble salt and when dissolved in water it ionises to produce NH_4^+ and NO_3^- ions, it reacts as follows:

$NH_4NO_3 \rightarrow NH_4^+ + NO_3^-$ *(Eqn. 10).*

The reaction is neutral and the effect of NO_3^- anions on pH is negligible. The NH_4^+ ions are subjected to volatilisation as follows:

$NH_4^+ \rightarrow NH_3(d) + H^+$ *Eqn. 2*

$NH_3(d) \leftrightarrow NH_3(gas)$ *Eqn.3 (Volatilization)*

The witnessed fast volatilisation trend of A. N was not pH related but was due to high moisture, high temperature and susceptible fertiliser type (Connell, *et al*., 1979; Gardinier, *et al*., 2013). With NBPT urea, the effects of moisture, temperature, pH were resisted for longer time, hence delaying the activity of urease to initiate volatilisation. Analysis of variance on the results obtained in this experiment when comparing the urea-based fertilisers alone, showed that Agrotain coated urea (Aborite) volatilised significantly faster than plain urea, Black urea and

NBPT urea up to ¾ level of the experiment while the speed at which ammonia was lost from plain urea and Black urea was equal at mid-way of the experiment. Reviewed literature states that, soils of less than 2% organic carbon (or where carbon is not bio-available), low in nutrients or soils with a lower nutrient holding capacity will further enhance Black urea resistance to volatilisation. (Advanced Nutrients). The field soil that was used for this experiment had high organic matter and high nutrient holding capacity that made it difficult to produce clearly different volatilisation results between plain urea and organic coated Black urea.

Plain white urea initially volatilised slightly slower than Agrotain coated urea (Aborite) but did not persist to the end at this rate and this showed the positive effect of fertiliser coating technologies at reducing volatilisation process on NH_4^+ based fertilisers where the rate retarded in the final quarter. Jones *et.al*., (2013) had similar observations that losses of $NH_{3(g)}$ were greatest during the first two weeks and were reduced or delayed by Agrotain. Black urea and plain white urea had almost a similar trend with the later finishing more resistant as shown in graph 4.3.2.1. NBPT coated urea was significantly the most resistant to volatilisation throughout the experiment. It took 2 days for NH_3(g) evaporated from NBPT coated urea to reach the 100ppm $NH_{3(g)}$ mark. The trend by NBPT urea has revealed that coating urea with N stabilisers or urease inhibitors delayed and reduced volatilisation. This aligns with the research by Jones *et al*., (1995) who explained that urease inhibitors or nitrogen stabilisers help arrest N losses via urea hydrolysis. Similar findings were reported by Zhao, *et al*., (2013) who observed that $NH_{3(g)}$ volatilisation was highest for the Common Compound Fertiliser (CCF) treatment, and most N losses occurred within the first 2–12 days after CCF application compared to first 9–20 days after Controlled Release Fertiliser (CRF) application. Krajewska, (2009) observed that when urease is absent, urea hydrolysis proceeds much slower, at 10^{14} times slower than the catalysed reaction. The trend of Agrotain coated urea (Aborite) in the first ¾ of the experiment shows that this stabiliser Agrotain is not very good and can lead to substantial N losses compared to plain white urea despite becoming more resistant to volatilisation compared to plain urea in the final ¼ of the trends. This tallies with the earlier discussion that average grain yields (8.11t ha^{-1}) achieved from Agrotain treated plots were the lowest in this research (fig. 4.3.1.2). Similar findings were from Zhao, *et.al*., (2013) who observed that the maximum flux of $NH_{3(g)}$ increased to 3.36 kg N ha^{-1} d^{-1} 2 days after the application of Common Compound Fertiliser (CCF), and then rapidly decreased to approximately 1.18 kg N ha^{-1} d^{-1}. However, the flux of $NH_{3(g)}$ from Controlled Release Fertiliser (CRF) treatments was significantly lower than that of the Common Compound Fertiliser (CCF) treatment. $NH_{3(g)}$ volatilisation fluxes from Controlled Release Fertiliser (CRF) treatments peaked later than those of Common Compound Fertiliser (CCF).

According to Du Preeze & Burger (1987), these differences in speed of $NH_{3(g)}$ volatilisation from the fertilisers can be explained in terms of their composition and properties including form of nitrogen, associated anions and pH of the fertiliser solution. The difference in quality and types of the urea coating/stabiliser materials contributed to the variation in the volatilisation trends of the 5 fertilisers at varying temperature.

It is probable that that the $NH_{3(g)}$ losses observed in the research were influenced by a combination of soil moisture, increasing day temperature, susceptible fertiliser type and raised pH in the surrounding urea granule micro-zone.

Leaching

Leaching was studied through repeated soil sampling and analysis for N at three depths per core and at two intervals of the maize production period across the two main research sites. The results from both stations for the two seasons did not show any significance of leaching on the five fertilisers and all values are above the 0.05 p-value. The sandy clay loam soil texture and high organic matter content reported from the initial soil analysis results mighty have caused the low leaching observed. High organic matter content, and high clay content in the soils are attributed to the retention of N via exchange and immobilisation. Leaching from the top 15cm depth was significant ($P = 0.0315$) at RARS in 2016 at mid-season sampling. This is suspected to have been influenced by the gravely sandy-clay-loam soil texture of the site. It is suspected that big particle size of the gravel in this field gave easier leaching passage to the fertiliser. The observations in this research show that lack of significant difference in N levels across the three depths ($P \geq 0.05$) from the effects of timing of the N application explains that leaching was independent of fertiliser application timing in this research but was influenced by other factors other than timing of application. Split application of N should theoretically result in increased N efficiency and reduced nitrate losses because of greater synchronization between time of application and crop uptake. Plain white urea, amongst the urea-based fertilisers recorded the lowest N levels in both the 15cm and 45cm depths in 2016 compared to the coated urea, signifying that it was prone to leaching movement beyond the root zone. This was observed in both season 1 and season 2 and across the two research sites. This also reveals that at least some N leached (though not substantial) from the applied top-dressing fertilisers while the little inherent N in the control plots is suspected to have been exhausted by plant uptake and other pathways other than leaching. Other studies (Hagmann, 1994; Vogel *et al*., 1994) on sandy soils in Zimbabwe revealed that most of the nitrogen fertiliser (up to 54% of applied N) was leached out of the top 0.5m of top soil when heavy rains followed N fertiliser application. It is suggested that the experiments on leaching are carried over various regions across the country with varying soil texture, soil structure and different rainfall among other factors.

4.4.4 Market perception on coated nitrogen for top dressing maize

The objective of the study was to establish the relationship between consumer awareness and consumer attitude towards perception and adoption of a product such as coated nitrogen.

Coated nitrogen fertilisers have been on the market for almost a decade in Zimbabwe, but their use is not rising due to various factors of which some of them were observed by the researcher through the questionnaire survey. Locally manufactured granular Ammonium nitrate (34.5% N) is the dominantly used type of top-dressing fertiliser by all farmer categories (at 46.7%) mainly because it is easily available throughout the retail chain and has been the traditional option for a very long time despite its volatilisation, leaching and or nitrification challenges. Access to A.N by the farmers or the contractors is far much easier, and it is believed to be cost effective as this is produced from the local industry. Eighty percent of surveyed farmers in Zimbabwe, of which 16% were smallholder communal growers, use top dressing fertiliser because they understand the positive effect of nitrogen on grain yield. The survey reported that the second commonly known type of top-dressing fertiliser for maize is plain white urea (46%N) because these two are the most dominant on the local market. Mostly commercial farmers use the plain urea option as they are in regions of better rainfall or have supplementary irrigation options to quickly incorporate it into the soil. Farmers concur that ammonium nitrate and plain white urea are prone to volatilisation and leaching challenges leaving their crops with little N available for uptake, but there is information deficiency on any other alternatives from modern improved technologies such as coated nitrogen for crop top dressing. This is attributed to high prices and lack of product marketing campaigns by the manufacturers and traders of the alternatives. The revealed challenges on application timing with ammonium nitrate and plain white urea that farmers face and the resultant inefficiencies from these challenges (Table 4.3.3.3) are attributed to lack of advancement on farming equipment, modern fertiliser technologies and lack of climate change information. Farmers explained how their applied fertiliser is wasted due to poor moisture availability and ultimately low production yield. The rain fed communal maize cropping systems that are mainly affected by low moisture, climate change constraints and other N loss factors will be improved by adoption of coated nitrogen. Findings from this research indicate that adoption of coated nitrogen that was observed to be tolerant to N loss by volatilisation in maize cropping especially with rain fed communal production systems is the future for maize production intensification. The positive characteristic on volatilisation tolerance of coated N is well evidenced not only from the carried-out volatilisation experiment by the researcher in chapter 4 and some of the reviewed literature but also from the surveyed farmers where coated Black urea is the second most preferred top- dressing option at 33% by commercial maize farmers.

Contractors and non-governmental farming organisations have been promoting adoption of coated nitrogen options especially among commercial growers in contract production schemes. However, 75% of surveyed farmers expressed that they needed more product information to get inspired to adopt the coated products. This has managed to put the technology on the limelight with commercial growers reached by contractors and they appreciate the differences in performance with the traditional A.N and white urea. Transfer of knowledge and information to the communal growers' category has been observed to be very slow due to factors such as risk aversion on the part of the farmers, unavailability of the products in the retail shops in their vicinity, lack of enough cash to afford them as they are perceived expensive. In tandem with survey findings on table 4.3.3.4, over reliance on donors and the government for fertiliser and other farming inputs was noted to have killed the desire by the smallholder communal farmers to adopt new technologies as they simply go by the free prescription from the donor. In the inputs schemes by the government, ammonium nitrate and urea are the dispensed top-dressing fertilisers because they are cheap, readily available and A.N is locally manufactured. Therefore, the survey recorded that for the market share of coated fertiliser to increase, the government and other private partners in farming inputs support programmes must be approached and convinced on the costs and benefits of these modern technologies for yield improvement at optimum cost and minimal losses that reduce pollution of the environment. To promote adoption and uptake of coated nitrogen by all farmer categories, more community-based product demonstration plots for farmers to witness performances of the technology from their local areas must be established. The survey exposed that market campaigns by the marketers of coated nitrogen must improve and synchronise with research-based agronomy explanations. Findings from this study that include prolonged resistance to volatilisation will ensure fertiliser cost efficiency and more N for plant uptake in dryland maize production systems where moisture levels are not consistent have to be narrated clearly to maize farmers for improved production. The survey noted that product pricing is one of the factors delaying adoption. This is suspected to be associated with the high cost of production and importation costs of coated N fertilisers. Marketers must review their pricing models to penetrate the market and avail the product within the retail chain otherwise the perception that coated nitrogen is expensive and is a special product for top class farmers will not go away. Top dressing fertiliser cost/ha analysis on table 4.3.3.5 defeats the notion that locally manufactured A.N is cheaper and cost effective per ha. The calculations show that urea or coated urea fertiliser has higher economic efficiency per unit of nitrogen because it is of high analysis (46%N). Fertiliser manufacturers and merchants make more business from selling ammonium nitrate, hence it is more available on the market, but farmers do not realise that they pay more on A.N than using coated urea. If this analysis is well explained to the farmers coupled with the evident positive volatilisation resistance results of stabilised urea, there will be more demand for coated top-dressing nitrogen from farmers. Table 4.3.3.6 shows how coated N fertiliser return on investment (ROI) significantly increases at 5% grain yield increase. Hirel *et al*., (2007), noted that nitrogen stabilizers on average increased corn yields by 370 kg/ha and held an average positive return on investment of $39.88/ha.

4.4.5 The effect of timing application of different quantities of coated/non-coated nitrogen top-dressing sources on soil mineral N availability and maize yield

The objective of the study was to investigate the impact of timing of variable quantities of coated/non-coated nitrogen top dressing options on soil mineral N availability and maize yield. Soil mineral N availability is a function of various factors that include soil organic matter, source/form of added N, prevailing N loss pathways, soil pH, soil moisture content and soil temperature (Mengel, 2013). The researcher found that timing of N application in maize had no significance in determining grain yield, and nitrogen use efficiency. This is attributed to availability of inherent N in the soil since there was no significant grain yield difference between top-dressed plots and control plots. There was higher but not significant GY and NUE (figures 4.3.4.1 and 4.3.4.2) from A. N top-dressing timed at V_6 compared to that timed at planting. This is attributed to the fact that nitrogen in A.N is half NH_4^+ and half NO_3, but ammonia is prone to volatilisation while nitrate is prone to leaching losses if applied before peak N demand in the crop's physiological development which commences from the V_6 stage. Only a fraction of N is needed (starter N) during the seedling stage, but corn's N requirements escalate rapidly by V_6 growth stage. During the next 30 days, corn can advance from approximately knee-high to the tassel stage of development if conditions are favourable, requiring over half its total N supply. Pioneer DuPont- Heartland Book, (2016). The interaction of fertiliser application timing and type of coated nitrogen fertiliser used for top dressing also was not significant in determining both grain yield and nitrogen use efficiency. This means there were other factors stronger than top-dressing application timing and type of coated N source that were driving grain yield. Measuring yield responses to nitrogen stabilizers in various crop species can be difficult because environmental conditions also dictate plant uptake of nutrients. Frame *et al., (*2013) saw an increase in nitrogen content in corn ear leaves using NBPT on granular urea at tasselling at 5 out of 10 locations in Virginia; however, a yield response to NBPT was only detected at 3 out of the 10 locations during the same study. The use of nitrogen stabilizers should be aimed at ensuring minimal loss of nitrogen. Minimizing loss of nitrogen will allow more nitrogen to be available for uptake and may increase yields compared to the appropriate reference nitrogen fertilizer. The results in figure 4.4.3, show that there is a linear relationship between grain yield and available soil mineral nitrogen at the end of the season

$Y = -0.0708X + 8.4169$. The maize yields were higher from the soils where late season mineral nitrogen was reported to be lower meaning there was also a linear relationship between available N and crop uptake of N. However, in congruence with earlier researches, the nitrogen is not used efficiently and exhaustively, and wheat plants, for example, assimilated only 41% of the nitrogen applied while with conventional fertilizers, only 50% of the available nitrogen is taken up by plants (Zebarth & Rosen, 2007). However, the results of the research suggest that management practices alone will not prevent all losses (e.g. by volatilisation or denitrification), and it may be necessary to use enhanced efficiency fertilisers, such as controlled release products, and urease and nitrification inhibitors, to obtain a marked improvement in efficiency. This inverse relationship in the above equation explains that maize plants also provided a sink for the mineral nitrogen, among other N loss or utilisation pathways, hence grain yield also reflects the amount of N left in the soil. Zebarth & Rosen, (2007) documented that some of these products (e.g. nitrification inhibitors) when used in Australian agriculture have increased yield or reduced nitrogen loss in irrigated wheat, maize, cotton, and flooded rice. When climatic extremes limit crop yield (e.g., drought, excess water, heat stress, wind damage), crop N uptake can be reduced, and excess N remains in the soil at the end of the cropping season. This concurs with the observations during this research in 2016 after the El Nino drought where higher levels of mineral N were reported in the soil analysis results. The findings in figure 4.2.4.3 underscores the need for early N application to avoid high residual N at the expense of grain yield.

Summary

In this research, coated nitrogen like NBPT showed distinct resistance to quick volatilisation over time and at increasing ambient temperature compared to non-coated plain urea and ammonium nitrate. Coated nitrogen is strongly recommended for use by the smallholder maize farmers in Zimbabwe and other sub-tropical regions with inconsistent climatic patterns that lead to quick nitrogen losses resulting in poor maize yields. The experiment results are clear that the current challenges of top-dressing split application and or poor application timing can be resolved by use of these fertiliser coating technologies and achieved improved yields. More product information to encourage uptake of efficiency enhanced nitrogen fertilisers (EEF) by not only the smallholder maize farmers but also the commercial maize farmers has to be dispensed to the practising farmers so that their real challenges with current conventional nitrogen sources on the market are addressed for improved N management, economic fertiliser efficiency and resultant better grain yields.

The researcher recommends further research of all parameters in this work across a broader region with variable climatic & soil characteristics, altitude, etc.

CHAPTER 5

CHAPTER 5 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

Like any other research, this work had findings that were contrary to other earlier research works by other researchers and on the other flip side of the coin, the work had findings that supported findings by other researchers.

5.2 Discussion

The study shows that there is no significant difference between the mean grain yield and nitrogen use efficiency at full nitrogen fertilizer top dressing recommendation of 138 kg N/ha and at the half nitrogen fertilizer top dressing recommendation of 69 kg N/ha compared to the zero top-dressing. This implies that the available N in the soil was adequate for the final grain yield and NUE. Coating fertilizer nitrogen did not result in any significant increase in Chlorophyll level, maize yield or nitrogen use efficiency. This means the source of N did not matter if the optimum N requirement is achieved through the correct application timing during optimum environmental conditions or achieved from residual soil nitrogen.

Non-coated nitrogen in the form of plain urea and A.N. lost N via volatilisation with the later expressing very significant volatilisation. Coated nitrogen fertilisers showed tolerance to N volatilisation with NBPT being the most tolerant. There was no significant increase in leaching rates from the five N fertiliser types. This implies that the soil texture and soil organic matter content had high capacity to hold nitrogen against leaching. The timing of N application did not result in significant increase of leached N across the three depths ($P \geq 0.05$) meaning that leaching was independent of application timing but is influenced by other factors other than timing of application.

The survey findings reveal that currently farmers mostly use locally manufactured ammonium nitrate top dressing fertiliser followed by plain white urea because they are readily available in the shops and they have been using them for many years. Contractors and non-governmental farming organisations have been driving adoption of coated nitrogen options especially with commercial growers in contract production schemes. Coated Black urea is the second most preferred top-dressing fertiliser by commercial maize farmers. The surveyed farmers elaborated their need for more product information to get inspired to adopt the coated nitrogen products. This implies that efforts to promote adoption of the coated N technologies remain futile if the mentioned contributing factors for slow adoption are not addressed first. The study showed a linear relationship between grain yield and available soil mineral nitrogen at the end of the season. This implies that higher maize yields are mostly likely to come from the soils where late season mineral nitrogen is reported to be lower meaning that optimum timing of N application is always advantageous compared to late application timing.

The results of the research study suggest that management practices alone will not prevent all N losses (e.g. by volatilisation, leaching or denitrification), and it may be necessary to consider other options like enhanced efficiency fertilisers (EEF), such as controlled release products, and urease and nitrification inhibitors, to obtain a marked improvement in fertiliser efficiency.

5.3 Conclusions

The results of this study demonstrate that there was no significant difference on grain. Yield, NUE and chlorophyll content across all treatments due to treatments meaning. The soils had adequate residual N and good levels of organic matter. Coating of nitrogen fertilizers improved its efficiency against volatilization. The study showed that as maize yields increase, more N is removed from the soil. There is potential for adoption of EEFs by the maize farmers in Zimbabwe once product knowledge is imparted to them.

5.4 Implications

Essence of soil analysis prior to planting is always helpful not only in fertilizer rates to be applied and the timing but also in avoiding economic cost on nutrition that is already available in the soil. In the study nitrogen was added to the crop but gave an indifferent performance to the control of which was attributed to availability of high residual nitrogen adequate for crop requirement. Smallholder farmers must be helped to understand and embrace the importance of soil analysis versus the use of traditional and general recommendations on crop fertilizer applications. The study gave light on the type of top-dressing fertilizers that are easily lost through volatilization at the expense of crop uptake and this will give important lessons to smallholder maize cropping to mitigate N losses at critical growth stages and improve crop available N uptake for improved grain yield. This is the only way in which our valuable natural resources (soil and the environment) can be maintained in this new era of climate change. A paradigm shift is essential in adopting the climate smart new products/technologies and approach to farming as a business. The study established an inverse relationship between residual soil mineral nitrogen and grain yield at the end of the season (figure 4.2.4.3). These findings underscore that late timing will always lead to higher residual mineral N and lower grain yield. Marketers in the fertiliser industry should seek to educate Zimbabwean maize farmers not only on the available top-dressing fertiliser options but also on the technical differences and economic impact of the available options with respect to maize production. The study revealed that farmers do not have information on available alternative N top-dressing products and technical understanding of what they are working with. This implies that farmers should be continuously imparted with information on both current and new technologies, products and equipment they use every day for the success of their business. A knowledgeable farmer is a reliable and successful business.

The study will help agriculture policy makers and grain contractors to introduce mandatory soil analysis to farmers coupled with a wider choice of N top-dressing products and technologies to ensure food security through sustainable maize production in this new era of precision farming, climate change and its adverse effects.

5.5 Recommendations

Maize production farmers in Zimbabwe are recommended to make sure they apply adequate amount of nitrogen from coated or non-coated sources, to get optimum grain yields and consider using volatilisation tolerant top-dressing fertiliser options where N loss potential through evaporation is very high. Farmers in maize cropping are recommended to time N top-dressing fertiliser early for optimum use of applied top-dressing nitrogen in maize production and avoid high levels of residual N levels in the soil system at the end of the season. It is recommended that farmers respect and consider residual N findings from soil analysis results before pumping more N where nitrogen levels are already satisfactory for good grain yield and reduce cost of production.

5.6 Suggestions for Further Research

Research gap is on total substitution of the conventional ammonium nitrate with coated/stabilised nitrogen sources across the cropping sector to deal with drawbacks from N loss via volatilisation. The researcher recommends that the experiments for volatilisation and leaching by future researchers, must be carried out at different soil pH, and variable fertiliser rates and variable soil texture. More conclusive results will be achieved if these laboratory experiments on volatilisation are repeated on a wider scale with replicate field experiments across various soils of different characteristics in different climatic regions. On leaching, it is suggested that the experiments are carried over various maize producing regions in the country with varying soil texture, soil structure, different rainfall/moisture, and over a couple of seasons.

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APPENDICES

Appendix 1: Farm 'treatment to plot' layout after randomization

RARS farm 'treatment to plot' layout

Rep 1

8	15	17	18	14	2	5	22	20	24	16	3
19	13	7	11	9	1	6	12	21	10	23	4

Rep 2

23	11	24	14	7	5	9	1	12	4	22	16
20	3	18	2	10	15	21	6	19	8	17	13

Rep 3

1	12	8	6	20	2	7	11	22	9	10	13
17	19	15	21	5	4	3	14	18	16	24	23

Stapleford Research Centre ‘treatment to plot’ layout

Rep 1

16	1	18	2	20	21	5	6	19	12	14	22
23	15	10	3	11	24	13	17	8	9	4	7

Rep 2

10	24	18	1	5	22	19	6	21	7	13	16
2	15	14	12	20	23	8	3	11	9	4	17

Rep 3

1	12	8	6	20	2	7	11	22	9	10	13
17	19	15	21	5	4	3	14	18	16	24	23

Glenara estate ‘treatment to plot’ layout

Rep 1

5	17	10	7	16	14	1	11	22	19	6	13
23	21	8	20	3	9	12	2	15	18	24	4

Rep 2

18	20	21	17	5	8	1	23	3	6	22	16
9	14	12	15	2	11	10	24	19	13	7	4

Rep 3

1	20	3	8	24	18	11	10	16	23	14	22
17	5	4	12	19	2	21	15	9	6	7	13

Appendix 2: 2015 -2016, 2016 -2017 Initial soil analysis results

RARS – 2015 Soil analysis results

Analysis description	**Rep 1**	**Rep 2**	**Rep 3**
Soil Texture	Sand Clay Loam	Sand Clay Loam	Sand Clay Loam
Soil pH (0.01M $CaCl_2$)	4.4	4.6	4.6
Available Phosphorus (ppm)	29	26	33
Exchangeable Potassium (me %)	0.84	0.83	0.72
Exchangeable Calcium (me %)	2.06	3.01	2.97
Exchangeable Magnesium (me %)	0.58	0.93	0.63
Exchangeable Sodium (me %)	0.11	0.09	0.09
Soluble Sulphur (ppm)	16	13	13
Available Copper (ppm)	9.92	10.72	10.09
Available Zinc (ppm)	5.22	5.15	4.64
Available Iron (ppm)	88	91	96
Available Manganese (ppm)	193	181	168
Available Boron (ppm)	0.27	0.28	0.27
Initial mineral nitrogen	11	14	12

(ppm)			
Organic matter (Humus) %	2.57	2.98	2.69

SRC – 2015 Soil analysis results

Analysis description	**Rep 1**	**Rep 2**	**Rep 3**
Soil Texture	Sand Clay Loam	Sand Clay Loam	Sand Clay Loam
Soil pH (0.01M $CaCl_2$)	4.5	4.6	4.5
Available Phosphorus (ppm)	39	33	43
Exchangeable Potassium (me %)	1.21	0.98	0.84
Exchangeable Calcium (me %)	2.12	3.06	2.38
Exchangeable Magnesium (me %)	0.54	0.7	0.61
Exchangeable Sodium (me %)	0.09	0.1	1.22
Soluble Sulphur (ppm)	16	11	13
Available Copper (ppm)	13.98	12.56	12.29
Available Zinc (ppm)	7.96	6.86	6.25
Available Iron (ppm)	107	99	101
Available Manganese (ppm)	215	198	169
Available Boron (ppm)	0.32	0.24	0.31
Initial mineral nitrogen	13	17	14

(ppm)			
Organic matter (Humus) %	4.08	4.16	4.12
Aluminum* (ppm)	850	824	799

RARS – 2016 Soil analysis results

Analysis description	Rep 1	Rep 2	Rep 3
Soil Texture	Sand Clay Loam	Sand Clay Loam	Sand Clay Loam
Soil pH (0.01M$CaCl_2$)	5.13	5.37	5.26
Available Phosphorus (ppm)	52	46	47
Exchangeable Potassium (me %)	0.34	0.69	0.54
Exchangeable Calcium (me %)	1.7	2.9	2.2
Exchangeable Magnesium (me %)	0.5	0.8	0.7
Exchangeable Sodium (me %)	0.00	0.00	0.03
Soluble Sulphur (ppm)	17.03	17.34	16.23
Available Copper (ppm)	0.52	1.11	0.68
Available Zinc (ppm)	0.02	0.23	0.26
Available Iron (ppm)	8.17	10.74	9.87
Available Manganese (ppm)	26.42	33.73	30.03
EC (micro S/cm)	64	62	65
Mineral nitrogen	9	11	7
Organic matter (Humus) %	0.99	1.15	1.08

SRC- 2016 Soil analysis results

Analysis description	Rep 1	Rep 2	Rep 3
Soil Texture	Sand Clay Loam	Sand Clay Loam	Sand Clay Loam
Soil pH (0.01M$CaCl_2$)	5.43	5.28	5.37
Available Phosphorus (ppm)	47	51	39
Exchangeable Potassium (me %)	0.36	0.59	0.51
Exchangeable Calcium (me %)	2.1	2.7	2.4
Exchangeable Magnesium (me %)	0.6	0.9	0.7
Exchangeable Sodium (me %)	0.14	0.09	0.10
Soluble Sulphur (ppm)	15.08	17.14	16.73
Available Copper (ppm)	0.42	1.21	0.57
Available Zinc (ppm)	0.02	0.29	0.22
Available Iron (ppm)	6.17	12.73	10.27
Available Manganese (ppm)	37.42	31.93	34.06
EC (micro S/cm)	76	66	59
Mineral nitrogen	15	12	13
Organic matter (Humus) %	2.84	3.11	3.34

Test conditions:

1. Trace elements – extracted using EDTA pH 7.00
2. Exchangeable cations – extracted using 1.0M Ammonium Acetate pH 5.8
3. Initial mineral nitrogen – Kjeldahl after extraction with 0.01M KCl
4. Electrical conductivity – 1part soil extracted with 5 parts distilled water

5. Ph – extraction with 0.01M $CaCl_2$
6. Phosphorus – Mehlich III method

Appendix 3: Questionnaire

Instructions to complete the Questionnaire.

1. Practicing commercial or smallholder maize farmer is only eligible to complete this questionnaire.
2. Please do not fill in the information that you do not know or not well informed of.
3. Strictly your own experiences or observations on top dressing fertilisers is required and do not consult for 3rd party's input.
4. Complete the questionnaire once off without leaving some questions for the next time.

QUESTIONNAIRE

Please tick your response unless otherwise indicated.

Section A: Farmer Background Information

i. Gender:

Male [ ]

Female [ ]

Age [ ]

Farming area ……………………………………

ii. Period you have been using nitrogen top dressing fertilisers

a) 0 –5 years [ ]

b) 6-10 years [ ]

c) 11-15 years [ ]

d) 16 years and above [ ]

iii. Type of nitrogen top dressing fertilizer commonly used

White urea [ ]

Ammonium Nitrate [ ]

Black urea [ ]

NitreX urea [ ]

Agrotain Green Urea [ ]

iv. Which nitrogen source in maize production was most cost effective for you

a) A.N [ ]

b) NutreX [ ]

c) Black urea [ ]

d) White urea [ ]

e) Green urea [ ]

Knowledge Needs of Farmers in Zimbabwe

i. What impact does coated nitrogen have on maize yield?

Positive [ ]

Negative [ ]

Explain ………………………………………………………………

ii. What are the knowledge needs for maize farmers in Zimbabwe that relate to use of coated and non-coated nitrogen sources?

Understanding of fertilizer types [ ]

Crop nutrition [ ]

Fertiliser prices/costs [ ]

Fertiliser application timing [ ]

iii. What reasons do you think are causing the slow adoption of coated nitrogen by farmers in Zimbabwe?

Lack of cash [ ]

Difficult to find from local shops/suppliers [ ]

It is expensive [ ]

Lack of product information [ ]

Explain…………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………….…..

iv. Which one of these knowledge management structures do farmers in your area rely on most in dealing with inputs procurement?

Indigenous knowledge systems (IKS) [ ]

Mass media [ ]

Telecoms [ ]

Agritex officers [ ]

Production contractors [ ]

Give reasons

………………………………………………………………………………………………

………………………………………………………………………………………………

………………………………………………………………………………………………

………………………………………………………………………………………………

…………………………………………

For the cost of coated, why shouldn't I just apply another bag of A.N?

v. Use of coated nitrogen seems quite a lot of money for something that may not give an economic response?

True [ ]

False [ ]

Explain your answer

………………………………………………………………………………………………

………………………………………………………………………………………………

………………………………………………………………………………………………

………………………………………………………………………………………………

………………………………………………

vi. How often do you get updates on new fertilizer brands on the market?

a) Weekly [ ]

b) monthly [ ]

c) bi-monthly [ ]

d) quarterly [ ]

e) whenever possible [ ]

Why...

....

....

....

Challenges faced by farmers in accessing fertilizer products information

vii. Do you face any challenges in receiving technical knowledge from Agritex and inputs suppliers?

Yes [ ]

No [ ]

State

them…………………………………………………………………………………

……………………………………………………………………..….

…………………………………………………………………………………………

…………………………………………………………………………………………

……………………………………….……………………….

viii. Do you have any policy strategies in place to counter these challenges?

Yes [ ]

No [ ]

Identify………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

………………………………………………………….

ix. Are there any strategies by fertilizer suppliers to make knowledge impartation to farmers easier?

Yes [ ]

No [ ]

Cite………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………….………..

x. Who benefits from increased use of maize top-dressing fertiliser?

Farmers [ ]

Extension Officers [ ]

Various off takers [ ]

Government [ ]

Crop Contractors [ ]

Strategies to improve diffusion of coated nitrogen sources in Zimbabwe

What suggestions do you have on how to increase diffusion and adoption of coated nitrogen usage in maize production in Zimbabwe?

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………