REPUBLIC OF TURKEY
ERCIYES UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
DEPARTMENT OF AGRICULTURAL SCIENCES AND TECHNOLOGIES

GENOTYPIC DIFFERENCES IN NITROGEN EFFICIENCY OF SOME SELECTED LOCAL MAIZE VARIETIES OF GHANA

(MSc. THESIS)

ABDUL-QUDDUS BAYUKO ABUBAKAR

4014131502

SUPERVISOR

ASST. PROF. DR. ABDULLAH ULAŞ

SEPTEMBER 2017

KAYSERI, TURKEY

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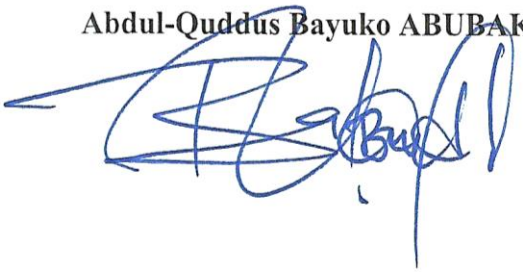
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SCIENTIFIC ETHICS SUITABILITY

I, Abdul-Quddus Bayuko Abubakar, hereby declare that this piece of work is the result of my research and that this work has never been submitted anywhere for any degree. All the sources of information used were obtained in accordance with academic ethics and have been duly acknowledged.

Abdul-Quddus Bayuko ABUBAKAR



COMPLIANCE WITH GUIDE

This master's thesis writeup on the topic "**Genotypic Differences in Nitrogen Efficiency of Some Selected Local Maize Varieties of Ghana**" was prepared in accordance with Erciyes University's Graduate Thesis Writing Directive.

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ABSTRACT

The effectiveness with which nitrogen (N) is used by corn (*Zea mays* L.) and other non-legume crops has become increasingly important because of increasing cost of manufacturing and distribution of chemical N fertilizers as well as its hazardous effects on the environment when used inappropriately. This along with the bad economic conditions of resource-poor farmers, has limited crop production, a threat to the world's food security. Breeding and cultivating of efficient but high yielding varieties is thus the solution to this 21st century time bomb. The aim of this study was thus to screen some local maize varieties of Ghana for the genotypic differences in N efficiency and to identify and recommend the efficient but high performing varieties especially under low nitrogen conditions to plant developers and farmers. A total of 8 local maize cultivars (*white Abontem*, *Honampa*, *yellow Abontem*, *Kunjorwar*i, *Sanzalsima*, *Ewulboyu*, *Wandataa* and *Tintim*) and 2 hybrids (*OSSK 644* and *DKC 7211*) were grown on soilless media in a controlled growth chamber for 6 weeks with low (0.3 mM) and high (3.0 mM) nitrogen doses. The results showed that, the maize cultivars varied significantly in N uptake and utilisation abilities. Shoot dry weights were higher under high while root dry weights were higher under low N. Observed differences among varieties was significant. Basing on biomass production, *Honampa, OSSK 644* and *White Abontem* were both efficient under low N and highly responsive under high N. *Tintim* and *Ewulboyu* were only responsive un high N supplies whereas *Kujorwari* was efficient under low N. All other varieties were neither responsive nor efficient. The well-developed strong root systems seemed to be the major contributing factor to N efficiency of the N efficient cultivars.

Keywords: difference, efficiency, genotype, maize, morphology, nitrogen, root, uptake, utilisation.

GANA'NIN BAZI SEÇİLMİŞ YERLİ MISIR ÇEŞİTLERİNİN AZOTUN VERİMLİLİĞİNDE GENOTİPİK FARKLILIKLARIN BELİRLENMESİ

Abdul-Quddus Bayuko ABUBAKAR
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ÖZET

Azot (N) etkinliği, mısır (*Zea mays* L.) ve diğer baklagil olmayan bitki türleri için oldukça önemli olup, bir yandan kimyasal gübrelerin üretim ve dağıtım maliyetlerinin artması, diğer yandan azotlu gübrelerin yanlış uygulanmaları sonucunda oluşan çevresel zararlar, bu konunun giderek daha da önem kazanmasına neden olmuştur. Ayrıca, ekonomik açıdan kötü durumda olan çiftcilerin yeterli düzeyde üretim yapamamaları da dünya gıda güvenliği için bir tehdit oluşturmaktadır. Yüksek verimli ve N-etkin çeşitlerin ıslah edilmesi ve kullanılması 21. yüzyıldaki gıda problemine bir çözüm olabilir. Bu çalışmanın amacı, Gana'ya ait bazı yerel mısır çeşitleri arasında azot etkinliği bakımından genotipik farklılıkların taranması vede özellikle düşük-N koşullarında yüksek verim performansı sergileyen üstün genotiplerin belirlenerek ıslahcılara ve çiftcilere önerilmesidir. Toplam 8 adet yerel mısır çeşidi (*White Abontem, Honampa, Yellow Abontem, Kunjorwari, Sanzalsima, Ewulboyu, Wandataa* and *Tintim*) ve 2 adet hibrit çeşit (*OSSK 644* ve *DKC 7211*) kontrollü iklim odasında, besin çözeltisi ortamında düşük-N (0.3 mM) ve yüksek-N (3.0 mM) dozlarında 6 hafta boyunca test edilmiştir. Neticelere göre çeşitler azot alım ve kullanım bakımından istatistiki olarak birbirinden farklıdır. Düşük-N'de kök kuru ağırlık yüksek iken, gövde kuru ağırlık da yüksek-N dozunda yüksektir. Ayrıca çeşitler arasında da farklılık tespit edilmiştir. Biyomasa göre *Honampa, OSSK 644* ve *White Abontem* hem düşük-N de N-etkin, hem de yüksek-N de N-duyarlı olarak karakterize edilmiştir. *Tintim* ve *Ewulboyu* sadece yüksek-N de N-duyarlı olarak karakterize edilirken, *Kujorwari* düşük-N de N-etkin olarak karakterize edilmiştir. Diğer çeşitler ne N-etkin ne de N-duyarlı olarak karakterize edilmiştir. Güçlü ve iyi gelişmiş bir kök sistemi, özellikle düşük azot koşullarıda üstün performas sergileyen N-etkin çeşitlerde temal rol oynamaktadır.

Anahtar kelimeler: alım, azot, etkinlik, farklılık, genotip, kök, kullanım, mısır, morfolojik, verimlilik.

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LIST OF ACRONYMS

°C : degrees Celsius
EC : Electrical conductivity
$(NH_4)_2SO_4$: Ammonium sulphate
$Ca(NO_3)_2$: Calcium nitrate
$CaCO_3$: Calcium carbonate
$CaSO_4$: Calcium sulphate
CO_2 : Carbon dioxide
O_2 : Oxygen (molecule)
N_2 : Nitrogen (molecule)
NH_4^+ : Ammonium
NO_2 : Nitrite
NO_3^- : Nitrate
$CuSO_4$: Cupper sulphate
H_2O : Water
H_2SO_4 : Sulphuric acid
H_3BO_3 : Boric acid
HCl : Hydrochloric acid
K_2SO_4 : Potassium sulphate
KH_2PO_4 : Monopotassium phosphate
KNO_3 : Potassium nitrate
$MgSO_4$: Magnesium sulphate
$MnSO_4$: Manganese sulphate
$MoNa_2O_4$: Sodium molybdate
NaCl : Sodium chloride
NaOH : Sodium hydroxide
$ZnSO_4$: Zinc sulphate
Fe-EDDHA : Ethylene diamine-N, N bis (2-hydroxyphenylacetic acid)
R-CH-(NH_2)-COOH : General formula of an amino acid
kLUX : Kilo lux
ND : No date
NR : Nitrate reductase
NUE : Nitrogen use efficiency
SPAD : single-photon avalanche diodes
UV : Ultra violet
IITA : International Institute of Tropical Agriculture
IPCC : Intergovernmental Panel on Climate Change
MoFA : Ministry of Food and Agriculture Ghana
SRID : Statistical Research and Information Department Ghana
CIMMYT : International Maize and Wheat Improvement Center
FAO : Food and Agriculture Organisation

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CHAPTER ONE

INTRODUCTION

From an agricultural prospective, the challenge of protecting the environment while meeting the world's food demand will be won or lost in maize, rice, and wheat (cereal) cropping systems **(**Cassman *et al*., 2002)**.** In recent times farmers have been growing crops on same pieces of land yearly. And under such conditions of cultivation, soil fertility declines if nutrients removed by crop products are not replenished or reincorporated into the soil (Fairhurst, 2012).

The environment by nature, (in its natural state) is made up of chains of relations through which every fauna and flora is being proportionally provided for. We have been reading since primary school, that energy is never created nor destroyed but transferable from one object to the other, and from a form to the other. It is said that the main source of energy is from the sun (light energy) which phototropic organisms are the only organisms that can utilise it. These, we call "producers", process this light energy together with carbon dioxide (CO_2) and water (H_2O) into sugars whilst releasing oxygen (O_2) as a by-product through a process termed photosynthesis. Another group of living things termed "consumers" feed on these phototrophic organisms, (their main source energy) alongside the utilisation of O_2 for respiration. In the process, they also produce CO_2 for the produces. However, producers do not only utilise CO_2, H_2O and light for photosynthesis, but they also take up some but necessary elements from the environment. These elements

that are being converted, transferred stored and utilised in different forms and later returned to the environment by the vital role of "decomposers" when the producers and consumers die. Taking nitrogen (N) as an example; plants take up N from the soil and is returned to the soil through microbial transformations termed as the "Nitrogen Circle" (Figure 1).

Removal and replacement the soil's N is naturally in a balanced proportion in the ecosystem. However, in agricultural ecosystems, (Hofman and Van Cleemput, 2004) this cycle is disturbed by the removal of substantial amounts of N from the soil with harvested products and therefore, the use of N fertilizers has been essential to keep the soil productive.

Mineral N can be said to be a constituent of almost all living structures (cells). Biochemist have opined that, living organisms are made up of building blocks of cells. And deep into the cell are proteins (the primary source energy for the cell). Biologist in simple put define a cell as the "basic unit of life". But if deep inside this "basic unit" is another basic thing whose constituents are long chains of amino acids [R-CH-(NH2)-COOH] of which nitrogen (N) is a major component, then one is not wrong to conclude that N is a basic element without which there would be no life! Schröder (2014) described N as an indispensable component of all living things without which none would exist as there would be no food.

Mineral N is the element that most limits food crop production across the globe (Weisler *et al.*, 2001; Fageria, and Baligar, 2005) and thus its efficient use is crucial for the economic sustainability of cropping systems (Fageria and Baligar, 2005). In agriculture, integrated N management approaches that take into consideration improved fertilizer, soil, and crop management practices are essential to improve N efficiency (Weisler *et al.*, 2001). Improving N use efficiency (NUE) is necessary to improve crop yields, reduce

cost of production (and distribution), whilst maintaining environmental quality (Fageria and Baligar, 2005).

However, plant developers generally focus on increasing grain yield under favourable conditions where nutrient (especially N) supply is high and does not affect yield. But under poor soil-fertility conditions of the fields, on which the small holder farmers operate annually, the result may be different (Bänziger *et al.*, 2000; Lafitte and Edmeades, 1994). Due to these, along with the rising prices of (nitrogen) fertilisers, high rates of rural poverty, underdeveloped farm input and commodity markets (Sanginga and Woomer, 2009) as well as the increasing rules limiting fertiliser usage in attempt to minimize environmental pollution, couple with the continues cultivation of marginal land due to population growth and pollution, the effectiveness with which N is been used by plants has increasingly become a key point of focus to researchers and stakeholders as crop (especially cereal) production is continually hindered.

A key approach to mitigating these problems is the breeding and cultivation of cultivars which use the available nitrogen efficiently. However, to facilitate the breeding process of N-efficient cultivars, the identification of secondary plant traits that contributes to N efficiency is necessary. It is thus essential (Hirel *et al.*, 2007) to have an in-depth knowledge of the uptake and utilisation mechanisms affecting crop N use efficiency and hence reducing the high demand for fertilisers, while ensuring optimal yields are obtainable.

Uptake and use efficiencies of N by maize cultivars have been widely studied, but little has been done on this subject in West Africa (Akintoye *et al.*, 1999). Nitrogen Use Efficiency (NUE) is the ratio between the amount of N fertilizer removed from the field by the crop and the amount of N fertilizer applied/available (Brentrup and Palliere, 2010).

According to Moll *et al.* (1982) it is the grain yield per a unit of N available in the soil. In any case, there are two major components of N use efficiency: (1) the uptake efficiency, and (2) the utilisation efficiency. Uptake and utilization efficiency of N in the production of grain requires that those processes associated with absorption, translocation, assimilation, and redistribution of N function effectively (Moll *et al.*, 1982). Variations in N efficiency are influenced by both the morphological and genotypic differences of crops (Gardner *et al.*, 1994) as well as different climatic, soil and management conditions (Muchow, 1998).

This study was thus carried out to determine the root and shoot morphological and physiological features that affects N uptake and utilisation efficiency in some sample maize cultivars. The specific aims of this work were (1) to determine the genotypic differences in N efficiency among various genotypes, (2) to determine the significance of root morphology for genotypic differences in N efficiency, (3) to identify the morphological and physiological traits contributing to genotypic differences in N efficiency as well as the chemical (enzymatic) process that affects nitrogen efficiency among the various genotypes. This work in the end is aimed at identifying and recommending the efficient but high performing cultivars especially under low nitrogen conditions to plant developers as well as farmers. It would also seek to help manage the application of fertilisers and farmer available resources in a manner that increase nitrogen use efficiency and makes fertiliser use more profitable.

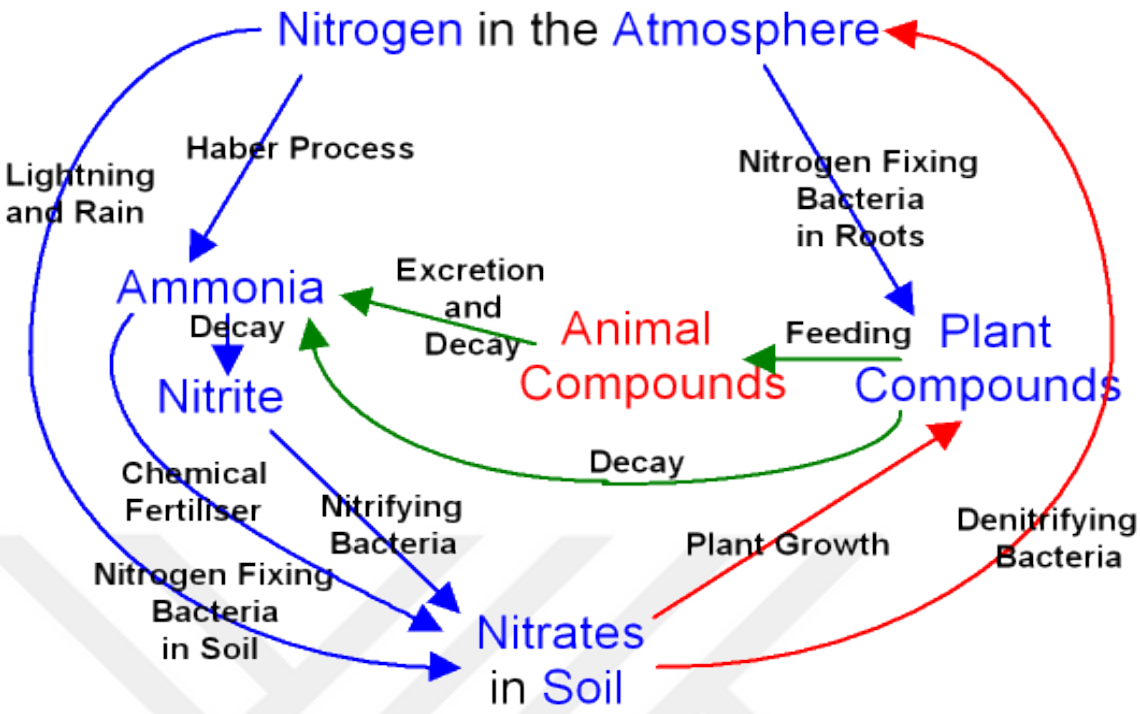


Figure 1: Nitrogen Cycle (www.gcsescience.com)

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview of Maize Production

Maize (*Zea mays* L) belongs to tribe *Maydeae* in the *Graminae* family now known as *Poaceae* (the grass family) and is considered the queen of cereals because of its wider adaptability. About 50 species of maize exist and are of varying colours, textures, grain shapes and sizes (IITA, 2009).

Introduced to the African continent in the 16th century, maize by the 19th century, had spread all over the continent and is perhaps the most important cereal crop of significant economic importance in Africa replacing the traditionally cultivated sorghum and millet (Olaniyan, 2015). Taking Ghana for example, it is one of the most important crops of the agricultural sector, ranking second after cocoa. However, the volume of maize production in Ghana has been fluctuating of late due to farmers' inability to afford or practice modern levels of technology (Oppong, 2013). Ghana has experienced annual domestic deficit of maize and had to import from neighbouring countries to augment local supply as observed by MoFA (2008). Agricultural analysts recommend that maize production on commercial basis can help bridge the increasing gap between domestic demand and supply of maize

in Ghana (Oppong, 2013) which can be achieved by improving farmers' technical know-how as well as using high yielding but nutrient efficient cultivars.

Maize yield in Ghana on average is approximately 1.7 metric tonnes per hectare (MoFA, 2011). But with the use of enhanced technologies, practices and the use of high yielding cultivars, yields as high as between 5.0 to 5.5 metric tonnes per hectare can be achieved (CSIR, 2012).

After wheat and rice, maize is ranked third globally in terms of area harvested but ranked first in terms of annual production. Maize production worldwide has been increasing which could be attributed to the use of modern technologies, expansion of cultivation area and increments in yield per hectare because of the use of improved varieties. Of the total global production, United States is the largest producer, contributing between 37-43% of the total world production, followed by China (177 million metric tonnes), Brazil (56 million metric tonnes), Mexico (23 million metric tonnes) and Argentina (21 million metric tonnes) (FAOSTAT, 2012). Maize production in the developed countries is usually on large scale and highly mechanized, where hybrids cultivars are commonly used with high inputs of agrochemicals (fertilisers). The FAO statistics for the year 2015 showed that, Africa's total maize produced was 77,623,465 accounting for only 6.27% of total global production. The approximate maize cultivation area in West and Central Africa expanded from 3.2 million hectors in 1961 to 8.9 million hectors in 2005, resulting in a production increase from 2.4 million metric tonnes in 1961 to 10.6 million metric tonnes in 2005 (IITA, 2009). Maize production in Sub-Sahara Africa rise mainly through the expansion of planting area until the middle of the 20th century, a strategy made feasible by the relative abundance of uncultivated and underutilised land (Morris, 1998). Unfortunately, continues cultivation of marginal lands due to land degradation and

urbanisation resulting from population growth has put a limitation to area expansion, bringing production to a constant declining state.

2.2 Importance and Uses

The economic importance of maize cannot be underestimated and it cut across different spheres of life; serving as food for human (Oyewo, 2011) and feed for poultry and livestock. Maize is also industrially important mostly to produce starch and alcohol (Oyewo, 2011).

Maize has always been preferred to any other crop, because most of the world's civilizations developed around grains rather than tuber crops (Fakorede, 2001) and fruits. In Africa, maize is a staple food crop grown in diverse environments and consumed by people of varying food preferences and socio-economic backgrounds and hence rapidly replacing traditional starchy foods like cassava (Olaniyan, 2015). Moreover, due to its relative cheaper cost than other cereals (such as rice and wheat), it is more affordable to the majority of the population, and therefore, occupies a prominent position in the agencies of agricultural development of several countries in Africa (Olaniyan, 2015). According to IITA (2009) maize is an important staple food for more than 1.2 billion people in Sub-Saharan Africa and Latin America with all parts of the crop capable of being used as food and non-food products. The stover, is used as roughage feed for livestock. In the developed world maize grain is largely used as livestock feed and raw material for industries while in developing countries it is mainly used as food (Olaniyan, 2015). The grains have abundant nutritional value as they contain about 72% starch, 10% protein, 4.8% oil, 8.5% fibre, 3.0% sugar and 1.7% ash (Chaudhary, 1983). In Ghana,

maize consumption per capita in 2005 was estimated to be 43.8kg per head (MoFA, 2011) and an estimated national consumption of 943000 metric tonnes in 2006 (SRID, 2007).

2.3 Maize Growth Requirements

Maize is a warm weather crop and grows well in areas where the mean daily temperature is above 19ºC though the minimum temperature for germination is 10ºC (Du Plessis, 2003). The most suitable conditions for maize is areas with a well-drained fertile soil of effective depth, favourable morphological properties, an optimal moisture regime with good annual rainfall distribution of about 1200mm, favourable soil chemical properties such as pH and lots of sunshine throughout the growing season (Du Plessis, 2003; Kim *et al.*, ND). Maintaining soil moisture level above 50% in the rooting depth of the soil profile throughout the growing season or at least maintaining an adequate soil moisture at the time of anthesis is essential to obtain an optimal maize yield (Ofori and Kyei-Baffour, 2009).

Maize has a high demand for nutrients whether grown for grain or silage (Birch *et al*., 2003). Major among these nutrients are nitrogen (N), phosphorus (P) and potassium (K) which must be supplied adequately for a good yield to be realised. In addition to N-P-K, several micronutrients are of importance especially for seed development; e.g. magnesium (essential for germination), boron (flower development and pollen germination), zinc (seed formation), and molybdenum for endosperm development (Beck, 2002). However, N is the main nutritional constrain affecting yield in maize production and the challenge is to manage N fertilisers for maximum utilisation efficiency under any agronomic condition (Birch *et al*., 2003). Maize's N uptake is high during the

vegetative growth, with a maximum uptake rate occurring closer to silking. leaf yellowing, stunted growth, delayed tasseling, poorly filled ears indicate N deficiency.

A common way of enriching the soil's fertility is through the application of mineral fertilisers, even though the role of animal manure cannot be underrated. After World War II, synthetic fertilisers especially N have been used extensively to increase crop yield (Hirel *et al.*, 2011). It is thus important to apply the right proportions of fertiliser to maize to obtain a good yield. The nutrient supply that will be adequate to meet daily demands of maize at an economic cost will differ and will depend on the crop's growing conditions, the kind of fertiliser product, time and method of application, the purpose and market for which the crop is being grown for (Birch *et al.*, 2003). Therefore, knowledge of soil properties and fertility from soil sample tests, crop N requirements, along with production data on varietal response to fertility are recommended (Montemurro *et al.*, 2006; Beck, 2002). Applying N, P, K 15:15:15 two weeks after planting and urea of 150 kg at 4-6 weeks after planting is recommended per hectare (IITA Youth Agripreneurs, 2014) to obtain optimal yields. Care must however be taken to avoid overapplication of fertilisers especially N, as plants turn to develop vegetatively and in the case of maize delays in silking under high N rates, thereby delaying crop maturity and reducing yields (Howard *et al.*, 2001; Tucker, 1999; Nawar *et al.*, 1992).

2.4 Maize Production Challenges

To produce to meet the current global food crises, the production of all food crops must increase. By 2050, an estimated 9 billion people aside animals need to be fed. To be able to provide for this projected number, it implies that the world's food production must increase from its current trend. For instance, due to rapid economic growth and

urbanisation, the demand for meat and for maize and soybeans for livestock feed has increased as well as an ever-increasing demand for staples such as rice and wheat as economic conditions in developing countries improves (Hubert *et al.*, 2010). However, agricultural productivity, especially in developing countries, continues to drop (Hubert *et al.*, 2010), which could be attributed to; (1) the exorbitant cost of fertilisers along with the widespread use of traditional crop varieties that are less responsive to fertiliser, (2) the lack of irrigation systems and (3) low incentives to invest in land-saving technologies especially in Africa (Kherallah *et al.*, 2002). Depending on the location as well as the season, maize requires well-distributed rainfall of at least 500-700mm during its growing season (CIMMYT, 2005) to produce. However, this is not always possible in either temperate or tropical climatic regions as rainfall can be very late and random in some years (Ofori and Kyei-Baffour, 2009), a consequence of climate change.

2.5 Nitrogen

Discovered in 1772 by the Scottish physician Daniel Rutherford, Nitrogen makes up about 78% of the earth's atmosphere (Jefferson Lab). Nitrogen is an essential element for agricultural production as plants require it for production, while animals require it for maintenance, growth, reproduction, production of milk, eggs, wool and energy for labour (Van der Hoek, 2001). In modern day agriculture, the foremost way of replenishing soil nutrients and increasing crop yields is the application of synthetic fertilizers (such as N) because of its easy storage simplicity and handling, as well as its straightforward application when it is needed most by plants (Hirel *et al.*, 2011). With respect to enhancing the soil’s organic carbon (C) and N stocks, the use of synthetic N fertilizers has eliminated a major elemental constrain which was traditionally managed using

organic manures, leguminous crops and land fallowing (Hirel *et al.*, 2011). N fertilizers have tremendously increased our supply of food, feed and other bio-based raw materials and improved the land and labour use efficiency. But have on the other hand negatively impacted environmental quality and has also contributed to the depletion of fossil fuel reserves (Schröder, 2014). Nitrogen pollution contributes to ground-level ozone, acid rain and acidification of soil and surface waters, disruption of forest processes, coastal over-enrichment and other environmental issues (Driscoll *et al*., 2003). Pollution to both ground and surface water can result from leaching and surface run-off respectively. Nitrogen in water causes eutrophication (the growth of algal blooms) which depletes oxygen in water bodies; a threat to marine life! The blue baby-drome is also one of the negative impacts of consuming nitrogen polluted waters. The detrimental impact of the overuse of N fertilisers on the environment can be lessened if it is accompanied by sustainable agricultural practices, such as crop rotation, fertiliser use rationalisation, ground cover establishment and reincorporation of crop residues (Hirel *et al.*, (2011).

2.5.1 Sources

Atmospheric N_2 is the ultimate source of N in the environment. While legumes convert atmospheric N_2 into mineral N through symbiotic associations with certain soil microorganisms (biological fixation), it is also artificially being synthesised using the Haber-Bosch process (Fairhurst, 2012; Doerge *et al.*,1991). A common widely use source of enriching the soil's N is by the application of synthetic (inorganic) fertilisers. According to Hirel *et al.* (2011) synthetic N fertilizers are particularly soluble for easy uptake and assimilation by plants and can easily be applied when plants need it most and have thus been extensively used to increase crop yield after World War II.

Another way of replenishing soil N is through the application of animal manures (organic fertilisers). The nutrient content of manure depends on the type of farming, grazing systems and nutrient composition of the different foods and fodder for the livestock (Hirel *et al.*, 2011). However, manure is not readily available to plants until is acted upon by soil microorganisms, whose presence and activities is totally dependent on the soil conditions. Aside animal manures, green manuring and cover cropping are also effective ways of enriching the soil's N. Here legumes are mostly used because of their less dependence on supplied N to grow. The amount of N that can be incorporated into the soil through legumes used for green manuring and cover cropping depends legume species, the total biomass produced, and the percentage of N in the plant tissue (Hirel *et al.*, 2011).

Mineral N, once in the soil, may exist either in inorganic or organic forms. Inorganic forms of N in the soil are NH_4^+, nitrates (NO_3^-) and nitrites (NO_2) whilst the organic forms are amino acids, amides and urea (Sinha, 2004). NH_4^+ and NO_3^- are the available form of N that plants can absorb from the soil (Fairhurst, 2012; Mc Cashin, 2000; Marschner, 1995). However, the NO_3^- form of N is highly soluble and is easily leached beyond the limits of root into ground water.

2.5.2 Functions and Deficiency Symptoms

Next to carbon, hydrogen and oxygen, N is the most abundant element in plants (Sinha, 2004). N combines with these elements to form amino acids, the building blocks of proteins and enzymes. It is an essential component of nucleic acids, some hormones, chlorophylls, cytochromes, alkaloids and plays a key role in photosynthesis, respiration, growth and other metabolic processes (Fairhurst, 2012; Sinha, 2004; Mc Cashin, 2000). N deficiency thus causes stunted growth due to inhibition of cell division and cell enlargement, decrease in respiration rate (photosynthesis), delayed tasselling, premature

growth, poorly filled ears, yield reduction and reduced protein content in grains. Deficiency symptoms first appear in old leaves which turns pale green to yellow starting from the tip because of remobilisation of N to younger tissues (Fairhurst, 2012; Sinha, 2004; Tucker, 1999). There are several factors that accounts for N deficiency (Fageria and Baligar, 2003; Raun and Johnson, 1999).

1 loss of N through surface runoff, leaching, volatilization, and denitrification,
2 lower N replenishing/application rates compared to N removal rate by crops,
3 low N use efficiency by the crops,
4 use of high yielding and N sensitive cultivars,
5 soil degradation with successive crop cultivation, and
6 losses resulting from gaseous emission by plants.

It must however be noted that under excess N supply, plants turn to develop vegetatively thereby delaying crop maturity and reducing yields (Howard *et al.*, 2001; Tucker, 1999; Nawar *et al.*, 1992). According to Sinha (2004) and Nawar *et al.* (1992) excess N supply results in reduction of fruit size in crops and smaller tuber in formation in potato and delays silking in maize. Also, excessive N fertilizer application increases production cost aside the negative effects on environmental quality (Zhao *et al*., 2003).

2.6 Nitrogen Efficiency

Efficiency as defined by Lynch (1998), as the ability of a system to convert inputs into desired outputs or to minimize the conversion of inputs into waste. Depending on what one's interest, Nitrogen Use Efficiency (NUE) has many definitions. Brentrup and Palliere (2010) defined NUE as the ratio between the amount of N fertilizer removed from the field by the crop and the amount of N fertilizer applied/available. While Moll *et al.* (1982) coined it as the grain yield per a unit of N available in the soil. NUE has

increasingly become a key point of focus to researchers and stakeholders owing to the ever-increasing cost of production and distribution of N fertilisers along with the arising environmental problems from their usage. Nitrogen fertilisers have been essential to boosting crop productivity in recent decades as they help farmers grow heartier and healthier crops that can feed the growing population. However, most plants can only absorb part of the nitrogen in fertilisers, which leaves essential nutrients unused (Croplife International, 2014).

Worldwide, nitrogen use efficiency (NUE) for cereal production is approximately 33% (Raun and Johnson, 1999). Though the efficiency of N utilisation varies under different climatic, soil and management conditions (Muchow, 1998), almost 2/3 of the applied/available N is lost to the environment through volatilisation, leaching and denitrification. According to Gupta *et al.* (2012) plants N use efficiency involves many complex genes that are also dependent on several internal factors such as photosynthetic carbon fixation (to provide precursors required for amino acid biosynthesis or respiration to provide energy) and external factors (weather conditions, water supply etc.) in addition to varying soil N. In low input agriculture, nutrient efficient crops improve crop productivity whilst reducing of surface and ground water pollution resulting from intense use of fertilisers (Lynch, 1998).

However, NUE is unlikely to increase, unless a system approach is implemented that uses varieties with high harvest index, uses incorporated NH_4^- nitrogen fertilisers and a system that applies low but prescribed rates consistent with in-field conditions (Raun and Johnson, 1999). The use of improved seeds traits (e.g. good root morphology) that enhances crops N use efficiency, can help boost productivity and help farmers to produce more food, especially as climate change threatens production (Croplife International, 2014).

2.7 Genotypic Variations in Nitrogen Efficiency

By 2050, agriculture will need to produce enough food to feed about 9 billion people while battling increasingly difficult growing environments due to climate change. Nitrogen-use efficient crops will enable farmers to improve productivity, even in the face of these challenges, and deliver yield benefits around the world (Croplife International, 2014). A genotype can be said to be N-efficient if it yields above average at low N level or if it converts high N input comparatively better into yield than other genotypes **(**Gueye and Becker, 2011) or plants which produce higher yields per unit of nutrient (nitrogen) applied or absorbed than other plants (standards) under similar agroecological conditions (Fageria *et al.,* 2008). Genotypic variation as defined by (Fageria, 1989) is the heritable character (trait) of a crop specie or cultivar that shows differences in growth or production in comparison with other species or the same species under favourable and/or unfavourable growth conditions. Usually, genotypes of the same crop species differ in their acquisition, transportation and utilisation efficiencies of nutrients especially as well as their interactions with the environment (Baligar *et al*., 2001). Larger canopies comprising of fewer but thicker larger leaves, having a low N concentration, larger leaf phloem trans-sectional area, rapid N solubilisation and remobilisation from older to younger leaves, and minimal dark respiration rates are some of the traits relating to high NUE (Gardner *et al.*, 1994). Information from previous researches have shown genotypic variations in NUE at various levels of N fertilisation; with reports of a strong genotype x nitrogen (GxN) interaction. Weisler *et al.* (2001) observed that, under reduced N supply there was a considerable genotypic variation in reproductive yield formation of both maize and oilseed rape. Same was the results from the works of Moll *et al*. (1982) who observed that there were significant differences in yield of 8 hybrid maize genotypes under high N, which was attributed to high N uptake. Knowledge on these genotypic

variations in NUE and their relationships to agronomic traits such as yield, is necessary to develop varieties with improved NUE (Gallais, and Coque, 2005).

During the last three decades, much research has been conducted to identify and/or breed nutrient efficient plant genotypes/cultivars within species and to further understand the mechanisms of nutrient efficiency in crops however, there has been a limited success in releasing these nutrient efficient cultivars (Fageria *et al.*, 2008) because the traits controlling nutrient acquisition and utilisation are highly complex and not well understood (Lynch, 1998).

2.8 Plant Characteristics Influencing N-Efficiency

Breeding for nutrient efficiency is still hindered by the lack of reliable screening criteria (Sauerbeck and Helal, 1990) to identify and explain the plant metabolic activities and characteristics of significance to nutrient efficiency. A crops' N use efficiency is examined by considering the uptake efficiency of applied or available N, and the utilisation efficiency of the absorbed N (Benincasa *et al.*, 2011). This requires that the mechanisms associated with absorption, translocation, assimilation, and redistribution of N operate effectively (Moll *et al.*, 1982).

The uptake efficiency of plants is related to the plants' root system, root-soil interaction and shoot-root relations (Sauerbeck and Helal, 1990). Roots play a vital role in N uptake, mainly when N is limited and is thus necessary to consider the size and activity of the roots (Gallais, and Coque, 2005). The root morphological characteristics such as length, diameter, number, length and duration of root hairs as well as mycorrhizae associations are most important in determining the uptake efficiency of nutrients in the soil (Sattelmacher *et al.*, 1994) though the root-length densities are not adequate to meet the N demand of plants as observed by Kuhlmann *et al.* (1989). On the other hand, the

utilisation efficiency refers to the efficiency or ability with which the absorbed available N is utilised at the plant level to produce grain (Gupta *et al.*, 2012; Moll *et al.*, 1982) considering the overall effect of the absorbed N on the crop's growth, leaf area, photosynthesis, shoot N partitioning (accumulation and remobilisation). Remobilisation of N from the stover to the grain is one important parameter that affects NUE and if remobilisation is not adequate, there will be a decrease in grain protein concentration (Gallais, and Coque, 2005).

CHAPTER THREE

MATERIALS AND METHODS

The trial was set up in a controlled growth chamber of Erciyes University's Faculty of Agriculture, Department of Soil Science and Plant Nutrition Plant Physiology Laboratory. A 13-hour photoperiod at an intensity of 12.3 kLux with a relative humidity of 50% was maintained. Day and night temperatures were also maintained at 30 and 20°C respectively. The setup was monitored daily and data collected on specific intervals. Data on plant height, leaf number, leaf chlorophyll (SPAD) value, photosynthetic rate, and leaf senescence were collected on weekly basis. Whereas data on shoot and root biomasses, leaf area index were determined at the end of the experiment. Other parameters that were measured were; enzyme activity (Nitrate reductases: NR), leaf chlorophyll and carotenoid contents, root length, root area and root volume. Macro and micro mineral elements content were also determined.

3.1 Plant Material

The plant material used in this study were 8 local (non-commercial) maize cultivars from Ghana and 2 hybrid maize varieties from Turkey (Table 1). Seeds of the local cultivars were taken from the office of Ministry of Agriculture (MoFA-Ghana) in Techiman, and from the Centre for Savannah Agricultural Research Institute of Scientific and Industrial Research (CSIR-SARI), Tamale, Ghana. There is no available literature regarding nitrogen use efficiency of the local cultivars.

Table 3.1: The cultivars used in experiments and their properties

Cultivar	Obtained From	Properties
White Abontem Honampa	MOFA office Techiman, Ghana	Open pollinated
Yellow Abontem Kunjorwari Sanzal Sima Ewul Boyu Wandataa Tintim	Centre for Savannah Agricultural Research Institute of Scientific and Industrial Research (CSIR-SARI), Tamale, Ghana	Open pollinated
DKC 7211	Monsanto Company, (Turkey outlet)	* FAO Group 750 * High green fodder potency. * Has strong root structure. * It has a very tall structure. * The number of leaves varies between 13-14.
OSSK 644	Tareks company incorporated, Turkey	* FAO 650 * High green fodder potency. * Tall and has lots of leaves. * Very high Silage quality (Protein and sugar ratio are high)

3.2 Treatments and Experimental Design

Two different N levels were used as treatments for the solution culture experiment:

- low N supply of 0.3 mM and
- high N supply of 3.0 mM per litre.

Treatments were administered in a Completely Randomised design with three replications for each cultivar. Seeds were pre-germinated in petri dishes and later transplanted and hardened in peat media for 10 days. Two uniform seedlings of each maize cultivar were then transferred into an 8L container containing a modified Hoagland nutrient solution; and grown for six weeks. Half the dose of the nutrient solution was given in the first five days of transferring the plantlets to the solution media as a precaution against a possible injury to the plants.



Figure 3.1: The experimental setup

3.3 The Nutrient Solution

The nutrient solution used for the experiment was prepared following the Hoagland's plant nutrient solution formula with minor modifications. Into each of the 8L container, we gave: 750 µM K_2SO_4; 1000 µM KH_2PO_4; 1300 µM $MgSO_4$; 100 µM NaCl; 10 µM H_3BO_3; 1.5 µM for $MnSO_4$ and $ZnSO_4$; 1.2 µM for $CuSO_4$ and $MoNa_2O_4$. Also given was 240 µM Fe-EDDHA. For the high N treatment, 750 µM and 2250 µM of $(NH_4)_2SO_4$ and $Ca(NO_3)_2$ were given respectively. Whilst 75 µM $(NH_4)_2SO_4$ and 225 µM $Ca(NO_3)_2$ were

given for the low N treatment. To avoid damage to root cells from the use of distilled water, 1000 μM per litter of $CaSO_4$ was added to the solution. Electric conductivity (EC) of 1.0 was maintained whereas a tea spoon full of $CaCO_3$ was applied to each container as a buffer to keep a 7.0 pH. Daily monitoring was done to correct any elemental deficiencies. The solution was routinely replaced at a 7-day interval.

3.4 Measurements

3.4.1 Single-Photon Avalanche Diode (SPAD)

After the second week of the start of the experiment, the Single-Photon Avalanche Diode (SPAD) was measured with a chlorophyll meter SPAD 502 Plus (Figure 3.2). This was done weekly till the end of the experiment.

3.4.2 Photosynthesis

With the aid of a Portable Photosynthesis System LI-COR (LI-6400XTP) as shown in Figure 3.3, the photosynthetic activity was measured weekly from the second week to the fifth week. Fully developed leaves were randomly chosen from one plant in each replication for measuring the photosynthetic activity.



Figure 3.2: Chlorophyll meter



Figure 3.3: Measuring of photosynthetic activity

3.4.3 Leaf Senescence and Leaf Number

One of the symptoms of nitrogen deficiency is the yellowing of old leaves starting from the tip (senescence) because of the translocation of N to younger tissues (Fairhurst, 2012). The number of days it took the plants to start showing the above-mentioned symptom was recorded from daily observations. At harvest, the total number of leaves on each plant was also counted.

3.4.4 Leaf Area

During the harvesting process, the total Leaf Area (LA) of the maize plants was measured with a leaf area measuring device (Figure 3.4) LI-COR (LI 3100, model C). The measurements were recorded in centimetre square (cm^2).

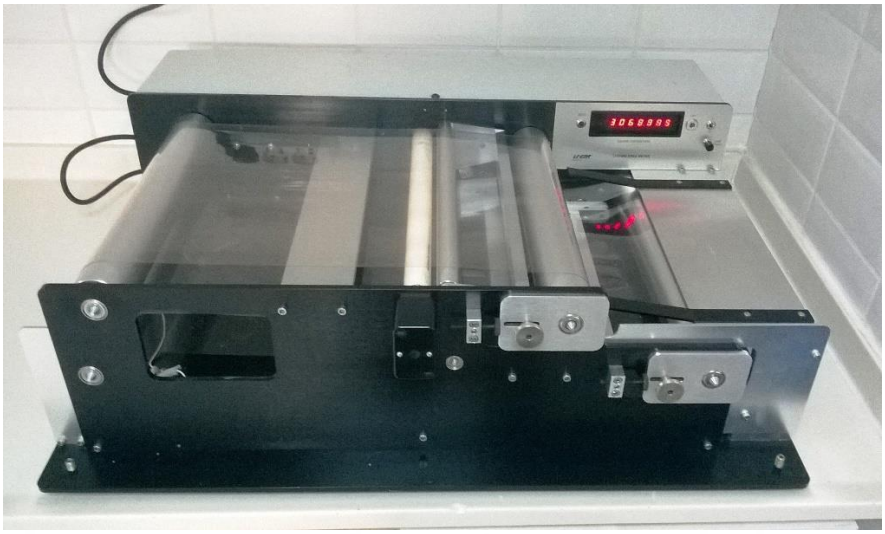


Figure 3.4: LI-COR leaf area meter

3.4.5 Root and Shoot Biomasses

During the harvesting as shown below (Figure 3.5), both the shoot and root fresh weights (g) were taken. The samples were dried in the drying oven at 75 °C for 10 days to attain a 5% moisture level. The dried samples were weighed to obtain the dry weight (g) for the shoot and root respectively.



Figure 3.5: Measuring root and shoot biomasses

3.4.6 Plant Height and Stem Diameter

The height (cm) of the plants was measured weekly and at harvest. But since height can be deceptive, we also measured the stem diameter (mm) weekly with a digital calliper as shown in Figure 3.6.



Figure 3.6: Stem Diameter Measurements

3.4.7 Nitrate Reductase Enzyme

The nitrate reductase (NR) enzyme was determined following the method proposed by Harley (1993). At harvesting;

- Fresh plant sample was taken and chopped into pieces.
- Into two falcon tubes each, was placed 2 grams of the fresh plant sample and labelled time-0 (T_0) and time-60 (T_{60}).
- The tubes were covered with aluminium foil to prevent exposer to light.
- 10 ml of assay buffer solution [100 mM phosphate buffer, pH 7.5; 30 mM KNO_3; 5%(v/v) propanol] was added to each to (T_0 and T_{60}).
- The T_0 container was immediately place into boiling water for 5 minutes, removed and allowed to cool to room temperature. While the T_{60} was kept for 60 minutes at room temperature; after which it was also placed into boiling water for 5 minutes and allowed to cool to room temperature.
- To detect nitrite in the assay tubes, colour development reagents were added. 5 ml of sulphanilamide (1% sulphanilamide in 25% HCl) and 0.02% N-(1-naphthyl)-ethylenediamine hydrochloride (NEED) solutions were added and shake vigorously and left for 20 minutes for colour to develop.

- The optical density (OD) of each standard tube was determine at 540nm wavelength in the spectrometer. The NR activity was computed as *"micromoles of nitrite produced per hour per gram of fresh weight"* using the formulae below.

$$\mu\text{moles } NO_2^- h^{-1} g^{-1} = \frac{\mu\text{moles } NO_2^- (T_{60}) - \mu\text{moles } NO_2^- (T_0)}{\text{weight of plant fresh sample}}$$

3.4.8 Leaf Total Chlorophyll and Carotenoid Content

A day before harvesting, 100mg (0.1g) of fresh leaf samples from each replication of the two treatments were taken for measuring the leaf total chlorophyll and carotenoid contents using UV-VIS Spectroscopy. The samples were put into 15ml capped containers where 10 ml of ethylene alcohol of 95% concentration was added. They were then kept in darkness at room temperature for overnight, to allow for the extraction of the leaf pigments **(**Figure 3.8**).** Measurements were done using the spectrometer (UV/VS T80+ of PG Instruments Limited, UK) at wavelengths of 470 nm, 648.6 nm and 664.2 nm. **Total chlorophyll** (Total-Chlo) and **total carotenoids** (TC) were then estimated from the spectrometric readings using the formulae of Lichtenthaler (1987).

$$\textbf{Total-Chlo} = \frac{(5.24\ WL664.2 - 22.24\ WL648.6) \times 8.1}{\text{weight of plant sample (g)}}\ \textbf{[mg/g plant sample]}$$

$$\textbf{TC} = \frac{[(4.785\ WL470 + 3.657\ WL664.2) - 12.76\ WL648.6] \times 8.1}{\text{weight of plant sample (g)}}\ \textbf{[mg/g plant sample]}$$

Note: *WL470, WL648.6 and WL664.2 refers to spectrometric readings at wavelength 470 nm, 648.6 nm and 664.2 nm respectively.*

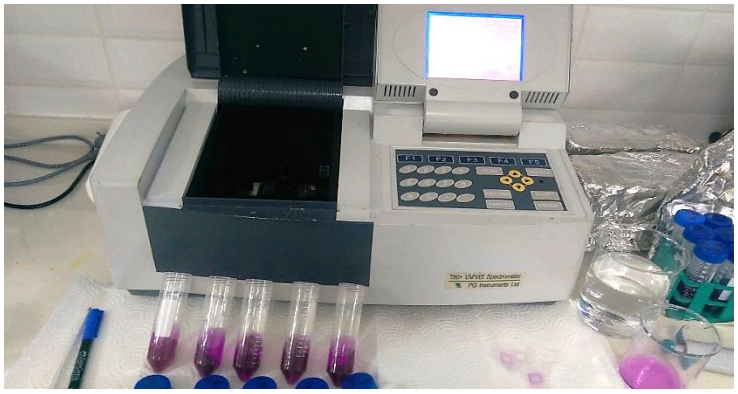


Figure3.7: Nitrate Reductase Enzyme measurement with UV spectrometer.

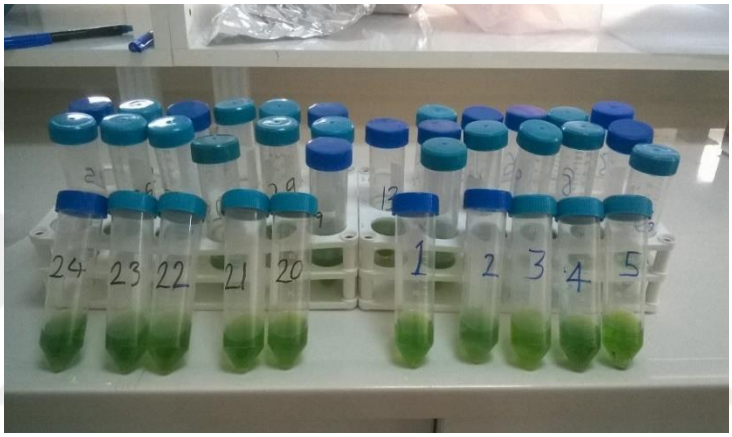


Figure 3.8: Samples for spectrometric measurement of total Chlorophyll and Carotenoid contents.

3.4.9 Root Length, Area and Volume

With the use of WinRhizo (Regular LA2400 of Regent Instruments Inc.) image analysis programme in combination with Epson Expression 11000XL scanner (Figure 3.9), the total root length (cm), area (cm^2) and volume (cm^3) were determined. 5 grams each of root samples were taken from the fresh roots after harvesting. The samples were each (one after the other) placed in the scanner's tray. Water is added and with the aid of a plastic forceps, the roots are homogenously spread across the tray; and the scanning and analysis done from the WinRhizo system's interface on a computer connected to the scanner. The total plant root length, area and volume was then determined as the ratio of sampled root weight to the total root weight.



Figure 3.9: The Epson scanner used for root scanning

3.4.10 Protein Analysis/Nitrogen Determination

In protein like many organic substances, nitrogen is a major component. And therefore, to determine the protein content in a sample such as plant materials, the nitrogen content is measured. A method widely used for protein analysis is the *Kjeldahl Nitrogen Determination Method*, introduced by Johan Kjeldahl in 1883 (Labconco Corporation, 1998). For the purpose of this work, this method was used to determine the protein/nitrogen content of the various maize genotypes under the two different nitrogen levels.

For each dry plant sample; (1) 200 mg was weighed into a digestion tube and one Kjeldahl reaction tablet was added. (2) 10 ml of concentrated H_2SO_4 (98%) was added (Figure 3.10a) and heated for four hours at 400ºC starting from 100ºC for 30 minutes and then increased by 50ºC at every 30 minutes interval until the 400ºC mark (Figure 3.10b). The digested samples were let to cool and diluted with 30 ml of distilled water. (3) the digested samples were then placed in the distilling unit (Figure 3.10c) and distilled against a 50 ml of 35% (w/v) NaOH for two minutes and collected with a container containing 10 ml [2% w/v] of a combined boric acid and indicator solution. (4) The content was then titrated

with 0.01 normality of H_2SO_4 using a digital titrator (figure 3.10d): And (5) The N% was calculated using the formula below.

$$\text{Nitrogen (\%)} = \frac{[(\text{Sample titre value} - \text{Blank titre value}) \times (\text{N of acid} \times 1.4007)]}{\text{weight of plant sample (g)}}$$

***Note**: The combined boric acid and indicator solution was prepared as follows: 0.1g of Methyl red and Bromocresol green was each weighed into two separate light proof containers and dissolved with 100 ml of ethylene alcohol. At the same time 1.0L boric acid with 2% concentration was prepared by dissolving 20g of boric acid powder in distil water. 7 ml and 10 ml of Methyl red and Bromocresol green respectively was added to the prepared boric acid and mixed. The final solution's pH was checked and maintained at 5.5.*

3.4.11 Element Analysis

At the end of the experiment, element analysis was done to determine the quantity of minerals accumulated by the shoot and the root of the various maize genotypes. This was done by ashing 0.5g of dry samples in the oven at 450 °C for four hours. 5 ml of HCl with 20% concentration was added to the ashed samples and filtered (Figure 3.11).

The filtered solutions were then diluted with distilled water to a volume 50 ml. Out of which 10 ml was taken for Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) analysis. The ICP-AES results were converted into percentages (%) and parts per million (ppm).



Figure 3.10: Scenes during the nitrogen determination process. (a) adding sulphuric acid to samples (b) burning of samples (c) distillation of burned samples (d) titration.



Figure 3.11: Preparation of samples for element analysis

3.5 Data Analysis

The collected data were checked for outliers and tested for homogeneity within replications. At 5% level of significance. Analysis of variance was done using Statistical Analysis Programme (SAS University Edition) to determine the effect of the different N level application on the developmental parameters of the 10 different maize genotypes used. The results were presented in tables and figures (graphs) where necessary and discussed accordingly.

CHAPTER FOUR

RESULTS

4.1 Shoot Biomass Production

At the end of the experiment, plants under high N supply produced higher fresh and dry shoot weights (Figures 4.1 and 4.2 respectively) than plants under low N supply. With a mean fresh shoot weight of 539.08g, *Honampa* (756.03g) and *Yellow Abontem* (343.77g) produced the highest and the lowest respectively under high N. Under low N, with an average fresh biomass production of 306.27g, the highest biomass was obtained from *OSSK 644* and *Kunjorwari* (360.50g and 350.16g respectively) and lowest biomass from *Sanzalsima* (278.17g).

At high N *OSSK 644* and *Honampa* (64.77 and 64.57 respectively) produced the highest shoot dry weights over the total average of 47.69g with *Yellow Abontem* being the lowest with 22.03g. Under low N, average shoot dry matter production was 29.38g where *Honampa* and *Kunjorwari* (37.33g and 36.48g respectively) had the highest. And with 22.03g, *Yellow Abontem* was the lowest. A highly significant difference ($p < 0.0001$) existed between the maize varieties under investigation as well as between N treatments. Variety-nitrogen interaction was also found significant.

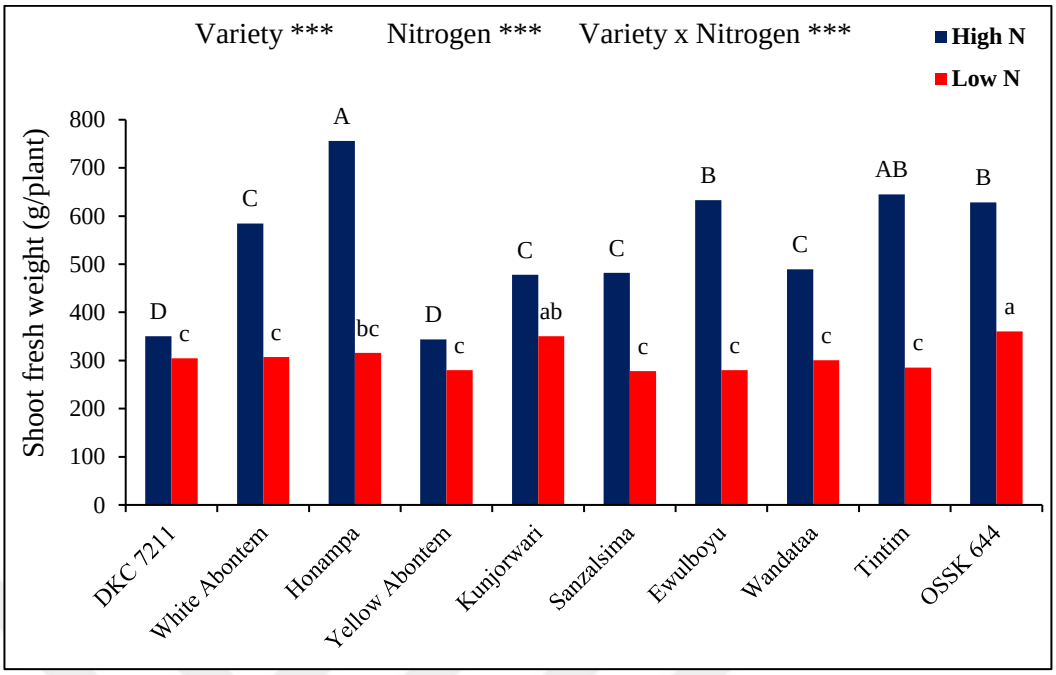


Figure 4.1: Shoot fresh weight of different maize varieties under high and low N doses.

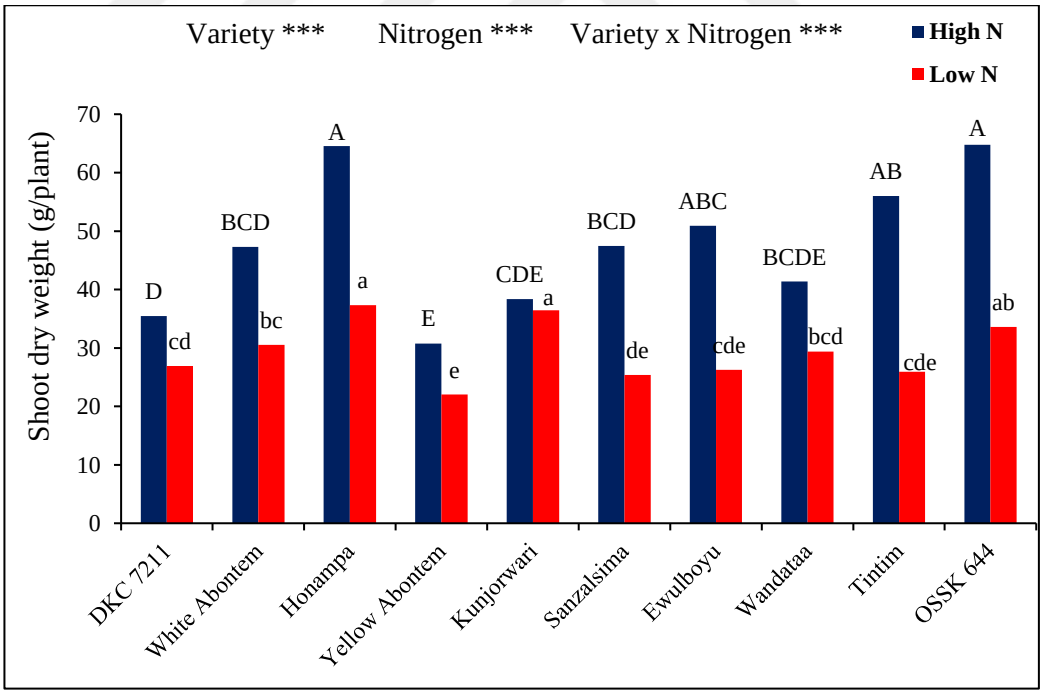


Figure 4.2: Shoot dry weight of different maize varieties under high and low N doses.

4.2 Root Biomass Production

While shoot biomasses were higher under high N, root biomasses were higher under low N except for *Ewulboyu*, *Tintim* and *OSSK 644* which produced higher root fresh weights (Figure 4.3) under high N supply; though the latter two had less dry biomasses (Figure 4.4). Highly significant difference ($p < 0.0001$) existed between the maize varieties under investigation. N treatments were also significantly ($p < 0.0001$) different as well as a significant variety-nitrogen interaction. The plants did not produce much root biomass under high N as compared to low N treatment. Average fresh root weight under high N was 90.06g. *Tintim* with 140.33g had the highest and *Wandataa* with 42.80g produced the lowest. And with an average of 3.16g, *Ewulboyu* and *Wandataa* (5.53g and 0.63g respectively) produced the highest and the lowest dry root biomass under high N. The average fresh root biomass production under low N was 114.89g, where *Honampa* and *Yellow Abontem* respectively produced the highest and the lowest. And per an average dry root matter production of 6.52g, *Honampa* with 12.77g, and *Yellow Abontem* with 2.63g, again produced the highest and the lowest respectively.

The ratios of the dry root weights to the dry shoot also reveals the relationship between root and shoot development. There is a significant difference among varieties as well as across N treatments. Also significant was variety-N interaction (Figure 4.5). Across all biomass parameters measured, *Honampa* performed better than all the other varieties.

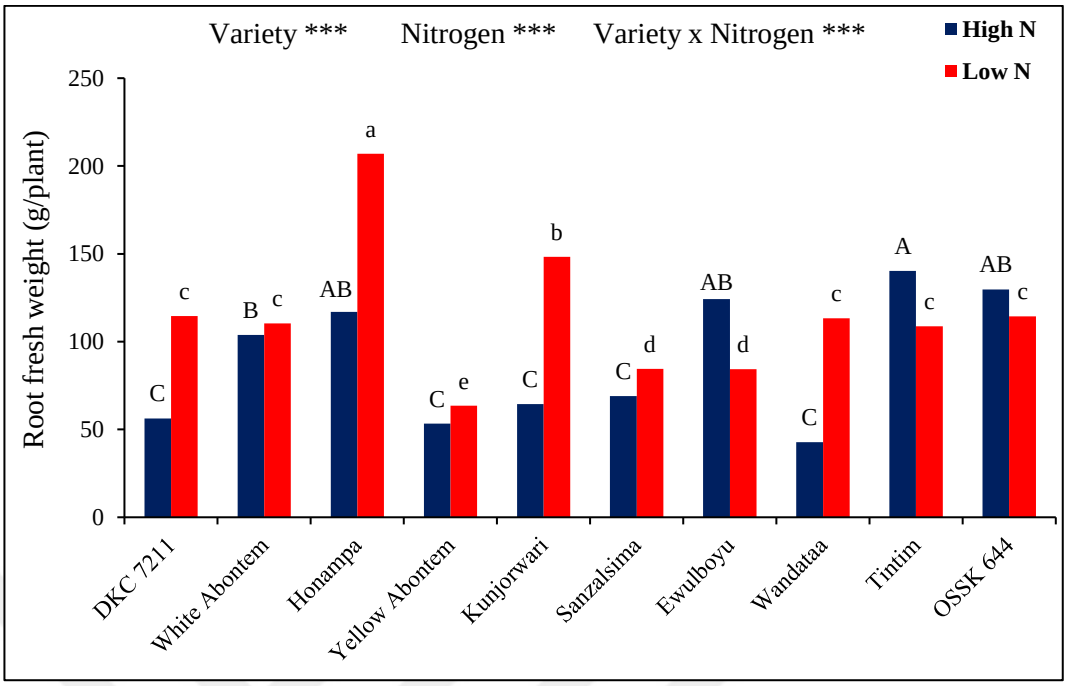


Figure 4.3: Root fresh weight of the maize varieties under high and low N doses.

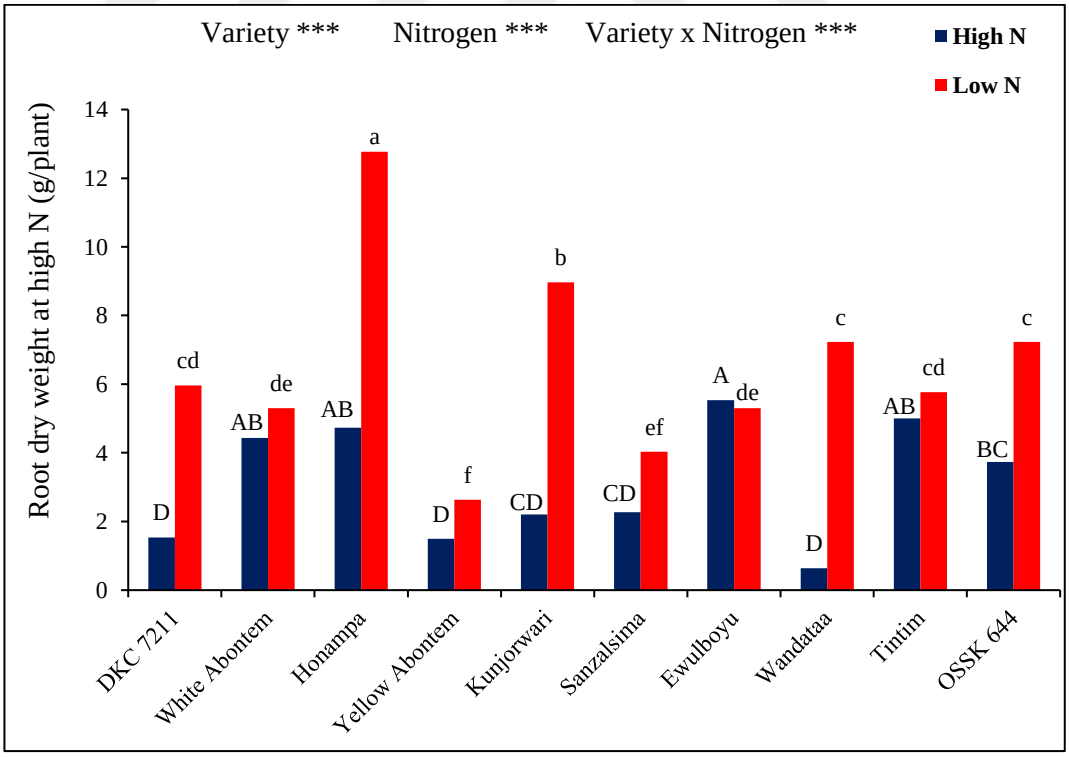


Figure 4.4: Root dry weight of the maize varieties under high and low N doses.

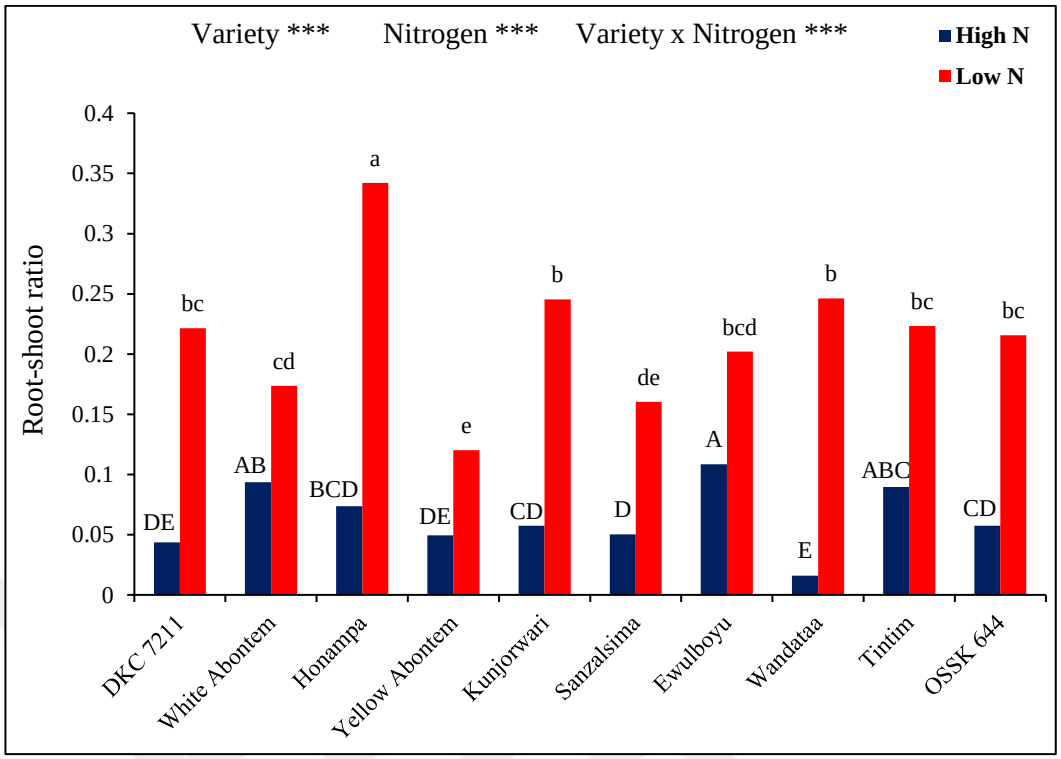


Figure 4.5: Root: shoot dry biomass ratios of the maize varieties under high and low N treatments.

4.3 Leaf Area

In this experiment, a highly significant interaction between N and variety on total leaf area was observed. Also, the varieties differed significantly ($p < 0.0001$) in total leaf area. N treatments also significantly affected the total leaf area. As shown below (Figure 4.6) *Honampa* had the highest leaf area under high N whilst *DKC 7211* had the lowest. Under low N however, *Wandataa*, *Sanzalsima*, *DKC 7211* and *Honampa* in order of arrangement were the highest leaf area but not significantly different from *White Abontem*, *OSSK 644*, *Ewulboyu* and *Kunjorwari*. Yellow Abontem had the smallest total leaf area under low N treatment.

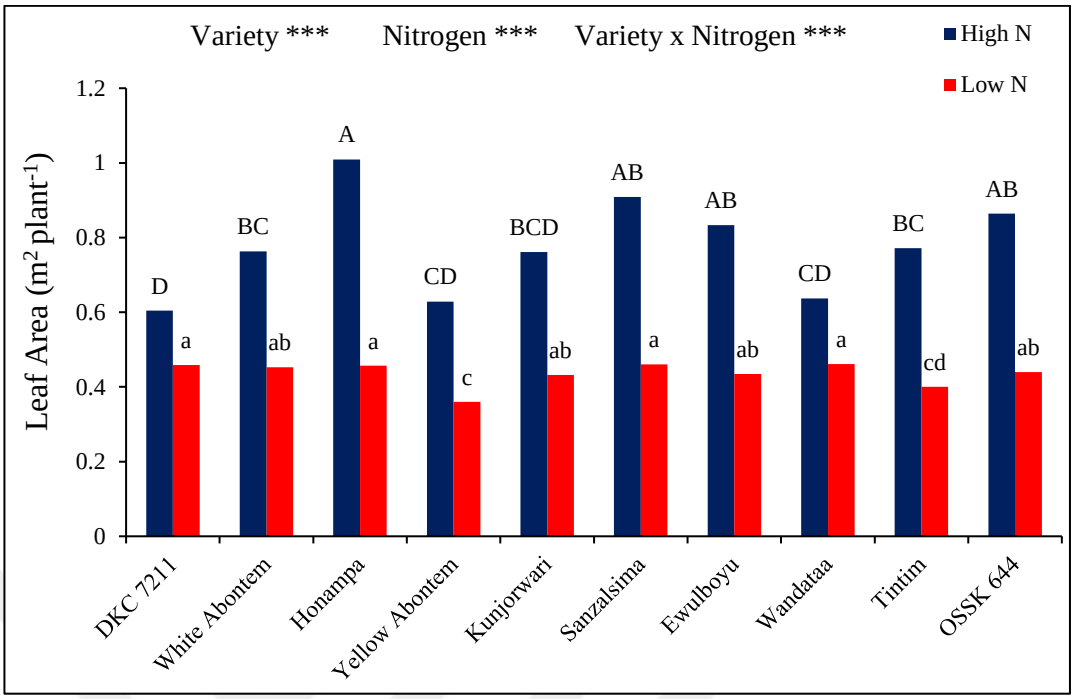


Figure 4.6: The effect of N levels on total leaf area. Means with the same letter are not significantly different.

4.4 Root Length, Volume and Diameter

Results from the solution culture experiment conducted revealed that, root length of plants under low N supply were greater than those under high N except for *Ewulboyu*, *Titim* and *Yellow Abontem* (Figure 4.7). The results also revealed that, except for three varieties (*OSSK 644*, *Tintim* and *Ewulboyu*), plants under low N treatment had larger total root volume (Figure 4.8) and average root diameter (Figure 4.9) than their counterparts under high N. Root parameters (length, volume and diameter), varied significantly ($p < 0.0001$) among the maize varieties. Also, significant ($p < 0.0001$) was N treatments on these root morphological features. Interaction between variety and nitrogen was also highly significant ($p < 0.0001$). The mean total root length, volume and diameter were 731.40 m, 57.44 cm^3 and 5.84 mm respectively under high N treatment. The highest and lowest root lengths were respectively recorded from *Honampa* (999.98 m) and *Wandataa* (334.34 m). *OSSK 644* (83.22 cm^3) and *Wandataa* (25.35 cm^3) had the highest and the

lowest root volumes. On the average root diameter, *Wandataa* (2.39 mm) had the smallest and *Tintim* (9.57 mm) with the largest root diameter. Under low N treatment, *Honampa* had the highest average root length volume and diameter than all the other varieties. *Yellow Abontem* had the lowest average root length, volume and diameter.

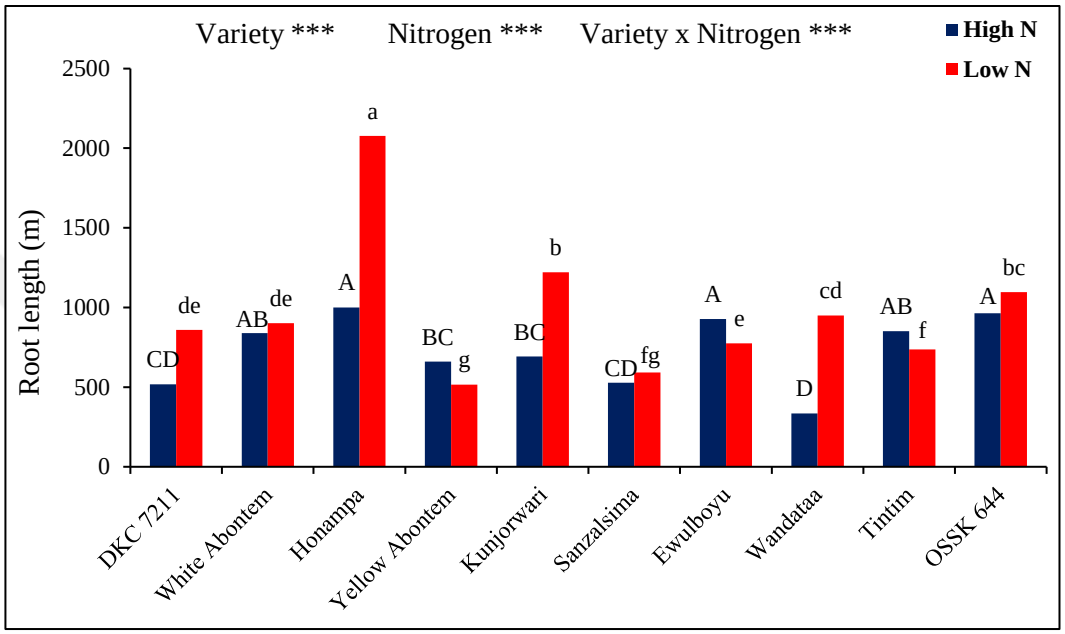


Figure 4.7: Root length. Means with same letter are not significantly different.

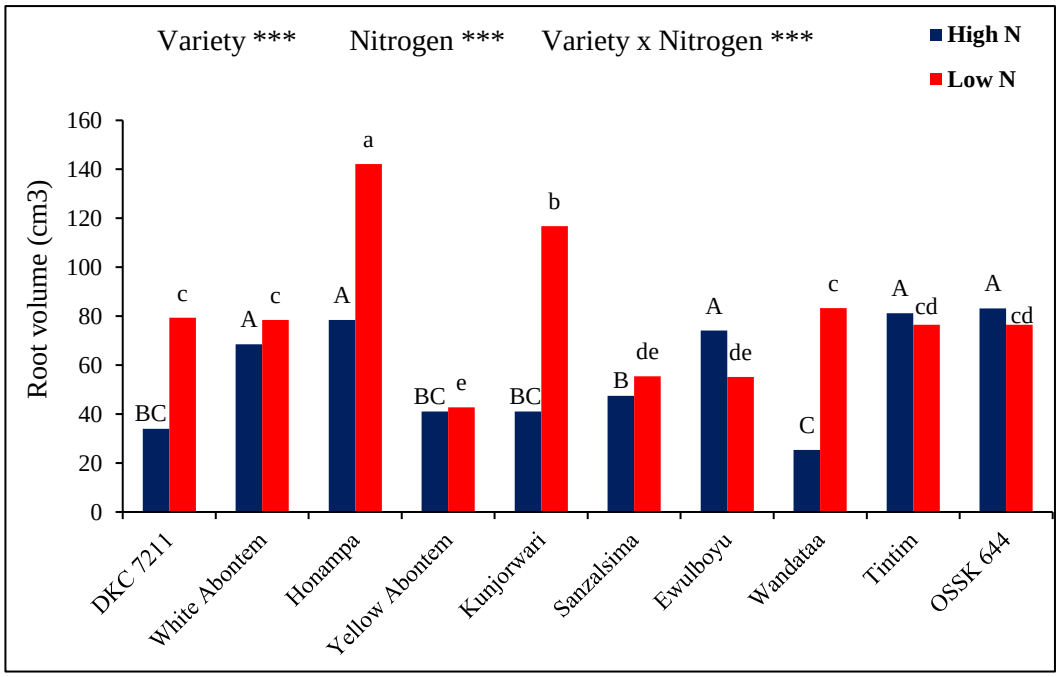


Figure 4.8: Root volume. Means with same letter are not statistically different.

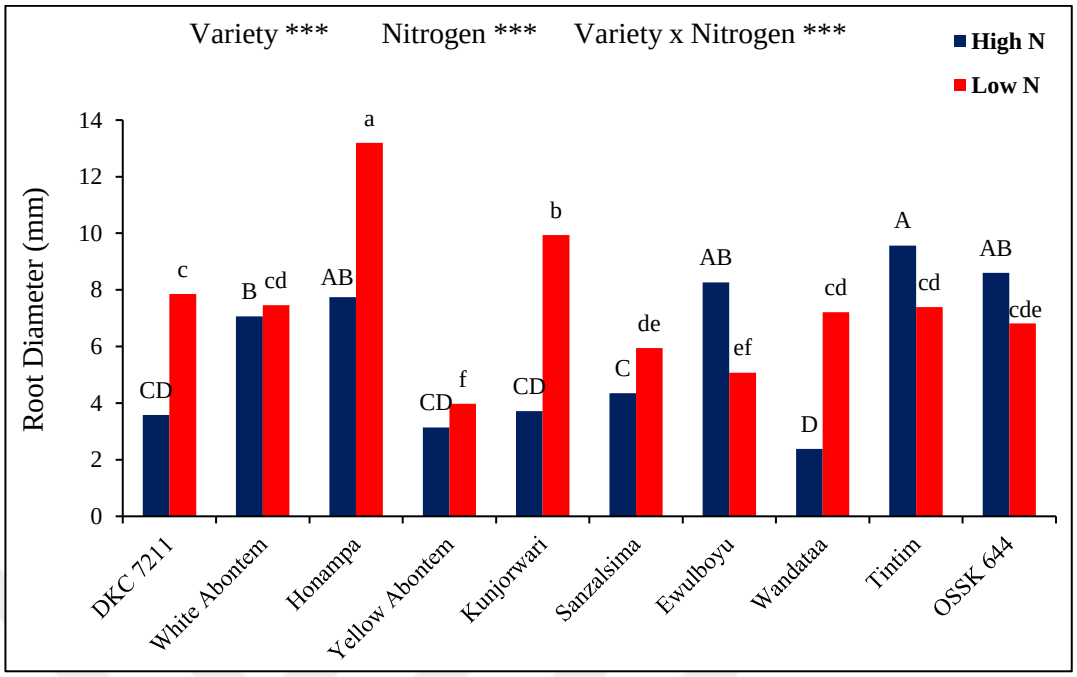


Figure 4.9: Root diameter. Means with same letter are not significantly different.

4.5 Nitrate Reductase Activity

The enzyme nitrate reductase (NR) activity determination is one of the measures of N utilisation efficiency in crops. Examining the NR activity of the maize varieties used for this work showed significant genotypic differences ($p < 0.0001$) in NR activity. Nitrogen levels also significantly ($p < 0.0001$) affected the NR activity. A significant interaction between variety and nitrogen also existed. Under both low and high N treatments, leaf NR activity (Figure 4.10) was higher than root NR (Figure 4.11) except *Honampa* which exhibited a high NR activity in roots than leaves under low N. *Tintim* had the highest leaf NR activity at high N whereas *Yellow Abontem* had the lowest. All the remaining varieties were within these extremes and did not vary significantly from one another. Leaf NR activity at low N saw *Yellow Abontem* and *DKC 7211* with the highest and *Honampa* with the lowest. Root NR activity at high N saw *White Abontem* with the highest and *Honampa*

with the lowest. At low N *Yelllow Abontem* and *Homapa* had the highest root NR activity whilst *OSSK 644* and *Ewulboyu* had the lowest.

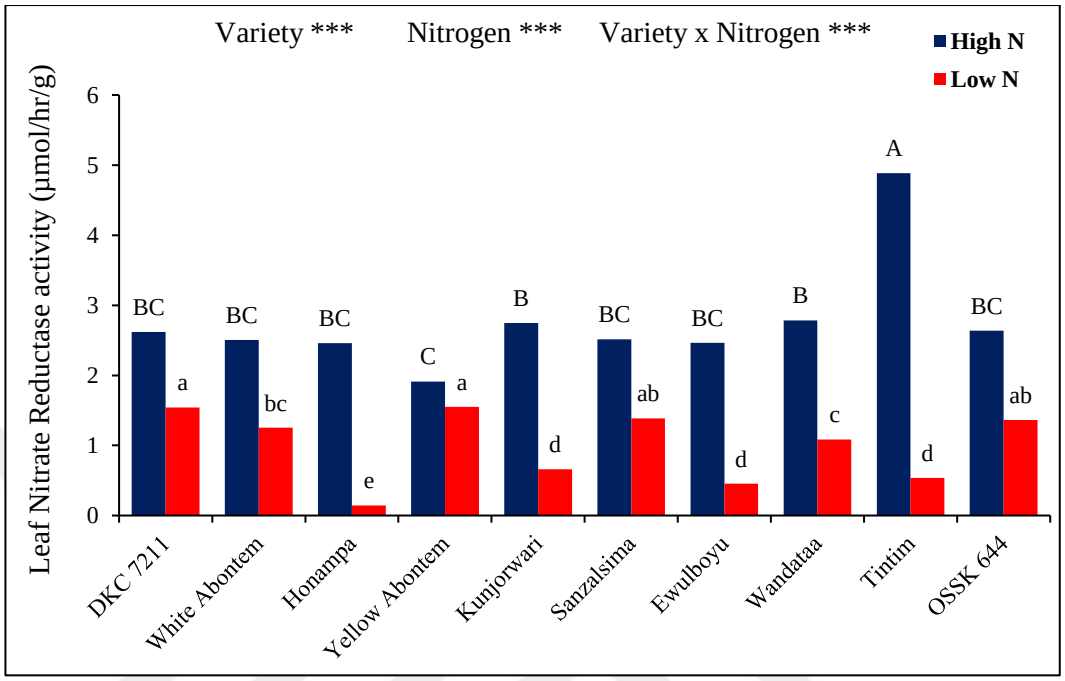


Figure 4.10: Leaf nitrate reductase activity rate. Means with the same letter are not significantly different.

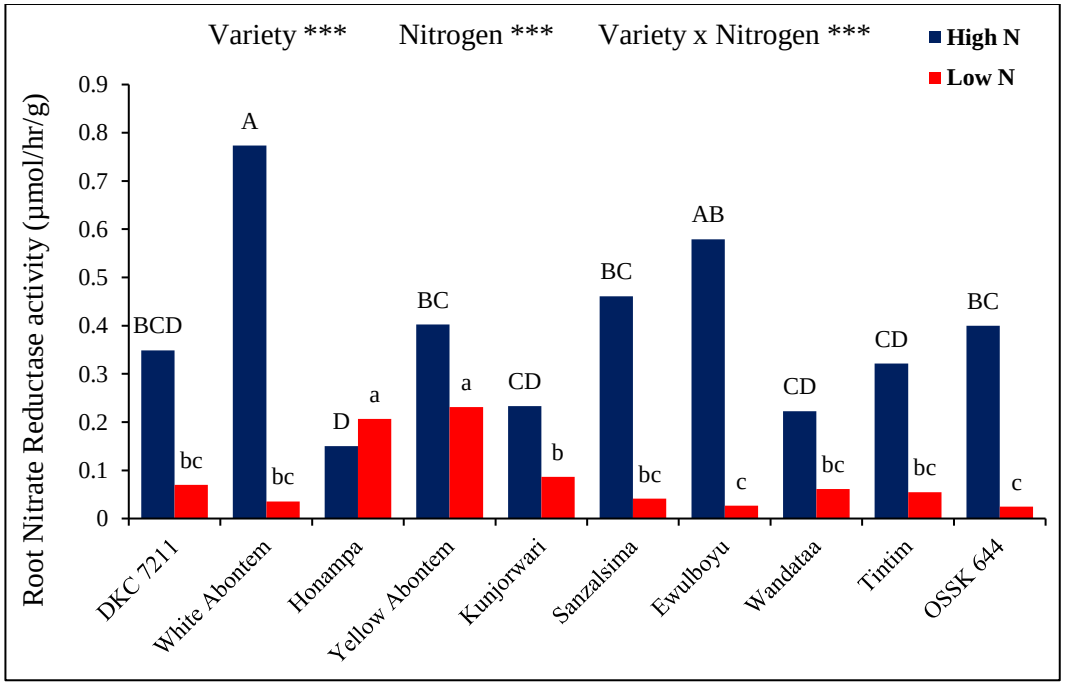


Figure 4.11: Root nitrate reductase activity rate. Means with the same letter are not significantly different.

4.6 Shoot and Root Nitrogen Concentration

As shown in Figures 4.12 and 4.13, the shoot and root N concentration (mg g^{-1}) varied significantly ($p < 0.0001$) among the varieties. Significant also was nitrogen doses on N concentration. There exists a strong interaction between the individual varieties and N treatments. In the overall, root N concentration was lower than that of shoot. Under high N, *Ewulboyu* and *Honampa* had the highest shoot N concentrations with the least N concentrations from *OSSK 644* and *White Abontem*. Root N concentration under high N saw *Yellow Abontem* and *Honampa* with the highest whilst *Wandataa* was the lowest.

And under low N *DKC 7211*, *Honampa* and *Kunjorwari* had the highest shoot N concentrations whilst *Wandataa*, *Ewulboyu* and *White Abontem* had the lowest. The root N concentration however showed contrasting results where *Yellow Abontem* had the highest concentration with the lowest from *Honampa* and *OSSK 644*.

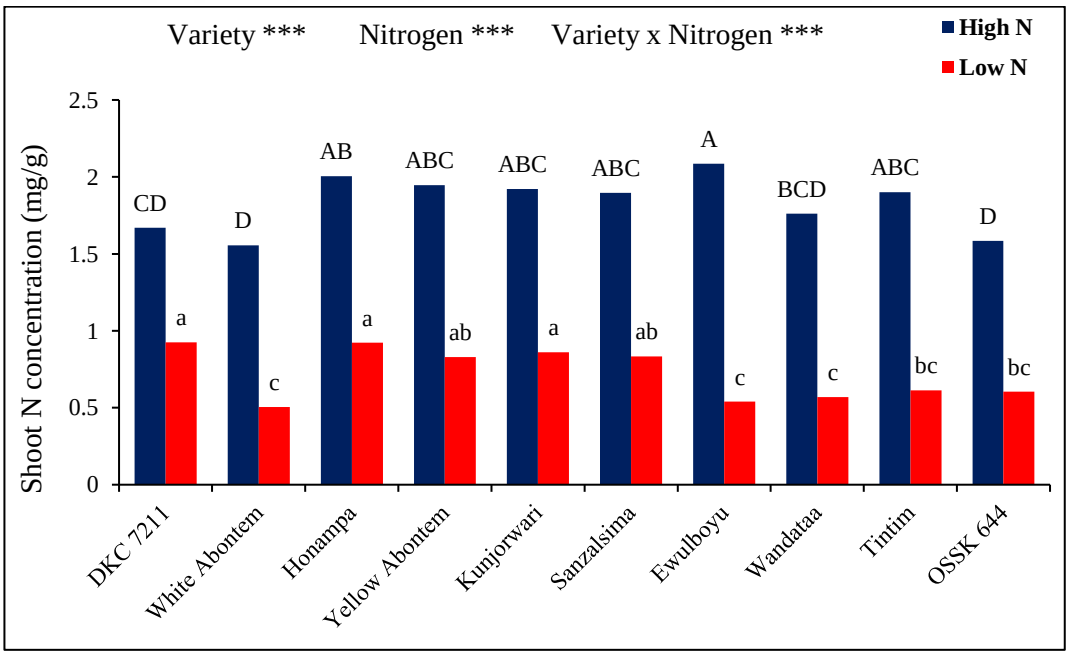


Figure 4.12: Shoot N concentration as influenced by genotype and N doses.

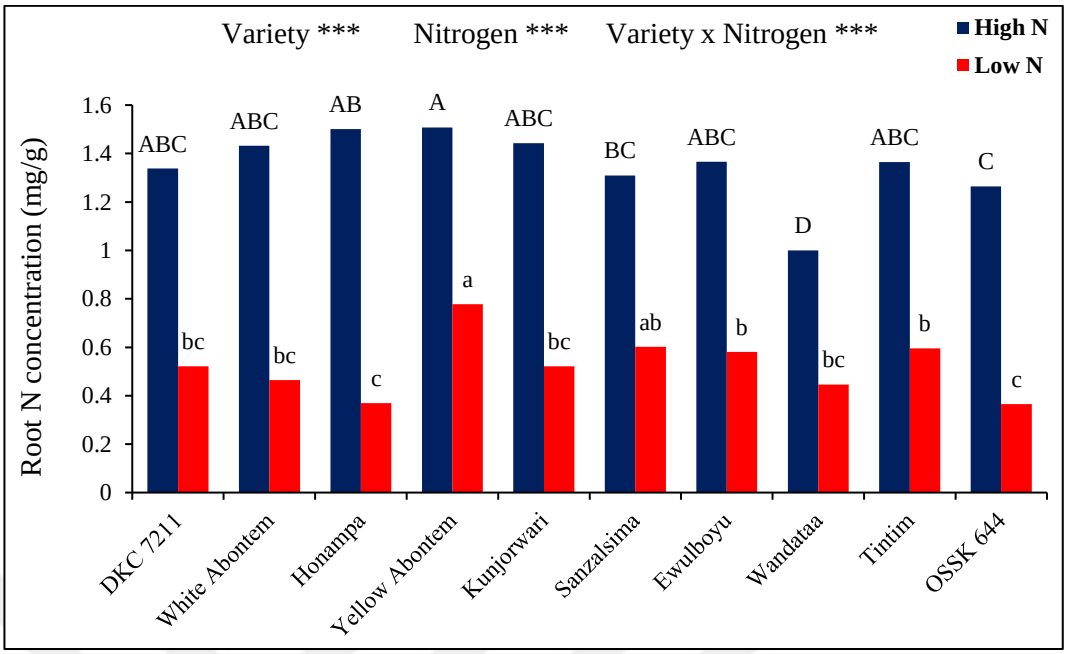


Figure 4.13: Root N concentration as influenced by genotype and N doses.

4.7 Total Nitrogen Content in Dry Biomass

Shoot and root total nitrogen content varies with reference to N levels. As illustrated in Figures 4.14 and 4.15, the total shoot and root N contents were proportionally higher under high N than low N treatments, though some varieties under low N had higher contents than under high N treatment. Statistical analysis revealed that, the total shoot and root N contents varied significantly ($p < 0.0001$) among the maize varieties as well as across N treatments. A significant variety-N interaction also existed.

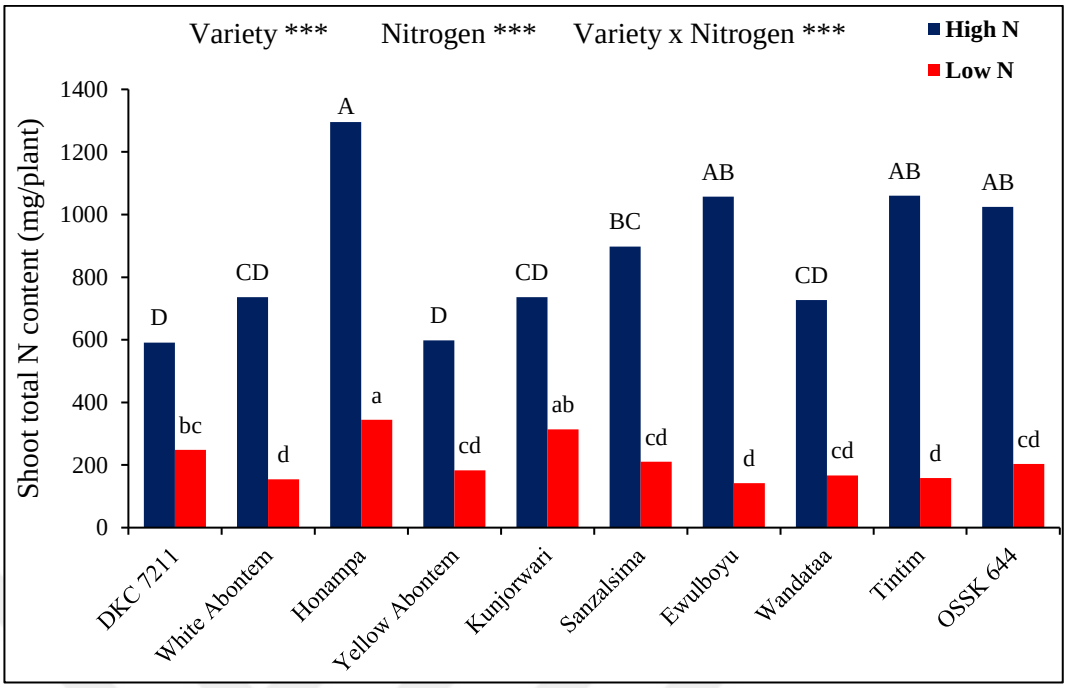


Figure 4.14: Shoot total N content as affected by genotype and N level.

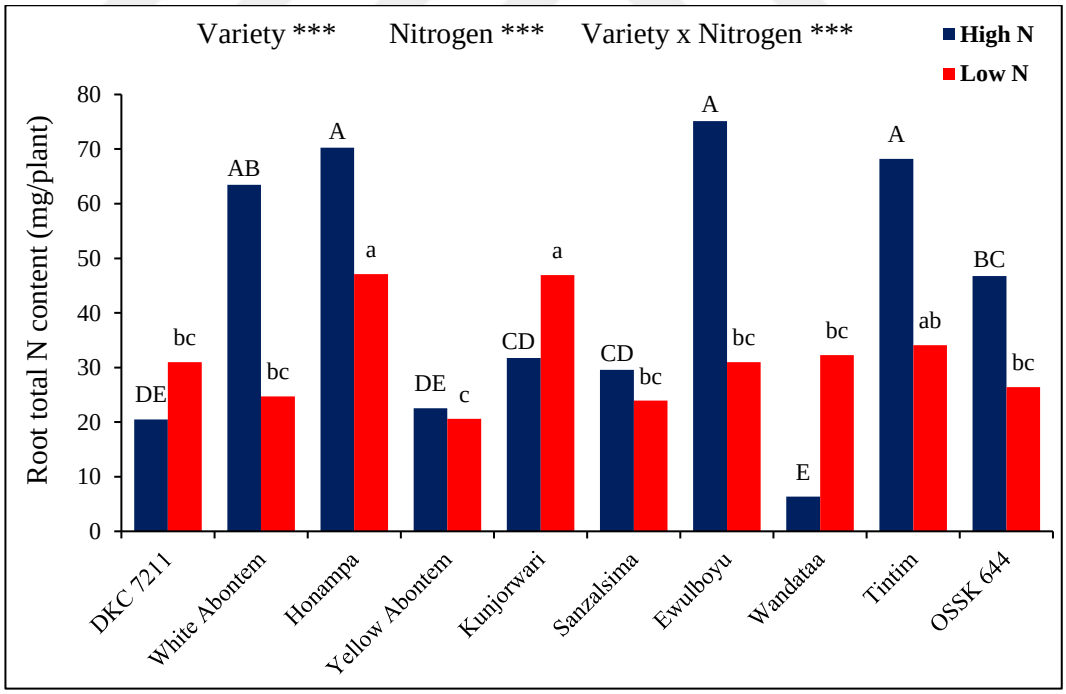


Figure 4.15: Root total N content as affected by genotype and N level.

4.8 Leaf Chlorophyll content (SPAD)

Among the most important compounds for plants is chlorophyll (the green pigment of the leaf), which can transform light energy into chemical energy through a process known as photosynthesis. As such, photosynthetic rate is somewhat directly dependent on leaf chlorophyll content though environmental factors such as light intensity also plays a part. The analysis of variance for the 10 maize genotypes under the high and low N supplies showed that, SPAD values were significantly different ($p < 0.001$) among varieties. N treatments also significantly ($p < 0.0001$) influenced leaf SPAD. A significant interaction existed between variety and nitrogen treatments. *OSSK 644* and *Honampa*, recorded the highest SPAD values under high N supply; with *Wandataa* recording the lowest. Under low N supply, *Kunjorwari* recorded the lowest, and *Tintim* with the highest. Overall, all the varieties under high N supply recorded high SPAD values except *Sanzalsima* and *Wandataa* which recorded higher values under low N supply (Figure 4.16).

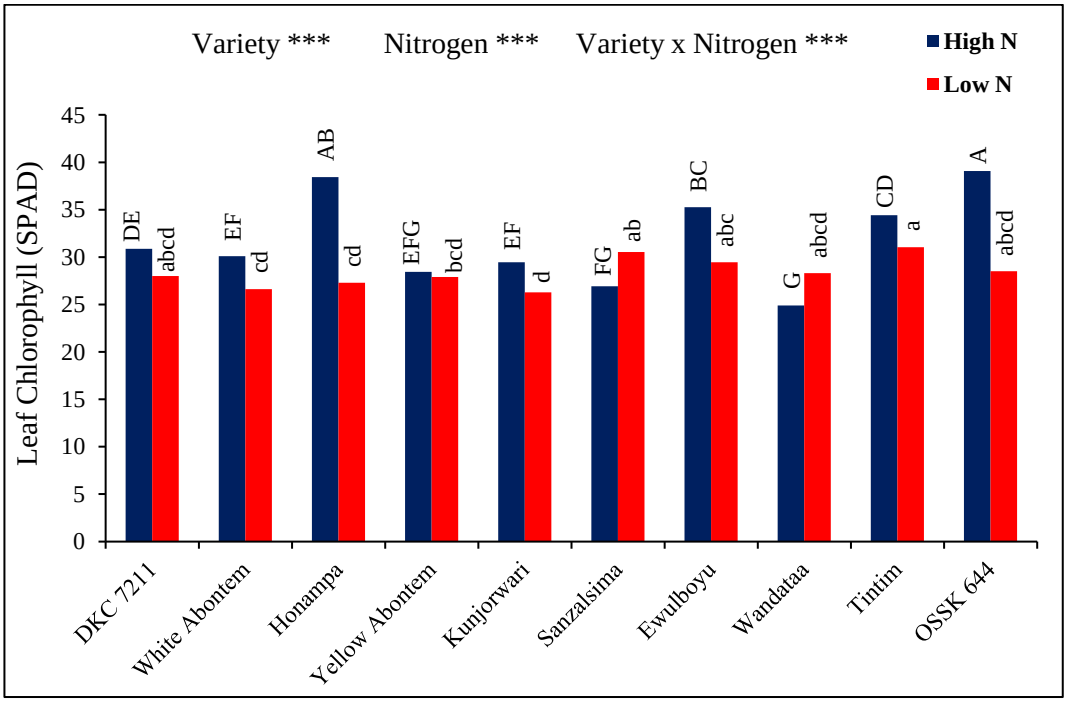


Figure 4.16: Leaf chlorophyll (SPAD). Means with the same letter are not significantly different.

4.9 Leaf Total Chlorophyll and Carotenoid Content (spectrometric readings)

The results of the spectrometric measurements and calculations of leaf total chlorophyll and carotenoid content (mg/g) showed that significant differences ($p < 0.0001$) existed between the maize varieties used. N treatments also significantly ($p < 0.0001$) affected total chlorophyll and carotenoid content. Variety-nitrogen interaction was also highly significant.

As shown in Figures 4.17 and 4.18 respectively, there was a mix response from the maize varieties in total chlorophyll and carotenoid content under the two N doses. Some of the varieties under low N supply had higher total chlorophyll and carotenoid content than those under high N supply. At high N, *OSSK 644* and *Ewulboyu* recorded the highest leaf total chlorophyll, and *Sanzalsima* with the least. At low N, *Wandataa* and *Yellow Abontem* recorded the highest, whereas *DKC 7211* recorded the lowest. On total carotenoids, just as in leaf total chlorophyll, *OSSK 644* had the highest leaf carotenoid content and *DKC 7211* with the least under high N. *White Abontem* and *DKC 7211* respectively recorded the highest and the lowest carotenoid contents under low N.

4.10 Photosynthesis

Leaf photosynthetic rate, which is partially dependent on the leaf chlorophyll content, varied significantly ($p < 0.001$) among varieties as well as among N treatments (Figure 4.19). A highly significant interaction between variety and nitrogen also existed. Under high N, *OSSK 644* recorded the highest leaf photosynthetic activity corresponding to its SPAD, total chlorophyll and carotenoid values, but not significantly different from *Kunjorwari* and *Tintim*. There were no significant differences among the other varieties under same high N supply. At low N supply, *Yellow Abontem* and *DKC 7211*

had the highest photosynthetic activity whereas, *Honampa*, *White Abontem* and *Ewulboyu* ranked the lowest.

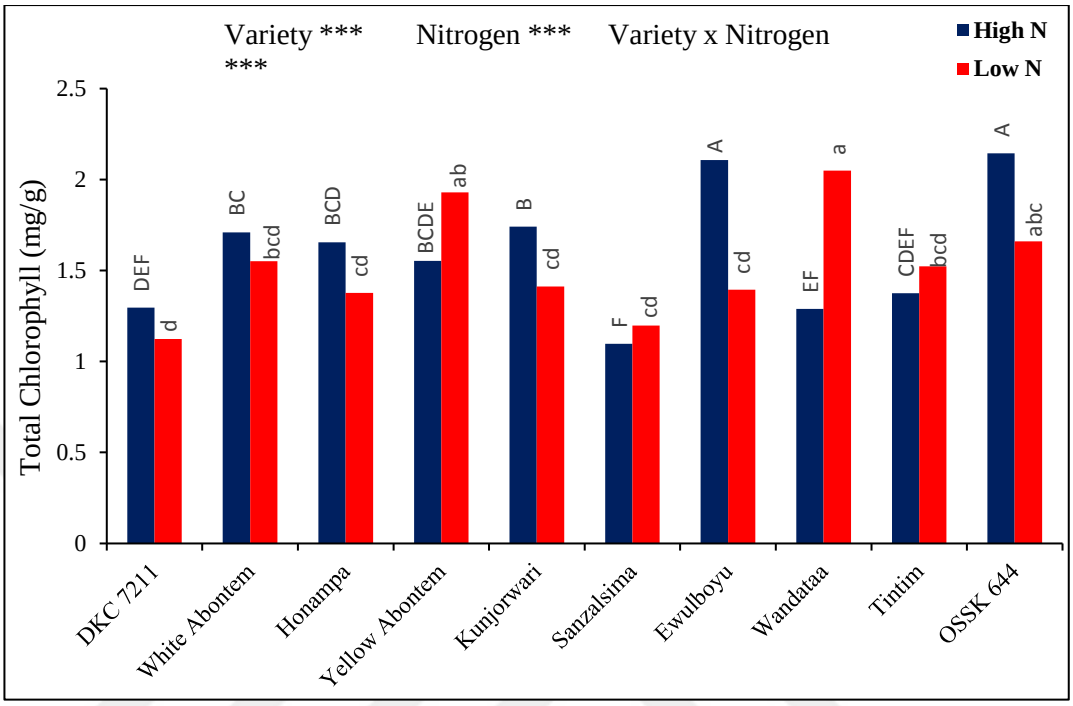


Figure 4.17: Leaf total chlorophyll content. Means with the same letter are not significantly different.

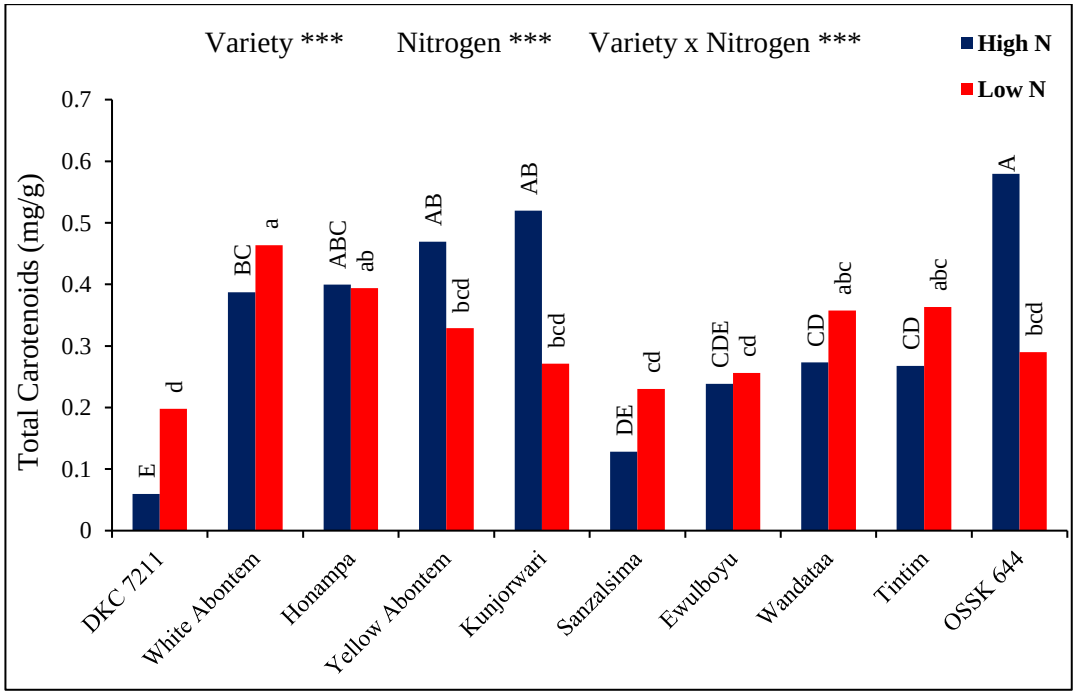


Figure 4.18: Total carotenoid content. Means with the same letter are not significantly different.

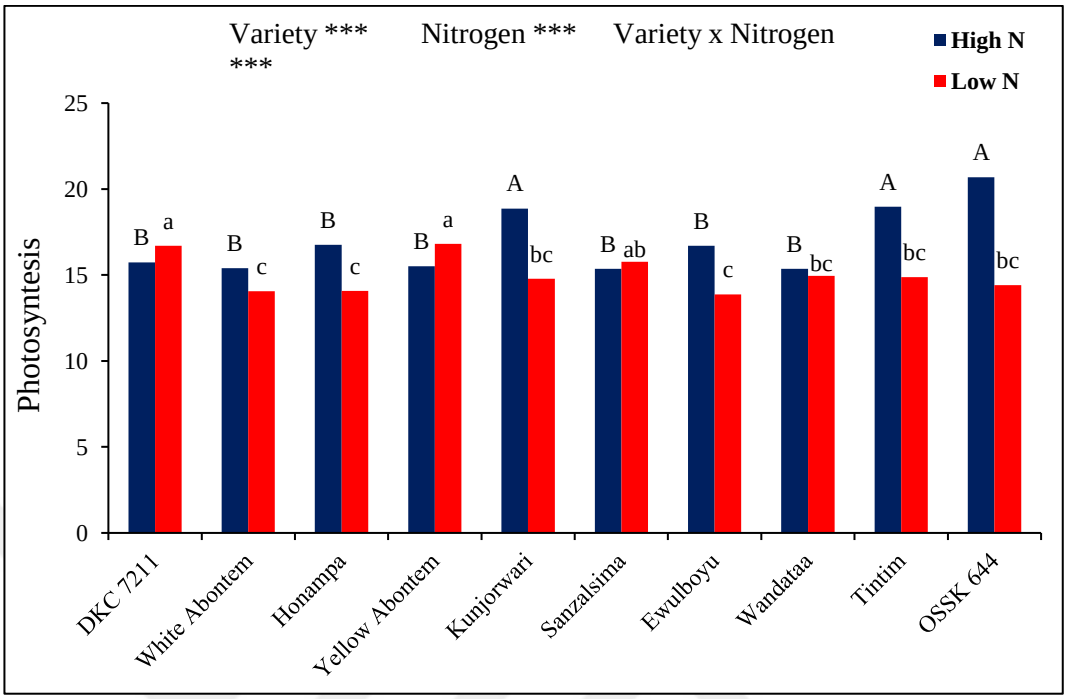


Figure 4.19: Photosynthetic activity. Means with the same letter are not significantly different.

4.11 Leaf Number and Senescence

The average number of leaves per plant varied significantly among N treatments ($p < 0.0001$) but not among varieties ($p > 0.05$) as shown in Figure 4.20. Under high N treatment, *OSSK 644* had more leaves (approximately 14) with *White Abontem* having the least of approximately 12 per plant. *DKC 7211* under low N ranked first with approximately 11 leaves per plant; and with approximately 10 leaves per plant, *Honampa* and *Kunjorwari* ranked the lowest. Overall there was no interaction between Nitrogen and variety. By the end of the experiment, (35 days after treatment) all the plants under low N treatment had a leaf senescence score of 4 except on the average for *DKC 7211* which registered only two (data not shown). Under high N treatment, absolutely no leaf senescence occurred on any variety.

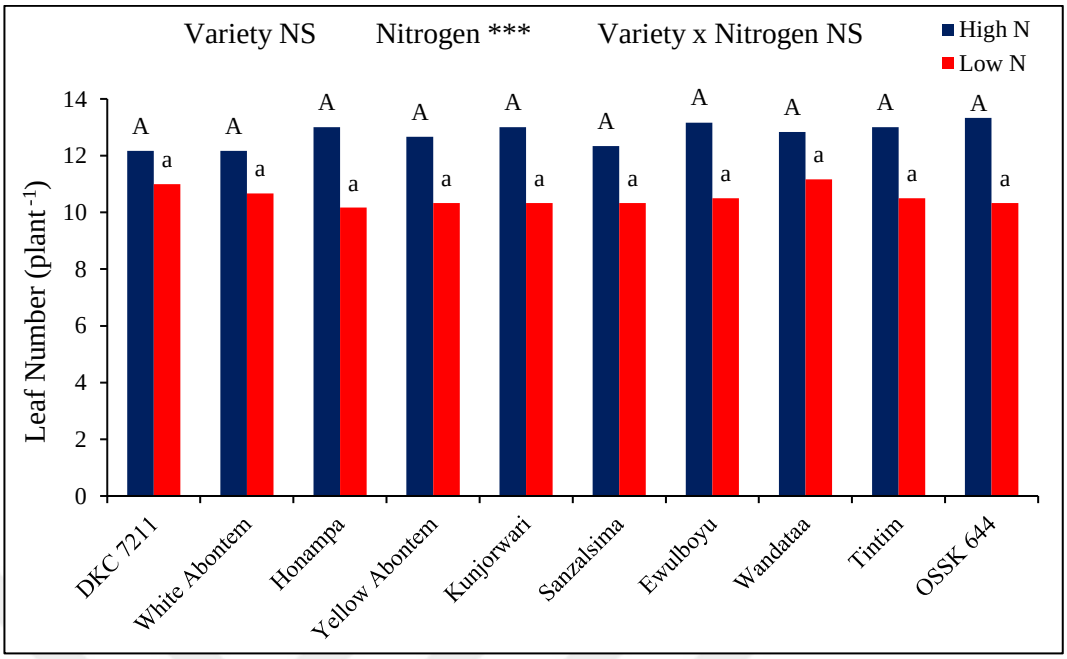


Figure 4.20: Average leaf number per plant. Means with the same letter are not significantly different. NS = not significant

4.12 Plant Height and Stem Diameter

One of the common symptoms of N deficiency is stunted (dwarfy) growth. As such, observed height differences were significant ($p < 0.0001$) among the varieties and across N treatments (Figure 4.21). Variety-nitrogen interaction was also highly significant. *Sanzalsima*, *OSSK 644*, and *Honampa* were respectively taller under high N supply, whereas under low N treatment, *OSSK 644* grew the tallest. *Wandataa* have the shortest average plant height under both treatments. However, some plants may grow taller but with thin stems. Hence the need to consider the stem diameter.

The analysis of variance from the measured stem diameters revealed that there were highly significant differences ($p < 0.0001$) in stem diameter among the varieties under different N doses. Nitrogen-variety interaction was also significant (Figure 4.22). Plants under high N treatment had larger stem diameters than those under low N. *Honampa* under high N had the largest stem diameter and *DKC 7211* with the smallest average stem

diameter. Under low N treatment, *Tintim* and *Kujorwari* registered the highest and the lowest respectively.

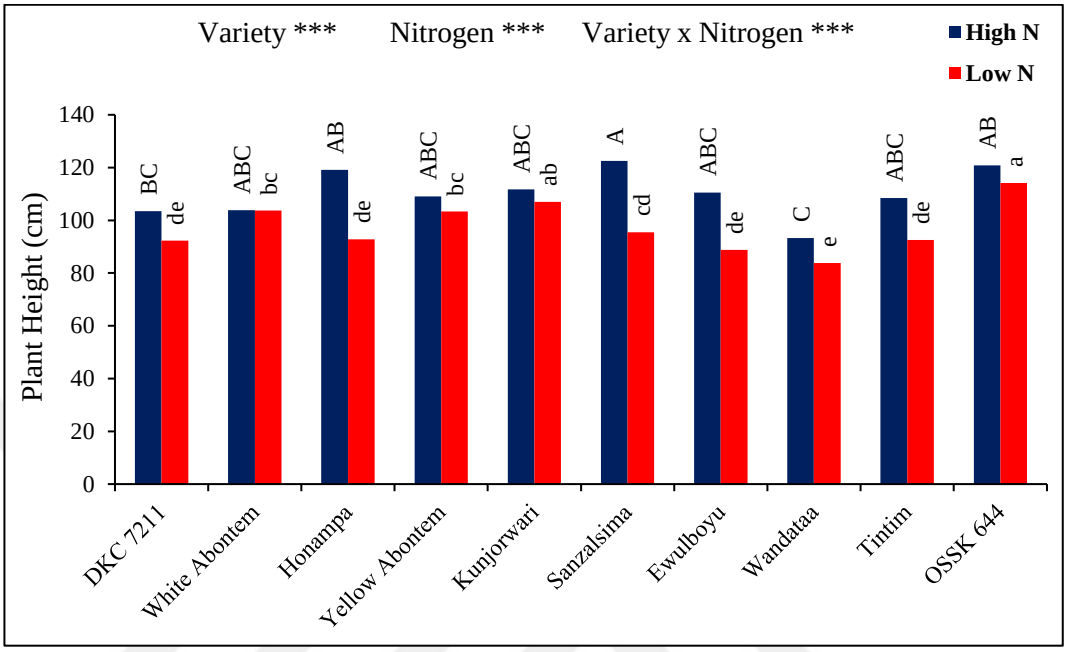


Figure 4.21: Plant height (cm). Means with the same letter are not significantly different.

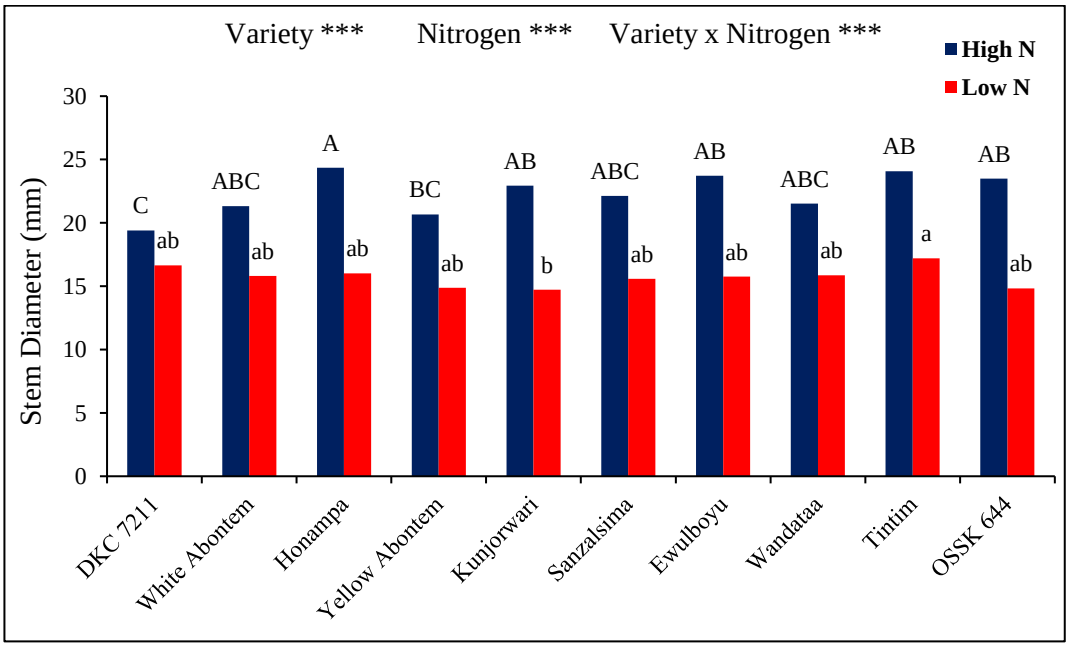


Figure 4.22: Stem diameter (mm). Means with the same letter are not significantly different.

4.13 Macro and Micro Element Concentrations

Just like nitrogen concentration, some macro and micro element concentrations also varied significantly among the maize varieties as well as across N treatments. As presented in Table 4.1 (page 46), the varieties differed significantly ($p < 0.0001$) in phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulphur (S), manganese (Mn) and zinc (Zn) concentrations. Nitrogen treatments also significantly ($p < 0.0001$) influenced the concentrations of P, K, Ca, Mn and Zn. Variety and nitrogen interaction significantly ($p < 0.0001$) influenced the concentrations of all the examined elements except copper (Cu).

4.14 General Correlation of Measured Parameters

A correlation between the measured parameters was made. Parameters with a role in **uptake** (*root fresh and dry weights; root length, volume and diameter*) was correlated with parameters relating to **utilisation** (*SPAD value, leaf total chlorophyll and carotenoid content, photosynthesis, leaf number and area, plant height and stem dimeter, leaf and root NRA's, shoot fresh and dry weights, N concentrations and total N content*). Many of the parameter correlations were highly significant ($p < 0.05$) though are either negative or positive. Refer to appendix 1 (page 63) for the table of correlation of parameters under high and low N treatments.

Table 4.1: Some macro and micro element concentrations in the dry biomass of the maize varieties under high and low nitrogen supply levels.

NS = not significant; *** = highly significant; V x N = Variety-nitrogen interaction

Category	Macro elements (%)								Micro elements (ppm)					
Elements	P		K		Ca		Mg		Mn		Cu		Zn	
N Level. / Variety	high	low	high	low	high	low	high	low	high	low	high	low	high	low
DKC 7211	0.25	0.26	2.22	2.67	0.19	0.16	0.06	0.07	57.52	31.35	5.99	4.37	95.03	41.05
White Abontem	0.27	0.26	2.63	2.53	0.16	0.16	0.09	0.08	60.63	55.88	5.19	5.17	33.17	31.48
Honampa	0.24	0.24	1.74	1.94	0.22	0.20	0.14	0.12	46.32	31.60	3.75	3.10	34.85	39.41
Yellow Abontem	0.27	0.21	2.61	2.78	0.17	0.18	0.09	0.09	50.39	43.45	4.45	3.39	52.07	58.47
Kunjorwari	0.25	0.22	2.12	2.58	0.16	0.16	0.06	0.08	50.72	52.55	5.23	5.21	49.21	25.01
Sanzalsima	0.33	0.28	2.40	2.59	0.20	0.14	0.09	0.10	84.15	49.43	5.27	3.47	73.07	28.84
Ewulboyu	0.25	0.33	2.73	2.67	0.19	0.19	0.11	0.11	44.49	53.56	5.11	3.60	45.40	49.17
Wandataa	0.27	0.24	2.70	2.75	0.22	0.18	0.09	0.08	60.09	52.56	4.51	2.80	36.19	32.49
Tintim	0.28	0.23	1.78	2.08	0.21	0.13	0.09	0.07	44.21	44.87	4.71	2.79	32.89	32.31
OSSK 644	0.32	0.26	2.26	2.30	0.20	0.17	0.08	0.07	47.77	39.03	5.01	5.28	46.79	30.45
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Means	**0.27**	**0.25**	**2.32**	**2.49**	**0.19**	**0.17**	**0.09**	**0.09**	**54.63**	**45.43**	**4.92**	**3.92**	**49.87**	**36.87**
F-test (5%)	Variety *** Nitrogen *** V x N ***		Variety *** Nitrogen *** V x N ***		Variety *** Nitrogen *** V x N ***		Variety *** Nitrogen =NS V x N ***		Variety *** Nitrogen *** V x N ***		Variety =NS Nitrogen =NS V x N =NS		Variety *** Nitrogen *** V x N ***	

CHAPTER FIVE

DISCUSSION

5.1 Biomass Production

The first thing that comes to mind when NUE is mentioned is, "obtaining a corresponding maximum result of importance that reflect the amount of N available/supplied to a plant". NUE has several different definitions depending on one's interest and target. Lynch (1998) gave a general definition of efficiency as the ability of a (plant) system to convert inputs into desired outputs or to minimize the conversion of inputs into waste. Moll *et al.* (1982) with specificity to NUE defined efficiency as the grain yield per a unit of available N. Maize is widely cultivated for its grain though it is also widely grown for fodder. Hence, the grain yield or biomass production per unit of available/applied N would be the most important measure of N efficiency in maize.

Akitoye *et al.* (1999) and Sattelmacher *et al*. (1994) have both observed that, significant variations in grain yield and biomass production exist between maize genotypes. Our results on biomass yield (fresh and dry) of the varieties under low and high N supplies agree with these exclusive observations of theirs. Also observed among the genotypes was a vast difference in root biomass production. A significant positive correlation existed between root biomass and shoot biomass under both low and high N supplies.

In an optimised management system with combinations of cropping and fertilisation, Wang *et al.* (2014) found that higher root biomass at silking enhanced NUE in maize plants mostly due to efficient N recovery. The impact of the root morphology is in fact more appreciated when growth conditions are not favourable (nutrient scarcity, toxicity, moisture level etc.). In this present study, the results showed that, root lengths, root volumes and root diameters were higher under limited N conditions; a mechanism by the plants to enhance N absorption. Smaller root diameter enhances uptake rates (Föhse *et al*., 1991) because with a small surface area, nutrients can be absorbed from larger volume of soil. However, as according to Sattelmacher *et al*. (1994), thicker roots are also advantageous as they may be able to overcome soil mechanical resistance against root elongation especially under compacted soil conditions.

5.2 Total Nitrogen Content and Concentration

One of the components important to note when discussing NUE is the uptake efficiency. According to (Brentrup and Palliere, 2010) NUE is the ratio between the amount of N fertilizer removed from the field by the crop and the amount of N fertilizer applied/available. Therefore, the ability of the uptake system to remove applied/available N is important to the plant and the environment. Usually, root absorption of nutrients (N) and translocation to the shoot and the subsequent distribution around the plant is overseen by complex interactions between shoots and roots (Sauerbeck and Helal, 1990). That is to say, plant roots do not just absorb nutrients anyhow; whereas not all the absorbed nutrients are translocated across the plant but are regulated by cellular activities within the plant. Plants vary genetically in their N uptake ability and thus, will differ in N concentration as well. As shown in our results, the variations in total N uptakes and

concentrations among the maize genotypes were mainly due variations in their respective genotypic ability to absorb and utilised available N. Under low N, varieties with higher total N content also have corresponding higher root morphological parameters (length, volume and area), indicating that the efficiency of the uptake system of a plant genotype is related to its root morphology. This was also the observation of Moll *et al*. (1982), who attributed observed differences among maize hybrids in N use to genotypic differences in uptake and utilisation of accumulated N.

5.3 Photosynthetic Pigments

Among the most important compounds for plants is chlorophyll (the green pigment of the leaf), which can transform light energy into chemical energy through a process known as photosynthesis. Leaf chlorophyll content is one of the important indicators of the health and potential physiological performance of a plant (Kumar *et al*., 2002). The chlorophyll concentration in the leaf is essential for crop growth and development (Bannari *et al*., 2007) hence quantifying it makes available vital information about the effects of environment on plant growth (Schlemmer et al., 2005). Carotenoids on the other hand, contributes to light harvesting whilst preventing photodamage to the photosynthetic systems (Ndukwe *et al*., 2016; Merzlyak *et al*., 2003; Gitelson, 2003) through their interconversion with the xanthophyll molecules (Ort, 2001; Young, 1991).

In this study, it was observed that, N supply and genotypic differences in plants (maize in our case) influences leaf SPAD, total chlorophyll and carotenoid content as well as photosynthesis. This view is in line with Bojovic and Stojanovic (2005) that, leaf chlorophyll and carotenoid content is dependent on the presence and ratio of mineral elements (especially nitrogen) in the substrate. The exclusive publications of (Singh, *et*

al., 2016; Ndukwe *et al*., 2016; Neufeld *et al*., 2006; Netto *et al*., 2005; Zhao *et al*., 2003; Girardin *et al.,* 1985) has it that, N supply influences the leaf chlorophyll synthesis/concentration. And one thus generally may expect that, under maximum/higher N supply levels, these photosynthetic pigments will be high. However, several other factors aside nitrogen fertilisation affects the chlorophyll and carotenoid content and for that matter photosynthetic activity in plant leaves. These include water stress, leaf injury, leaf age, genotypic differences, nutrient supply (Bojović and Stojanović, 2005; Schepers *et al*., 1992) and environmental factors such as temperature and light intensity. We have also observed in this present study that there was a positive correlation between biomass production and leaf SPAD, total chlorophyll and photosynthetic activity. Under severe N stress conditions, Zhao *et al*. (2003) related lower biomass production in maize to the significant decreased in leaf area and photosynthetic rate. A view we share also.

5.4 Leaf Number, Leaf Area, Senescence, Plant Height and Stem Diameter as Affected by Nitrogen and Genotype

Under stress conditions, the leaf number and size (area) can be significantly affected. Genotypic differences in adaptions to these stress conditions also plays a greater role. In this present study, the observed differences in leaf number was only as an effect of nitrogen treatments but not genotypic differences. This non-significant variation in leaf number among the maize genotypes under the two respective N treatments could be said to be species specific. However, number of leaves on a maize plant may not necessarily correlates to high grain or biomass production.

Plants under N stress conditions do not only produce few leaves but they also shed off old leaves in order to remobilise the N in them to the younger ones. Leaf senescence is

said to affect the plant's total photosynthetic rate and thus affecting biomass production and yield. The consequence of senescence is a decrease in photosynthesis, leading to low assimilates availability for all plant functions (Gallais and Coque, 2005) and therefore affecting yield. However, senescence does not always affect final biomass or grain yield, even at low N-input because of the redistribution of the remobilised N (Gallais and Coque, 2005). Moreover, stay-green plants do not necessarily guarantee higher yields, more especially when their nutrient remobilisation and chlorophyll catabolism are disabled (Pic *et al*., 2002).

Another important morphological feature to maize as a C_4 plant is leaf size; very vital for light harvesting. According Sinclair (1984), leaf area is an important parameter primarily for light interception which has a major influence on crop yield. Our findings indicated that the average leaf area of the maize varieties under high N treatment were almost twice that of low N. Comparing with biomass yield, the varieties with higher shoot biomasses also had higher average leaf areas. This is in line with the observations of Zhao *et al*. (2003) who attributed low biomass production under limited N supply to smaller leaf area.

5.5 Nitrate Reductase Activity

The enzyme nitrate reductase (NR) activity determination is one of the measures of N utilisation efficiency in crops. Its activity in plants gives a good estimate of the plant's N status and is usually correlated with growth and yield (Srivastava, 1980). When plants take up nitrogen in the form of nitrates (NO_3^-), it is first reduced to ammonium (NH_4^+) by a NR enzyme before it is being incorporated into plant compounds. High NR activity in a plant implies that the plant has a greater ability to convert absorbed NO_3^- to usable forms. NR activity however, is usually affected by CO_2 levels, light intensity,

temperature, water supply, the plant's genetic composition and mineral nutrition (especially NO_3^- availability) (Beevers, and Hageman, 1969).

According to Hofman, and Van Cleemput (2004) and Campbell (1988), depending on NO_3^- availability and plant species, NR activity is greater in plant leaves though in some plants there is little or no nitrate reduction in leaves but in roots. Our results agree to these observations of theirs. We found that the average leaf NR activity of the maize genotypes tripled that of the NR activity in the roots under both high and low N with *Honampa* an exception (refer to Figures 4.10 and 4.11). The exceptionality of the *Honampa* variety was that, at low N supply, NR activity in its roots was higher than in its leaves; which we think has contributed to higher dry biomass production. Because the NO_3^- is readily rapidly reduce at the root level before translocation to the shoot. Investigations further into this exceptional behaviour of *Honampa* revealed that, despite the high NR activity in the roots, it still had the less root N concentration compared to its shoots (refer to Figures 4.12 and 4.13). This prompts a pre-conclusion that *Honampa* could be a potential N efficient variety.

In general, NR activity is said to be positively correlating with yield of plants. A positive correlation between NR activity and silage yield was observed by Feil *et al*. (1993). Earlier on, Messmer *et al*. (1984) in a selection experiment on maize showed that, genotypes with high reduced N had greater grain yields than those with low reduced N.

5.6 Conclusion and Recommendation

The results of the indoor solution culture experiment to access the genotypic differences in N efficiency among 8 local and 2 hybrid maize varieties showed categorically clear that, genotypic differences exist in N uptake and utilisation. Considering all the parameters discussed above whilst taking biomass production as the desire output;

Honampa, *OSSK 644* and *White Abontem* (in order of arrangement) were both efficient under low N and highly responsive under high N. *Tintim* and *Ewulboyu* were only responsive under high N supplies whereas *Kujorwari* was efficient under low N. All other varieties were neither responsive nor efficient. Root morphology was found to be a major contributing factor to N efficiency among the genotypes. It would however be recommended that; these varieties should be tried on field conditions to compare their responses to the solution culture results before a possible conclusion that, so-and-so variety is efficient.

REFERENCES

Akintoye, H. A., Kling, J. G., and Lucas, E. O. (1999). N-use efficiency of single, double and synthetic maize lines grown at four N levels in three ecological zones of West Africa. ***Field Crops Research*, 60**(3), 189-199.

Bannari, A., Khurshid, K. S., Staenz, K., & Schwarz, J. W. (2007). A comparison of hyperspectral chlorophyll indices for wheat crop chlorophyll content estimation using laboratory reflectance measurements. ***IEEE Transactions on Geoscience and Remote Sensing*, *45***(10), 3063-3074.

Bänziger, M., Edmeades G.O., Beck D. and Bellon M. (2000). Breeding for Drought and N Stress Tolerance in Maize: From Theory to Practice, Mexico, D.F., CIMMYT.

Beck, D. L. (2002). Management of hybrid maize seed production. CIMMYT; Mexico, DF 68 p.

Beevers, L., & Hageman, R. H. (1969). Nitrate reduction in higher plants. ***Annual Review of Plant Physiology*, *20***(1), 495-522.

Benincasa, P., Guiducci, M., and Tei, F. (2011). The nitrogen use efficiency: meaning and sources of variation—case studies on three vegetable crops in central Italy. ***Hort Technology*, *21***(3), 266-273.

Birch, C. J., Robertson, M. J., Humphreys, E., and Hutchins, N. (2003). Agronomy of maize in Australia: in review and prospect. In *Versatile Maize-Golden Opportunities: 5th Australian Maize Conference* (pp. 45-57).

Bojović, B. M. and Stojanović, J. (2005). Chlorophyll and carotenoid content in wheat cultivars as a function of mineral nutrition. ***Archives of Biological Sciences*, *57***(4), 283-290.

Brentrup F., and Palliere C. (2010). Nitrogen use efficiency as an agro-environmental indicator. OECD workshop "Agri-environmental indicators: lessons learned and future directions", 23-26 March 2010, Leysin, Switzerland. **http://www.oecd.org/tad/sustainable-agriculture/45449155.pdf** (14th April 2016)

Campbell, W. H. (1988). Nitrate reductase and its role in nitrate assimilation in plants. ***Physiologia Plantarum, 74***(1), 214-219.

Cassman, K. G., Dobermann, A., and Walters, D. T. (2002). Agroecosystems, nitrogen-use efficiency, and nitrogen management. AMBIO: ***A Journal of the Human Environment,*** **31**(2), 132-140.

Chaudhary, A. R. (1983). Maize in Pakistan, Punjab Agri. *Research Coordination Board* Univ. of Agri. Faisalabad.

CIMMYT (2005). Moisture stress. Available at **http://www.cimmyt.org/english**.

Council for Scientific and Industrial Research (2012). Annual Report.

Croplife International, (2014). Nitrogen-Use Efficiency Technology. **https://croplife.org/resources/page/2/?type=infographic** (7th July 2017)

Doerge, T.A., Roth, R.L., and Gardner, B.R., (1991). Nitrogen Fertilizer Management in Arizona, 191025, University of Arizona; May 1991.

Driscoll, C.T., Whitall, D., Aber, J.D., Boyer, E.W., Cronan, C.S., Goodale, C.L., Groffman, P., Hopkinson, C., Lambert, K.F. and Lawrence, G.B. (2003). Nitrogen Pollution: from the sources to the sea. *Hubbard Brook Research Foundation*.

Du Plessis, J. (2003). *Maize production.* Department of Agriculture, Republic of South Africa (pp. 1-38).

Fageria, N. K., and Baligar, V. C. (2003). Methodology for evaluation of lowland rice genotypes for nitrogen use efficiency. ***Journal of Plant nutrition, 26***(6), 1315-1333.

Fageria, N. K., and Baligar, V. C. (2005). Enhancing nitrogen use efficiency in crop plants. ***Advances in agronomy,* 88**, 97-185.

Fageria, N. K., Baligar, V. C., and Li, Y. C. (2008). The role of nutrient efficient plants in improving crop yields in the twenty first century. ***Journal of plant nutrition, 31***(6), 1121-1157.

Fageria, N.K., (1989). *Tropical Soils and Physiological Aspects of Crops*; EMBRAPA-CNPAF: Brasilia, Brazil.

Fairhurst, T. (ed.) (2012). Handbook for Integrated Soil Fertility Management. Africa Soil Health Consortium, Nairobi.

Fakorede, M.A.B. (2001). Revolutionizing Nigerian Agriculture with Golden seed. Inaugural lecture series. Obafemi Awolowo University Press Limited Ile-Ife, Nigeria 82pp.

FAO (2005). Fertilizer Use by Crop in Ghana. Technical report, Food and Agriculture Organization of the United Nations, Rome.

FAOSTAT (2012). **http://faostat.fao.org/site/567/desktopdefault.aspx#ancor** (July 2017)

FAOSTAT (2015) Food and Agriculture Organization of the United Nations.

Feil, B., Thiraporn, R., and Stamp, P. (1993). In vitro nitrate reductase activity of laboratory-grown seedlings as an indirect selection criterion for maize. ***Crop science, 33***(6), 1280-1286.

Föhse, D., Claassen, N., and Jungk, A. (1991). Phosphorus efficiency of plants. ***Plant and Soil, 132***(2), 261-272.

Gallais, A., and Coque, M. (2005). Genetic variation and selection for nitrogen use efficiency in maize: a synthesis. ***Maydica, 50***(3/4), 531.

Gardner J.C., Maranville J. W., and Paparozzi E. T. (1994). Nitrogen Use Efficiency among Diverse Sorghum Cultivars. Nebraska Agric. Exp. Stn. Paper no. 9441, Journal Series: ***Crop Sci*. 34**:728-733

Gcsescience (2015). Water, Carbon and Nitrogen Cycles. **http://www.gcsescience.com/w3-nitrogen-cycle.html** (29th May 2017)

Girardin, P., Tollenaar, M., and Muldoon, J. F. (1985). Effect of temporary N starvation on leaf photosynthetic rate and chlorophyll content of maize. ***Canadian Journal of Plant Science, 65***(3), 491-500.

Gitelson, A. A., Gritz, Y., & Merzlyak, M. N. (2003). Relationships between leaf chlorophyll content and spectral reflectance and algorithms for non-destructive chlorophyll assessment in higher plant leaves. ***Journal of plant physiology, 160***(3), 271-282.

Gueye, T. and Becker, H. (2011). Genetic variation in nitrogen efficiency among cultivars of irrigated rice in Senegal. ***Journal of Agricultural Biotechnology and Sustainable Development,* 3**(3), 35.

Gupta, N., Gupta, A. K., Gaur, V. S., and Kumar, A. (2012). Relationship of nitrogen use efficiency with the activities of enzymes involved in nitrogen uptake and assimilation of finger millet genotypes grown under different nitrogen inputs. ***The Scientific World Journal***, *2012*.

Harley, S. (1993). Use of a simple colorimetric assay to determine conditions for induction of nitrate reductase in plants. ***The American Biology Teacher* 55**: 161-164.

Hirel B., Le Gouis J., Ney B. and Gallais A. (2007). The challenge of improving nitrogen use efficiency in crop plants: towards a more central role for genetic variability and

quantitative genetics within integrated approaches. ***Journal of Experimental Botany***; pp 1-19.

Hirel, B., Tétu, T., Lea, P. J., and Dubois, F. (2011). Improving nitrogen use efficiency in crops for sustainable agriculture. ***Sustainability, 3***(9), 1452-1485.

Hofman, G., & Van Cleemput, O. (2004). *Soil and plant nitrogen*. Paris, France: International Fertilizer Industry Association.

Hofman, G., and Van Cleemput, O. (2004). Soil and plant nitrogen. Paris, France: International Fertilizer Industry Association.

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

Hubert, B., Rosegrant, M., Van Boekel, M. A., and Ortiz, R. (2010). The future of food: scenarios for 2050. ***Crop Science, 50***(Supplement 1), S-33.

IITA Youth Agripreneurs (2014). Maize Seed Production Manual. International Institute of Tropical Agriculture. Ibadan, Nigeria 13p.

International Institute of Tropical Agriculture (IITA) (2009). Research for Development: Cereals and Legume System.

Jefferson Lab (ND). Science Education: The Periodic Table of Elements. **http://education.jlab.org/itselemental/ele007.html** (7th July 2017)

Kherallah, M., Delgado, C. L., Gabre-Madhin, E. Z., Minot, N., and Johnson, M. (2002). *Reforming agricultural markets in Africa: Achievements and challenges*. Intl Food Policy Res Inst.

Kim, S. K., Joshua, A., Efron, Y., Fajemisin, J., and Mareck, J., (ND). *Hybrid maize seed production manual* (No. C045. 079). International Institute of Tropical Agriculture (IITA); National Seed Service.

Kuhlmann, H., Barraclough, P. B., and Weir, A. H. (1989). Utilization of mineral nitrogen in the subsoil by winter wheat. ***Journal of Plant Nutrition and Soil Science, 152***(3), 291-295.

Labconco Corporation (1998). A Guide to Kjeldahl Nitrogen Determination Methods and Apparatus; *An Industry Service Publication*: Houston, TX, USA.

Lafitte, H.R. and Edmeades G.O. (1994). Improvement for tolerance to low soil N in tropical maize. III. Variation in yield across environments. ***Field Crops Research*** **39**:27-38.

Lichtenthaler, H. K. (1987). [34] Chlorophylls and carotenoids: pigments of photosynthetic biomembranes. ***Methods in enzymology, 148***, 350-382.

Lynch, J. (1998). The role of nutrient-efficient crops in modern agriculture. ***Journal of Crop Production,*** **1**(2), 241-264.

M.A. Chaudhry, K. Yasmin, M.I. Lone and K.S. Khan, 1999. Effect of Nitrogen Application on Biomass Production, Yield and Nitrogen Fixation of Legumes and Maize Crops. ***Pakistan Journal of Biological Sciences, 2***: 743-745.

Marschner, H. (1995). *Mineral nutrition of higher plants*. 2nd ed. Academic Press, London, UK. 889 p.

Mc Cashin, B. G., (2000). Induction of nitrate reductase in plant shoots. Pages 193-224, *in* Tested studies for laboratory teaching, Volume 21 (S. J. Karcher, Editor). Proceedings of the 21st Workshop/Conference of the Association for Biology Laboratory Education (ABLE), 509 pages.

Merzlyak, M. N., Solovchenko, A. E., & Gitelson, A. A. (2003). Reflectance spectral features and non-destructive estimation of chlorophyll, carotenoid and anthocyanin content in apple fruit. ***Postharvest Biology and Technology, 27***(2), 197-211.

Messmer, M. J., Lambert, R. J., and Hageman, R. H. (1984). Classification of certain N traits as criteria for the identification of productive maize genotypes. ***Crop science, 24***(3), 605-610.

Ministry of Food and Agriculture (2008). Agriculture Sustainable Land Management Strategy and Action Plan (2009 – 2015). Ministry of Food and Agriculture, Accra.

Ministry of Food and Agriculture (2011). Agriculture in Ghana: Facts and Figures (2010). Ministry of Food and Agriculture, Statistics, Research and Information Directorate (SRID), 12-14pp.

Moll, R.H., Kamprath E.J. and Jackson W.A. (1982). Analysis and interpretation of factors which contribute to efficiency of N utilization. ***Agronomy Journal*** **74**:502-564.

Montemurro, F., Maiorana, M., Ferri, D., & Convertini, G. (2006). Nitrogen indicators, uptake and utilization efficiency in a maize and barley rotation cropped at different levels and sources of N fertilization. ***Field Crops Research, 99***(2), 114-124.

Morris, M. L. (Ed.). (1998). *Maize seed industries in developing countries*. Lynne Rienner Publishers.

Muchow, R. C. (1998). Nitrogen utilization efficiency in maize and grain sorghum. ***Field Crops Research,*** **56**(1), 209-216.

Nawar, A. A., Ibrahim, M. E., and Attia, M. B. (1992). Grain yield, yield components and infestation rates of corn borers and aphid of maize genotypes as influenced by nitrogen fertilization. ***Egyptian Journal of Agronomy*** *(Egypt).*

Ndukwe, O. K., Edeoga, H.O., Okwulehie I. C. and Omosun, G. (2016). Variability in the chlorophyll and carotene composition of ten maize (zea mays) varieties. ***European Journal of Physical and Agricultural Sciences,* 4** (1), 1-6.

Netto, A. T., Campostrini, E., de Oliveira, J. G., and Bressan-Smith, R. E. (2005). Photosynthetic pigments, nitrogen, chlorophyll a fluorescence and SPAD-502 readings in coffee leaves. ***Scientia Horticulturae, 104***(2), 199-209.

Neufeld, H. S., Chappelka, A. H., Somers, G. L., Burkey, K. O., Davison, A. W., & Finkelstein, P. L. (2006). Visible foliar injury caused by ozone alters the relationship between SPAD meter readings and chlorophyll concentrations in cutleaf coneflower. ***Photosynthesis Research, 87***(3), 281-286.

Ofori, E., and Kyei-Baffour, N. (2009). Agrometeorology and maize production. *Guide on agricultural meteorological practices (GAMP)*, 1-22.

Olaniyan, A. B. (2015). Maize: Panacea for hunger in Nigeria. ***African Journal of Plant Science, 9***(3), 155-174.

Oppong, C. D. (2013). Measurement of Technical Efficiency and Its Determinants Among Maize Farmers in Asante Akyem-North Municipality. *Faculty of Arts and Social Sciences Department of Economics* (Master of Philosophy Dissertation, Kwame Nkrumah University of Science and Technology, Kumasi).

Ort, D. R. (2001). When there is too much light. ***Plant physiology, 125***(1), 29-32.

Oyewo, I. O. (2011). Technical efficiency of maize production in Oyo state. ***Journal of Economics and International finance, 3***(4), 211.

Pic, E., de la Serve, B. T., Tardieu, F., and Turc, O. (2002). Leaf senescence induced by mild water deficit follows the same sequence of macroscopic, biochemical, and

molecular events as monocarpic senescence in pea. ***Plant Physiology, 128***(1), 236-246.

Raj Kumar, R., Marimuthu, S., Jayakumar, D., & Jeyaramraja, P. R. (2002). In situ estimation of leaf chlorophyll and its relationship with photosynthesis in tea. ***Indian journal of plant physiology, 7***(4), 367-371.

Raun, W. R., and Johnson, G. V. (1999). Improving nitrogen use efficiency for cereal production. ***Agronomy journal, 91***(3), 357-363.

Sabo, M., Teklic, T., & Vidovic, I. (2002). Photosynthetic productivity of two winter wheat varieties (Triticum aestivum L.). ***Rostlinna vyroba, 48***(1), 80-86.

Sanginga, N., and Woomer, P. L. (eds.) (2009). Integrated Soil Fertility Management in Africa: Principles, Practices and Developmental Process. Tropical Soil Biology and Fertility Institute of International Centre for Tropical Agriculture. Nairobi. 263 pp.

Sattelmacher, B., Horst, W. J., and Becker, H. C. (1994). Factors that contribute to genetic variation for nutrient efficiency of crop plants. ***Journal of Plant Nutrition and Soil Science, 157***(3), 215-224.

Sauerbeck, D. R., and Helal, H. M. (1990). Factors affecting the nutrient efficiency of plants. In *Genetic aspects of plant mineral nutrition* (pp. 11-17). Springer Netherlands.

Schepers, J. S., Francis, D. D., Vigil, M., & Below, F. E. (1992). Comparison of corn leaf nitrogen concentration and chlorophyll meter readings. ***Communications in Soil Science and Plant Analysis, 23***(17-20), 2173-2187.

Schlemmer, M. R., Francis, D. D., Shanahan, J. F., & Schepers, J. S. (2005). Remotely measuring chlorophyll content in corn leaves with differing nitrogen levels and relative water content. ***Agronomy journal, 97***(1), 106-112.

Schröder, J.J. (2014) The Position of Mineral Nitrogen Fertilizer in Efficient Use of Nitrogen and Land: A Review. ***Natural Resources,* 5**, 936-948.

Sinclair, T. R. (1984). Leaf area development in field-grown soybeans. ***Agronomy journal, 76***(1), 141-146.

Singh, M., Khan, M. M. A., and Naeem, M. (2016). Effect of nitrogen on growth, nutrient assimilation, essential oil content, yield and quality attributes in Zingiber officinale Rosc. ***Journal of the Saudi Society of Agricultural Sciences, 15***(2), 171-178.

Sinha, R.K. 2004). *Modern Plant Physiology*. Alpha Science **https://books.google.com.tr/books?id=03S6VbTjCmUC** ISBN:9780849317149

Srivastava, H. S. (1980). Regulation of nitrate reductase activity in higher plants. ***Phytochemistry, 19***(5), 725-733.

Statistical Research and Information Department (2007). National Crop Production Estimates, 2002-2006. Ministry of Food and Agriculture, Ghana.

Tucker, M. R. (1999). *Essential plant nutrients: their presence in North Carolina soils and role in plant nutrition*. Department of Agriculture and Consumer Services, Agronomic Division.

Van der Hoek, K. W. (2001). Nitrogen efficiency in agriculture in Europe and India. ***The Scientific World Journal,* 1**, 148-154.

Wang, Z., Gao, J., and Ma, B. L. (2014). Concurrent improvement in maize yield and nitrogen use efficiency with integrated agronomic management strategies. ***Agronomy Journal, 106***(4), 1243-1250.

Weisler, F., Behrens, T., and Horst, W. J. (2001). The role of nitrogen-efficient cultivars in sustainable agriculture. ***The Scientific World Journal,* 1**, 61-69.

Young, A. J. (1991). The photoprotective role of carotenoids in higher plants. ***Physiologia Plantarum, 83***(4), 702-708.

Zhao, D., Reddy, K. R., Kakani, V. G., Read, J. J., & Carter, G. A. (2003). Corn (*Zea mays* L.) growth, leaf pigment concentration, photosynthesis and leaf hyperspectral reflectance properties as affected by nitrogen supply. ***Plant and soil, 257***(1), 205-218.

LIST OF APPENDICES

Appendix 1: Pearson Correlation Coefficients of some measured parameters. Each number represents the rank of a variety on a measured parameter. Significant at 5% *; significant at 1% **

Uptake / Utilisation	Fresh root weight		Dry root weight		Root length		Root volume		Root diameter	
	High N	Low N	High N	Low N	High N	Low N	High N	Low N	High N	Low N
SPAD	0.79764***	-0.1889	0.71536***	-0.33382	0.82430***	-0.2335	0.80531***	-0.2308	0.79113***	-0.1709
Total chlorophyll	0.53150***	-0.1615	0.53556***	-0.18808	0.69947***	-0.1149	0.55964***	-0.1376	0.49631***	-0.204
Total Carotenoids	0.2091	0.25556	0.12464	0.14258	0.43505*	0.26002	0.29558	0.21045	0.18387	0.25423
Photosynthesis	0.55128***	-0.2492	0.326	-0.451***	0.50782***	-0.331	0.51068***	-0.2459	0.52488***	-0.1973
Photosynthesis	0.55128***	-0.2492	0.326	-0.451***	0.50782***	-0.331	0.51068***	-0.2459	0.52488***	-0.1973
Leaf area	0.57415***	0.39161*	0.59311***	0.38223*	0.58488***	0.35638*	0.61994***	0.36801*	0.55528***	0.40744*
Plant height	0.37486*	0.02531	0.35555*	-0.11164	0.47113***	0.0297	0.44081*	0.02717	0.3277	0.01095
Stem dimeter	0.68094***	0.12393	0.62572***	-0.08685	0.62795***	0.03087	0.66020***	0.09578	0.62754***	0.14328
Leaf NRA	0.43301*	-0.4569***	0.32719	-0.611***	0.11387	-0.4829***	0.30519	-0.4459***	0.44577***	-0.41920*
Root NRA	0.20595	0.27798	0.32039	0.11626	0.19077	0.31138	0.22708	0.24809	0.21892	0.26205
Fresh shoot weight	0.80705***	0.30482	0.78505***	0.129	0.70482***	0.264	0.78991***	0.29034	0.80185***	0.29714
Dry shoot weight	0.78543***	0.58998***	0.66063***	0.42617*	0.65848***	0.54942***	0.77422***	0.57541***	0.78190***	0.57317***
Shoot N concentration	0.04922	0.30306	0.16081	0.09111	0.11954	0.24234	0.03025	0.28586	0.02854	0.33538
Root N concentration	0.19402	-0.41099*	0.29884	-0.598***	0.43259*	-0.4611***	0.25337	-0.40259*	0.20475	-0.36796*
Shoot total N content	0.73704***	0.76690***	0.67740***	0.72533***	0.64363***	0.73198***	0.71342***	0.76243***	0.72770***	0.77470***
Root total N content	0.89966***	0.82334***	0.98879***	0.83292***	0.87887***	0.74364***	0.89329***	0.84867***	0.89415***	0.82705***

Appendix 2: Table of tukey grouping of variety means from studentized range (hsd) test under high N. Each number represents the rank of a variety on a measured parameter with one (1) being the highest and ten (10) the lowest.

Variety / **Parameter**	DKC 7211	White Abontem	Honampa	Yellow Abontem	Kunjorwari	Sanzalsima	Ewulboyu	Wandataa	Tintim	OSSK 644
SPAD	5	6	2	8	7	9	3	10	4	1
Total Chlorophyll	8	4	5	6	3	10	2	9	7	1
Carotenoids	10	5	4	3	2	9	8	6	7	1
Photosynthesis	6	8	4	7	3	10	5	9	2	1
Plant height	9	8	3	6	4	1	5	10	7	2
Stem diameter	10	8	1	9	5	6	3	7	2	4
Leaf NRA	5	7	9	10	3	6	8	2	1	4
Root NRA	6	1	10	4	8	3	2	9	7	5
Leaf area	10	6	1	9	7	2	4	8	5	3
Fresh shoot weight	9	5	1	10	8	7	3	6	2	4
Dry shoot weight	9	6	2	10	8	5	4	7	3	1
Fresh root weight	8	5	4	9	7	6	3	10	1	2
Dry root weight	8	4	3	9	7	6	1	10	2	5
Root shoot ratio	9	2	4	8	6	7	1	10	3	5
Root length	9	5	1	7	6	8	3	10	4	2
Root volume	9	5	3	7	8	6	4	10	2	1
Root diameter	8	5	4	9	7	6	3	10	1	2
Shoot N concentration	8	10	2	3	4	6	1	7	5	9
Root N concentration	7	4	2	1	3	8	5	10	6	9
Shoot N uptake	10	7	1	9	6	5	3	8	2	4
Root N uptake	9	4	2	8	6	7	1	10	3	5

Appendix 3: Table of tukey grouping of variety means from studentized range (hsd) test under low N. Each number represents the rank of a variety on a measured parameter with one (1) being the highest and ten (10) the lowest.

Variety / **Parameter**	DKC 7211	White Abontem	Honampa	Yellow Abontem	Kunjorwari	Sanzalsima	Ewulboyu	Wandataa	Tintim	OSSK 644
SPAD	6	9	8	7	10	2	3	5	1	4
Total Chlorophyll	10	4	8	2	6	9	7	1	5	3
Carotenoids	10	1	2	5	7	9	8	4	3	6
Photosynthesis	2	9	8	1	6	3	10	4	5	7
Plant height	8	3	6	4	2	5	9	10	7	1
Stem diameter	2	5	3	8	10	7	6	4	1	9
Leaf NRA	2	5	10	1	7	3	9	6	8	4
Root NRA	4	8	2	1	3	7	9	5	6	10
Leaf area	1	5	4	10	8	3	7	2	9	6
Fresh shoot weight	5	4	3	8	2	10	9	6	7	1
Dry shoot weight	6	4	1	10	2	9	7	5	8	3
Fresh root weight	3	6	1	10	2	8	9	5	7	4
Dry root weight	5	7	1	10	2	9	8	4	6	3
Root shoot ratio	5	8	1	10	3	9	7	2	4	6
Root length	6	5	1	10	2	9	7	4	8	3
Root volume	4	5	1	10	2	8	9	3	7	6
Root diameter	3	4	1	10	2	8	9	6	5	7
Shoot N concentration	1	10	2	5	3	4	9	8	6	7
Root N concentration	1	10	2	5	3	4	9	8	6	7
Shoot N uptake	3	9	1	6	2	4	10	7	8	5
Root N uptake	5	8	1	10	2	9	6	4	3	7

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PERSONAL DETAILS

Date of Birth: 4th November 1989. **Hometown:** Dasima

Nationality: Ghanaian. **Gender:** Male. **Marital Status:** Single

Religion: Islam

Educational Information

2015 to date:	Student at Erciyes University - Kayseri, Turkey, MSc. Agricultural Sciences and Technologies
June 2015:	A two-month Office Management and Executive Assistance certificate course organised by TURKMEK, Istanbul/Turkey
April 2015:	A two-month Basic Computer Skills and Microsoft Office Software Training certificate course organized by TURKMEK, Istanbul/Turkey

2014 – 2015:	Ankara University (TÖMER), Turkish and Foreign Languages Research and Application Centre. Istanbul, Turk
2010 – 2014:	University for Development Studies (UDS) – Tamale/Ghana. BSc. Agriculture technology, Second Class (Lower Division)
2006 –2009:	Tumu Senior Secondary Technical School, Tumu Ghana. General Agriculture.
2003 –2006:	Dasima Junior Secondary School, Dasima/Ghana.

Personal Skills

I. T. Proficiency:	Basic Computer Skills and Microsoft Office Software applications. Proficient in data modeling and the use of statistical programs like SAS, GENSTAT and SPSS.
Languages:	English, Turkish, Arabic (A2 level) Sissali and Twi.

Work Experience

2016 –2017:	Research on **"Genotypic Differences in Nitrogen Efficiency of Some Selected Local Maize Varieties of Ghana".**
May 2017:	Poster presentation at Ecology International Symposium (Erciyes University, Turkey) on the topic **"Root-growth Characteristics Contributing to Genotypic Variation in Nitrogen Efficiency of Maize"**.

2013-2014:	General Secretary for the Ghana Muslim Students' Association (GMSA), University for Development Studies.
2013-2014:	Deputy Course Representative for the Agronomy Students' Association, University for Development Studies.
2013-2014:	Research on the **"Effects of Different Soil Fertility Management Options on the Grain Yield of Cowpea, Soya Bean and Maize."**
2013-2014:	Teacher at Madrasatul Hudaibiyyah of GMSA UDS, Nyankpala. Also, a voluntary teacher at Ziong Junior high school for two years
2014:	Data processing on a baseline study of communities by SIMLI AID. A project on enhancing food security and nutrition of poor households in the Tolon and Kumbungu districts through family drip on treadle pump and tied ridge system of conservation farming.
2012:	Third Trimester Field Practical Programme (TTFPP II): **TOPIC**: Report on The Review of Community Profile, Problems, Potentials and Proposal for Intervention, for the Ziong Community in The Sevelugu-Nanton District of The Northern Region.
2011:	Third Trimester Field Practical Programme (TTFPP I): A rural community study programme. **TOPIC:** Profile of Ziong Community in the Savelugu-Nanton District of Northern Region.

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I dedicate this work to my dear mother ALIMATU BAYUKO (the late). May the peace and mercies of the Lord be upon thy soul

Forever thy shall be remembered!!!