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EFFECT OF NPK FERTILISER ON GROWTH, FLOWERING AND YIELD OF
FONIO (*Digitaria exilis*) IN A COASTAL AGRO-ECOLOGICAL
ENVIRONMENT OF GHANA

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DECLARATION

This thesis is wholly an outcome of research work undertaken by Amekli Yayra in the Department of Nuclear Agriculture and Radiation Processing, School of Nuclear and Allied Sciences, University of Ghana, under the supervision of Dr. Daniel Kwasi Asare and Prof. George Y.P. Klu.

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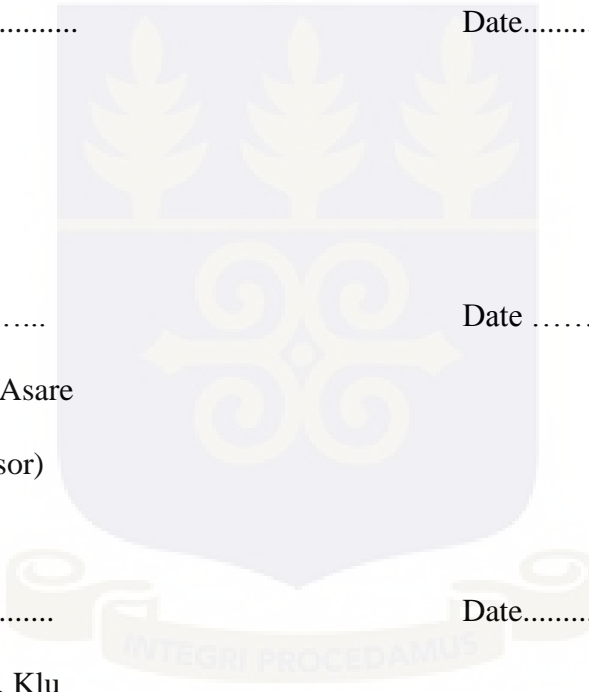
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DEDICATION

To JEHOVAH God Almighty be all the Glory. This work is dedicated to my guardians and family for their immeasurable support, inspiration, guidance, love and prayers.



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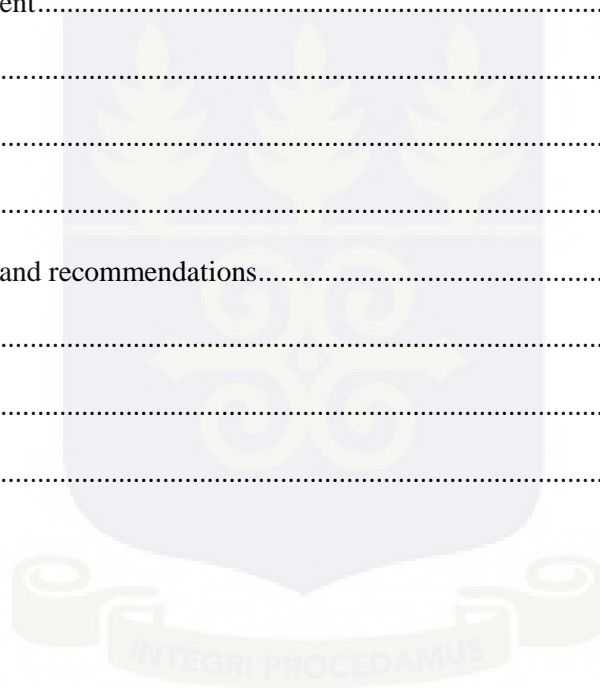
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LIST OF ABBREVIATIONS AND ACRONYMS

AFLP	Amplified Fragment Length Polymorphism
AFNR	Apparent Fertiliser Nitrogen Recovery
ANOVA	Analysis of Variance
BNARI	Biotechnology and Nuclear Agriculture Research Institute
CIRAD	Centre de Cooperation Internationale en Recherche
DAE	Days After Emergence
DFH	Days to 50% Heading
FAO	Food and Agricultural Organisation
FAOSTAT	Food and Agriculture Organisation Statistical Database
GAEC	Ghana Atomic Energy Commission
GHARR-1	Ghana Research Reactor 1
GY	Grain Yield
HC	Height Classification
HD	Days to Heading
INAA	Instrumentation Neutron Activation Analysis
MOFA	Ministry of Food and Agriculture
NIDDM	Non-Insulin Dependent Diabetes Mellitus
NUS	Neglected and Underutilized Species
RDI	Recommended Daily Intake
TGW	1000 Grain Weight

ABSTRACT

Fonio (*Digitaria spp*) is a neglected and underutilised crop traditionally grown in the Sahelian savannah agro-ecological zone of Ghana for its grain which is rich in crude protein, fibre and has medicinal properties. Decline in production of the crop is attributed to poor agronomic and yield characteristics and changing agro-climatic conditions as a result of global warming which has rendered traditional growing areas too dry to support cultivation of the crop. There is a need to explore the possibility of growing the crop in new agro-ecologies to sustain the production. The study was therefore conducted in Kwabenya-Atomic area which is located in the coastal savannah agro-ecological zone of Ghana, to evaluate the adaptability of three fonio landraces (Yadema, Nomber and Nvoni) to the coastal zone, their growth and response to NPK 15:15:15 fertiliser treatment, apparent fertiliser nitrogen recovery (AFNR) as well as presence of basic elements, in the grains. Field experiments were conducted in 2012 during the major cropping season, using three fonio landraces grown at a planting distance of 0.05 m × 0.45 m. The experiment design used was the split plot in three replicates. Plants were sampled every two weeks throughout the growing season. Grain yield (GY) and its associated apparent fertiliser nitrogen recovery were significantly different ($P \leq 0.05$) among the fonio landraces during the cropping season with the landrace Nvoni producing the highest grain yield of 964 kg ha⁻¹ at NPK fertiliser rate of 60 kg ha⁻¹ and with a AFNR of 33.1%. The study also established a positive correlation between biomass accumulation and grain yield. The efficiency of grain production per unit of fertiliser nitrogen (FN) increased, but at a diminishing rate with each additional unit of FN. Additionally, ten essential mineral elements (Na, Mg, K, Ca, I, Cl, Cu, Al, Mn and V) were detected among the grain of the three fonio landrace using Instrumental Neutron Activation Analysis (INAA).

CHAPTER ONE

1.0 Introduction

Fonio [*Digitaria exilis* (Kippist) Stapf, and *Digitaria iburua* Stapf, Poaceae] is a minor cereal crop cultivated throughout West Africa, from Senegal to Lake Chad (Purseglove, 1975). This crop is a small-grain, C4-metabolism cereal with a short growth cycle and it is one of the first cereal crops to have been domesticated by West African farmers (Adoukonou-Sagbadja *et al.*, 2007). It is either a staple food or food for the hunger period (Vodouhè *et al.*, 2003) and it, therefore, plays an important role in food security in the West African sub-region. The crop supplies food to 3-4 million people (National Research Council, 1996). Its production is restricted to the Dogons ethnic group of Mali for which it has high socio-cultural and economic values. The cultivation of fonio millet in Guinea, Mali, Burkina Faso and Cote d'Ivoire is indicative of its wide ecological adaptability (Vall *et al.*, 2008).

Fonio has been described as one of the world's best tasting and most nutritious cereals, being rich in methionine (a sulphur containing amino acid) and cysteine (Temple and Bassa, 1991). Although considered to be a minor millet, fonio is of vital importance in the Sahelian regions of Africa where it produces relatively high yields (500–800 kg/ha) in spite of poor soil conditions and low and erratic rainfall, the region still depend on the crop for survival (Food Lorists, 2011; Kuta *et al.*, 2003; Ibrahim, 2001).

Fonio has continued to be important in northern Ghana because it is both nutritious and has a short cropping season and therefore can be grown 3–4 times annually, reaching

maturity in as short as six to eight weeks. Fonio is an important cereal crop with many names. Some of the popular names are fonio, findi, kabuga, fundo, pom and acha while Europeans coined the English name “Hungry rice” which is considered misleading (Anonymous, 2003; Ibrahim, 2001; Purselove, 1988). Fonio is suggested to be the oldest indigenous African cereal with cultivation records dating back to 7000 years (Cruz, 2004). The two major and most widely known cultivated species of fonio in West Africa are *Digitaria exilis* (Kippist) Stapf, commonly referred to as the white fonio and *Digitaria iburria* Stapf which is called the black fonio. Fonio is also known in the Dominican Republic and Island of South America (Pablo *et al.*, 2003).

The global land area put under fonio production is estimated to be 450 000 ha with an annual production of 362 000 tonnes (Cruz, 2004). Fonio is small-scale farmers’ crop and its production is still essentially at the subsistence level. Productivity varies greatly across growing areas, years and is highly influenced by climate. In general, the regional average yield oscillates between 0.6 t ha⁻¹ and 0.9 t ha⁻¹ with the best productivity reaching 1.5 t ha⁻¹. In the Sahelian zone, yields are extremely low and often fall under 0.2 t ha⁻¹. The average production of fonio has remained low, ranging from 600–700 kg ha⁻¹ (Cruz, 2004).

This crop fits into the low-input farming systems of the resource-poor African farmers as it has a unique ability to tolerate poor and marginal soils, in addition to being able to withstand drought (Aslafy, 2003; Vietnameyer *et al.*, 1996). Studies by Dachi and Omueti (2000) have shown that fonio responds positively to fertiliser application. Though

the crop has been completely neglected in the past, it is now considered an important crop in Mali, Côte d'Ivoire and Burkina Faso (Morales-Payan *et al.*, 2002; Ibrahim, 2001).

Fonio is essentially produced for human consumption. It is an important household food security crop as the grains can be conserved many years without insect damage. Fonio is well appreciated for its tasty and easily digestible grains. In many tribal areas of Guinea, Mali, Togo and Nigeria, fonio can be consumed two to three times a day and it is preferred to other cereals (Haq and Ogbe, 1995). It is also the most prestigious and hence the first food choice reserved for guests on special occasions such as marriage ceremonies and major festivals. Traditionally, fonio is routinely consumed as stiff or thin porridge, couscous and can be mixed with other flours to bake bread. It is also popped or used to brew local alcoholic or non-alcoholic drinks (Nzleibe and Nwasike, 1995). Nowadays, fonio foods are gaining popularity in many urban centres in Guinea, Mali and Nigeria while precooked products are gradually entering the European market under the bio-label (Regmi and Dyck, 2001).

Biochemical investigations indicated that the nutritive value of fonio grain is favourably comparable with that of other cereals (Haq and Ogbe, 1995). Specifically, fonio has excellent protein content (9–12%) rich in methionine and cystine, two vital amino acids almost deficient in sorghum (*Sorghum bicolor*), rice (*Oryza sativa*), wheat (*Triticum aestivum*) and barley (*Hordeum vulgare* L.) (Vietmeyer *et al.*, 1996).

Fonio cultivation and utilization is popular among West African Francophone countries. Ghana is now making a slow attempt to improve and popularize the crop as it serves as a staple food in rural areas of the Northern Region, namely Yendi, Cheriponi and Saboba where it is grown extensively. Fonio faces a stiff competition from other cereals such as rice, maize and millet which are readily available. Besides, the processing of fonio is tedious. Inadequate information on the nutritional value of the crop and low level of utilization are major setbacks in placing fonio among the staple foods in Ghana (MoFA, 2001).

1.2 Problem statement

Despite the importance of fonio in traditional agriculture, research efforts to improve the crop are still at a low level. The crop, therefore, remains primitive and hence, faces diverse agronomical and technological problems. Fonio cultivation relies only on traditional landraces which are less productive, regardless of their adaptability to marginal areas (Vodouhè *et al.*, 2007). In addition, traditional farming practices characterised by low productive and eroded soils, poor crop husbandry, inappropriate fertiliser application regimes and frequent drought occurrence, may considerably affect the productivity of fonio (Adoukonou-Sagbadja *et al.*, 2006).

Bioversity International, a plant genetic research centre based in Italy, listed fonio under a group of neglected and underutilized species of crops (NUS) in West Africa in its 2000 Annual Report. Neglected and underutilized species of crops are traditionally grown by farmers in their centre of diversity (place of origin) where they support nutrition, food security and other livelihood goals of local communities while contributing to meet their

socio-cultural needs (FAO, 2010). Until recently, fonio has been largely ignored by researchers for improvement and has become less competitive than the well-established major and popular cereals and therefore, gradually losing its diversity and associated traditional knowledge (Convention on Biological Diversity, 2010).

Progress in genetic improvement of fonio has also been hindered by the biological characteristics of the crop and the fact that nothing is yet known on the inheritance of traits of agronomic relevance (NAS, 1996). The biological limitations include the miniature size of floral organs, dearth of information on reproductive biology and poor knowledge of the level and organization of the genetic diversity present in the crop (Sarker *et al.*, 1993). Great efforts are therefore needed to evaluate the available fonio species so as to identify species suitable for different agro-ecological environment as well as design appropriate breeding programme for improving the crop. Additionally, it may be necessary to determine appropriate fertiliser regimes for enhancing the productivity of the crop (Gigou *et al.*, 2009).

1.3 Justification and relevance of the study

One of the world's greatest challenges is to secure adequate food that is healthy, safe and of high quality for all in an environmentally sustainable manner (Pinstrup-Andersen, 2009). With the growing demand of an ever-increasing human population, it remains unclear how our current global food system will sustain the population. Compounded with climate change, ecosystems and biodiversity under stress, population growth and urbanization, social conflict and extreme poverty, there has never been a more urgent time for collective action to address food and nutrition security globally than it is now

(Regmi and Dyck, 2001). It is in this quest that research has identified varieties of indigenous crops of outstanding qualities of which fonio stands tall in terms of nutritional composition (National Research Council, 1996).

Fonio is crucial to food security, particularly in seasons of hunger and critical periods when food reserves in the household are low. The seed is rich in methionine and cysteine, two vital amino acids for humans. Fonio is also regarded as a grain with medicinal and healing properties as it is recommended for lactating women and diabetic patients and it is used in diets of the convalescent as well (Obilana, 2005). Fonio is a small scale farmers' crop with little input in its cultivation but provides quite a substantial income to the household (Vodouhè *et al.*, 2003).

Fonio is fast becoming a staple food in most West African countries namely Senegal, Guinea, Mali, Nigeria, Togo and Benin. In Ghana, fonio is gaining popularity particularly in the Northern Region. Changing agro-climatic conditions as a result of global warming have rendered traditional growing areas in Ghana too dry to sustain the production of fonio. There is therefore the need to explore the possibility of growing the crop in different agro-ecologies and to assess its response to supplementary nutrient application so as to promote and enhance sustainable production of fonio. Good yields are typically 600–800 kg ha⁻¹, but have reached over 1000 kg ha⁻¹ as a result of fertiliser application (Cruz, 2004).

Although research has confirmed the nutritional composition of fonio, that of elemental composition is not certain due to the methods employed in the analysis (Chuku and

Abdul-kadir, 2008). It is therefore hoped that using analytical technique based on radiation of radionuclides like the Instrumentation Neutron Activation Analysis (INAA) will reveal and confirm elements associated with fonio, so as to throw more light on the importance and usefulness of this neglected and underutilised crop within the West African sub-region and beyond.

1.4 Objective of the research

The main objective of this research was to evaluate the most cultivated fonio landraces in Ghana for their growth, productivity as well as nutrient use efficiency in the Atomic–Kwabenya site, located in a coastal savannah agro-ecological environment of Ghana.

Specific objectives were to:

- i. evaluate growth (plant height and biomass accumulation) and tillering of the three most cultivated landraces of fonio in Ghana.
- ii. estimate apparent N, P and K use efficiencies of the three fonio landraces grown at three different levels of applied NPK fertiliser.
- iii. determine biomass partitioning of the landraces at different levels of applied NPK fertiliser.
- iv. determine the elemental composition of the landraces using the instrumentation neutron activation analysis (INAA) technique.

CHAPTER TWO

LITERATURE REVIEW

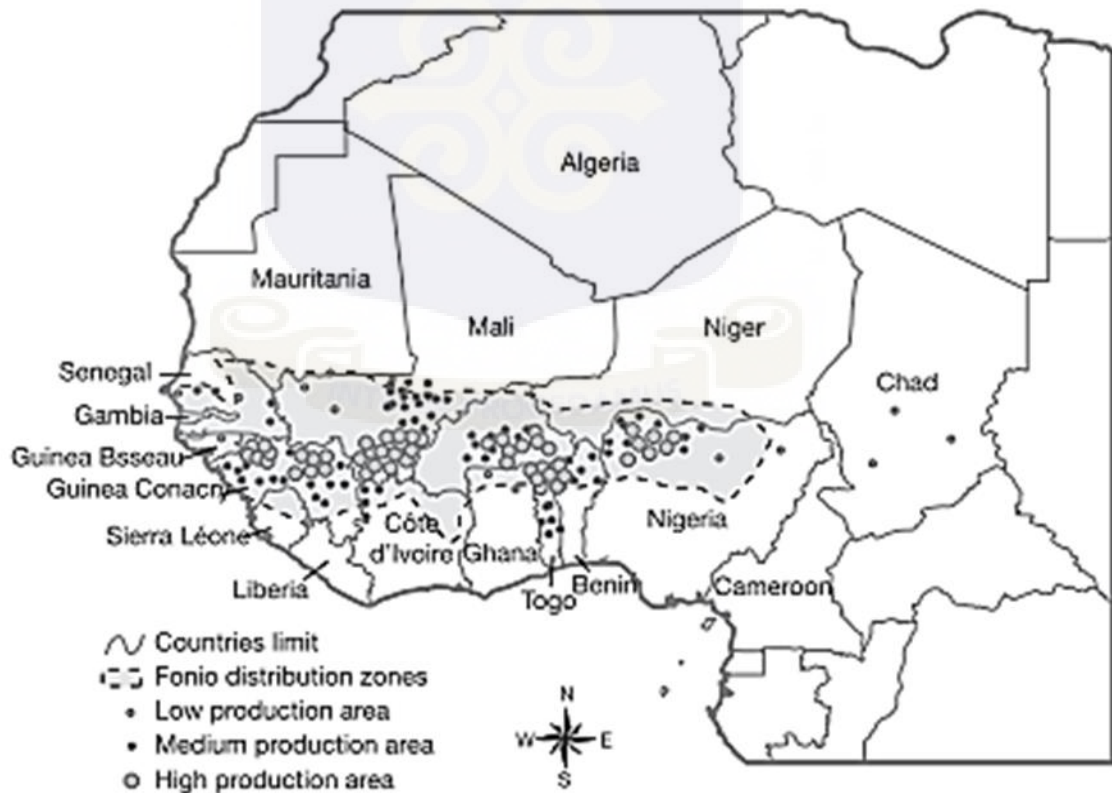
2.1 Introduction

This review highlights some of the relevant research work on fonio under rain-fed conditions in the West African region where the crop has gained quite an appreciable scientific attention and utilization.

2.2 Origin and distribution

Fonio [*Digitaria exilis* (Stapf)] is a cereal indigenous to the savannah regions of West Africa (Dalziel, 1937), with the savanna regions of Guinea having the greatest diversity of the crop. It has a cultivation history dating back to 5 000 BC (Purseglove, 1988). The cultivation of *Digitaria exilis* expands from Cape Verde in the west to the Lake Chad in the east, from the edge of the Sahara in the north to the end of the rain forest from the south (Fig. 1). *Digitaria iburua* is currently much more limited in cultivation, being found mainly in Northern Nigeria, Togo and Benin (Haq and Ogbe 1995). Unlike *Digitaria iburua*, only *Digitaria exilis* is reported to have reached the Dominican Republic in the 15th century (Deive, 1974) but its cultivation as food crop is said to be very recent (Morales-Payán *et al.*, 2002). While the West African origin of the crop is well accepted, the precise areas of domestication of fonio in West Africa are yet to be established. Referring to historic, linguistic, varietal and ecological considerations, Portères (1976) and Murdock (1959) located the earliest domestication of *D. exilis* in the vicinity of the central delta in the upper Niger River basin. These authors explained that the vernacular name “fonio” or “fonyo” comes from Mande linguistic group living in the middle Niger, the area where the largest diversity of the crop is found.

In a recent molecular study Amplified Fragment Length Polymorphism (AFLP) the possibility of multiple domestications associated to different centres of diversification of this species has been advocated (Hilu *et al.*, 1997). Regarding *D. iburua*, Portères (1976) related its local name “*iburu*” to the Haussa culture and indicated that its domestication may have been achieved in the Air Mountain (Northern Niger); the crop may have thence spread southward after the desertification of the Sahara. Ancestral species or wild progenitors of fonio crop are not conclusively identified. Diverse wild species were proposed either as ancestors or close relatives based on their morpho-botanical affinities to cultivated fonio species. Among these, *D. longiflora* Pers. and *D. ternate* Stapf are respectively the ones most botanically allied to *Digitaria exilis* (Kuta *et al.*, 2005).



Source: Portères (1976)

Figure 2.1. Fonio production areas in West Africa.

2.3 Taxonomy and classification

Fonio belongs to the grass family Poaceae, subfamily Panicoideae, the subtribe Digitariinae, the genus *Digitaria* and has many species such as *exilis*, *iburia*, *longiflora* etc Purselove (1988). There are about 300 annual and perennial species which are important pasture grasses under the genus *Digitaria* (Chapman and Peat, 1992). Langer and Hill (1991) and Purselove (1988) reported that, Pangalo grass (*Digitaria decumens* Sent) and African couch grass, (*Digitaria scalarum* Schweinf) are used as pasture grasses in the Caribbean or Tropical America and Africa respectively.

The two major and most widely known cultivated species of fonio in West Africa are *Digitaria exilis* (Kippist) Stapf, commonly referred to as the white fonio and *Digitaria iburia* Stapf, which is popularly known as the black fonio (Purselove, 1988). Fonio is known by various names in different parts of Africa and other parts of the world. Fonio is therefore classified as follows;

Kingdom: Plantae
(unranked): Angiosperms
(unranked): Monocots
(unranked): Commelinids
Order: Poales
Family: Poaceae
Genus: *Digitaria*
Species: *D. exilis*

2.3.1 Morphological description

Fonio is an erect, free-tillering annual grass that grows up to about 80 cm tall, with delicate kneed stems. Its leaves are alternate and simple. The inflorescence is a terminal digitate panicle of 2–5 slender, raceme-like primary branches up to 15 cm long (Hilu *et al.*, 1997). The fruit is a caryopsis (grain), oblong to globose ellipsoid, 0.5 mm long, white to pale brown or purplish (Purseglove, 1988; Dalziel, 1937). Digitaria is a taxonomically difficult genus comprising about 230 species in tropical, subtropical and warm-temperate regions, particularly in the Old World (Dalziel, 1937). They are larger than poppy seeds and much larger than teff seeds, but smaller than chia or perilla seeds. Fonio seeds are about the same size as camelina seeds. In germination tests, fonio seeds sprouted in 48 to 60 hours. When planted, the first green seedlings appeared 3 to 4 days after planting (Clayton and Renvoize, 1986).

The spikelet contains two bisexual florets with the lower part remain unfertile whilst the upper part is fertile having three stamens with yellowish anthers, two lodicules and a pink or purplish stigma (Fig. 2.2a) The reproductive system in these species remains less understood. For some authors, fonio species are likely self-fertilised crops (Sarker *et al.*, 1993; Watson and Dallwitz 1992); however an outbreeding system has also been advocated (Hilu *et al.*, 1997; Fogg 1976). Grains are very tiny (0.5-1 mm diameter, 0.75-2 mm length) with 1000 seeds weighing 0.5-0.6g. The caryopsis is tightly enclosed within two brown husks (lemma and palea) (Fig. 2.2b). In *D. iburua*, the husks are intensively dark-brown; hence it is commonly named black fonio in contrast to *D. exilis* known as white fonio. Within each genus, diverse species occur with a growth cycle varying from 60 to 130 days (Hilu *et al.*, 1997).



Figure 2a.



Figure 2b.

Figure 2.2(a) potted fonio plant and (b) grain of fonio on the raceme.

Source (CIRAD, 2000).

2.4 Soil, climatic and agronomic conditions

In West Africa, fonio is grown in traditional rain-fed farming systems under a wide range of agro-climatic conditions. *Digitaria exilis* is cultivated from sea level up to 1500 m altitude and mainly in areas receiving 700 - 1000 mm rainfall annually (Portères, 1976). However, the crop easily enters pluvial areas of critical rainfall deficiency with its current cultural limit at the annual isohyet of 150 mm whereas, in general, sorghum and pearl millet are limited by isohyets of 200-250 mm (Portères, 1976). Southwards, the cultivation becomes rare when the annual rainfall reaches 2000 mm (Diallo, 2003). *Digitaria iburua* is grown in similar but mostly in upland conditions (Portères 1976).

Both species of fonio are adapted to various soils including poor, sandy, degraded or marginal soil but heavy and saline soils are less suitable. In Fouta Djallon locations, for instance, *D. exilis* copes well with acidic clays with high aluminium content, a combination often toxic to most food crops (Haq and Ogbe, 1995). The optimal growing temperature range is 25-30 °C with approximately 12 h daylight. In contrast to black fonio, white fonio seems to be sensitive to day length (Adoukonou-Sagbadja, 2010).

Fonio cultivation is fairly simple and remains exclusively manual. The crop is mainly grown in pure culture and on rare associations with sorghum, pearl millet, guinea millet, okra and roselle (Jideani, 1999). Fonio is considered a very low demanding crop, and therefore generally occupies the last place in rotation systems after beans, groundnut and pearl millet or sorghum. Farm size is small and often below 1 ha. The sowing period varies among producing zones and depends on the onset of the rainy season. Soil preparation is minimal, usually limited to slight hoeing. Seeds are mainly broadcast-sown, at a seeding rate of 10 - 30 kg of seed ha⁻¹ (Cruz *et al.*, 2000). Weed control is performed manually two to three times from planting to heading. Pesticides and fertilisers are not applied by farmers and adequate information on the nutrient requirements of fonio is lacking. At maturity, fonio is harvested by uprooting or cutting the straw. Harvesting of fonio is the most laborious activity, involving the farmer, his family and friends (Jideani, 1999). Threshing is performed by beating or tramping on the fonio sheaves. Grains are well storable (5-10 years) but their viability seems to decrease considerably after two years (Adoukonou-Sagbadja *et al.*, 2006).

Farmers generally grow only one landrace but some few households can grow two to three landraces depending on labour availability (Adoukonou-Sagbadja *et al.*, 2006).

Fonio seeds destined to be sown the next season are directly taken from the newly harvested stock. In case of shortfall, farmers obtain planting materials from relatives or friends but buying from local market is not or less practised because of possible seed mixture of different landraces (Ibrahim, 2001).

2.4.1 Fertiliser requirement

Fonio requires at least thirteen elements for its normal growth and development in addition to carbon, hydrogen and oxygen which are obtained from air and water (Sprague and Duddley, 1988). Of the thirteen elements, nitrogen (N), potassium (K) and phosphorus (P) are needed in greatest amount and are classified as major or primary nutrients (Abunyewa and Padi, 2003). Calcium (Ca), magnesium (Mg) and sulfur (S) are taken up in fairly large quantity and are regarded as secondary nutrients. Additionally, iron (Fe), manganese (Mn), copper (Cu), boron (B), molybdenum (Mo) and chlorine (Cl) are required in small amount and are classified as micronutrients (Sprague and Duddly *et al.*, 1988).

The crop requires NPK fertiliser at an application rate of 30-60 kg ha according to type and nature of soil (Gigou *et al.*, 2009). The availability of adequate soil moisture improves the efficiency of fertiliser utilisation of the fonio crop (Abunyewa and Padi, 2003). Therefore, adequate soil moisture enhances N, P and K uptake leading to high grain yield/total biomass yield. Generally, high application of N with adequate irrigation schedules gives faster rate of photosynthesis and increased radiation interception and radiation use efficiency. Moderate levels of NPK fertiliser application to the fonio crop is

more effective than large amount of one of these nutrients (Gigou, 1986).

2.5 Pests and diseases

Fonio species have shown low susceptibility to pests and diseases. However, the fungi *Phyllachora sphearosperma* and *Helminthosporium spp.* have been seen to affect the crops (Haq and Ogbe, 1995). Fonio is also found to be susceptible to rust caused by *Puccinia cahuensis*. The parasitic plant, Striga, particularly *Striga rowlandi* known to occur abundantly in West-Africa, causes serious damage to the crop (Haq and Ogbe, 1995). At storage fonio weevils are also found to cause a negligible damage to the fonio seed (Sanou, 1993). Occasionally, weaver birds of genus *ploeus* found on rice fields visit fonio farms to pick matured seeds. But most of the recorded loses of fonio (up to 25%) occur through lodging due to the thin and weak culms of the plant and shattering when harvesting is delayed (Portères, 1976).

2.6 Economic importance and potential of fonio

Fonio is a staple food in dry areas of many West African countries including Benin, Burkina Faso, Gambia, Guinea, Mali, Senegal and Togo (FAO, 2009). It contributes significantly to food security particularly in seasons of hunger and critical periods when food reserves in the household are low (Robert, 2004). In the Hausa regions of Benin, Ghana, Nigeria and Togo, a special type of couscous ('wusu-wusu') is prepared from fonio. In southern Togo, the Akposso and Akebou people prepare fonio with beans for special occasions. In Nigeria, fonio flour is made into thick, unfermented porridge ('tuwoacha'), and fermented grains are used for thin porridge ('kunuacha') (Vodouhè

et al., 2003). Boiled whole grains are eaten with vegetables, fish or meat. In northern Togo, the Lamba people brew beer ('tchapalo') from fonio. It is also popped and can be mixed with other flours to make bread. In the Dominican Republic fonio flour is made into porridges and creams, mixed with other cereal flours to make cookies, and also used in preparing candy and fermented beverages (Adihou, 2001).

Fonio is also regarded as a grain with medicinal and healing properties; it is recommended for lactating women and is often used in diets of convalescent (Ruskin, 2011). The composition of whole fonio grain per 100 g edible portion is: water - 11.2 g, energy - 1390 kJ (332 kcal), protein - 7.1 g, fat 3.0 g, fibre - 7.4 g, Ca - 41 mg, P - 191 mg, Fe - 8.5 mg, thiamine - 0.24 mg, riboflavin - 0.10 mg and niacin 1.9 mg (Leung *et al* 1968). Essential amino acids contents per 100 g of grain are tryptophan - 111 mg, lysine - 205 mg, methionine - 441 mg, phenylalanine - 402 mg, threonine - 315 mg, valine - 457 mg, leucine - 772 mg and isoleucine - 315 mg (FAO, 1970). The amino acid composition of fonio is comparable to that of other cereals, but it has relatively high methionine content (Temple and Bassa,1991).

Fonio grain is a valuable, easily digested feed for farm animals. The straw and chaff are excellent fodder and are often sold in markets for this purpose (Karbo *et al.*,2002). Chopped fonio straw is mixed with clay to build walls of houses. The straw is also used as fuel for cooking or to produce ash for potash (Jideani, 1999). Aside everyday meals, fonio is also associated with various African religious festivities (Kwon-Ndung and Misari, 1999). It is considered a sacred crop in some areas and plays a central role in social events and celebrations. It is also used for the reception of important and

prestigious personalities in addition to being an important part of dowry in many Sahelian communities (Kwon-Ndung and Misari, 1999).

2.6.1 Chemical composition and nutritional value of fonio grains

The proximate chemical composition and major nutrient contents of fonio grain are of great interest. The energy value of fonio is approximately 19400 KJ/kg (Jideani and Akingbala, 1993). Carbohydrates are major components in cereals and constitute the main energy sources used by man. Carbohydrates form the basis of several important industries in the food and feed sectors, and provide renewable and environmentally friendly raw materials for industrial applications such as biodegradable plastics, adhesives, and ethanol-based fuels. The carbohydrates of fonio grains can also have many uses in industrial sector and their contents were ranged from 67.1 to 91 % with a mean value of 79.05 % (Jideani *et al.*, 1996). According to Nzleibe and Nwasike (1995), a high fiber diet may contribute to reduce the risk of cardiovascular diseases, colonic cancers and diabetes.

Fonio is also endowed with the four protein fractions, frequent in most cereals, mainly albumin (3.5 %), globulin (1.8 %), prolamin (5.5 %) and glutelin (14%). Studies showed that the glutelin was the most important protein fraction in the fonio grains. The prolamin content of fonio (5.5 %) can be compared with rice-prolamin content of about 5% (Padhye and Salunkhe, 1979). However, in cereals such as maize, wheat and barley, prolamin is present in greater amounts (Laszity, 1986). Amino acid profiles of fonio as compared to other cereals showed that, prolamin and glutelin of fonio were storage proteins while albumin and globulin fractions contained methionine, threonine,

tryptophan and valine (Serna, 2003). However, lysine an essential amino acid is deficient in fonio grain.

The fonio grain on the other hand is rich in methionine and cysteine, two most important amino acids almost deficient in the major cereals like sorghum, rice, wheat and barley (Serna, 2003).

In gross nutritional composition, fonio differs slightly from rice, millet, maize and sorghum (Table 2.1). The husked grain of white fonio contains 9% protein, and black fonio 11% protein (Temple and Bassa,1991).

Table 2.1 Nutritional contents of fonio and other cereals.

Cereal	Protein (%)		Lipid (%)		Minerals (%)		Carbohydrate (%)	
	whole	polished	whole	polished	whole	polished	whole	polished
Fonio	9 – 11	7 – 9	3.3 - 3.8	0.8 – 1	1 – 1.1	0.3 – 0.6	84 – 86	89 – 91
Sorghum	11	10	3.5	1.2	1.2	0.5	84	88
Millet	12	11	4	1.2	1.2	1.2	83	87
Maize	11	10	4.5	1	1.3	1	83	88
Rice	–	8	–	0.9	–	0.5	–	90

Source; International Plant Genetic Resource Institute (2004).

2.1.8 Elemental composition of fonio

Fonio contain basically ten essential mineral elements in varying concentrations (Table 2.2). Major mineral elements in the fonio grains are magnesium, phosphorus and potassium while the minor elements includes, iron, copper, manganese and zinc (Ballogou *et al.*, 2013). However, essential elements in foodstuffs of one region may vary from the other since food supplies are affected by various agricultural practices, type of soil, fertiliser, and chemicals used (Waheed *et al.*, 2002).

Table 2.2 Mineral composition of fonio grain.

Macro element	min	average	max	Micro element	min	average	max
	% Concentration				% Concentration		
Calcium (Ca)	0.0067	0.018	0.03	Iron (Fe)	36	84.8	133.6
Phosphorus (P)	0.09	0.17	0.25	Copper (Cu)	1.5	8.25	15
Potassium (K)	0.02	0.14	0.26	Manganese	21.6	28.8	30
Sodium (Na)	0.005	0.017	0.03	Zinc (Zn)	30	36.15	42.3
Sulphur (S)	0.07	0.46	0.85				
Magnesium	-	0.16	-				

Source: (Ballogou *et al.*, 2013)

2.1.9 Re-considering the role of fonio in strategies against the global food crisis

With the global food crisis, trends in malnutrition, household food security and increasing poverty in Sub-Saharan Africa, the need for an accelerated reduction of malnutrition and poverty has been emphasized (SCN 5th Report, 2004). Evidence of the potential micronutrient value of some underutilized species has been reported along with information on ways to consider those available biological food resources in strategies to reduce malnutrition. Therefore, national and international research and development institutions have come to appreciate the roles that traditional grains like fonio can play for nutrition and food security. Subsequently, many neglected species and varieties have been reconsidered to become potential vehicles for improved nutrition, as well as convenient sources of increased food supply and income (Toledo and Burlingame, 2006). Hence, a renewed interest in fonio is growing, especially in West African urban areas (Vodouhè *et al.*, 2003). During the past decade, national agricultural research centres of the main producing West-African countries have made series of attempts to identify and conserve important germplasm of fonio genetic resources (Adoukonou Sagbadja *et al.*, 2006). Moreover, in the perspective of defining appropriate strategies for conservation of fonio on farm, information has been produced on ethnobotanical and indigenous knowledge related to fonio production (Adoukonou Sagbadja *et al.*, 2007). To improve fonio processing and cooking techniques, modern and new equipment have been developed by small companies and women's groups in West Africa (Cruz, 2004). Also, modern small-scale processing industries for ready to cook products have been developed in urban areas and modern fonio-based recipes have been developed (Cruz, 2004). However, less

effort has been made to document and improve the potential of fonio to contribute to nutritional and health-related issues in West Africa.

2.1.10 Production of fonio in West Africa

The total production of fonio in West Africa is not known as precise production statistics are lacking for many producing countries. According to Bezpaly (1984), approximately 300 000 ha are yearly devoted to the cultivation of the crop in the region. In 2008/2009 agricultural season, the available statistics indicate a total of 488 247 ha of fonio were harvested with 380 227 tons of grains produced (FAOSTAT, 2011). White fonio which is widely grown, accounts for most of the recorded production (Ndoye and Nwassike 1993). Guinea and Nigeria are the two leading fonio producers in the region, followed by Mali, Côte d'Ivoire and Burkina Faso (Table 2.3).

Fonio production is minimal in the region because of the tediousness of fonio cultivation and processing, strong competition from maize and other cash crops like cotton and absence of improved varieties (Adoukonou-Sagbadja *et al.*, 2006; Sanou, 1993).

Table 2.3 Fonio production levels in West Africa.

Country	Area (ha)	Production (tonnes)
Guinea (Conakry)	200 000	222 000
Nigeria	162 000	80 000
Mali	45 000	26 000
Cote d'ivoire	13 000	14 000
Burkina Faso	13 000	9 500
Niger	5 000	2 000
Guinea Bissau	3 500	2 000
Senegal	3 000	2 000
Benin	2 000	1 500
Togo	2 000	1 500
Ghana	2 000	1 500
Total	450 000	362 000

Source: (Cruz *et al.*, 2011)

2.1.11 Fonio production in Ghana

In Ghana the exact date of fonio production is not precisely known but the crop gained national attention around the 1960s. It is believed that the fonio crop was introduced into the country by migrant farmers from Togo and Benin (MoFA, 2001).

The area of cultivation in Ghana is 2000 ha, which is limited to the north eastern corridor of the Northern Region, along the borders of neighbouring Togo. The cultivation of the

crop spans across four districts namely: Yendi, Saboba, Chereponi, and Zabzugu-Tatale, where it is intensively cultivated by Chokosis and Kokomba people (Dokosi, 1977). Generally thirteen genotypes have been identified in the production areas in Ghana with the most grown cultivars being Yadema (3 months) and Nomba (4 months) (Clottey *et al.*, 2006). There is no record of fonio export from Ghana, as production is on subsistent level. The estimated total annual production is about 500 metric tonnes (MoFA, 2001).

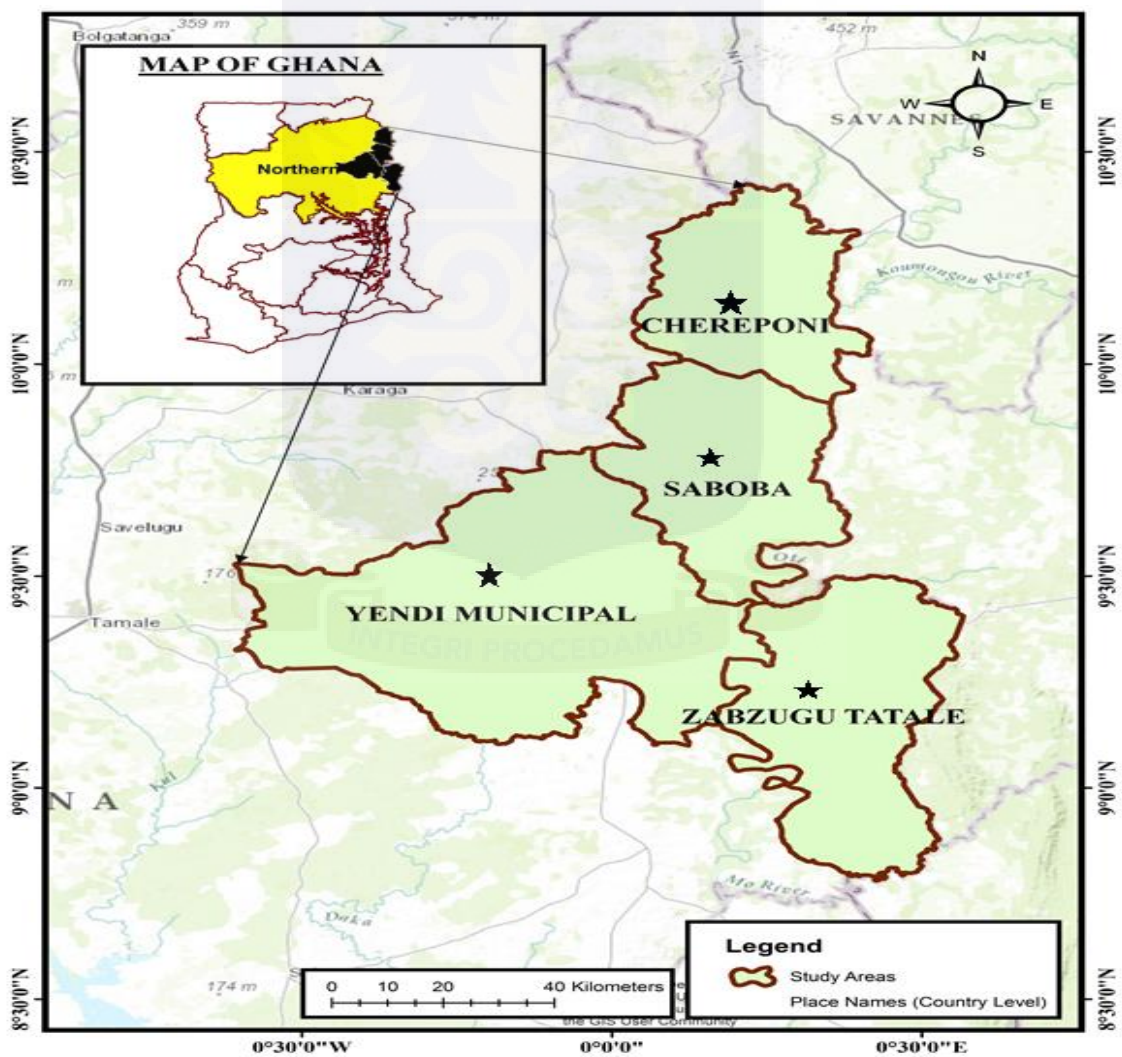


Figure 2.3 Fonio production areas in Ghana

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CHAPTER THREE

Experiment one

Growth and response of three fonio (*Digitaria exilis*) landraces to NPK fertiliser

3.1 Introduction

Fonio (*Digitaria exilis*, *Digitaria iburria*) is the most ancient traditional cereal cultivated across West African dry savannah regions along the Sudanese zone (Vietnemeier *et al.*, 1996). Particularly white fonio (*Digitaria exilis*) is primarily grown in Guinea, Mali, Burkina Faso, Cote d'Ivoire, Nigeria and Benin, in marginal, mountainous and hilly zones with sandy, poor and degraded soils, without fertilizers and pesticides (Adoukonou-Sagbadja *et al.*, 2004).

In 2009, approximately 460 685 tons were produced on 519 846 hectares in West Africa (FAO, FAOSTAT, 2009). In Mali, Burkina Faso and Guinea semiarid and sub-humid areas, fonio contribute 17-21 % of staple cereals requirement (Vall *et al.*, 2011). Due to its large ecological adaptability and the relatively short crop cycle of some varieties, fonio is believed to have a high potential as an important crop in agriculture and food supply in its traditional cultivation zones, particularly when annual harvests fail or during local crop shortfall periods (CC/GR, 1995; Vietnemeier *et al.*, 1996). In West African semiarid areas, fonio is the major part of the diet during harvest periods, and in sub-humid zones, it is stored during the postharvest period, for use as food supply during the food shortage periods (Vall *et al.*, 2011).

Although accounting for only about 10% of the global aggregate cereal output, the contribution of fonio and other traditional grains to food requirement is significant in many developing countries, for they are subsistence-oriented food staples (CC/GR, 1995). They may have high nutritional value, with some potential for alleviating the hunger and malnutrition caused by micronutrient deficiencies. Beside their importance to food supplies and health, fonio is the tastiest of all grains and also contribute to improved income among the most food-insecure population groups within the West African sub-region (Vietnameyer *et al.*, 1996).

3.1.1 Objective of the research

The aim of this research was to evaluate three fonio landraces cultivated in Ghana for their growth, productivity as well as N use efficiency in the Atomic–Kwabenya site, located in a coastal savannah agro-ecological environment of Ghana. Specific objectives were to:

- i. evaluate growth (plant height and biomass accumulation) and tillering of three different landraces of fonio.
- ii. estimate apparent N, recovery of the three fonio landraces grown at three different levels of applied NPK fertiliser.
- iii. determine biomass partitioning of the three landraces at different levels of applied NPK fertiliser.

3.2 Materials and methods

3.2.1 Study area

The experiment was conducted at the Nuclear Agriculture Centre - Biotechnology and Nuclear Agriculture Research Institute (BNARI) of the Ghana Atomic Energy Commission (GAEC). The experimental site (05°40' N, 0° 13' W, 76 m above sea level), is located within the Coastal Savannah agro-ecological environment in the Greater Accra Region of Ghana and receives less than 1000 mm annual precipitation (Morris *et al.*, 1999). The soil at the site is the Nyigbenya-Haatso series, which is a typically well-drained savannah Ochrosol (Ferric Acrisol) derived from quartzite Schist (FAO/UNESCO, 1994). The vegetation of the site is mainly grassland with clusters of shrubs and trees. The mean monthly weather information for the period under study is presented on Table 3.1 whiles Table 3.2 represents chemical characteristics of the soil at the study site.

3.2.2 Land preparation and field layout

A total land area of 25 m × 25 m, given a total area of 625 m² was ploughed, harrowed to turn the soil and to break the soil clods, and to level the surface. The complete randomized block experimental design was used with three replications, in a four factorial arrangement (factor A– three fonio landraces and factor B– three levels of NPK fertilizer application). Each subplot measured 5.0 m by 4.0 m. A distance of 2.0 m and 1.5 m was left between blocks and within subplots respectively.

In all, 200 kg ha⁻¹ of NPK of 15:15:15 fertiliser was applied by band placement two weeks and four weeks after germination (Gigou *et al.*, 2004). The ratios of the NPK

fertiliser application were 0, 30 and 60 kg ha⁻¹. Each of the small subplots received 0.6 kg and 0.12 kg NPK fertiliser based on the experimental design and the fertiliser treatment.

3.2.3. Weather Conditions

The following weather conditions prevailed at the site during the experiment.

Table 3.1. Mean monthly weather data during the growing season.

Month	Temp. max. (°C)	Temp. min. (°C)	Max. RH (%)	Min. RH (%)	Wind speed (m s ⁻¹)	Solar Rad. (W m ⁻²)
May	32.1	24.6	100.0	74.3	16.30	244.4
June	31.4	23.5	100.0	76.8	15.80	228.7
July	29.7	23.3	100.0	85.0	14.88	190.8
August	28.7	23.4	100.0	86.2	13.92	194.5
Sept.	29.5	23.2	100.0	86.5	16.11	201.9
Average	30.28	23.6	100.0	81.76	15.40	212.0

Source: BNARI weather station (2012).



Table 3.2 Some of the chemical properties of the soil at the experimental site.

Parameter	Value	Interpretation
pH	7.8	optimal
OC/OM	1.83/3.2 %	low
NH ₄ N	56 gm/kg	low
NO ₃ N	76 mg/kg	low
P	84 mg/kg	high
K	170.1 mg/kg	high

Source: Field Analysis (2012).

3.2.4. Experimental material

Three most cultivated landraces of fonio (*Digitaria exilis*) in Ghana with the local names Nvoni, Yadema and Nomba were obtained from Cherepuni in the Northern Region. Nvoni and Yadema mature at 85 days and 95 days respectively while Nomba matures at 120 days.

3.2.5 Sowing of Seeds

Seeds of the three landraces of fonio were sown on 21st June, 2012 at a seeding rate of 30 kg ha⁻¹ and germination occurred 4 days after seed sowing in all the landraces. The sowing was done on seedbed which was first leveled with hoe and later holes were drilled on the bed to a depth of 4 cm and covered with a thin film of soil after sowing.

The seedlings were spaced at 15 cm inter rows and 5 cm intra rows. Seedlings were thinned to 5 plants per hill, one week after germination.

Randomized Complete Block Design (RCBD) in a factorial arrangement was used for the study in 3 replications with 3 fonio landraces as factor A and 3 NPK fertilizer treatments as factor B. The NPK fertiliser treatment were 0, 30 and 60 kg ha⁻¹.

3.2.6. Data collection

Data were collected on vegetative, growth as well as yield characteristics of the three fonio landraces. The vegetative characteristics which were taken every 2 weeks until flowering include plant height, leaf width, leaf blade colour, ligule shape and biomass accumulation.

Data were taken on reproductive characteristics, culm length, resistance to lodging and number of days to 50% heading. Data on the culm length and culm diameter were taken after heading of the fonio crop.

Total numbers of tillers (effective and non-effective), grain yield and straw weight were recorded. Other yield parameters recorded include 1000 grain weight, number of days to maturity and harvest index.

3.3 Cultural practices

3.3.1 Fertiliser application

Fertiliser response depends upon the production potential of a particular area. Fonio is grown in areas with high production potential, such as in Guinea, as well as in areas with a low production potential, such as the Segou area in Mali (Vall *et al.*, 2008). Cultivation tends to stop when the yields become too low or when weeds, particularly *Striga hermonthica*, become difficult to control.

3.3.2 Weeds and insect control

As reported earlier, fonio has no major insect pest except weed infestation of related species. The weed flora consisted mainly of annuals most of which are grasses and some broadleaved weeds. The most dominant weed species were *Digitaria horizontalis*, *Eleusine indica* and *Cynodon dactylon*. Weeds were controlled by hoeing whenever necessary.

3.3.3 Plant sampling

Five plants of each fonio landraces were sampled at 15 DAE, 30 DAE, 44 DAE, 60 DAE, 74 DAE, and 88 DAE from an area of 0.5 m² in each subplot. Plants sampled were separated into leaves, stem and grain components. Sub-samples of each component were taken for total dry matter determination after drying in an oven at 65 °C for three days. Additionally, final grain yield was determined from 1 m² area at crop maturity which occurred at 27th September 2012. Grain yield was determined at grain moisture content

ranging between 13.0 % – 15.0 % after sun drying. The total dry matter and grain yield at maturity were determined using the relations (Laszity *et al.*, 1984) :

$$DMY = \frac{\left(\frac{SDW}{SFW} \times TFW\right)}{H} \times \frac{1000 \text{ m}^2 \text{ ha}^{-1}}{1000 \text{ g kg}^{-1}} \quad [1]$$

where:

DMY is the dry matter yield (kg ha⁻¹)

SDW is the dry weight of sub-sample (g)

TFW is the total fresh weight of sample (g)

SFW total fresh weight of sub-sample (g)

H is the area from which total fresh sample was taken (m²)

$$GYp = \left(\frac{GY_M}{H}\right) \times \left(\frac{10000 \text{ m}^2 \text{ ha}^{-1}}{1000 \text{ g kg ha}^{-1}}\right) \quad [2]$$

Where:

GYp is the grain yield (kg ha⁻¹)

GY_M is the grain yield adjusted with respect to grain moisture content (g)

H is the harvested area (m²)

3.4 Determination of N, P and K in plant samples

3.4.1 Determination of N

Sub-samples of the different biomass component were oven-dried at 60 °C for 3 days for dry matter determination, grounded and chemically analyzed for total nitrogen using the Kjeldahl-nitrogen procedure (Novosarnsky *et al.*, 1983). Accumulated nitrogen was calculated, multiplying the concentration of the nitrogen in the digested plant part after titration by the corresponding dry matter and the value summed up to obtain the total Nitrogen using the following equation:

$$\%N \text{ (DM basis)} = \frac{(VHCl \times NHCl) - (VBK \times NNaOH) - (VNaOH \times NNaOH)}{1.4007 \times W \times \text{Lab DM}/100} \quad [3]$$

where:

VNaOH = mL standard NaOH needed to titrate sample

VHCl = mL standard HCl pipetted into titrating flask for sample

NNaOH = Normality of NaOH

NHCl = Normality of HCl

VBK = mL standard NaOH needed to titrate 1 mL standard HCl minus B

B = mL standard NaOH needed to titrate reagent blank carried through method and distilled into 1 mL standard HCl

1.4007 = milliequivalent weight of nitrogen x 100

W = sample weight in grams

3.4.2 Determination of P

The Kjeldahl digestion procedure was used to convert condensed and organic P compounds, including particulate P to orthophosphate. Total P was measured (without further digestion) by simply using the molybdate colorimetric test as described in the Dissolved Reactive P (Pierzynski, 2000) to determine the P content of the digested solution through the Kjeldahl digestion process.

3.4.3 Determination of K (flame photometry)

Samples of the fonio species to be tested were ground into powder and digested according to the method used by Novosarnsky *et al.*, (1983). The stock solution was sprayed into flame, the solvent evaporated and the ions were converted into atomic state. In the heat of the flame (temperature about 1800 °C), small fraction of the potassium atoms contained in the stock solution was excited. Relaxation of the excited potassium atoms to the lower energy level was accompanied by emission of light (photons) with characteristic wavelength (K: 766 nm). The intensity of the emitted light was recorded as the concentration of potassium ions in the fonio samples using a calibration curve (Fig. 3.1).

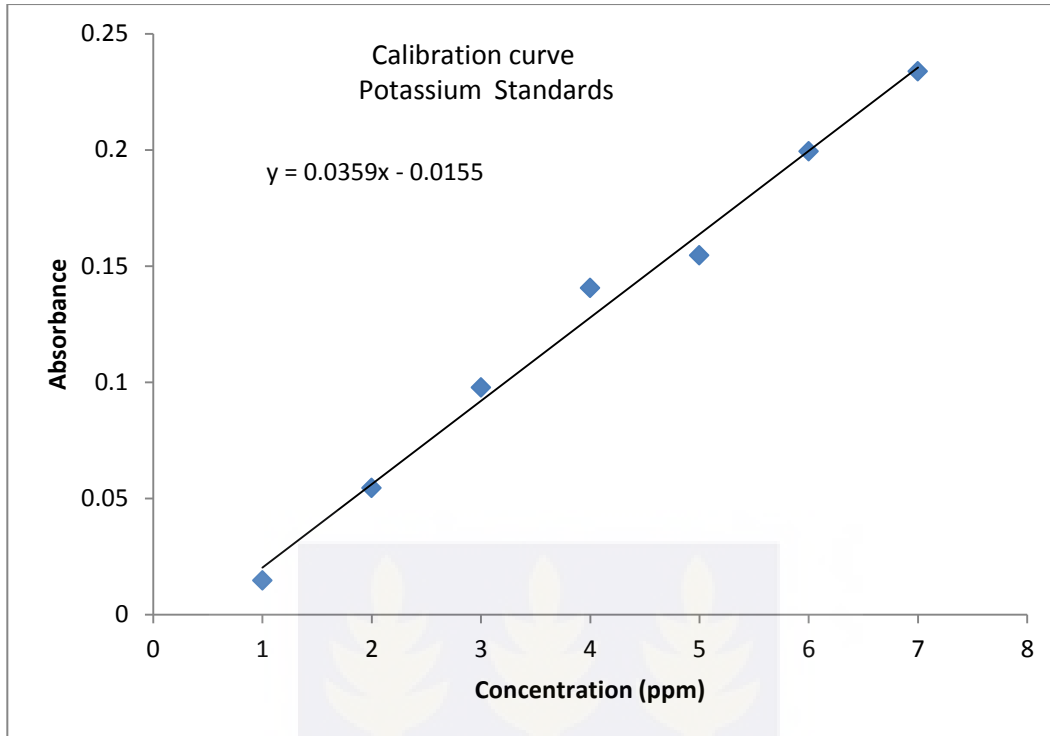


Fig. 3.1 Calibration curve for Potassium Standards.

3.4.4 Apparent fertiliser N recovery

The apparent fertiliser-nitrogen recovery (ANR) was calculated using the difference method as described by Cambel *et al.* (1978).

$$ANR = \left[N_{acf} - N_a \right] \times \frac{100}{N_b} \quad [4]$$

where

N_{acf} is total nitrogen accumulated by fonio at the rate of fertiliser-nitrogen applied.

N_a is the total nitrogen accumulated by fonio at no fertiliser- nitrogen application.

N_b is the total fertiliser-nitrogen applied.

3.5 Statistical analysis of data

The experiment was based on two factor experiment. Factor (a) three fonio species and factor (b) rate of NPK fertiliser application laid in a Split Block Design. Data collected on NPK fertiliser and the rate of application on plant height, leaf dry matter yield, biomass accumulation, grain yield and harvest index were subjected to analyses of variance and the Least Significant Difference (LSD) test used to separate means when significant differences were observed. The GenStat (12th edition) statistical package was employed in the analyses of the data. Additional significant differences in variance of the result were analysed using the Statgraphics Centurion statistical tool and the results displayed on tables and graphs.

3.7 Results

3.7.1 Weather conditions at the experimental site

The average annual rainfall figure at the site during the 2012 cropping season was 1150 mm, which fell during the major and minor seasons. The major rainy season begun in April and ended in August, whilst the minor rainy season occurred in September to December. The major rainfall season recorded a total of 785.5 mm and the minor season recording a total of 364.0 mm. There was very little variation in temperature throughout the year. The mean monthly temperature ranged from 23.5 °C in June (the coolest) to 30.0 °C in April (the hottest), with an annual average of 26.8 °C (BNARI Weather Station).

Rainfall was erratic during the 2012 cropping season at the experimental site. A total of 240.0 mm of rain was obtained in 60 days (from June to August), with the highest amount

of 118.0 mm occurring in July in 12 days while a minimum of 75 mm was recorded in August (Figure 3.2). The highest amount of the rainfall (July) 118 mm occurred during the early vegetative growth phase of the fonio crop. The mean solar radiation for the cropping season was 212.1 W m^{-2} . For average relative humidity, an average value of 85% was observed during the cropping season for all the months with the minimum relative humidity of 18.0% recorded in August.

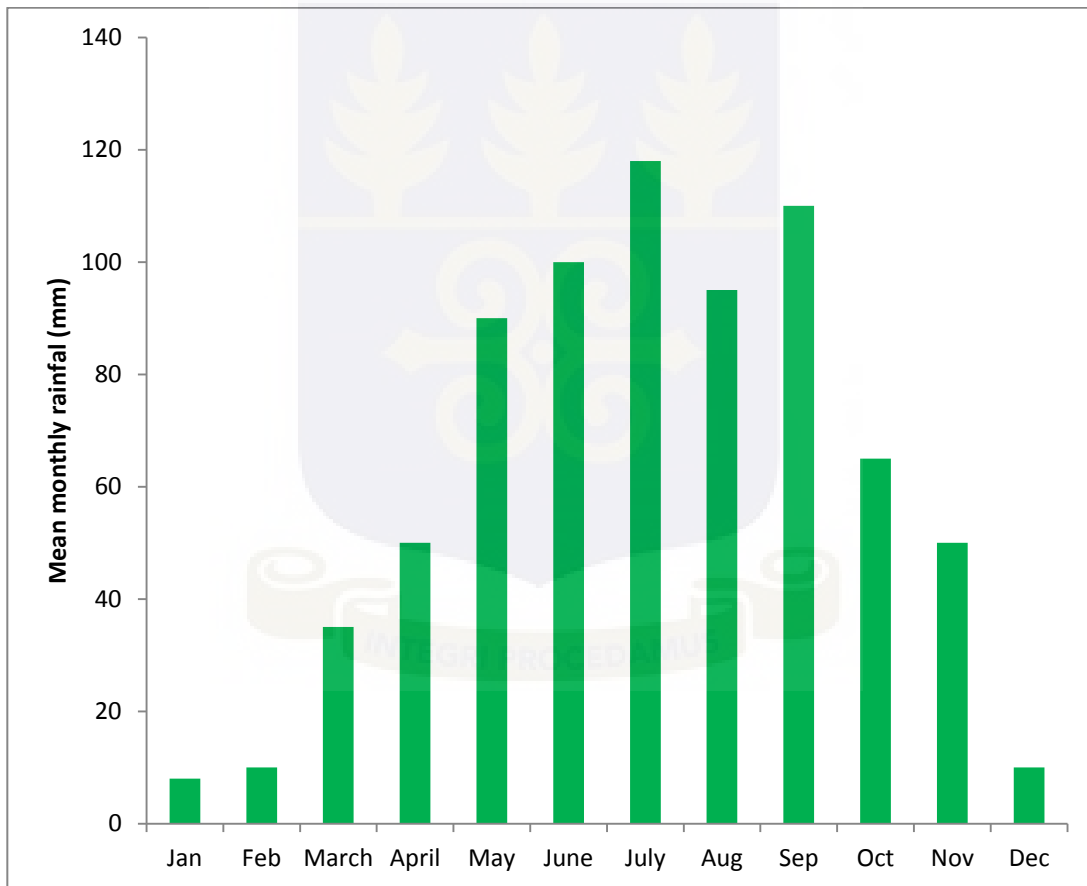


Figure 3.2 Monthly rainfall for the year 2012 at the experimental site, Kwabenya – Atomic.

3.7.2 Plant height

The NPK fertiliser treatment had no significant effect on plant height as all the three fonio landraces attained the same height of 0.7 cm at 70 DAE (Figure 3.3). The height of the fonio crop increased rapidly during the vegetative phase.

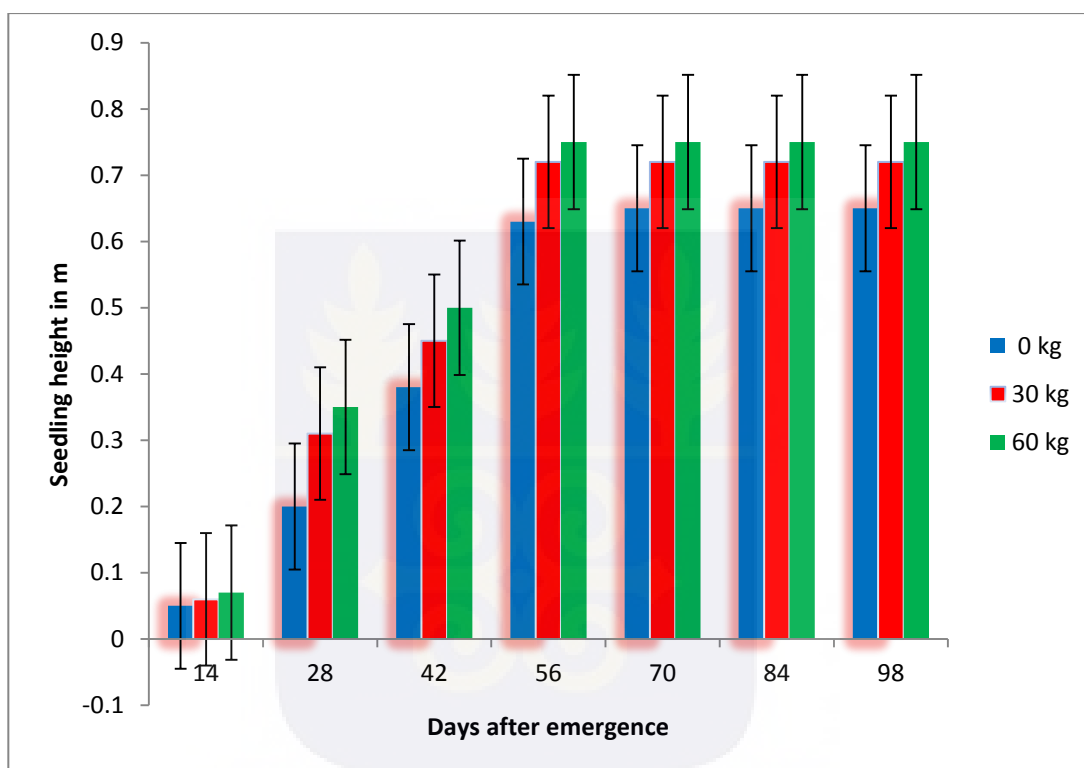


Figure 3.3 Seedling height at different growth stages of the three landraces of the fonio crop.

3.7.3 Number of days from seedling emergence to 50% heading

Results obtained from the field experiment indicated differences in days to 50% heading, deduced vegetative phase and days to maturity for each of the fonio landraces. However, each of the fonio landraces attained the same height of 0.75 m (Table 3.3). The result indicated the landrace Yadema as early maturing, taking a total of 90 days. Number

and Nvoni are both late maturing, taking a total of 105 and 118 days respectively to maturity (Table 3.1).

Table 3.3 Days to 50% heading, maturity, deduced vegetative phase plant height at maturity and classification.

landrace	DFH (days)	DM (days)	DVP (days)	PHM (m)	HC
Yadema	74	90	57	0.75	Dwarf
Nomber	88	105	64	0.75	Dwarf
Nvoni	97	118	72	0.75	Dwarf
Mean	86	104	64	0.75	–
Sd	11.5	14	7.5	0	–
CV(%)	0.1	0.1	0.1	0	–

DHF=Days to 50% Heading; DM=Days to Maturity; DVP=Deduced Vegetative Phase; PHM=Plant Height at Maturity; HC= Height Classification; Sd=Standard deviation and CV=Coefficient of Variation.

3.7.4 Total number of tillers

The NPK fertiliser application had a significant effect ($P \leq 0.05$) on both the total number of tillers per squared sample and the effective tillers of the three landraces (Figure 3.4a). Nvoni had the highest response to the fertiliser treatment with respect to the total tiller number: 450, 700 and 800 tillers at zero, 30 and 60 kg ha⁻¹ of NPK respectively (Figure 3.4a).

A similar effect of the NPK fertiliser on number of effective tillers was observed, as the landrace Nvoni produced the highest number of effective tillers of 300, at 400 and 450 at 0, 30 and 60 kg ha⁻¹ of NPK respectively (Figure 3.4b). Yadema, however produced

comparatively the lowest number of effective tillers of 250, 350 and 400 at 0, 30 and 60 kg ha⁻¹ NPK respectively (Figure 3.4b)

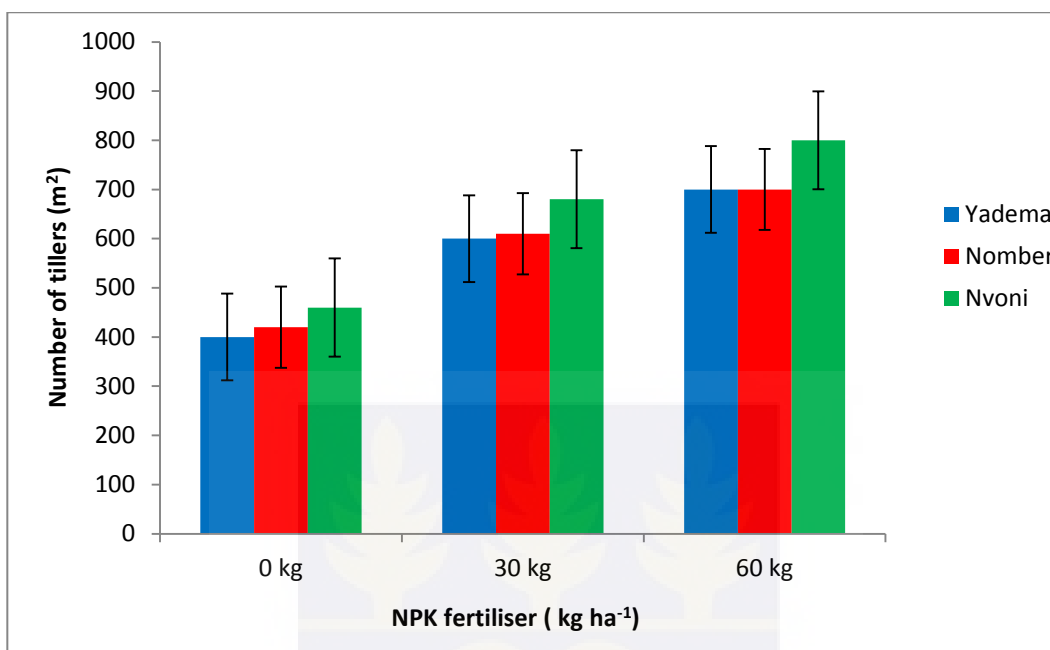


Figure 3.4a Total number of tillers formed by the three landraces of the fonio plant during the cropping season

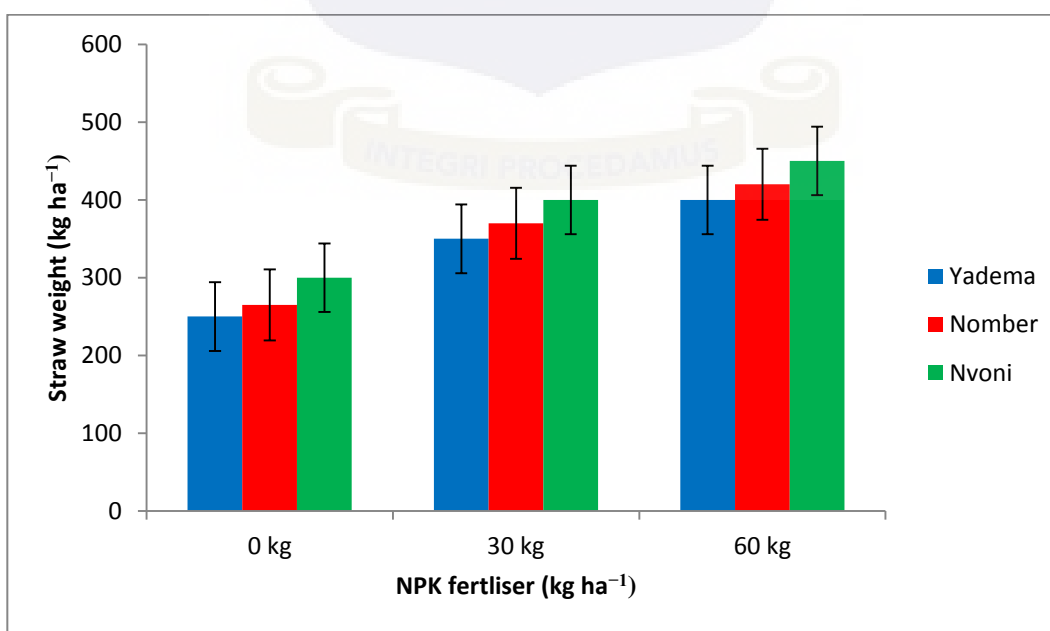


Figure 3.4b Total number of effective tillers formed by the fonio landraces during the cropping season.

3.7.5 NPK fertiliser effect on biomass accumulation of the fonio landraces

The total biomass accumulation ranged from 95.0 kg ha⁻¹ to 1600 kg ha⁻¹ (Table 3.4). Specifically, the three fonio landraces accumulated biomass progressively with time with peak biomass values at 70 DAE before declining at 84 DAE (Table 3.4). Similar biomass levels ($P > 0.05$) were produced by the landraces at 70 DAE with no NPK fertiliser application (Table 3.4). However, for 30 and 60 kg ha⁻¹ NPK applications, significant differences were observed on biomass at 70 DAE.

Additionally, Nvoni produced the highest biomass at zero, 30 and 60 kg ha⁻¹ of NPK (Table 3.4). The rate of biomass accumulation was comparatively faster for Yadema than Nvoni and Nvoni. The decline in biomass accumulation was different for each of the fonio landraces, 60 DAE for Yadema, 70 DAE for Nvoni and 84 DAE for Nvoni.

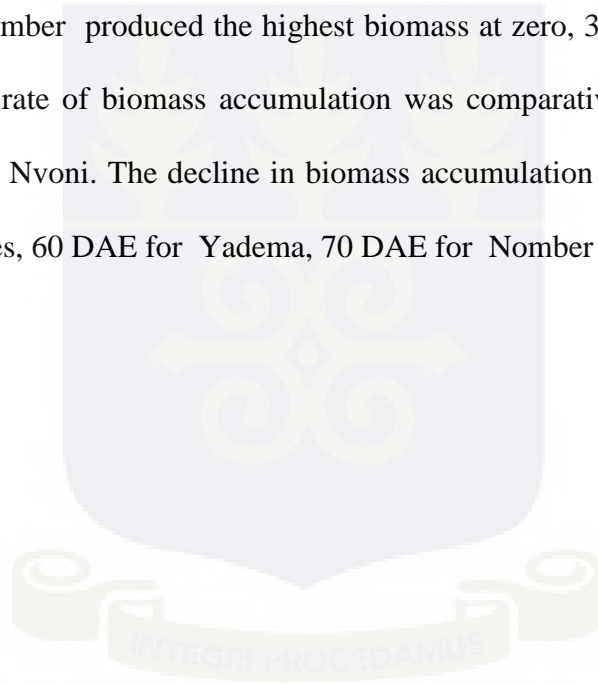


Table 3.4 Effect due to differences in rates of NPK fertiliser (15:15:15) on biomass accumulation at different growth stages of three fonio landraces.

DAE	0 kg ha ⁻¹ NPK			30 kg ha ⁻¹ NPK			60 kg ha ⁻¹ NPK		
	Biomass accumulation (kg ha ⁻¹)			Biomass accumulation (kg ha ⁻¹)			Biomass accumulation (kg ha ⁻¹)		
	Number	Nvoni	Yadema	Number	Nvoni	Yadema	Number	Nvoni	Yadema
14	105.0a	87.7b	95.0ab	156.7a	148.3a	151.7a	212.7a	190.0b	205.0ac
28	198.7a	192.3a	205.7a	304.7a	286.7b	305.0ac	405.0a	365.0b	405.7ac
42	407.7a	361.7b	352.3b	613.7a	567.0b	562.3b	706.7a	682.7b	682.3b
56	522.3a	591.0b	508.7c	683.3a	709.7b	651.7c	813.0a	852.3b	790.0c
70	1189.7a	1200.3a	1214.0a	1438.3a	1461.3a	1421.0b	1559.7a	1606.3b	1559.3ac
84	942.0a	320.8a	908.0a	1272.0a	1216.0a	1252.0a	1324.0a	1320.0a	1316.0a
98	445.7a	370.7b	363.0b	651.0a	596.7b	572.3b	725.3a	691.3b	688.0b

The same lowercase letter indicated there was no significant difference between the treatments, but the different letters indicated significant difference was present at $P \leq 0.05$ level.

3.7.6 Concentration of N, P and K in the grain of fonio

Levels of NPK fertiliser applied had significant effect ($P \leq 0.05$) on the concentration of N, P and K in the seeds of the fonio landraces. The concentration of N in the landraces ranged from 1.33% to 2.03% (Table 3.5). Landraces without NPK fertiliser treatment had low concentration of N, while those with NPK fertiliser application had increased concentration of N.

P and K showed no significant ($P \geq 0.05$) effect on the levels of NPK fertiliser treatment. There was no difference in the concentration of both P and K in the three landraces as concentration was low in all the three. However, analyses of the chemical properties of the soil prior to the experiment indicated high concentration of P and K in the soil (Table 3.2).

The crude protein content of the three fonio species was generally high for all the three landraces as a result of the NPK fertiliser treatment. Nember had the highest crude protein content of 9.2%, 13.3% and 12.7% at 0, 30 and 60 kg ha⁻¹ of NPK fertiliser application (Table 3.5).

Table 3.5 Concentration of N, P and K concentration and crude protein content in the grains of three fonio landraces at 0, 30 and 60 kg ha⁻¹ NPK fertiliser treatment.

Fonio landraces	%N			Crude Protein (%)			%P			%K		
	0 kg N (kg ha ⁻¹)	30 kg N (kg ha ⁻¹)	60 kg N (kg ha ⁻¹)	0kg N (kg ha ⁻¹)	30 kg N (kg ha ⁻¹)	60 kg N (kg ha ⁻¹)	0 kg N (kg ha ⁻¹)	30 kg N (kg ha ⁻¹)	60 kg N (kg ha ⁻¹)	0 kg N (kg ha ⁻¹)	30 kg N (kg ha ⁻¹)	60 kg N (kg ha ⁻¹)
Yadema	1.33	1.65	1.89	8.30	10.40	11.80	0.605	0.711	0.896	0.639	0.612	0.533
Number	1.47	1.97	2.03	9.20	13.30	12.70	0.408	0.698	0.883	0.658	0.648	0.516
Nvoni	1.46	1.68	1.79	9.13	10.53	11.20	0.617	0.713	0.719	0.566	0.543	0.545
Mean	1.42	1.77	1.90	8.88	11.41	11.90	0.574	0.707	0.832	0.622	0.902	0.531
Sd	0.078	0.177	0.121	0.501	1.638	0.755	0.116	0.008	0.099	0.049	0.053	0.015
CV (%)	0.055	0.100	0.063	0.056	0.144	0.063	0.203	0.012	0.119	0.078	0.059	0.028

3.7.7 Grain yield at physiological maturity

Grain yield ranged from 540 to 900 kg ha⁻¹ for Yadema, 560 to 910 kg ha⁻¹ for Number and 600 to 965 kg ha⁻¹ for Nvoni at three levels of NPK fertiliser treatments (Figure 3.5). The NPK fertiliser application, thus produced high significant ($P \leq 0.001$) differences in grain yield with the landrace Nvoni generally out-yielding Number and Yadema. Specifically, Nvoni produced the highest grain yield of 540 kg ha⁻¹ at control, 900 kg ha⁻¹ at 30 kg ha⁻¹ and 978 kg ha⁻¹ at 60 kg ha⁻¹ NPK fertiliser applications. This was followed by Number and Yadema 920 kg ha⁻¹ and 900 kg ha⁻¹ respectively at 60 kg ha⁻¹ NPK fertiliser application (Figure 3.5).

Statistically, the grain yield of Yadema at 60 kg ha⁻¹ NPK fertiliser treatment was about 60% more than the level produced at 0 kg ha⁻¹ of NPK (control) and 10% more than the level produced at 30 kg ha⁻¹ of NPK treatment. Similar increase in grain yield levels in response to the NPK fertiliser treatments were observed for Number and Nvoni (Figure 3.5).

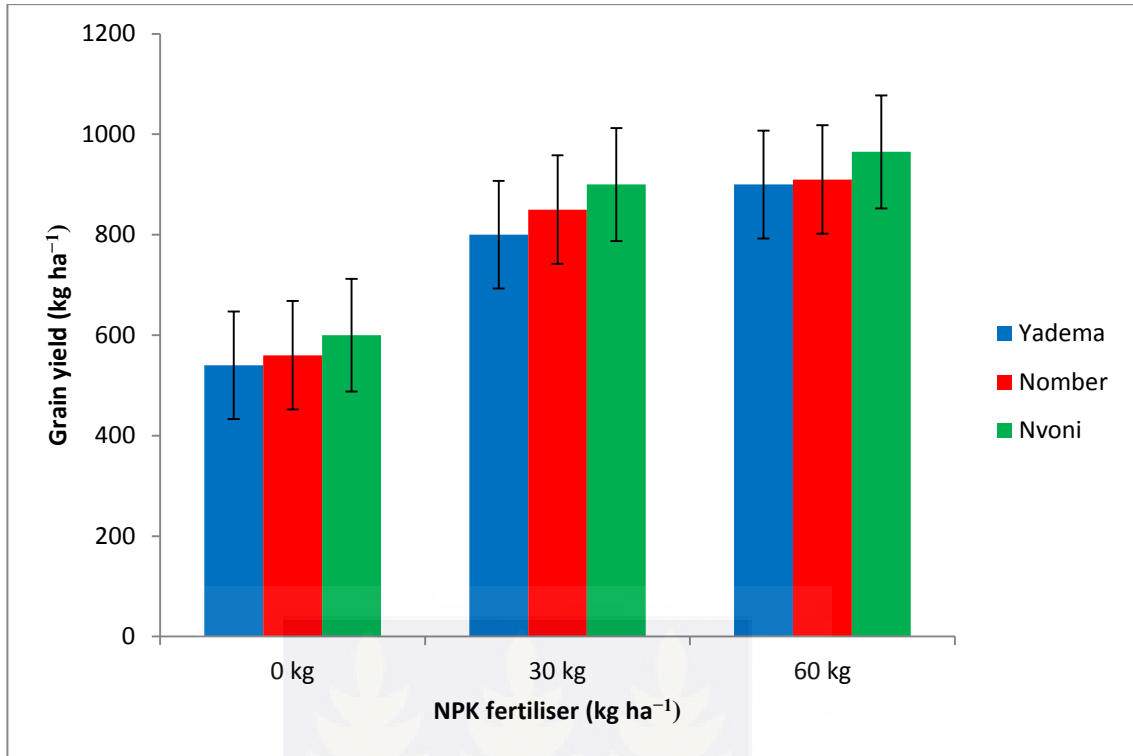


Figure 3.5 Physiological grain yield for the three landraces of fonio at three levels of NPK fertiliser treatments.

3.7.8 Harvest index

Harvest index for the landraces generally increased with increasing level of applied NPK fertiliser (Figure 3.6). The fonio landrace Yadema consistently had the lowest harvest index at all the three levels of applied NPK. In contrast, Nvoni had the highest harvest index at all the levels three of applied NPK fertiliser.

The highest harvest index of 54% was for the landrace Nvoni at 30 kg ha⁻¹ of NPK fertiliser which was significantly different ($P \leq 0.05$) from the harvest index of Yadema and Nomber (Figure 3.6).

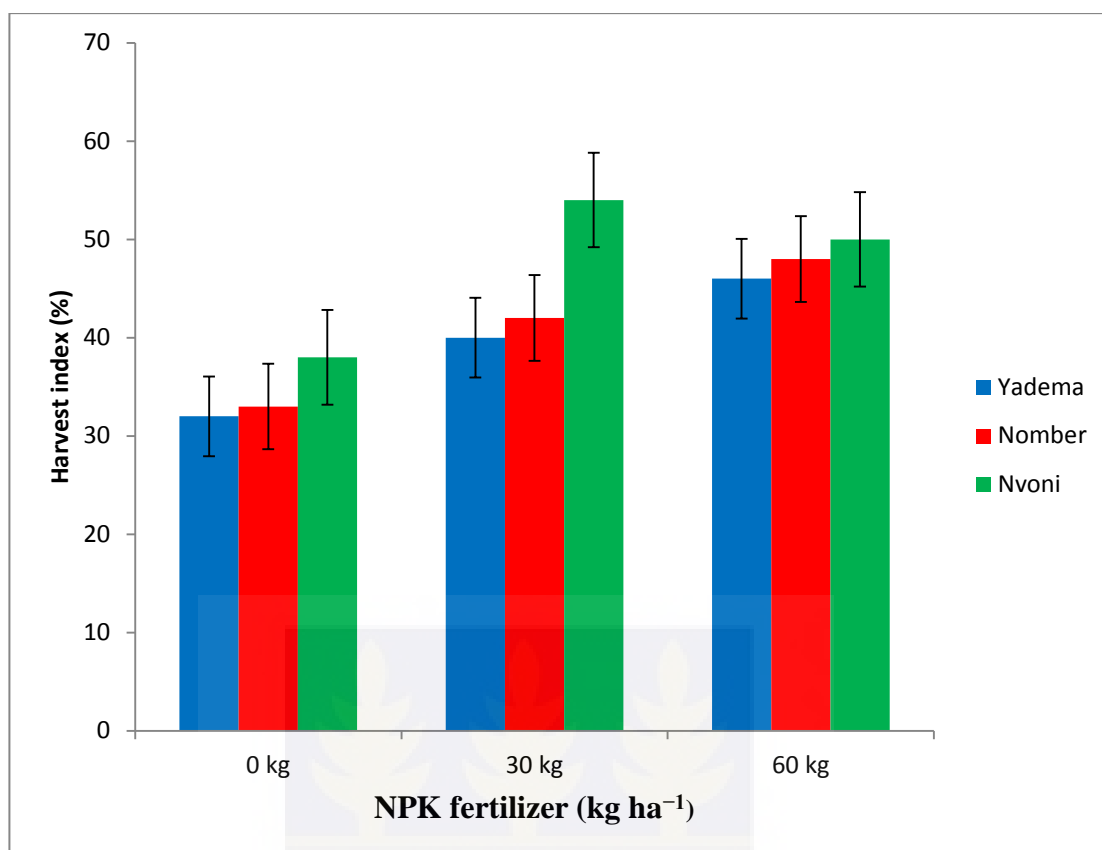


Figure 3.6 Harvest indices of the three fonio landraces in response to NPK fertiliser treatment during the cropping season.

3.7.9 Straw weight

The straw weight of the fonio landraces increased with increasing levels of applied NPK fertiliser (Figure 3.7). Specific significant increase in straw weight over the levels at no fertiliser treatment was observed for 30 kg ha⁻¹ NPK fertiliser application. Thus the straw weight of the landraces increased over 100%, over the straw weight at no fertiliser treatment, when 30 kg ha⁻¹ of NPK was applied (Figure 3.7). In effect, the application of 30 kg ha⁻¹ of NPK fertiliser led to significant increase in straw weight over the levels produced at zero fertiliser treatment.

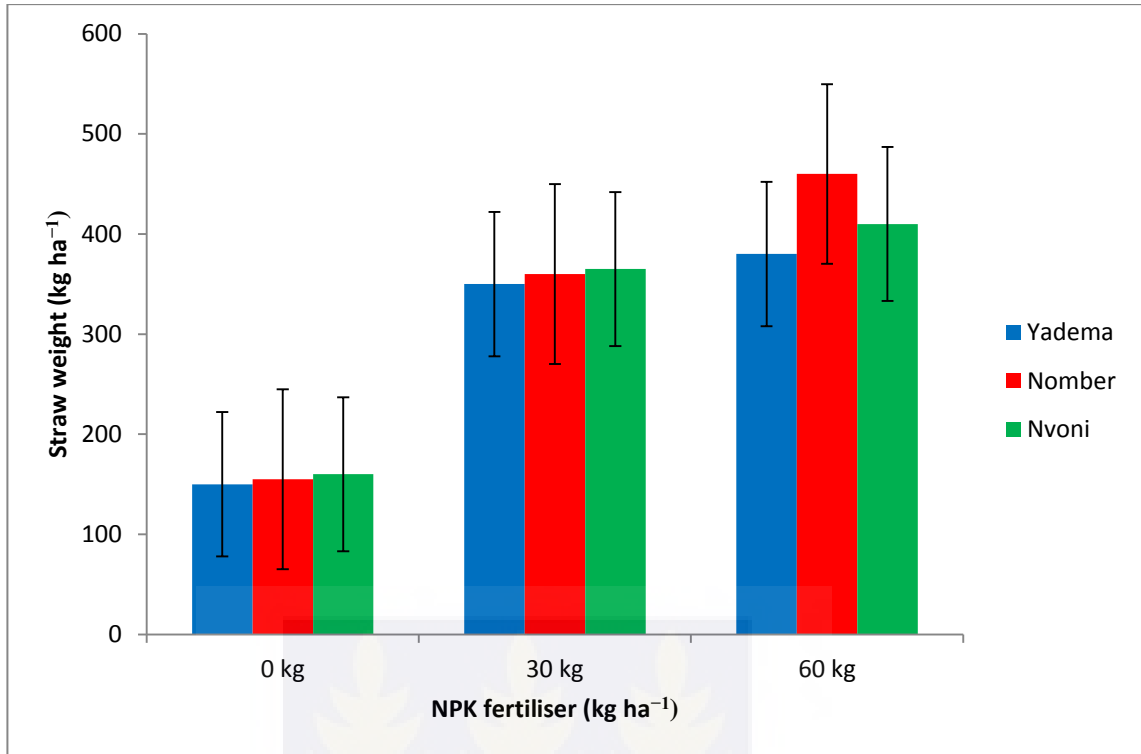


Figure 3.7 Straw weight of the three NPK fertiliser treatment during the cropping season of fonio.

3.7.10 Apparent Fertiliser Nitrogen Recovery

The apparent fertiliser N recovery (AFNR) ranged between 20.5% and 44.4% (Table 3.6) with the landrace Number, having a significantly ($P \leq 0.05$), the highest AFNR value of 44.4% at 30 kg ha⁻¹ of NPK fertiliser treatment. Generally, the landraces recovered comparatively lower N at 60 kg ha⁻¹ of NPK application to 30 kg ha⁻¹ of NPK application.

3.7.11 Nitrogen use

Nitrogen use by the fonio landraces increased with increasing levels of applied NPK fertiliser ranging from 10.4 to 28.62 kg ha⁻¹. The application of 30 kg ha⁻¹ of NPK resulted in about 80%, 118% and 84% above the N use at control by Yadema, Nomber and Nvoni respectively. Though N recovery was significant ($P \leq 0.05$) among the landraces, there was no significant difference in N use by the fonio species at control (no NPK fertiliser application). However, Nomber had the highest amount of N as compared to that taken by the other two landraces at NPK application levels of 30 and 60 kg ha⁻¹.

Table 3.6 Apparent N recovery rate among the three landraces of fonio.

Fonio landraces	Applied N (kg ha⁻¹)	TDMY (kg ha⁻¹)	N content (%)	N Uptake (kg ha⁻¹)	Apparent fertiliser N recovery (%)
Yadema	0	755	1.33	10.40	–
	30	1120	1.65	18.48	26.9
	60	1200	1.89	22.68	20.5
Nomber	0	770	1.47	11.32	–
	30	1250	1.97	24.63	44.4
	60	1410	2.03	28.62	28.3
Nvoni	0	815	1.46	11.90	–
	30	1300	1.68	21.84	33.1
	60	1500	1.79	26.85	24.9

TDMY = Total Dry Matter Yield.

3.8 Discussion

3.8.1 Plant height

All the three fonio landraces attained a maximum height of 0.75 m. According to Portères (1976) Fonio is a dwarf crop with height rarely exceeding 1.0 m. This shows that the NPK 15:15:15 fertiliser treatment did not have any significant effect on the height of the fonio plant. On the contrary, Dachi and Gana (2008) recorded plant height between 0.7 m and 1.2 m in fifteen accessions of fonio at Niger State in Nigeria. This difference in plant height could be attributed to differences in geographical factors. There was a progressive increase in the height of the fonio through the various growth stages in agreement with Zadok *et al.*, (1974).

3.8.2 Number of days from seedling emergence to 50% heading

The number of days from seedling emergence to 50% heading was also not affected by the NPK fertiliser treatment although there were differences in the vegetative phases of the landraces. In a related study, Adoukonou-Sagbadja *et al.* (2007) observed differences in number of days to 50% heading in 27 fonio accessions and classified them as early (≤ 90 days), medium (91-120 days) and late (> 120 days). This shows that the landrace Yadema is early maturing taking an average of 90 DAE, followed by Nember (105 DAE) and Nvoni (118 DAE).

3.8.2 Total number of tillers

The NPK fertiliser treatment had a significant effect ($P \leq 0.05$) on tiller production of the fonio landraces. Number of tillers for each of the landraces varied from 4 to 8 for the control and 8 to 15 for both 30 kg ha^{-1} and 60 kg ha^{-1} NPK fertiliser application. Differences in the number of tillers per plant had been reported by Clotey *et al.*, (2006) averaging 8 tillers in thirteen fonio landraces assembled in Ghana. Similarly, Dachi and Gana (2008) observed varying number of tillers, from 8 to 15, in a fertiliser experiment involving black fonio in Niger state, northern Nigeria.

Thus the tillering ability of fonio is enhanced when additional nutrient is supplied. Each tiller produced represents the potential for a fonio plant to develop an additional stem complete with its own leaves, roots, and head. However, Pursglove (1988) observed lodging in free tillering grass species when additional nutrient was supplied.

3.8.3 Total above ground biomass

All the three landraces of fonio generally followed a similar pattern of biomass accumulation over various growth stages, with biomass increasing at early growth stages, and peaking at late growth stages (Table 3.2). In an earlier study, Dachi and Omueti (2000) also observed similar seasonal biomass accumulation among different fonio cultivars in spite of considerable differences in morphology and absolute values of biomass. The fonio crop in this study reached the estimated maximum biomass at ripening growth stage (70–84 DAE). Similarly, Greenwood *et al.* (1990) recorded peak biomass of 1320 kg ha^{-1} at 70 DAE for *Digitaria exilis* (white fonio) which is named Nvoni in this study. Biomass accumulation rate increased with time, reaching a maximum at late flowering stage (70–84 DAE). Maximum biomass accumulation

rates for the fonio landraces were similar within each fertiliser treatment but varied between different NPK fertiliser treatments. Additionally, Lasztity *et al.* (1984) and Karlen and Whitney (1980) also observed rapid biomass accumulation rate for winter wheat at booting to milking growth stage which also coincide with the highest adsorption point of plant mineral and water.

On average, NPK application increased biomass production by 240 kg and 370 kg for the fertiliser treatment 30 kg ha⁻¹ and 60 kg ha⁻¹ respectively (Table 3.2). The findings suggest that the supply of nutrients from soil and fertilisers must be sufficient at early growth stages to obtain high crop yield.

3.8.4 Yield and harvest indices

The highest value of grain yield was 920 kg ha⁻¹ at NPK fertiliser rate of 60 kg ha⁻¹ and 850 kg ha⁻¹ at NPK rate of 30 kg ha⁻¹ while the lowest yield of 560 kg ha⁻¹ was observed for the control. The effect of NPK fertiliser treatment was highly significant ($P \leq 0.001$) on grain yield of the fonio and that increasing nitrogen rates up to 60 kg ha⁻¹ increased grain yield up to 60%. This corroborates the findings of Cruz (2004) in a fertiliser trial in selected regions within the West African sub-region where NPK fertiliser increased yield of fonio up to 75%. However, Gigou *et al.* (2009) recorded over 100% grain yield of fonio in a similar fertiliser experiment at different locations in Mali, where the yield was as high as 1600 kg ha⁻¹ at a fertiliser rate of 15 kg ha⁻¹ N. One explanation for this exceptional grain yield could be that the trial locations in Mali were close to the centre of origin of fonio where the greatest diversity of unselected fonio ecotypes still exist.

Highly significant ($P \leq 0.03$) harvest index of 54% accounted for the significant highest grain yield of Nvoni during cropping season as compared to Yadema and Nember which produced statistically similar grain yield levels. Altom *et al.*, (1996) obtained a harvest index 57% for wheat and 53% for rye whereas the fact that 60 kg ha⁻¹ NPK increased harvest indices of fonio species well above 40% suggest that effective fertiliser management strategy could enhance the productivity of the fonio species under the study environment. Arnout (2001) obtained 47% harvest index for winter wheat which were generally higher than the harvest indices (32-37%) under no fertiliser application.

3.8.5 Apparent fertiliser nitrogen recovery (AFNR)

Apparent fertiliser nitrogen recovery (AFNR) measured with the N-difference method was significantly influenced by the levels of N fertiliser. Generally, AFNR decreased with increasing fertiliser N specifically, the mean value of AFNR was 34.6% and 24.6% at 30kg ha⁻¹ and 60 kg ha⁻¹, respectively, for the three fonio landraces. This suggests that the rain-fed conditions did not produce enhanced recovery of high levels of applied fertiliser nitrogen by the fonio species. Thus fonio crops grown under rain-fed conditions could recover substantial proportion of applied nitrogen when the soil moisture is adequate throughout the growing season to enhance the uptake of applied nitrogen. Using the difference method, Garabet *et al.* (2009) estimated 49 to 66% AFNR by barley grown under rain-fed conditions in the semi-arid Mediterranean environment, suggesting that inadequate soil moisture potentially limits the recovery of fertiliser-nitrogen, particularly in the study environment characterised by poor rainfall pattern and amount. Similarly, Asare *et al.* (2009) observed a decreasing trend in AFNR of cassava genotypes with decreasing amount of rainfall. Thus, under rain

fed condition, AFNR could be adversely affected by erratic and inadequate amount of rainfall.

3.9 Relationship between NPK (15:15:15) fertiliser application, biomass accumulation and apparent fertiliser nitrogen recovery (AFNR)

A regression analysis showed a positive linear relationship between rates of fertiliser treatments and biomass accumulation, grain yield and the AFNR. Rates of NPK fertiliser application and biomass accumulation were linearly related with the coefficient of determination, r^2 , being 0.61, 0.82 and 0.78 for the landraces Yadema, Nomber and Nvoni respectively (Figures 3.8a, b and c) Thus between 61% and 82% of the variability in the data was accounted for by the regression models. Consequently, the regression model could be used to predict the rate of biomass accumulation for other fonio landraces in a related experiment.

Regression of rate of NPK fertiliser application against AFNR for each of the fonio landraces resulted in a good linear models with r^2 values ranging between 0.66 and 0.83 (Figures 3.9a b and c) Thus, AFNR correlates adequately with levels of fertiliser nitrogen. Both biomass accumulation and grain yield responded to NPK fertilization, with greater effect for Nomber than for Nvoni and Yadema suggesting a greater N deficit in the first case (Figure 3.9b).

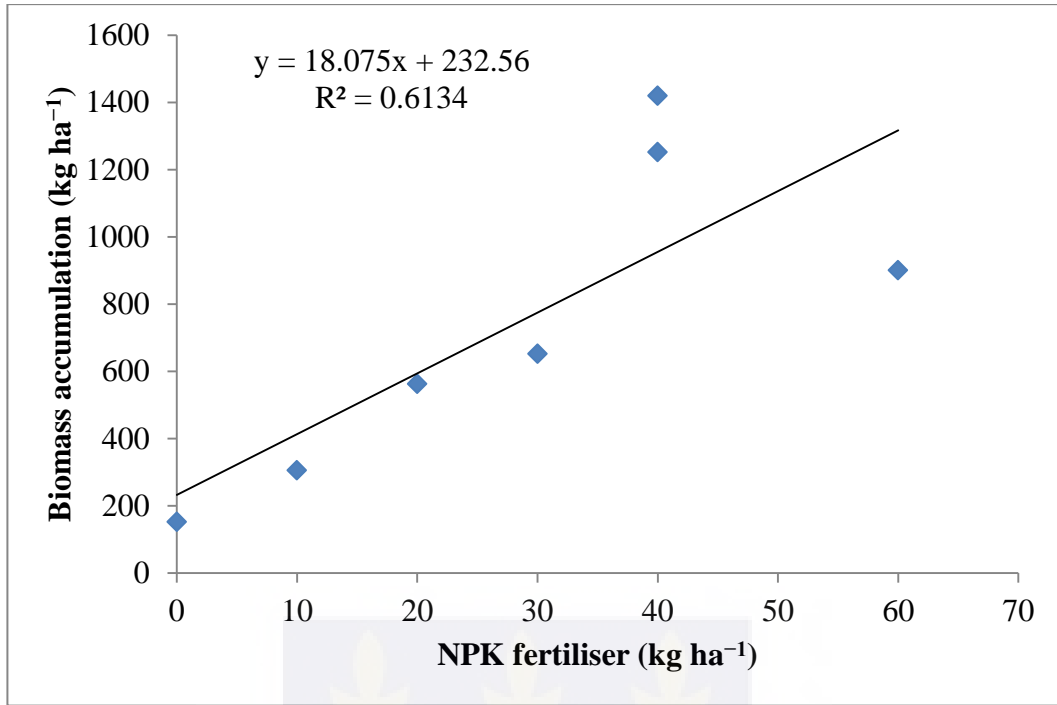


Figure 3.8a Relationship between NPK fertiliser levels and biomass accumulation for the fonio landrace Yadema.

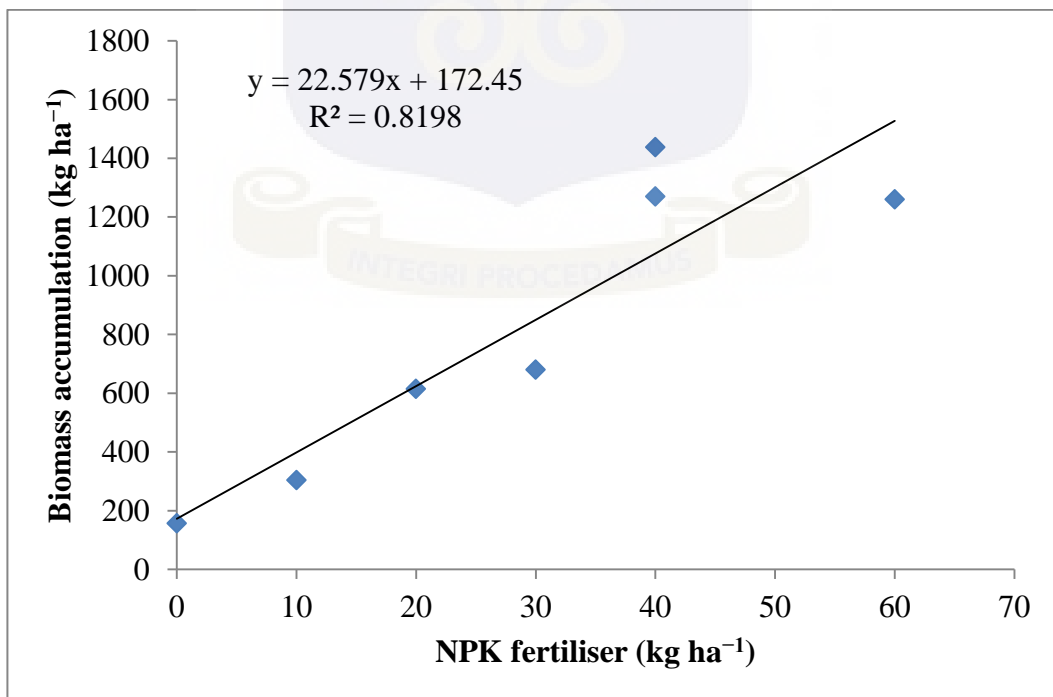


Figure 3.8b Relationship between NPK fertiliser levels and biomass accumulation for the fonio landrace Number.

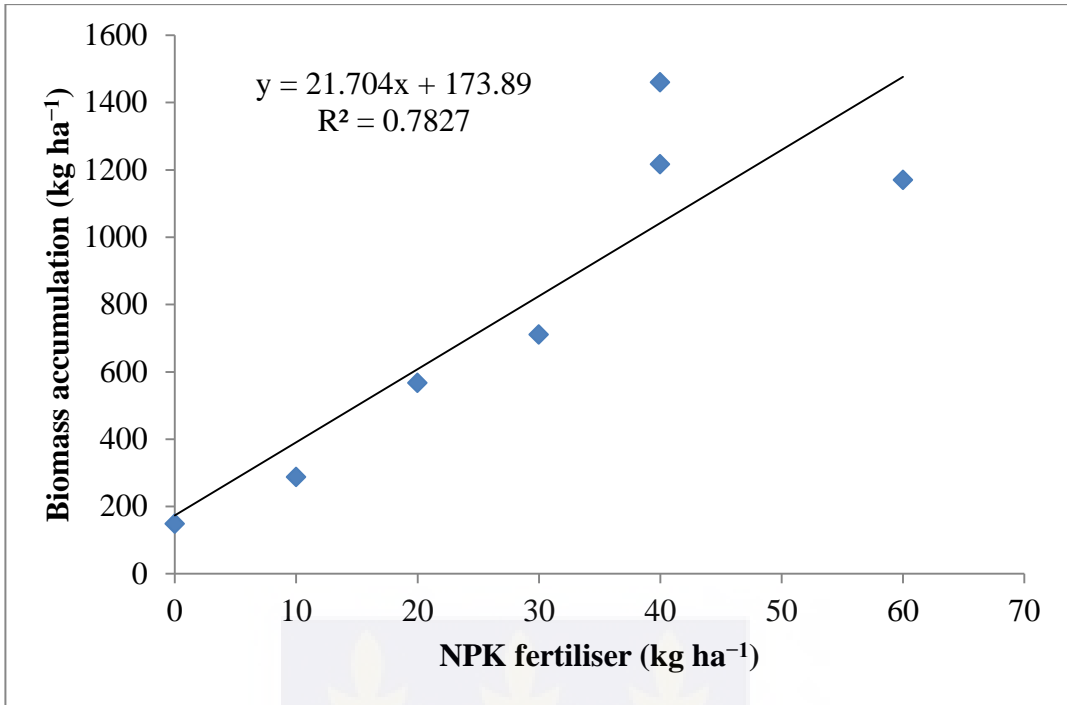


Figure 3.8c Relationship between NPK fertiliser levels and biomass accumulation for the fonio landrace Nvoni.

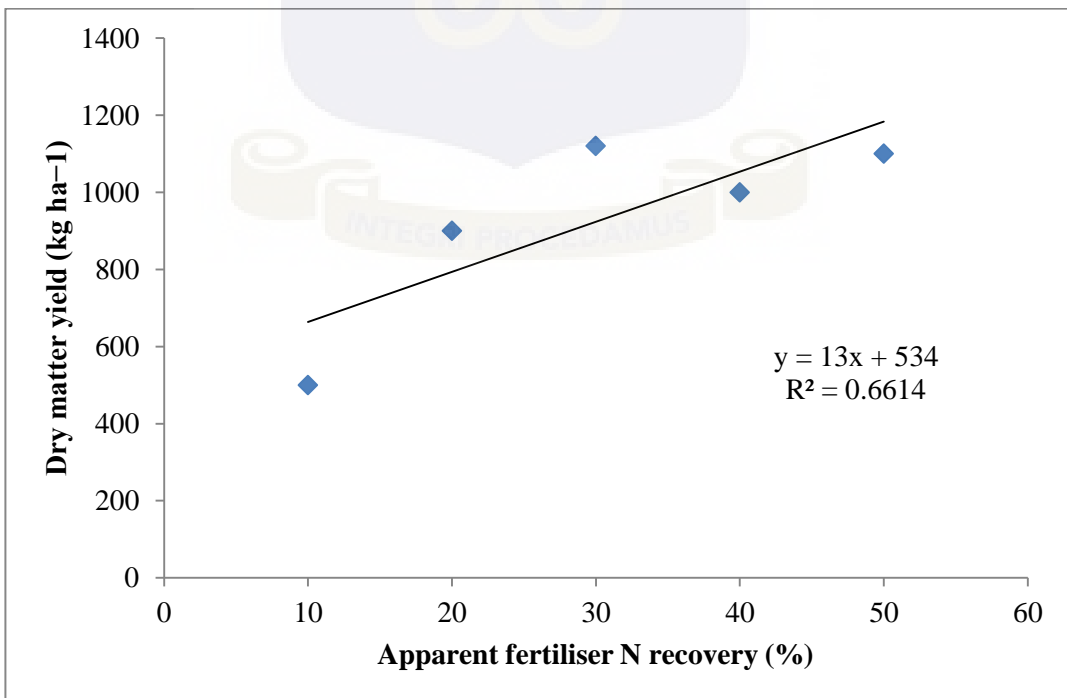


Figure 3.9a Relationship between total dry matter yield and apparent fertiliser N recovery for the fonio landrace Yadema.

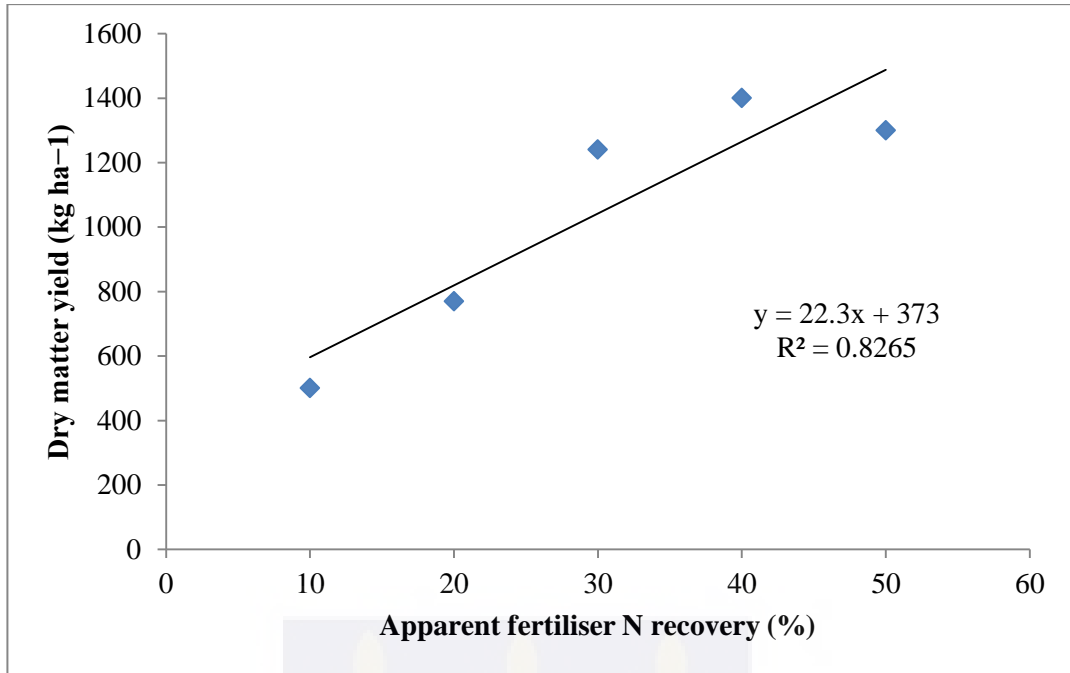


Figure 3.9b Relationship between total dry matter yield and apparent fertiliser N recovery for fonio the landrace Number.

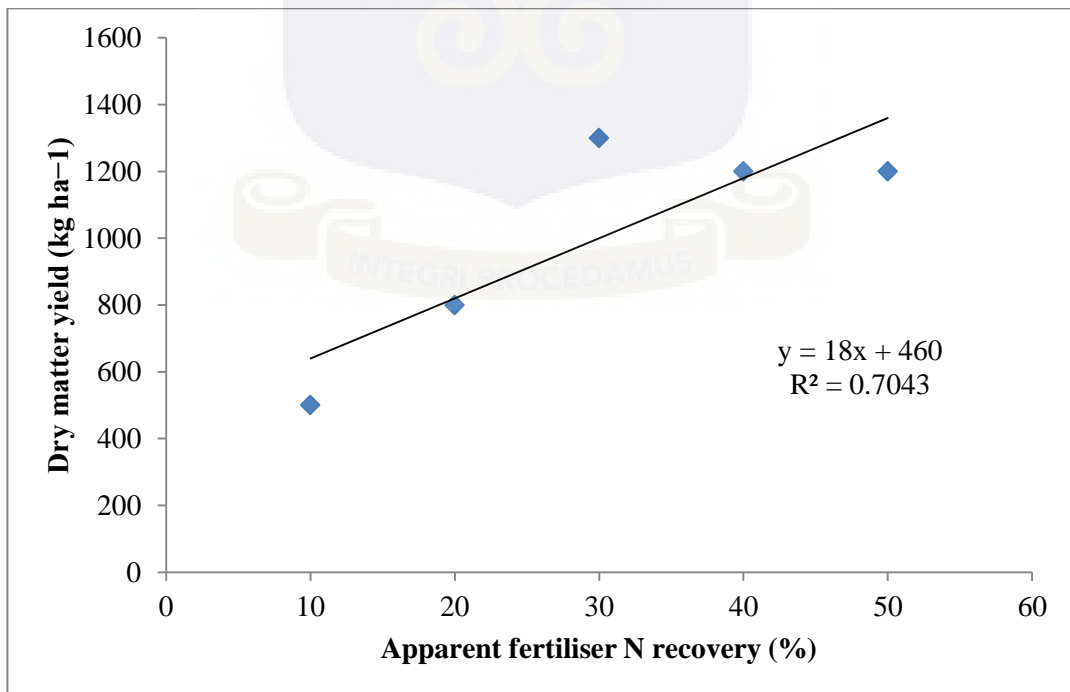


Figure 3.9c Relationship between total dry matter yield and apparent fertiliser N recovery for the fonio landrace Nvoni.

5.9 Conclusions

The study showed that fonio landraces has wide ecological adaptability as it grew successfully in a coastal agro ecological environment of Ghana. The NPK fertiliser application had a positive effect on the biomass accumulation and increased grain yield of the fonio landraces up to 60% at 30 kg ha⁻¹ of applied NPK fertiliser. Inadequate soil moisture limited the recovery of fertiliser-nitrogen applied as a result of poor and low rainfall pattern during the cropping season. Notwithstanding the poor rainfall pattern, Nvoni consistently outperformed the other two landraces in most of the growth parameters measured.



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CHAPTER FOUR

Experiment two

Multi element analysis for grains of three fonio landraces (*Digitaria exilis*)

4.1 Introduction

Fonio (*Digitaria exilis*) is the most ancient West African cereal representing an important crop in food supply chain during crop shortfalls (Adoukonou Sagbadja *et al.*, 2007). Less is known about the potential of fonio to contribute to nutrition and health in West Africa. With the increasing nutritional and health challenges related to the global food crisis, the potential contribution of traditional foods to alleviation of poverty, nutritional deficiencies and health issues is of prime concern to both governments and researchers (FAOSTAT, 2009).

For decades, food security in developing communities has been dependent on traditional food products locally produced and consumed in identifiable geographical areas (Vietnameyer *et al.*, 1996). In sub-Saharan Africa, traditional grains encompass white maize (*Zea mays*), sorghum (*Sorghum bicolor*), millets (*Pennisetum* sp), fonio (*Digitaria* sp), teff (*Eragrostis tef*) and also amaranth seeds (*Amaranthus caudatus*) (Vall *et al.*, 2011).

Fonio is the most ancient traditional cereal cultivated across West African dry savannah regions along the Sudanese zone (Cruz *et al.*, 2011). Particularly white fonio (*Digitaria exilis*) is primarily grown in Guinea, Mali, Burkina Faso, Ivory Coast, Nigeria and Benin, in marginal' mountainous and hilly zones with sandy, poor and degraded soils, without fertilizers and pesticides (Fanou-Fogny *et al.*, 2009). In 2009, about 460 685 tons of fonio were produced on 519 846 hectares in western Africa (Cruz, 2004). In Mali, Burkina Faso and Guinea semiarid and sub humid areas, fonio contributes to 17-21 % of staple cereals requirement (Val *et al.*, 2011). Due to its large ecological adaptability and the relatively short crop cycle of some varieties, fonio is believed to have a high potential as key crop in agriculture and food supply in its traditional cultivation zones,

particularly when annual harvests fail or during local crop shortfall periods (CCP/GR, 1995 ; Vietnameyer *et al.*, 1996).

In West African semiarid areas, fonio is the major part of the diet during harvest periods, and in sub-humid zones it is stored during the post-harvest period, for use as food supply during the food shortage periods (Vall *et al.*, 2011). Although accounting for only about 10% of the global aggregate cereal output, the contribution of fonio and other traditional grains to food requirement is significant in many developing countries, for they are subsistence-oriented food staples (CCP/GR, 1995). They may have high nutritional value, with some potential for combating the 'hidden hunger' caused by micronutrient deficiencies. Beside their importance to food supplies and health, traditional grains as fonio can also contribute to improved income among the most food-insecure population groups (CCP/GR, 1995).

4.1.2 Nutritional potentials and prospects of fonio

In general, fonio as a staple food is able to provide adequate energy; it has a crude protein content of 11%, a carbohydrate content of 85%, which is highly digestible and limited amounts of micronutrients (Jideani and Akingbala, 1993). Milling, which produces the white rice, most commonly consume, removes large amounts of protein, fibre, fat, iron, iodine, vitamin A and B. The medicinal properties of fonio is still under investigation whiles food nutritionist recommend fonio as Dietary Intervention in Non-Insulin Dependent Diabetes Mellitus (NIDDM) and also recommended for convalescent (Temple and Bassa, 1991). Fonio is also reported to have brewing potential as well as serve as feed for farm animals (Nzleibe and Nwasike, 1995).

4.1.3 Significance of mineral elements to human

Essential elements function as constituents of bones and teeth, as soluble salts which help to control the composition of body fluids and cells and serve as essential adjuncts to many enzymes and other functional proteins (Dashti *et al.*, 2004). They are grouped into the major (or macro) elements (sodium, magnesium, phosphorus, chloride, potassium and calcium) and the minor (or micro) elements (chromium, manganese, iron, cobalt, copper, zinc, selenium, molybdenum and iodine). In addition, there are the newer trace elements, which are possibly essential; these are lithium, boron, fluorine, silicon, vanadium, nickel, arsenic and tin (Crews, 1998). Inorganic micronutrients play an important role in various metabolic processes, and their deficiency or excess may alter the normal biochemical functions of the human body, although they constitute a small fraction of the whole diet within the human body (Akhter *et al.*, 2004).

Calcium is required for vascular contraction and vasodilation, muscle function, nerve transmission, intracellular signalling and hormonal secretion though less than 1% of total body calcium is needed to support these critical metabolic functions (National Academies Press, 2010). It is also important in blood clotting process. Calcium deficiency is associated with rickets in young children, osteoporosis and osteomalacia (softening of bones) in adults (<http://ods.od.nih.gov/factsheets/Calcium-HealthProfessional>). Fonio has been identified as one of the rich natural sources of plant calcium.

Sodium and potassium occur almost entirely in the fluids and soft tissues of the body. Sodium is found mainly in the body fluids, and potassium occurs mainly in the cells. They provide a vital function in controlling osmotic pressures and acid-base equilibrium. They also play important roles in water metabolism. Through its role in

enzyme activation, magnesium (like calcium) stimulates muscle and nerve irritability (contraction), is involved in the regulation of intracellular acid-base balance and plays an important role in carbohydrate, protein and lipid metabolism. (<http://www.fao.org/docrep/field/003/ab470e/ab470e06.htm>).

Sulphur is an essential component of several key amino acids (methionine and cystine), vitamins (thiamine and biotin) and insulin. Sulphur is believed to be involved in the detoxification of aromatic compounds within the body. Iron on the other hand is an essential component of the respiratory pigments haemoglobin and myoglobin. As a component of the respiratory pigments and enzymes concerned in tissue oxidation, iron is essential for oxygen and electron transport within the body (<http://www.fao.org/docrep/field/003/ab470e/ab470e06.htm>)

4.1.4 The instrumentation neutron activation analysis

Instrumental Neutron Activation Analysis (INAA) is an analytical technique based on the measurement of characteristic radiation from radionuclides formed directly or indirectly by neutron irradiation of the material of interest (Parthasarathy, 1998). It is a less frequently used technique in the determination of essential elements in food samples because of the necessity of accessing a nuclear reactor. Despite this, INAA possesses a number of advantages and possibilities. Among the advantages is lack of necessity of chemical destruction, appropriate accuracy and possibility of simultaneous quantification of many elements in a small amount of sample (Žukowska and Biziuk, 2008). In the last three decades, neutron activation analysis has been found to be extremely useful in the determination of trace and minor

elements in many disciplines. These include environmental analysis applications, nutritional and health related studies, geological as well as material sciences.

The technique of INAA measures the total amount of an element present in sample matrices without regard to chemical or physical form and without any pre-treatment of the sample (www.ne.ncsu.edu/nrp/naa.html#ag).

For certain elements, INAA offers sensitivities that are superior to those possible by other techniques approximately in parts per billion or lower. In addition to the elemental and isotopic analysis of samples, INAA permits the analysis of non-radioactive tracers introduced into biological, chemical, and/or industrial processes for process identification and optimisation. It is non-destructive and has very high sensitivities for most of the elements that can be determined (most detection limits span from ~0.05 to ~50 ppm) It is highly precise and accurate and permits the analysis of samples ranging in volume from 0.1 ml to 20 ml, and in mass from ~0.001 gram to 10 grams, depending on sample density. Samples for INAA can be solids, liquids, gases, mixtures and suspensions (<http://www.ne.ncsu.edu/nrp/naa.html>) making it convenient to use.

4.2 Objective of the study

The objective of the study was to assess the composition of essential mineral elements and their concentration in grains of three fonio (*Digitaria exilis*) landraces and to determine the mineral element composition, so as to select and recommend landraces with superior mineral concentration for future breeding programmes. Specific objective was to find any association between pairs of essential minerals elements found in the fonio landraces.

4.3 Material and methods

4.3.1 Methods for analysis of mineral elements

Samples from the 18 sub-plots were analysed for variability in composition of mineral elements using Instrumentation Neutron Activation Analyses (INAA). Sample analyses using the INAA were carried out at the Ghana Research Reactor 1 (GHARR-1) at the National Nuclear Research Institute, Ghana Atomic Energy Commission in Kwabenya (Accra), Ghana. The reactor uses 90.2% enriched uranium (U-235)–Aluminium alloy as fuel. It is cooled and moderated with light water while beryllium acts as reflectors (Akaho and Nyarko, 2002).

4.3.2 Preparation of samples for neutron activation

With regards to the neutron activation analysis, each of the fonio landraces was grounded into fine powder and 0.2 g of each sample was weighed, wrapped in a clean transparent polythene rubber, labelled and hot sealed. The wrapped materials were further placed in a 2/5 dram vials (1 ml capsule) and hot sealed. Each sample was then irradiated in the nuclear research reactor (GHARR-1) for 1 minute to detect short-lived radionuclides and then followed by another 2 hours irradiation to detect the medium-lived radionuclides. These were immediately followed by quantification of the samples.

4.3.3 γ -activity measurement of samples and standards

Analyses of induced radioisotopes of interest were performed on a PC- based gamma-ray spectrometer system. The spectrometer system consists of a Canberra high purity germanium (HPGe) N-type coaxial detector (model GR 2518-7500SL) with a resolution (FWHM) of 1.8 keV γ -energy line of ^{60}Co ; a relative deficiency of 25% ; and a peak-to-Compton ratio of 55 (Fig. 4.1).



Figure 4.1 A PC based gamma-ray spectroscopy system coupled to high germanium (HPGe) γ -ray detector

Samples and standards were placed on the high germanium (HPGe) γ -ray detectors and the γ -activity of the induced radioisotopes measured at the same time, position and distance from the detector. The measurement time for short-lived, medium-lived and long-lived radioisotopes depended on the activity of the induced radionuclide (Table 4.2). Samples were measured first followed by standards. A plexiglass source support was mounted on the detector in order to ensure easy and reproducible source positioning. The irradiation scheme employed prevented any serious elemental interference.

Table 4.1 Nuclear data of radionuclides used for instrumental neutron analyse of major and traced elements (Filby *et al.*, 1970).

Element	Reaction	Half life	Us γ -ray energy (Mev)
K	$^{41}\text{K}(n,\gamma)^{42}\text{K}$	12.36h	1524.7
Na	$^{23}\text{Na}(n,\gamma)^{24}\text{Na}$	15.02h	1368.6; 2754.1
Ca	$^{48}\text{Ca}(n,\gamma)^{49}\text{Ca}$	8.7 min	3084.4
Mg	$^{26}\text{Mg}(n,\gamma)^{27}\text{Mg}$	9.45 min	1014.4
Mn	$^{55}\text{Mn}(n,\gamma)^{56}\text{Mn}$	2.58h	846.7; 1810.7; 2112
Al	$^{28}\text{Al}(n,\gamma)^{29}\text{Al}$	2.246 min	1779
Cl	$^{37}\text{Cl}(n,\gamma)^{38}\text{Cl}$	37.3 min	1642.4; 2167.5
Cu	$^{63}\text{Cu}(n,\gamma)^{64}\text{Cu}$	12.70h	1.35477
I	$^{128}\text{I}(n,\gamma)^{129}\text{I}$	25 min	443
V	$^{51}\text{V}(n,\gamma)^{50}\text{V}$	3.75 min	1434

4.3.4 Evaluation of peak area of γ -spectrum

The peak area of the samples and standards were evaluated using the HPGe semiconductor detector γ -spectroscopy accumulation software, ORTEC MAESTRO-32. The areas under the peaks were integrated and converted into concentration using the relative method of standardization for neutron analysis.

4.3.5 Data analysis

The statistical design employed was the completely randomised design (CRD) and replicated three times for each species Microsoft Excel (ver. 2010) was used to collate results of the Brabender readings. Samples were evaluated for statistical significance with one-way analysis of variance (ANOVA) and means separated by the Duncan's multiple range test (Statgraphics Centurion XVI, version 16.1.11, USA, 2010) and expressed as the Mean upon three independent analyses. A p-value of 0.05 or less was considered as statistically significant.

4.4 Results

4.4.1 Elements detected

In all, ten elements were detected in varying concentrations using the INAA. The elements were calcium (Ca), potassium (K), sodium (Na), magnesium (Mg), copper (Cu), aluminium (Al), chlorine (Cl), iodine (I), manganese (Mn) and vanadium (V).

4.4.2 Concentrations of ten essential elements in the fonio (*Digitaria exilis*)

Concentrations of five (5) essential macroelements (Na, Mg, Ca, K and Cl), four microelements (Al, Mn, I and Cu) and one trace element (V) detected by the INAA in the three fonio landraces are shown in Table 4.2. Yadema (grown at 30 kg ha⁻¹ NPK) had the highest content (56.03±3.9 mg kg⁻¹) of Ca while Nvoni (grown at 60 kg ha⁻¹ NPK) had the lowest (23.60±5.4 mg kg⁻¹) Ca concentration. Similarly, the fonio landrace Yadema (grown at 30 kg ha⁻¹ NPK) had 48.39±5.4 mg kg⁻¹ of K with Number (grown at 0 kg ha⁻¹ NPK) having the lowest concentration (22.21±4.4 mg kg⁻¹) of K. Also, Yadema (grown at 60 kg ha⁻¹ NPK) had the highest concentration

(219.32±8.3 mg kg⁻¹) of Na. The fonio landrace Nvoni (grown at 60 kg ha⁻¹ NPK), however, had the lowest Na concentration of 77.83±9.5 mg kg⁻¹. Sodium concentration for all the fonio landraces was high compared to concentrations of all the other macro elements (Table 4.2). However, the concentration of I, an essential microelement, was very low in all the fonio landraces (Table 4.2).

Additionally, measured concentrations of Mg, Al, Cu, Cl and V varied considerably among all the three fonio landraces. Specifically, Yadema (grown at 0 kg ha⁻¹ NPK) had the highest concentration (40.90±2.3 mg kg⁻¹) of Mg while Number (grown at 60 kg ha⁻¹ NPK) had the lowest concentration (16.21±6.3 mg kg⁻¹) of Mg. The concentration of Mg is low in the three fonio landraces compared to RDI of 320-420 mg kg⁻¹. Number (grown at 0 kg ha⁻¹ NPK) also had the highest Cl concentration (89.91±3.1 mg kg⁻¹) while the lowest Cl concentration of 11.14±3.0 mg kg⁻¹ was in Yadema (grown at 60 kg ha⁻¹ NPK). Nvoni had the highest (83.52±3.3 mg kg⁻¹) and lowest concentration (23.18±2.5 mg kg⁻¹) of Al when grown at 30 kg ha⁻¹ and 60 kg ha⁻¹, respectively. Similarly, Yadema (grown at 60 kg ha⁻¹ NPK) had the highest Mn concentration (47.57±4.3 mg kg⁻¹), while Nvoni (grown at 30 kg ha⁻¹ NPK) had the lowest Mn concentration (10.28±5.1 mg kg⁻¹). Trace mineral elements Cu and V were all present in low concentrations in all the three fonio landraces compared to their respective RDI (Table 4.2). Finally, no single fonio landrace had the highest concentration of all the mineral elements detected (Table 4.2).

Table 4.2 Concentration (mg kg⁻¹) of ten mineral elements in the fonio landraces grown with and without NPK fertiliser.

Fonio landraces	Macro elements			Micro elements						
	Ca	K	Na	Mg	Cl	Al	Mn	I	Cu	V
Yadema										
0 kg NPK	27.31±4.8	22.74±4.4	99.77±1.5	40.90±2.3*	78.11±3.3	40.90±2.3	24.42±4.3	0.07±0.02	2.80±0.6	0.52±0.1
30 kg NPK	56.03±3.9*	48.39±5.4*	200.30±8.3	29.97±4.5	12.14±3.1	43.28±1.3	40.57±4.2	0.25±0.08	2.20±0.8	0.35±0.2
60 kg NPK	51.03±3.9	48.39±5.4	219.32±8.3*	29.97±4.5	11.14±3.0	46.28±2.1	47.57±4.3*	0.25±0.07	2.43±0.5	0.35±0.1
Number										
0 kg NPK	27.25±4.8	22.21±4.4	131.10±8.9	17.78±5.6	89.91±3.1*	31.91±2.0	20.33±4.9	0.21±0.08	16.68±4.0*	0.32±0.2
30 kg NPK	31.07±4.6	26.75±3.5	106.70±2.5	18.05±5.9	62.84±3.7	48.01±2.3	23.02±4.8	0.23±0.07	3.03±2.8	0.46±0.1
60 kg NPK	36.73±4.0	30.78±29.3	211.80±5.9	16.21±6.3	89.20±3.0	116.70±2.2	37.15±3.5	0.27±0.01*	9.61±0.2	1.83±0.1
Nvoni										
0 kg NPK	32.56±4.2	34.28±2.2	111.81±9.3	20.02±4.6	60.45±3.4	33.22±2.3	20.42±4.6	0.18±0.05	3.51±2.8	0.32±0.1
30 kg NPK	27.61±2.0	28.58±4.7	199.30±5.1	29.84±2.5	87.16±3.1	83.52±3.3*	10.28±5.1	0.19±0.02	0.88±0.2	1.84±0.6*
60 kg NPK	23.60±5.4	34.65±2.7	77.83±9.5	19.75±5.2	66.41±3.3	23.18±2.5	17.9±5.8	0.17±0.03	3.87±3.0	0.24±0.1
Mean	34.80	34.97	150.88	24.72	61.93	51.88	26.85	0.20	5.10	0.69
CV%	0.32	0.30	0.37	0.34	0.49	0.57	0.45	0.30	1.00	0.94
RDI	500-1200	2000	1400-2500	320-420	100-500	100-150	75-100	150-1000	75-100	1.0-10.0

Bolded values with asterisks are the highest concentration for a particular element,
 Bolded values with no asterisks are the lowest concentration for a particular element;
 CV = coefficient of variation;
 RDI = recommended daily intake; source: Dietary Reference [18]
 NPK = NPK fertiliser 15:15:15

4.4.3 Association of pairs of essential mineral elements

Table 4.3 shows the association between pairs of elements in the fonio landraces. Calcium showed strong association with Mn and moderate association with I, Na and Mg. Potassium showed strong positive association with Mg and negative association with I, Na, V and Cu. Sodium exhibited strong association with Al, I and Mn and has moderate to weak association with V, Mg, Cl, and Cu (Table 4.3). Magnesium shows completely negative correlation with all the other nine elements detected in the fonio landraces except for Mn and V.

Chlorine correlated moderately with Al, Cu and V but negatively correlated with Mn and I. Aluminium registered a moderate positive association with V, Mn and I but weakly correlated with Cu. Manganese gave a moderate positive association with I and negatively correlated with Cu and V. Both I and Cu showed negative association with V and has no association with other seven elements while vanadium registered no correlation with any of the nine elements detected in the landraces.

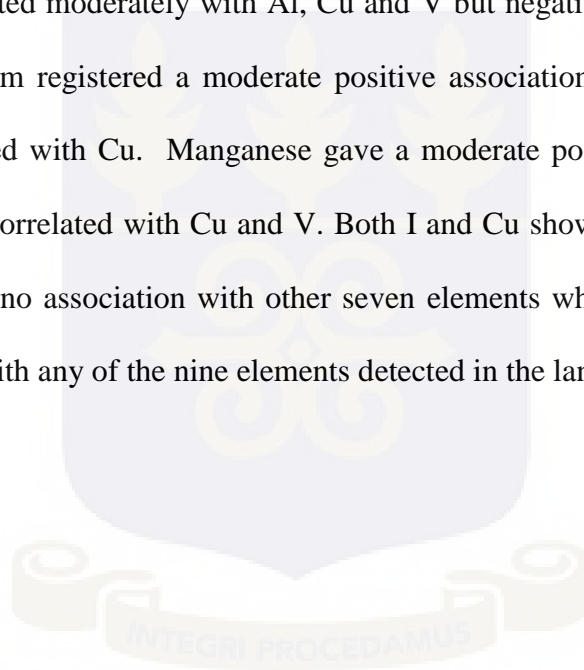


Table 4.3 Pair comparison of elements detected in the fonio landraces based on the Neutron Activation

	Ca	K	Na	Mg	Cl	Al	Mn	I	Cu	V
Ca										
K	-0.10145									
Na	0.378395	-0.33655								
Mg	0.045555	0.734001	0.154331							
Cl	-0.80233	0.187008	-0.39613	-0.2859						
Al	-0.1471	-0.14554	0.629025	-0.11758	0.317627					
Mn	0.922343	-0.0488	0.603398	0.10787	-0.66781	0.211654				
I	0.488846	-0.85432	0.606709	-0.46078	-0.53591	0.175616	0.468459			
Cu	-0.04492	-0.0924	-0.32147	-0.33992	0.278559	-0.44937	-0.20796	-0.0029		
V	-0.70795	-0.12918	0.31918	0.216012	0.32929	0.444758	-0.52892	-0.0313	-0.307	

Bolded values with no asterisks are highly and positively correlated. Bolded values with asterisks are highly and negatively correlated.

4.5.0 Discussion

4.5.1 Assessment of essential mineral elements in fonio

Assessment of ten mineral elements composition present in the fonio species further clarified genetic diversity among the species. The species show greater potential to be utilized as food and other dietary formulations based on nutritional relevance presence. Although none of the species recorded essential mineral concentration higher than the recommended daily intake (FAO/WHO, 2002), they contain appreciable concentration. Yadema (grown at 30 kg ha⁻¹ NPK) has a Ca concentration of 56 mg kg⁻¹ 100g of grain, a concentration that is more than double concentration of 30 mg kg⁻¹ recorded by Irving and Jideani (1997). However, this calcium content is lower with reference to the highest value of 12.4 mg kg⁻¹ recorded by Jideani and Akingbala (1993) for fonio.

According to Waheed *et al.* (2002), essential mineral elements in foodstuffs of one region may vary from the other since food supplies are affected by various agricultural practices, type of soil, fertiliser and chemicals used. Yadema species (30 kg ha⁻¹ NPK) contained K concentration of 54.9 mg kg⁻¹ which is lower than the value of 260 mg kg⁻¹ reported by Cruz (2004). Variations in the mineral concentrations established in this study and that by other authors may be due genetic factors and differences in environmental conditions. Nvoni (0 kg ha⁻¹ NPK) has a very high concentration of 89.91 mg kg⁻¹ of Cl far higher in excess of 10 mg / kg to that recorded by Irving and Jideani (1997). Albeit the experimental site is ochrosol (Ferric Acrisol) (FAO UNESCO, 1994), there was no iron present in the samples. The Instrumentation Neutron Activation Analysis (INAA) also detected V a relatively rare mineral element

in cereals. Furthermore, all the fonio landraces had moderate amounts of Mg compared to the recommended daily allowance of 19.5 g contained in one cup (160-195 g) of white fonio (<http://nutritiondata.self.com/facts/cereal-grains-and-pasta/5707/2>). In the case of Al, all the landraces has high concentrations from 83 mg to 23 mg kg⁻¹ compared to the recommended daily intake of the element contained in one cup of cooked fonio Temple and Bassa (1991). Aluminium concentration in all the landraces were comparatively higher than clover (23.6 mg kg⁻¹), oats (7.3 mg kg⁻¹) bean (5.1 mg kg⁻¹), corn (11.90 mg kg⁻¹), red lentil (3.7 mg kg⁻¹) and rice (8.4 mg kg⁻¹) as reported by Hicsonmez *et al.* (2012). The significant variable concentrations of Al in the landraces may partly be explained by the genetics of the individual fonio species and the influence of the soil at the experimental field.

Concentrations of the rest of the micro elements (Cu, Mn, I and Cl) detected were considerably low. Quartey (2010) and Adotey *et al.* (2009) reported seemingly low values for these elements in tomato, in agreement with concentrations of these elements in this study. Children, women of reproductive age and pregnant women are most vulnerable to micro nutrient deficiency and anaemia (Ghana Demographic Health Survey, 2004); hence, diets for this group of persons ought to be rich in micro nutrients. Fonio could serve as source of Al, Mn and other essential micro nutrients in the diets of children and pregnant women in Ghana.

4.5.2 Degree of association between pair of mineral elements

Analyses of association between pairs of the elements contained in the fonio species revealed 80% very weak or even negative correlations between pairs. There were, however, good correlations among some of the elements. Calcium and Mn showed a strong positive correlation of $r = 0.922$, and also K and Mg similarly gave a value of $r = 0.734$. This suggests that it may be possible for the breeder to simultaneously select for higher concentrations of these pairs of elements in a breeding programme. Calcium and K are present in Yadema (grown at 30 kg ha^{-1} NPK) in concentrations higher than in the other two landraces, making this species a good candidate for biofortification in breeding. Also, Na and Mn are two elements that were highly concentrated in Yadema (grown at 60 kg ha^{-1} NPK), a correlation that makes the fonio specie suitable for use in nutritional intervention against malnutrition.

Interestingly the study did not identify the presence of both Fe and Zn, two elements considered vital in alleviating micro-nutrient malnutrition (Welch, 2008; Kennedy *et al.*, 2006). However, two important traced minerals, I and V has been detected in all the landraces analysed. Number (grown at 0 kg ha^{-1} NPK) contained the highest amount of Cl ($89.91 \pm 3.1 \text{ mg kg}^{-1}$). Two landraces, Number (grown at 0 kg ha^{-1} NPK) and Yadema (grown at 30 kg ha^{-1} NPK) exhibited great potential in mineral concentration and may therefore be utilized in a hybridisation programme towards developing new micronutrient-rich lines of new cultivars of fonio.

Quite recently, improvements in fonio breeding have focused primarily on increasing the size of the tiny seed (Kuta *et al.*, 2003). However, the importance of the quality of the food source for reducing micronutrient deficiencies has now come to the forefront.

There is greater recognition of the global prevalence of many forms of micro-nutrient malnutrition, such as I, Z and vitamin A deficiency (Kennedy *et al.*, 2006). Currently, improvement in fonio requires variety of approaches including improving biofortification techniques, and increasing micronutrient content of the grain through genetic modification. However, enhancing nutritional quality through hybridisation has remain a barrier to be crossed by fonio breeders.

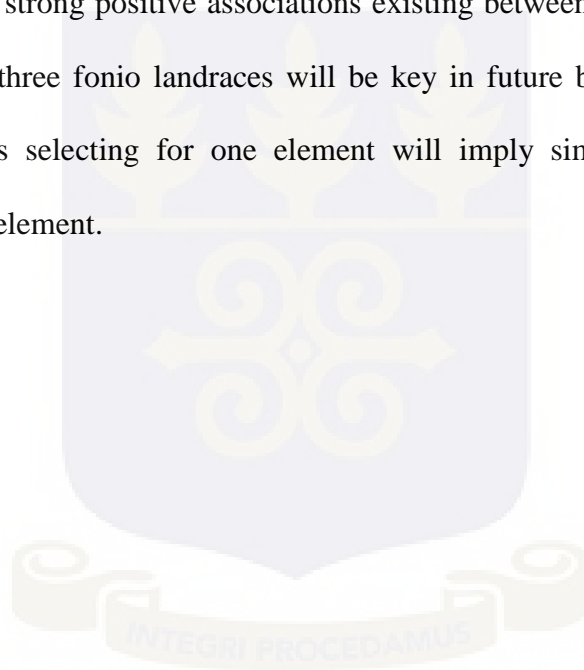
4.5.3 New trace element

The INAA detected the presence of vanadium (V) a trace element with atomic number 23 discovered in the past few decades, in all the fonio species. The concentration is however in trace and varying concentration in the three landraces. Nvoni (grown at 30 kg ha⁻¹ NPK) obtained the highest V concentration of 18.19±6.0 mg kg⁻¹, higher than the controls and all other NPK fertiliser treatments.

No report has so far been published on the presence and detection of V in fonio. The detection of this essential mineral element in the fonio species used in the study indicates the accuracy and efficiency of INAA method used for multi element analysis. The RDI for vanadium is 5–30 mg (<http://www.acu-cell.com/vmo.html>). Assimilation of vanadium inhibits cholesterol from forming in the blood vessels (Takida, 2003). But more importantly, vanadium is a precursor for insulin-like effects that may help in the management of Type 1 and Type 2 diabetes (<http://healthyeating.sfgate.com/vanadium-nutrition-8686.html>).

4.6 Conclusions

The INAA detected ten (10) mineral elements in the fonio landraces with varying concentration levels, indicating genetic variability and the influence of fertiliser treatments on the fonio landraces. The study further established Yadema as the fonio landrace with the highest concentration of five mineral elements (Ca, K, Na, Mg and Mn). The ten (10) mineral elements detected in the landraces with varying mineral concentration suggest fonio as a healthy food and a crop for the future. However, the absence of zinc and iron poses a new challenge which must be investigated. Notwithstanding, the strong positive associations existing between most pairs of elements contained in the three fonio landraces will be key in future breeding programme for biofortification as selecting for one element will imply simultaneous inclusion of another essential element.



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CHAPTER FIVE

5.0 General conclusion and recommendations

5.1 Conclusions

This study has confirmed the adaptability of fonio, an indigenous but neglected cereal crop, to a coastal agro-ecological zone of Ghana. Fonio is a potential crop for the future which requires little input in the cultivation and has a relatively short growth cycle of 90-100 DAE. Increased harvest indices of fonio species well above 40% suggest that effective fertiliser management strategy coupled with adequate soil moisture could enhance the productivity of the fonio crop under varying environment. The fonio landrace Nvoni consistently outperformed the other two landraces in most of the growth parameters measured.

Fonio has an outstanding nutritional composition with a crude protein of 13.0% in the Nomer landrace. Instrumentation neutron activation analyses detected ten essential mineral elements including vanadium, which are worthy of scientific attention. In view of its importance in fighting hunger in Africa, among the poor resourced farmers and its exceptionally high nutritional quality, it is hoped that more attention will be given in promoting the fonio crop through research and development so as to enhance the nutritional status of all, especially vulnerable women and children.

5.2 Recommendations

Owing to the potential and nutritional qualities of fonio in averting hunger and malnutrition, MoFA and Ghana Grain Development Board (GGDB) should liaise with researchers to improve the crop and introduce it to farmers and the market alike. For further studies in order to promote fonio production and ensure its conservation, a comprehensive and a participatory breeding program is recommended.

1. to update the crop germplasm collections to all its production zone (Benin, Cote d'Ivoire, Ghana, Niger, The Gambia, Mauritania, Chad), and complete the agro-morphological and genetic characterization of all the existing accessions.
2. Develop a participatory variety selection using both farmers and research selection criteria and suggest possible improvement to farmers' seed-conservation methods
3. To promote the adoption of improved threshing and husking methods that can improve the quality of the final product and make the crop more attractive to consumers and develop a market access policy that will get urban population aware of the properties of fonio.
4. Variations in the elemental and proximate analyses of fonio by various authors should be investigated by a joint research team drawn from all the producing areas within the West African sub-Region and
5. Future proximate and elemental analysis of fonio should be partitioned based on the grain, leaves and culm and the result compared to other cereals to consolidate the potentials of fonio as food for man and also feed for farm animals.

APPENDIX

Appendix 1: Analyses of variance on plant height at week 14.

Source of variation	d.f.	s.s.	m.s.	v.r.	P- value
Replication stratum	2	0.02325	0.01163	1.00	
Replication.Variety					
Variety	2	0.02081	0.01040	0.89	0.478 ^{ns}
Residual	4	0.04664	0.01166	1.03	
Replication.Variety.Rates					
Rates	2	0.01301	0.00650	0.57	0.578 ^{ns}
Variety.Rates	4	0.04401	0.01100	0.97	0.459 ^{ns}
Residual	12	0.13598	0.01133		
Total	26	0.28370			
ns = not significant				cv = 45%	

Appendix 2: Analyses of variance on plant height at week 28.

Source of variation	d.f.	s.s.	m.s.	v.r.	P-value
Replication stratum	2	0.0000222	0.0000111	0.08	
Replication.Variety s					
Variety	2	0.0000000	0.0000000	0.00	1.000 ^{ns}
Residual	4	0.0005778	0.0001444	1.44	
Replication.Variety.Rates					
Rates	2	0.1086000	0.0543000	543.00	<.001**
Variety.Rates	4	0.0000000	0.0000000	0.00	1.000 ^{ns}
Residual	12	0.0012000	0.0001000		
Total	26	0.1104000			
ns = not significant			**= highly significant	cv = 3.5%	

Appendix 3: Analyses of variance on plant height at week 42.

Source of variation	d.f.	s.s.	m.s.	v.r.	P-value
Replication stratum	2	0.0000889	0.0000444	0.35	
Replication.Variety					
Variety	2	0.0000667	0.0000333	0.26	0.783 ^{ns}
Residual	4	0.0005111	0.0001278	1.28	
Replication.Variety.Rates					
Rates	2	0.0658667	0.0329333	329.33	<.001**
Variety.Rates	4	0.0001333	0.0000333	0.33	0.850 ^{ns}
Residual	12	0.0012000	0.0001000		
Total	26	0.0678667			
ns = not significant	**= highly significant			cv = 2.2%	

Appendix 4: Analyses of variance on plant height at week 56.

Source of variation	d.f.	s.s.	m.s.	v.r.	P-value
Replication stratum	2	0.00038519	0.00019259	9.45	
Replication.Variety					
Variety	2	0.00005185	0.00002593	1.27	0.373 ^{ns}
Residual	4	0.00008148	0.00002037	0.26	
Replication.Variety.*Units*					
Rates	2	0.07302963	0.03651481	469.48	<.001**
Variety.Rates	4	0.00010370	0.00002593	0.33	0.850 ^{ns}
Residual	12	0.00093333	0.00007778		
Total	26	0.07458519			
ns = not significant	**= highly significant			cv = 1.3%	

Appendix 5: Analyses of variance on plant height at week 70.

Source of variation	d.f.	s.s.	m.s.	v.r.	P-value
Replication stratum	2	0.0004222	0.0002111	4.75	
Replication.Variety					
Variety	2	0.0000000	0.0000000	0.00	1.000 ^{ns}
Residual	4	0.0001778	0.0000444	0.44	
Replication.Variety.Rates					
Rates	2	0.0474000	0.0237000	237.00	<.001**
Variety.Rates	4	0.0000000	0.0000000	0.00	1.000 ^{ns}
Residual	12	0.0012000	0.0001000		
Total	26	0.0492000			
ns = not significant	**= highly significant			cv = 1.3%	

Appendix 6: Analyses of variance on plant height at week 84.

Source of variation	d.f.	s.s.	m.s.	v.r.	P-value
Replication stratum	2	0.0004222	0.0002111	4.75	
Replication.Variety					
Variety	2	0.0000000	0.0000000	0.00	1.000 ^{ns}
Residual	4	0.0001778	0.0000444	0.44	
Replication.Variety.Rates					
Rates	2	0.0474000	0.0237000	237.00	<.001**
Variety.Rates	4	0.0000000	0.0000000	0.00	1.000 ^{ns}
Residual	12	0.0012000	0.0001000		
Total	26	0.0492000			
ns = not significant	**= highly significant			cv = 1.4%	

Appendix 7: Analysis of Variance on biomass accumulation at week 14 (kg ha⁻¹)

Source of variation	d.f.	s.s.	m.s.	v.r.	P-value
Replication stratum	2	227.56	113.78	2.13	
Replication.Variety					
Variety	2	1169.56	584.78	10.95	0.024 ^{ns}
Residual	4	213.56	53.39	1.25	
Replication.Variety.Rates					
Rates	2	51254.00	25627.00	600.37	<.001**
Variety.Rates	4	187.78	46.94	1.10	0.401 ^{ns}
Residual	12	512.22	42.69		
Total	26	53564.67			

ns = not significant **= highly significant cv = 4.3%

Appendix 8: Analysis of Variance on biomass accumulation at week 28 (kg ha⁻¹)

Source of variation	d.f.	s.s.	m.s.	v.r.	P- value
Replication stratum	2	313.41	156.70	1.74	
Replication.Variety					
Variety	2	3144.96	1572.48	17.42	0.011 ^{ns}
Residual	4	361.04	90.26	1.41	
Replication.Variety.Rates					
Rates	2	167689.41	83844.70	1310.83	<.001**
Variety.Rates	4	1036.37	259.09	4.05	0.026 ^{ns}
Residual	12	767.56	63.96		
Total	26	173312.74			

ns = not significant **= highly significant cv = 2.7%

Appendix 9: Analysis of Variance on biomass accumulation at week 42 (kg ha⁻¹)

Source of variation	d.f.	s.s.	m.s.	v.r.	P- value
Replication stratum	2	382.30	191.15	3.25	
Replication.Variety					
Variety	2	10325.85	5162.93	87.78	<.001**
Residual	4	235.26	58.81	2.15	
Replication.Variety.Rates					
Rates	2	465525.63	232762.81	8521.49	<.001**
Variety.Rates	4	941.93	235.48	8.62	0.002**
Residual	12	327.78	27.31		
Total	26	477738.74			

**= highly significant

cv = 1.0%

Appendix 10: Analysis of Variance on biomass accumulation at week 56 (kg ha⁻¹)

Source of variation	d.f.	s.s.	m.s.	v.r.	P-value
Replication stratum	2	192.89	96.44	10.09	
Replication.Variety					
Variety	2	21262.89	10631.44	1112.59	<.001**
Residual	4	38.22	9.56	0.74	
Replication.Variety.Rates					
Rates	2	347246.22	173623.11	13451.43	<.001**
Variety.Rates	4	1439.56	359.89	27.88	<.001**
Residual	12	154.89	12.91		
Total	26	370334.67			

**= highly significant

cv = 0.5%

Appendix 11: Analysis of Variance on biomass accumulation at week 70 (kg ha⁻¹)

Source of variation	d.f.	s.s.	m.s.	v.r.	P- value
Replication stratum	2	3852353.	1926176.	1.01	
Replication.Variety					
Variety	2	3336088.	1668044.	0.87	0.485 ^{ns}
Residual	4	7650171.	1912543.	1.00	
Replication.Variety.Rates					
Rates	2	996116.	498058.	0.26	0.776 ^{ns}
Variety.Rates	4	7091858.	1772964.	0.92	0.482 ^{ns}
Residual	12	23019367.	1918281.		
Total	26	45945953.			
ns = not significant				cv = 97.7%	

Appendix 12: Analysis of Variance on biomass accumulation at week 84 (kg ha⁻¹)

Source of variation	d.f.	s.s.	m.s.	v.r.	P- value
Replication stratum	2	3914.9	1957.4	6.81	
Replication.Variety					
Variety	2	3974.9	1987.4	6.92	0.050*
Residual	4	1149.6	287.4	1.19	
Replication.Variety.Rates					
Rates	2	644918.2	322459.1	1330.54	<.001**
Variety.Rates	4	3760.9	940.2	3.88	0.030*
Residual	12	2908.2	242.4		
Total	26	660626.7			

*= significant

** = highly significant

cv = 1.1

Appendix 13: Analysis of Variance on biomass accumulation at week 98 (kg ha⁻¹)

Source of variation	d.f.	s.s.	m.s.	v.r.	P- value
Replication stratum	2	2144.7	1072.3	2.65	
Replication.Variety					
Variety	2	22464.9	11232.4	27.81	0.005*
Residual	4	1615.8	403.9	1.80	
Replication.Variety.Rates					
Rates	2	449243.6	224621.8	1002.94	<.001**
Variety.Rates	4	2346.2	586.6	2.62	0.088 ^{ns}
Residual	12	2687.6	224.0		
Total	26	480502.7			
ns = not significant * = significant ** = highly significant cv = 2.6%					

Appendix 14: Analyses of Variance on Tiller numbers (m²)

Source of variation	d.f.	s.s.	m.s.	v.r.	P- value
Replication stratum	2	2428.1	1214.0	1.02	
Replication.Variety					
Variety	2	27201.9	13600.9	11.40	0.022 ^{ns}
Residual	4	4772.6	1193.1	1.91	
Replication.Variety.Rates					
Rates	2	439585.4	219792.7	351.08	<.001**
Variety.Rates	4	629.9	157.5	0.25	0.903 ^{ns}
Residual	12	7512.7	626.1		
Total	26	482130.5			
ns = not significant ** = highly significant cv = 4.3%					

Appendix 15: Analyses of Variance on Effective Tiller numbers (m²)

Source of variation	d.f.	s.s.	m.s.	v.r.	P- value
Replication stratum	2	19.9	9.9	0.04	
Replication.Variety					
Variety	2	11017.2	5508.6	21.50	0.007 ^{ns}
Residual	4	1025.0	256.3	1.25	
Replication.Variety.Rates					
Rates	2	112948.1	56474.0	274.47	<.001**
Variety.Rates	4	213.5	53.4	0.26	0.898 ^{ns}
Residual	12	2469.1	205.8		
Total	26	127692.7			
ns = not significant	**= highly significant			cv = 4.0%	

Appendix 16: Analyses of Variance on grain yield (kg ha⁻¹)

Source of variation	d.f.	s.s.	m.s.	v.r.	P-value
Replication stratum	2	114.0	57.0	0.47	
Replication.Variety					
Variety	2	26233.6	13116.8	108.60	<.001**
Residual	4	483.1	120.8	0.54	
Replication.Variety.Rates					
Rates	2	647438.2	323719.1	1447.57	<.001**
Variety.Rates	4	1957.6	489.4	2.19	0.132 ^{ns}
Residual	12	2683.6	223.6		
Total	26	678910.0			
ns = not significant	**= highly significant			cv = 1.9%	

Appendix 16: Analyses of Variance on straw weight (kg ha⁻¹)

Source of variation	d.f.	s.s.	m.s.	v.r.	P- value
Replication stratum	2	2340.	1170.	0.70	
Replication.Variety					
Variety	2	3825.	1912.	1.15	0.403 ^{ns}
Residual	4	6655.	1664.	0.75	
Replication.Variety.Rates					
Rates	2	275308.	137654.	62.08	<.001**
Variety.Rates	4	10454.	2613.	1.18	0.369 ^{ns}
Residual	12	26609.	2217.		
Total	26	325191.			
ns = not significant		**= highly significant		cv = 14.9%	

Appendix 17: Regression Analysis between NPK fertiliser application and biomass accumulation for Yadema landrace.

Source	d.f.	s.s.	m.s.	v.r.	P- value
Regression	1	1526.7	1526.7	7.96	0.037 ^{ns}
Residual	5	959.0	191.8		
Total	6	2485.7	414.3		
ns = not significant					

Appendix 18: Regression Analysis between NPK fertiliser application and biomass accumulation for Nember landrace.

Source	d.f.	s.s.	m.s.	v.r.	P-value
Regression	1	2089.9	2089.85	26.40	0.004*
Residual	5	395.9	79.17		
Total	6	2485.7	414.29		

*= significant

Appendix 19: Regression Analysis between NPK fertiliser application and biomass accumulation for Nember landrace.

Source	d.f.	s.s.	m.s.	v.r.	P-value
Regression	1	1945.6	1945.6	18.01	0.008 ^{ns}
Residual	5	540.1	108.0		
Total	6	2485.7	414.3		

ns = not significant

Appendix 20: Regression Analysis between apparent fertiliser N recovery and Total Dry Matter Yield for Yadema landrace.

Source	d.f.	s.s.	m.s.	v.r.	P-value
Regression	1	767.0	766.96	9.87	0.052 ^{ns}
Residual	3	233.0	77.68		
Total	4	1000.0	250.00		

Ns = not significant

Appendix 21: Regression Analysis between apparent fertiliser N recovery and Total Dry Matter Yield for Nomber landrace.

Source	d.f.	s.s.	m.s.	v.r.	P-value
Regression	1	847.9	847.95	16.73	0.026 ^{ns}
Residual	3	152.1	50.68		
Total	4	1000.0	250.00		

ns = not significant

Appendix 22: Regression Analysis between apparent fertiliser N recovery and Total Dry Matter Yield for Nvoni landrace.

Source	d.f.	s.s.	m.s.	v.r.	P-value
Regression	1	704.3	704.35	7.15	0.075 ^{ns}
Residual	3	295.7	98.55		
Total	4	1000.0	250.00		

ns = not significant