RESPONSE OF YAM (*Dioscorea* spp.) ACCESSIONS TO DROUGHT AND ARBUSCULAR MYCORRHIZAL FUNGI

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ABSTRACT

Moisture deficit limits yam production. Availability of drought tolerant yam will improve yield and expand area of production. Soil inoculation with Arbuscular Mycorrhizae Fungi (AMF) improves tolerance of plants to drought. However, there is limited information on the response of yam to drought and AMF inoculum. This study was conducted to identify drought tolerant yam accessions and determine the effects of AMF.

Two glasshouse and one field experiments were conducted, each in a randomized complete block design with three blocks. In the first glasshouse experiment, 32 accessions of *Dioscorea alata* and 49 of *D. rotundata* obtained from the International Institute of Tropical Agriculture, Ibadan were screened for drought tolerance. Pre-sprouted setts were planted in pots containing 5 kg soil, watered to Field Capacity (FC), wrapped with transparent polyethylene sheets and observed for 90 days. Twelve accessions of each species selected on the basis of their superior performance were further evaluated at three moisture levels: 75% FC at 11 Weeks After Planting (WAP) 25% FC at 15 WAP and 25% FC at 11 WAP,with and without AMF inoculation. Three promising drought tolerant accessions of each species were selected from the second experiment and evaluated in the field. Treatments were two irrigation intervals with 12 mm water (four-day and monthly), three planting dates (monthly: July, August, September) and AMF inoculations (with and without) laid out as split-split-split plot. Data were collected on Fresh and Dry Tuber Weight (FTW and DTW), Harvest Index (HI), mycorrhizal colonisation and number of AMF spores. Data were analysed using descriptive statistics, correlation and ANOVA at $\alpha_{0.05}$.

The accessions differed significantly in their response to water- and AMF- levels for most growth and yield parameters. The FTW per plant ranged from 24.0±7.7 g (TDa02/00012) to 54.0±10.0 g (TDa297) in *D. alata* and 13.0±1.8 g (TDr99/02789) to 57.0±9.2 g (TDrAbi) in *D. rotundata*. Drought stress at 25% FC, 11 WAP resulted in 83% reduction in FTW as compared to a decline of 67.8% at 25% FC, 15 WAP in *D. alata*. Mycorrhizal inoculation significantly increased the FTW by 58% and DTW by 112% for *D. alata* while increases of 33% and 38%, respectively were recorded for *D. rotundata*. The FTW (*D. alata* and *D. rotundata*) was significantly correlated with DTW (r= 0.89, 0.91), HI (r= 0.80, 0.78), number of AMF spores (r= 0.53, 0.55) and mycorrhizal colonisation (r= 0.32, 0.30) respectively. In the field, irrigation at four-day intervals improved tuber yield of *D. rotundata* by 50% relative to monthly irrigation. The highest FTW (10±0.7 t/ha) for *D. alata* was obtained with the July planting while the September planting had the least (3±0.7 t/ha).

Across treatments, accessions TDa02/00012 of *D. alata* and TDrSaminaka of *D. rotundata* had the highest FTW of 7.0±1.0 t/ha and 5.0±1.0 t/ha, respectively.

Variation for drought tolerance exists among *D. alata* and *D. rotundata* accessions studied. Mycorrhizal inoculation improved yam yield under moisture stress. Accessions TDa02/00012, TDa93-36, TDaKesofunfun of *D. alata* and TDrSaminaka, TDrAloshi, TDrAbi of *D. rotundata* were most drought tolerant.

Keywords: Drought tolerance, *Dioscorea* spp., Mycorrhizal inoculation, Yam tuber yield.
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We certify that this work was carried out under our joint supervision by Miss Nkiruka Celestina Odoh, of the Department of Agronomy, University of Ibadan in collaboration with the International Institute of Tropical Agriculture (IITA) Ibadan, Nigeria.

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DEDICATION

To God Almighty who turned my toils to testimonies.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

Yam is one of the major tuber crops cultivated in West Africa; the main species being *D. rotundata*, *D. alata* and *D. cayenensis.* It is among Nigeria's leading crops in terms of land coverage (more than 3 million hectares yearly) and productivity (about 38 million tons). Nigeria also account for about 64.7% of total world production (Asiedu and Sartie, 2010). Yam contributes approximately one third of the calorific intake of the people in West Africa, coming third after maize and rice and it is also a source of protein (Asiedu and Sartie, 2010). In West Africa, yam is a food security crop of great socio-cultural value. Besides its importance as food source, it generates income to a wide range of smallholders, including women producers, processors and traders (Asiedu, 2003; Ijoyah *et al*., 2006) at local and international levels (Ugwu, 1996). Yam production is almost exclusively for human consumption, especially as choice food in many ceremonies and festivities (Hahn *et al*., 1987). It is also of great ritual and socio-cultural importance (Coursey, 1967).

Despite its importance, unlike other major staple crops such as cassava, maize, rice and sorghum; yam is classified within the "less supported crops species" owing to poor funding and commitment to its research (Chukwu and Ikwelle, 2000; Cornet *et al*., 2014). Futhermore, yam production in West Africa is constrained by several threats such as scarcity, and high cost of planting materials and labour. Planting materials alone could account for about 50% of the total production cost (Nweke *et al.*, 1991, Aighewi *et al*., 2015). Other limitations include increasing levels of field and storage pests and diseases with intensification of cultivation, declining soil fertility and seasonal moisture deficit due to climate change. Moisture could be critical in yam cultivation throughout its active growth period and this may drastically impact on yield.

In the traditional farming systems, yam has been grown under shifting cultivation without any external inputs after periods of fallow. The practice of shifting cultivation to restore fertility for agricultural production is no longer feasible because of human population pressure. As a result, the yield of yam is low and unstable,

varying annually among species and production zones (Van der Zaag *et al.*, 1980). Crop productivity in the tropics is tending towards intensification, through the use of improved varieties, fertilizers and pesticides.

Crop production in West Africa is constrained by poor fertility, fragile and highly degraded soils (Schlecht *et al*., 2006) as well as environmental stress such as drought (Payne *et al*., 1995). Climate change has made rainfall pattern highly unreliable and erratic such that most yam growing areas in Nigeria are now prone to seasonal moisture deficit (Jafarzadet and Abbasi, 2006). In spite of the need to intensify its production, yam cannot be cultivated in some parts of northern Nigeria where rainfall has become scanty and irregular.

The root is an important physiological organ for drought tolerance in crops. Yam has a relatively shallow root system which makes it susceptible to drought (Okwor and Ekanayake, 1998) leading to dramatic fluctuations in yield (Kang *et al*., 2004). Yam sensitivity to moisture stress is similar to that of potato (*Solanum tuberosum* L.), its root length concentrates at the upper 0.3 m of soil depth (Fabeiro *et al*., 2001 and Kang *et al*., 2002). Notably, yam requires moisture throughout its active growth period and being a long season crop, its region of cultivation is highly limited by reduced water supply.

Water stress is characterized by reduction of water content, turgor, total water potential, wilting, closure of stomata, and decrease in cell enlargement and growth. Drought stress control in plants is not only very complex, but also highly influenced by other environmental factors and by the developmental stage of a particular plant (Waseem *et al*., 2011). Different plant species have developed different mechanisms to cope with abiotic stress (Munns and Tester, 2008), through control of their metabolism. Such regulatory responses may include changes such as reduction in plant growth by regulating water loss through partial closure of stomata and/or reduced leaf development. Transcriptional activation/inactivation of specific genes as well as transient increases in abscisic acid (ABA) levels could also occur. Other responses may include accumulation of compatible solutes and protective enzymes, increase in levels of antioxidants as well as suppression of energy-consuming pathways, long before there is a substantial loss of their leaf turgor or some irreversible damage to inner membrane systems (Davies and Zhang, 1991; Zhang *et al*., 2006; Waseem *et al.*, 2011).Reports have shown that the number of leaves, leaf area as well as biomass production of cassava are significantly reduced by water stress (Oyetunji *et al.*, 2007).

The reduction in yield of potato due to moisture stress can be caused by a reduction in leaf size and leaf area, resulting in a reduction of the amount of intercepted radiation and then to a decrease in tuber dry mass accumulation (van Loon, 1981; Jefferies and MacKerron, 1987; Jefferies, 1993). Lahlou *et al*. (2003) reported an 11% to 44% reduction of potato fresh tuber yield in the field and 40 to 53% in screenhouse, depending on the cultivar.

The development of economically important crops with high tolerance to drought is of great value, as this will improve the water-use efficiency of the plant and alleviate the problem of excessive water consumption in agriculture. Drought tolerance in plants is defined as their ability to thrive, grow and yield satisfactorily with limited soil water supply or under periodic water deficiencies (Ashley, 1993). Therefore, selection of drought tolerant varieties of crops is of paramount importance for the maximization of production potential in drought-prone areas (Okogbenin *et al*., 2003). The use of drought tolerant varieties coupled with appropriate management practices favouring mycorrhizal activities could help reduce water losses and manage available water resources for higher productivity (Quisenberry, 1982; Turner, 1991).

Arbuscular mycorrhizal fungi (AMF) are commonly occurring soil microorganisms whose symbiotic association with the roots of most plant families (Smith and Read, 1997) can have wide range effects on the growth of the host plant (Klironomos, 2003). The positive effects of AMF on plant growth have often been attributed to an increased uptake of nutrients in place of carbon compounds, production of growth promoting substances, tolerance to environmental stress such as drought, resistance to plant pathogens. Other benefits include synergistic interaction with other beneficial soil microorganisms (nitrogen fixers, phosphorus solubilisers) and promotion of soil stability (Smith and Read 1997, Singh *et al*., 2000, Dare *et al*., 2010). AMF symbiosis contributes to plant drought tolerance through the accumulation of physical, nutritional, physiological and cellular effects (Auge, 2001). AMF symbiosis can alleviate drought-stress in plants through osmoregulation (Ruiz-Lozano, 2003).

Drought tolerance screening has been carried out in other tuber crops such as sweet potato and cassava but only to a limited extent in yams (Osonubi *et al*., 1998; Ekanayake *et al*., 2004). In an effort to meet the demand for yam, through the expansion of its areas of cultivation, particularly in the drought-prone areas such as the northern Guinea savanna, it is imperative to identify drought tolerant varieties of yam.

The identification and selection of accessions with drought tolerant potentials would help breeders develop drought- tolerant yam varieties through genetic manipulation. Such advances could lead to significant increases in yam production.

This study was thus conducted to:

i. assess the diversity of 81 yam accessions for tolerance to moisture stress,
ii. identify drought-tolerant yam (*D. alata* and *D. rotundata*) accessions and
iii. determine the contributions of AMF to drought tolerance in yam.

CHAPTER 2
LITERATURE REVIEW

2.1 Origin, distribution and utilization of yam

Yams are members of the genus *Dioscorea* with over 600 species. However, the six most economically important species grown as staple food in Africa are *D. rotundata* Poir (white guinea yam), *D. cayenensis* Lam. (yellow yam), *D. alata* L. (water yam), *D. esculenta* (Lour) Burk. (Chinese yam), *D. dumetorum* (Kunth) Pax (bitter yam), and *D. bulbifera* L. (aerial yam). These six species account for over 90% of all the food yams grown in tropical Africa (Onwueme, 1978). Research has shown that different yam species originated and were brought into cultivation in three independent areas of the tropics: South East Asia (*D. alata* and *D. esculenta*), West and Central Africa (*D. rotundata, D. cayenensis* and *D. dumetorum*), and pre-Columbian tropical America (*D. trifida*) (Onwueme and Charles, 1994).

The yam-belt of West Africa, stretching from Cameroon to Cote d' Ivoire, accounts for about 93% of the world's annual production of 48 million tons(Asiedu and Sartie 2010). Nigeria is the leading yam-producing country with about 64% of the world's production (Asiedu and Sartie, 2010). The largest genetic base in cultivated *D. rotundata* is found in eastern Nigeria and in areas adjoining the Niger and Benue rivers in the country. The occurrence of a large number of cultivars of *D. rotundata* in eastern Nigeria (Uzozie, 1971; Coursey, 1976) suggests that *D. rotundata* is of Nigerian origin. In the Caribbean and South Pacific Islands, yam is an important export crop with Jamaica as the leading exporter (Ekanayake and Asiedu, 2003).

Yam is used for food, income and socio-cultural activities. In West Africa, yam is a food security crop of great socio-cultural value; it contributes more than 200 dietary calories per person each day for over 60 million people and generates income from local and international trade (Ugwu, 1996). Yam, unlike sweet potato and cassava is produced almost exclusively for human consumption. On fresh weight basis, the tubers contain about 70% water, 25% carbohydrate, 1-2% fat and 1-2% protein (FAO, 1988). According to Hahn *et al.* (1987), yam besides being an important staple food, is

considered as man's crop and has ritual and socio-cultural significance. It is a totem of masculinity and a calendar crop around which the Ibo farming season and annual festivals revolve. It is the preferred food for many ceremonies and festivals, and an indispensable part of bride price in traditional marriage contracts in Tiv, Igbo and Yoruba culture (Hahn *et al.*, 1987). New yam festivals are celebrated annually particularly in Eastern Nigeria (Coursey and Coursey, 1971). Yams are processed into different forms such as pounded yam, boiled yam, roasted or fried yam slices, yam ball, yam chips and flakes and mashed yam. Fresh yam tubers can also be processed into yam flour which could also be turned into paste like 'fufu'. Pounded yam is the most popular yam food in Nigeria; it serves as food for royalty, special guests and is served during festive occasions (Hahn *et al*., 1987). 'Amala' a special delicacy among the Yorubas is obtained from parboiled sun-dried yam, milled into flour and processed into semi-solid paste eaten with 'gbegiri' and 'ewedu' soup. Recently, roasted and fried yams have become popular street or fast foods even in urban areas.

2.2 Environmental requirements for yam cultivation

Yams are calendar crops that determine the field preparation and planting of other crops in the West African yam belt (Okwor and Asadu, 1998). There are three major ecological zones for yam production in the yam belt of West Africa, namely the rainforest zone, southern Guinea savanna and the wetter portion of the northern Guinea savanna. These zones extend from latitude 5° N to latitude 9° N in Nigeria (Okwor and Asadu, 1998). Yams grow better under rainfall distribution of 1000 to 1500 mm over a period of 6 to 7 months of the cropping season. Yam requires moisture throughout its active growth period for vine and leaf development and most critically during tuber initiation and bulking. The optimum temperature range for yam production is between 25 °C and 30 °C. (Okwor and Asadu, 1998).

Photoperiod is an important growth factor in crop production. In yam, it influences tuber initiation (Njoku, 1963). Tuber yield is a function of photosynthetic efficiency, which is closely related to the effective spread of leaf area to ensure maximum light interception (Akoroda, 1993). Yam performance is affected by soil morphological properties which are in turn influenced by factors such as length of fallow, species and varieties of crops grown, moisture and intensity of cropping system (Mutsaers *et al*., 1986). Ezumah (1986) noted that yams require well pulverized,

loosesoil consistency with high organic matter levels for easy penetration and expansion of tubers.

2.3 Agronomic management of yam

2.3.1 Land preparation

Adequate land preparation is a prerequisite for good yam production on fertile soils. Loosening the soil constitutes an integral part of soil management in yam production. There are different land preparation methods for yam cultivation depending on the ecology, cultivar, and length of fallow period. These include mounds, ridges and holes (when planting on flats) (Okwor, 1992). Mounds are the most common and their size varies depending on ecology, production zone, yam cultivar, production purpose, and sett size.

Large mounds of 0.5 to 1.0 m x 1.0 to 1.5 m high are used for ceremonial yams. In areas with very high water table, very large mounds are made, with each taking about three seed yams. In upland parts of Edo and Delta states, yams are planted in holes, a form of minimal tillage (Okwor and Asadu, 1998). Organic manure is put into the holes some weeks prior to planting, while small mounds are made on top after sowing. Ridging, a form of improved land preparation method, is used in mechanized yam production. In intercropping within the ridges, spacing ranges from 75 cm to 100 cm x 100 cm. Agronomic practices such as fertilizer, herbicides and other agrochemical application and staking are easier on ridges than on holes and mounds. Planting of yams on flat ground is common among Delta and Edo farmers in the forest zones of Nigeria (Okwor and Asadu, 1998).

2.3.2 Planting materials

Yams can be propagated vegetatively by tubers referred to as seed yam or by cut tubers called yam setts. Healthy seed yam, usually a whole tuber of 250 to 1500 g weight is used as planting material. Bigger seed yams planted on larger mounds produce higher outputs (Okwor and Ekanayake, 1998). Planting materials have been noted to constitute about 50% of yam production cost, this high cost of planting material could be reduced by cutting seed yams of 1-2 kg into setts of 300 to 500 g. Minisett technique has been developed to overcome the problem of the unavailability of good quality seed yam as planting material (Okwor *et al*., 2000). The minisett technique involves the cutting of ‘mother’ seed tubers into small setts (minisetts) of 25-100 g. This technique has advantages over the traditional seed production methods

and has improved the multiplication ratio from 1:5 to 1:30 (Okwor *et al*., 2000; Aighewi *et al.*, 2014).

Chemical treatments (mixture of insecticide, fungicide, and nematicide) are applied on minisetts to prevent diseases and pests attack. With minisetts techniques, small whole seed tubers are produced under proper management. These small tubers are in turn planted to produce ware yams used as food. Yam sett unlike whole yam tuber, takes a longer time to sprout. The source of sett pieces also affects sprouting and tuber development. Setts from tuber head region sprout faster, followed by the tail before the middle (Okwor and Ekanayake, 1998).

2.3.3 Planting time

Traditionally, the planting time for yam depends on the onset of rains. The planting time is determined by the ecology, edaphic properties and the purpose of production. In the forest zone, planting is done from March to April with the early rains (Okwor and Asadu, 1998). In the southern Guinea savanna, dormant whole seed yam are planted early in the dry season from November to December and sprouting takes place later in the dry season at the approach of rains (Okwor and Asadu, 1998).

2.3.4 Yam growth conditions

In the early part of growth period, yam is particularly affected by weed competition; this could result in a decline in yield (Ekanayake and Asiedu, 2003). The extent of the initial field preparation determines the extent of the weed challenge later in the season. Weeding could be done two to five times depending on the variety and time of harvest. Hand weeding could be done at an interval of 3, 8, 12 and 16 weeks after planting (Okwor and Asadu, 1998). Weeding could be done manually using hoes or hand pulling and by the use of herbicides.

Mulching after planting especially in dry season in the southern Guinea savanna, is done by placing a cap of dry grass, straw or leaves on the mound and weighted with stones or earth to prevent it from being blown away. Mulch is most often applied in the hotter and drier areas and mostly for setts planted early, which are to remain in the ground throughout most of the dry season. Mulching helps to substantially reduce deterioration during dormancy, conserve soil moisture and protect the young vines from scorching by soil heat (Ekanayake and Asiedu, 2003).

Yams are generally climbing plants, though some varieties with creeping vines need no support; the vines creep over the ground the same way as sweet potato is

grown. In order to get substantial yield from this method, attention must be paid to regular weeding to prevent weed smothering. Staking is a common cultural practice in yam production particularly in the humid forest zone and facilitates yield through improved photosynthetic efficiency. Staking is done when the vines are about 1.0 to 1.5 m long (Okwor and Asadu, 1998). Onwueme (1978) described several methods of staking and grouped them as individual staking, pyramidal staking and trellising. Stakes of bamboo or wood 2 to 5 m long are used separately for individual plants. Crop stem residues or live crops like sorghum, pigeon pea and maize usually in intercrops can be used as support for yam vines. This is common in the savanna where staking materials may be scarce. After harvesting the component crops, their stalks provide a fair degree of support until the yam is ready for harvest.

Pyramidal staking as described by Onwueme (1978) is a practice where a few adjacent stakes each carrying separate vines are slant and bound together near the tops to form a pyramidal structure. This gives greater rigidity and carries a greater vine weight and can withstand strong storms without danger of collapse. Trellis-work frame of wood or bamboo has been advocated. They are however expensive and rarely used at farm levels. This type of support is best used when growing yam for research or multiplication purposes.

2.3.5 Fertilizer recommendation and use in yam production

Yams, due to their high nutrient demand are traditionally the first crop grown after fallow. Fallowing as an integral part of cropping system improvement has been abandoned due to population pressure. Thus, the use of mineral fertilizers is now common in yam- growing areas in Nigeria. Higher yields have been obtained from fertilized plots and this has increased the desire to use chemical fertilizers. Sotomayor-Ramirez *et al*., 2003 also stressed on the importance of macro and micronutrients application in yam production. The critical nutrient elements in yam production are nitrogen and potassium; this is inferred from the respective amounts of these elements yam absorbed from the soil during growth (Okigbo, 1980). It has been noted that yam can efficiently utilize soil phosphorus and that it responds poorly to phosphate fertilizer application (Coursey, 1967).However reports on the efficiency of inorganic fertilizer application to yam have been inconsistent. Baimey *et al*., 2006 reported that yam yields did not increase following application of ammonium super phosphate in the Southern Guinea savanna of Benin. Earlier reports indicated that yam did not respond

favourably to inorganic fertilizer (van der Zaag and Fox, 1980; Dare *et al*., 2010). Yam may thus require a combination of organic and inorganic nutrients to perform maximally than application of inorganic fertilization alone.

Despite the micro-variability of soil characteristics and the differences in agro ecological zones, the general fertilizer recommendations for yam have been based on only a few research results from a limited number of sites mostly in the forest zone. Such blanket recommendations could be misleading as they fail to take ecological peculiarities into consideration. Fertilizer use in Nigeria is generally affected by factors such as quantity, type, time and method of application, environmental factors such as rainfall, edaphic factors, crop combinations, cultural practices and socio-economic factors (cost and government policy).

2.4 Impact of drought on the environment and challenges to crop production

The change in global climate is faster than projected. The potential impacts of climate change on rainfall patterns, soil salinization by irrigation, temperature extremes and atmospheric CO_2 concentration led to an increasing attention on the need to maintain or increase agricultural productivity, especially on arid lands (IPCC, 2007; Srivastava *et al*., 2012) . In fact, drought stress is among the factors that adversely affect plant growth and productivity (Venkataramana *et al*., 1986; Olesen *et al*., 2007). Consequently, the interaction between changes in climate and drought stress that affect crop yields could become a major problem.

Drought, from an agricultural perspective, is ultimately defined in terms of its effects on crop yield. In the field, plant may experience varied abiotic stresses during the growing period. Drought effect on crop production is more pronounced than the combined effect of all other environmental stress (Tester and Bacic, 2005). The timing of water stress (e.g. sowing, crop establishment, flowering, or grain filling, or at tuber initiation and bulking for root and tuber crops) rather than the intensity of stress could have a larger impact on yield (Aranjuelo *et al.*, 2011; Pinheiron and Chaves, 2011). Together with over population, drought leads to an over exploitation of water resources for agriculture purposes and increased constraints on plant growth and survival. Desiccation is a more severe loss of water that can potentially lead to gross disruption of metabolism, and eventually to the cessation of enzyme catalyzing reactions and finally death (Amarjit *et al*., 2005; Shao *et al*., 2008).

Drought is an extended period of months or years when a region receives consistently below average precipitation. It is a subtle, insidious natural hazard whose effects often accumulates slowly over a considerable period of time, and may linger for years after the termination of the drought event (Wilhite and Glantz, 1985). The absence of a precise and universally accepted definition of drought adds to the confusion about whether drought exists and its degree of severity (Sheffield and Wood, 2011). The cause of drought is easily understood, but difficult to prevent. There are numerous and a diverse disciplinary perspective of drought which leads to considerable confusion over what constitutes drought. Despite this disparity of views, the overriding feature of drought is its negative impacts on the environment. Droughts differ from one another in three essential characteristics: intensity, duration and spatial coverage. It is normally grouped by type as meteorological, hydrological and agricultural drought.

Meteorological drought is expressed by a period of substantially diminished precipitation duration and or intensity. The commonly used definition of meteorological drought is an interval of time, generally on the order of months or years, during which the actual moisture supply at a given place consistently falls below the climatically appropriate moisture supply. Agricultural drought, occurs when there is inadequate soil moisture to meet the needs of a particular crop at a particular time. It usually occurs after or during meteorological drought but before hydrological drought. Hydrological drought refers to deficiencies in surface and subsurface water supplies. It is measured as stream flow, snowpack, lake, reservoir and groundwater levels rather than with precipitation shortfalls. Hydrological droughts usually lag the occurrence of meteorological and agricultural droughts because more time elapses before precipitation deficiencies are detected in reservoirs, groundwater, and other components of the hydrologic system (Wilhite, 2000).

The occurrence of drought results in a myriad of economic, social and environmental impacts in developed as well as developing nations, although the characteristics of its impacts differ considerably between the two settings. Economic impacts of drought are associated with agriculture and the income generated from crops. During drought, lack of water can often lead to a decline in crop yields, and consequently a reduction in income for farmers as well as increase in market price of products. When prolonged, it may lead to unemployment and loss of revenue to local, state and federal government, thus having a significant impact on the economy of the

area. Environmental impact of drought can result in insect infestations and plant diseases, increased loss in species biodiversity, migration changes, reduced air quality and environmental degradation. On a long term, desertification could set in and these losses are difficult to quantify. Socially, drought could increase chances of conflict over commodities, fertile land and water resources. It could also lead to abandonment of cultural traditions, loss of homelands, changes in lifestyle and increased chance of health risks due to poverty and hygiene issues.

2.5 Drought tolerance mechanisms in crops

Due to the unreliable and erratic nature of rainfall resulting from climate change, seasonal drought often occurs in non-arid regions and as a result many farmers depend on irrigation to meet production goals. Yet, water for irrigation is a limiting and contentious resource with a critical effective management in terms of production costs and sustainable productivity. The amount of water used by a crop is closely associated with photosynthetic activity, dry matter production as well as yield (Qing *et al.*, 2001). Environmental stresses trigger a wide variety of plant responses, ranging from altered gene expression and cellular metabolism to changes in growth rates and crop yields. Crops can hardly survive, grow and reproduce under severe and extended water stress periods. However, plants make metabolic and structural adjustments to cope with the stress conditions under short periods of water stress.

Crop response to drought stress depends on the genotypes, intensity, rate and duration of exposure, weather conditions as well as the growth and developmental stage of the crop (Brar *et al*., 1990; Norouzi *et al*., 2008; Aranjuelo *et al.*, (2011). Plant characteristics associated with improved performance under drought include those that give plants greater access to water, help them to absorb more water, reduce rates of water loss or to maintain higher physiological activities at low water status (Ludlow and Muchow, 1990). Plants have a plethora of mechanisms that allow them to perceive the incoming stresses and circumvent them by a rapid regulation of their physiology and metabolism (Reddy *et al.*, 2004). These mechanisms may cover many aspects from genetic molecular level, biochemical and physiological processes to ecosystem levels (Izanloo *et al*., 2008; Xu *et al.*, 2009). This includes many aspects such as drought escape, drought avoidance, drought tolerance, drought resistance, drought abandon and drought-prone biochemical- physiological traits (Penuelas *et al*., 2004; Chaves *et al.*, 2003; Sherrard *et al*., 2009).

Drought escape is attained when the life cycle plant is completed before severe water deficit (early flowering in annual species). Plants are able to reproduce before the environment becomes dry as crop phenological development coincides with the periods of soil moisture availability (Araus *et al*. 2002). Crop duration is dependent on the genotype and environment and it determines crops ability to escape from environmental stresses like water deficit. With early maturing varieties, yield loss from terminal drought are minimized (Kumar and Abbo 2001) however yield are highly correlated with crop duration under favourable growing conditions, thus a decline in the length of crop duration below the optimum would impact on yield (Turner *et al*., 2001).

Drought avoidance consists of mechanisms that reduce plants water loss through evapotranspiration from aerial parts or enhance its capacity for moisture absorption or conservation through stomatal control, leaf area, leaf size and canopy cover and as well through an extensive and prolific root system (Schulze 1986; Jackson *et al.*, 2000; Turner *et al*., 2001; Kavar *et al*., 2007). Root characteristics such as biomass, length, density and depth are the main drought avoidance traits contributing to final yield under drought environments (Subbarao *et al*., 1995, Kavar *et al*., 2007). Glaucousness of leaves is also a desirable drought tolerance trait as helps in high tissue water potential (Ludlow and Muchow 1990).

Drought tolerance is mainly through improved ability for osmotic adjustment, osmoprotection, antioxidation and a scavenging defense system increase in cell wall elasticity to maintain tissue turgidity. Osmotic adjustment helps the cell to decrease osmotic potential with a consequent increases in the water influx gradient and turgor maintenance. This is essential for maintaining physiological activity for extended periods of drought (Morgan, 1984, Penuelas *et al*., 2004).

Some biochemical- physiological traits of plants under long-term drought condition may lead to genetic mutation and modification (Sherrard *et al*., 2009). Abscisic acid (ABA), a plant stress hormone, induces the closure of leaf stomata (microscopic pores involved in gas exchange), thereby reducing water loss through transpiration and decreasing the rate of photosynthesis. These responses improve the water-use efficiency of the plant in the short term (Waseem *et al*., 2011). Environmental variables such as moisture stress obviously influences plant fundamental processes such as plant growth and biomass production. Deblonde *et al*. (1999) and Lahlou *et al* (2003) reported that the effect of water stress on potato yield

resulted from its effect on the aerial parts. Plant height, stems number and ground cover at tuber initiation are used for indirect selection for tuber yield in potato (Moll and Klemke, 1990). In potatoes, these parameters are very important for attainment of high and stable tuber yields and these are well correlated to aboveground plant biomass. Short periods of water stress can cause significant reduction in tuber yield of potato due to its high sensitivity to moisture stress (Haverkort *et al*., 1995). Fresh tuber weights of potato, plant height, stem and number of leaves was reported to be significantly affected by the different levels of irrigation (Yuan *et al*. 2003). Leaf numbers were observed to differ significantly among the sampling time.

Leaf expansion has been shown to be the most sensitive process to moisture deficit and it responds rapidly to changes in leaf water status (El-Sharkawy and Cock, 1987). Sobrado (1986) found a strong relationship between leaf expansion rate and leaf turgor potential. Water stress accelerates the senescence of the lower leaves in maize but cultivars with increased capacity for osmotic adjustment are able to delay leaf senescence under drought (Bolanos *et al*., 1993).

Studies show that when water is available, cassava maintains a high stomatal conductance and can keep internal CO_2 concentrations high, however, with limiting water conditions, the stomata closes in response to even small decreases in soil moisture (El-Sharkawy and Cock, 1984). The rapid closure of stomata and decline in transpiration lessens the decrease in leaf water potential as well as soil water depletion thereby protecting leaf tissue from turgor loss and desiccation (Palta, 1984). This observation has also been made in other crops including cowpea and maize (Tardieu and Simonneau, 1998).

2.6 Arbuscular Mycorrhizal Fungi (AMF)

Arbuscular mycorrhizal fungi are obligate biotrophs forming a symbiotic association with the roots of many plant families such as angiosperms, pteridophytes and bryophytes (Smith and Read, 1997). They are probably the most abundant symbiosis in agricultural soils (Sieverding and Liehner, 1984), accounting for about 5 to 50% of the biomass of soil microbes (Olsson *et al*., 1999). There are three important components of AMF namely the roots, the fungal structure within the cells and extra radial mycelium in the soil. The fungal filaments supply the root with mineral salts to which it normally would not have access. The fungus in return, receives metabolized nutrients such as sugars, amino acids and secondary metabolites from the plant (Smith

and Read, 2007). Thus, it is an interdependent mutualistic relationship where the host plant receives mineral nutrients, while the fungus obtains photosynthesis derived carbon compounds from the plant (Harley and Smith, 1983).

Arbuscular mycorrhizal fungi belong to the monophyletic phylum Glomeromycota comprising four orders, ten families, and fourteen genera (Walker and Schüßler, 2004; Sieverding and Oehl, 2006; Palenzuela *et al.*, 2008; Walker 2008). The most numerous group of fungi in the Glomeromycota is the genus *Glomus* including 53% of all AMF described to date, that is, 210 species (B1aszkowski*et al*., 2004). Morton (2000) noted that when 154 species were known in the literature, the number of existing species of AMF may be at least 2-fold higher, thus the actual number of AMF species is unknown. This was confirmed by Helgason *et al* (2002), on the bases of the selectivity between fungal and plant species and also the high proportion of total AMF diversity found in natural communities, compared to the number of plant species.

2.6.1 Role of AMF in Agriculture

Arbuscular mycorrhizal fungi are of great importance in sustainable agriculture. The relevance of AMF on plant growth and development is well established. The most pronounced is often attributed to an increased uptake of nutrients (especially diffusion limited nutrients like P and some micronutrients) in exchange of carbon compounds. Besides its importance in improvement of mineral uptake, other benefits include production of growth promoting substances, tolerance to drought, salinity and transplant shock, resistance to plant pathogens and synergistic interaction with other beneficial soil microorganisms such as N_2-fixers and P solubilisers, promote soil stability and increase of plant diversity (Smith and Read 1997, Singh *et al*., 2000, Koske *et al*., 2004). Numerous studies have shown the positive effects of AMF on growth and yield of plants. Plants with highly branched root systems (Graminae) are less mycotrophic (less dependent on AMF for normal growth) than those with coarser roots (cassava, onion), which determines the dependence of the plant on the symbiosis.

Arbuscular mycorrhizal fungi have the potential to increase dry weight of micropropagated banana (*Musa* spp.) plantlets (Elsen *et al*., 2003), growth and yield of watermelon (*Citullus lanatus*) (Kaya *et al*., 2003), improved development of pineapple (*Ananas comosus*) and micropropagated oil palm (*Elaeis guineensis*) plants (Schubert *et al*., 1990; Jaizme-Vega and Azcón, 1995).

2.6.2 Arbuscular Mycorrhiza and Plant Nutrient Uptake and Growth

Increased uptake of limited nutrients (especially P, Zn, Cu, etc.) in exchange of carbon compounds (Singh *et al*., 2000), have often been attributed to effects of AMF on plant growth. Most agricultural soils in the tropics are generally low in plant available phosphorus due to high phosphate –fixing capacity, AMF is particularly beneficial to crop growth in such P deficient soils. The hyphae absorb and translocate P into the root from a larger soil volume than is normally exploited by non-mycorrhizal roots (van der Zaag *et al*., 1980). Besides, as AMF enhances the mineral nutrition, the chlorophyll content is increased, thus leading to higher photosynthetic rate (Bian *et al.*, 2001; Feng *et al.*, 2002). The extent of AMF colonization and plant response varies with the plant species and genotypes of a single plant (Hetrick and Bloom, 1986, Mercy *et al.*, 1990), thus the functional properties of mycorrhizal community depend on its composition (Jansa *et al*., 2006). Certain combinations of host plant and AMF are more effective than others for either the fungus or host plant (Douds *et al*., 1998; van der Heijden *et al*., 1998), though AMF have a wide host range. Within the plants root system, AMF development depends on the genotype and the infection by one fungal species may reduce colonization by another (Pearson *et al*., 1993). The presence of different AMF showed a varied response on the growth of potatoes (Mc Arthur and Knowles, 1993), while different spore production was influenced by different host plants (Hetrick and Bloom, 1986).

Growth and yield of root and tuber crops have been enhanced by AMF. Howeler and Sieverding (1983) observed that *Glomusmanihotis* and *Entrophospora colombiana* are highly efficient for improving cassava (*Manihotis* spp.) growth in the greenhouse. Inoculation of potato microplants with Vaminoc and Endorize (a commercial AMF product) and also with *G. intraradices* resulted in increased tuber yield and quality (Duffy and Cassells, 2000). Potato cultivars (*S. aethiopicum)* inoculated with *G. aggregatum* or with *G. mosseae* had higher shoot dry weight than the non-inoculated plants (Diop *et al.*, 2003). According to Yao *et al*, (2002), inoculation of potato (*Solanum tuberosum)* with *G. etunicatum* produced significantly greater shoot fresh weight, root dry weight and number of tubers per plant. Enhanced biomass production and improved nutritional status of sweet potato (*Ipomoea batatas*) was due to higher efficiency of *Glomus* spp. rather than *Acaulospora* or *Scutellospora* spps (Gai *et al*., 2006).Despite the numerous reports on the positive effects of AMF on the growth and yield of plants, a few studies have also indicated negative or neutral

effects of AMF on plant growth and yield. Inoculation of *Solanum* spp. plantlets with *G. intraradices* showed a reduction of growth (Duffy and Cassells, 2000), while no effect of *G. versiforme* inoculation on *S. aethiopicum* cultivars was recorded (Diop *et al*., 2003).

The host plant can influence AMF community composition directly by regulating carbon allocation to roots, producing secondary metabolites or by changing the soil environment. Thus, the AMF infectiveness and effectiveness may be under the genetic control of the host, AM fungus or more likely a complex interaction of both symbiotic partners with soil environmental factors (Sylvia *et al*., 2003).

2.6.3 Arbuscular Mycorrhizal Fungi and Plant Protection

AMF could protect plant from the damage caused by soil-borne pathogenic fungi, nematodes and bacteria. Various effects have been noted from AMF and pathogenic fungi interactions. AMF tend to decrease the harmful effects of fungal pathogens through a negative impact on pathogen development, leading to increased crop yields. For example, *Rhizoctonia solani* infected potato (*Solanum* spp.) plantlets, inoculated with *G. etunicatum*, produced greater tuber fresh weights than non-AMF plantlets (Borowicz, 2001).

Plant root systems are shared by AMF and plant parasitic nematodes as a resource for food and space. The effects of these organisms and their interaction on plant growth have been reviewed (Hol and Cook, 2005; Borowicz, 2006). In olive plants *(Elaeagnus angustifolia),* the presence of AMF significantly reduced the severity of root galling as well as the reproduction of *Meloidogyne* spp. (Castillo *et al.*, 2006), hence AMF increased the resistance to nematode infestation by slowing down nematode development.

2.6.4 Arbuscular Mycorrhizal Fungi and Drought Stress

Crop management practices that enhance drought tolerance, plant water-use efficiency and plant growth are particularly beneficial (Egilla *et al*., 2001). Research has shown that AM symbiosis affects the water relation of many plants. AMF improve water use efficiency in plants and AMF inoculation may directly enhance root water uptake providing adequate water to preserve plant physiological activities, especially under drought conditions (Faber *et al*., 1991, Smith and Read, 1997). The influences of AMF colonization on plant water stress tolerance have been observed in crops such as soybean (Auge *et al*., 2001; Ruis-Lozano *et al*., 2001), sorghum (Auge *et al*., 2001),

cassava (Fagbola *et al*., 2001; Oyetunji *et al.,* 2007) and wheat. The result of a study showed that the dry tuber weight of the mycorrhizal inoculated cassava was significantly higher than that of the non-inoculated (Oyetunji *et al.,* 2007). Fagbola *et al*. (2001) also noted that *Gliricidia sepium* inoculation with mycorrhizae increased root colonization under drought environment.

Symbiosis involving AMF have been demonstrated by several eco-physiological studies to often result in altered rates of water movement into, through and out of host plant, with consequent effects on tissue hydration and plant physiology. The following mechanisms have been suggested; improve hydraulic conductivity (Cooper, 1984), increase in transpiration rate and reduced stomatal resistance (Bethlenfalvay *et al*., 1988), reduced leaf elasticity and leaf water as well as turgor potential (Auge *et al*., 1987), osmoregulation in plants (Ruiz-Lozano, 2003), increased effective rooting length and depth (Davis *et al.*, 1992) and increased contact with soil particle through hyphal binding effect (Auge, 2001).

Drought- stressed mycorrhizal plants have a higher water uptake than non-mycorrhizal plants. Besides, more rapid recovery from water stress and greater soil moisture extraction at low soil water potential has been observed in mycorrhizal plants (Hardie and Leyton, 1981). Allen (1982) stated that AMF hyphae absorb and translocate water directly to their hosts, thus acting as a bridge between the dry zone around root and adjacent moist region. Mycorrhizal plants have been reported to have a higher stomatal conductance than non-mycorrhizal plants under drought stress. Arbuscular mycorrhizal and non-arbuscular mycorrhizal plants often show different photosynthetic characters as the concentrations of chlorophyll were higher in mycorrhizal than non-mycorrhizal plants under drought stress. Wu and Xia (2006) observed that AM inoculated citrus seedlings had higher photosynthetic rate, stomatal conductance and transpiration rate than corresponding non-AM plants under drought stress.

2.6.5 Arbuscular Mycorrhizal Fungi Use in Yam Production

Nutrient amendments such as inorganic fertilizer are used to improve yam productivity. However reports on the negative influence of fertilizer on yam tuber quality coupled with unavailability, cost and harsh effects of fertilizer on the environment makes its use uninteresting to farmers. A biological approach involvingmycorrhizae symbiosis which is ecologically friendly and less costly could

help reduce the dependence on fertilizer for yam production (Obigbesan, 1981; Dare *et al*., 2010).

Mycorrhizal symbiosis is a sustainable method of enhancing crop productivity under marginal soil conditions. This is achieved through increased availability and uptake of immobile nutrients such as phosphorus and micronutrients, nitrogen uptake and enhanced root systems (Smith and Read, 1997; Liu *et al*., 2003; Dare *et al*., 2010). Yam is highly mycotrophic, as its roots are densely colonized by a plethora of AMF species (Tchabi *et al*., 2009). Mycorrhizal symbiotic association with roots of yam and its role in yam productivity in terms of protection and nutrition have been widely reported (van der Zaag and Fox, 1980, Koide 1993, Oyetunji and Afolayan, 2007; Tchabi *et al*., 2010, Dare *et al*., 2014). Mycorrhizal inoculation was found to play significant role in the relative water contents of yam plants. Yam roots when colonized by mycorrhizae had higher specific water uptake compared to the uninfected roots (Koide, 1993). Similarly, Allen (1982) showed that water extraction by plant roots could be enhanced if infected by VAM. Yam tuberous dry weights were found to be higher with VAM-inoculation compared with non-inoculated counterpart. Oyetunji *et al*. 2007 attributed increased shoots, roots and tuberous dry weights of the yam under VAM inoculations to enhanced relative water and chlorophyll contents as well as enhanced nutrient uptake which VAM are known for. Van der Zaag and Fox (1981) also stressed that poor response of yam to phosphate fertilizer application was due to high level of root colonization by mycorrhizae. Poor yam performance was observed under no- mycorrhizal inoculation treatment across all measured parameters. This supports the earlier report that yam is a high nutrient-demanding crop and develops poorly with low yield in degraded soils (Orkwor and Ekanayake (1998).

Improved yam tuber yield due to the combined effect of AMF inoculation and other soil amendments clearly indicates that mycorrhizae management together with appropriate agronomic practices will be beneficial to yam productivity in degraded soils. Besides, sustenance of productivity through root colonization by arbuscular mycorrhizal (AM) fungi could be of interest for yam breeders. Thus, breeding for yam sustainability will involve a process of fitting yam accessions to an environment instead of altering the environment to suit yam accessions (Dare *et al*., 2012).

CHAPTER 3

MATERIALS AND METHODS

The study consisted of three experiments, two of which were conducted in glasshouses at the International Institute of Tropical Agriculture (IITA), Ibadan between 2009 and 2012. The third, a field trial, was carried out at Minjibir (12° 08'N, 8° 39'E), Kano State, Nigeria between 2011 and 2012.

3.1 EXPERIMENT 1: Screening of yam accessions for tolerance to moisture stress

3.1.1 Experimental site and soil preparation for pot experiment

This study was conducted in a glasshouse at IITA, Ibadan, from June to September, 2009 to identify drought-tolerant yam accessions from different agro-ecological zones. Soil used for the study was collected from an experimental plot in IITA (7° 26´ N, 3°54´ E), Ibadan (in the derived savanna agro-ecological zone of Nigeria). The soil was an Alfisol, of suborder Ustalf (Soil Survey Staff, 2010), belonging to the Egbeda-Iwo series (Moormann *et al.*, 1975), with a coarse-textured surface layer, clay-enriched and a fairly high level of weatherable mineral reserve (Aweto, 2001). Bulk soil sample was collected from an experimental field in IITA-Ibadan at a depth of 0-30 cm. After a thorough mixing, subsamples were taken for the determination of the physical and chemical properties of the soil. Prior to filling the pots, soil was sterilized at 110°C for 2 hours and allowed to cool. Gravimetric soil moisture content was determined by weighing soil before and after drying at 110°C to a constant weight according to Hillel (1982). Gravimetric soil moisture was calculated using the formula: weight of soil moisture (g) / weight of oven dried soil x 100. Each perforated plastic pot of 20 cm depth was filled with 5 kg sterilized top soil.

3.1.2 Experimental design, procedure and treatments

A set of 81 accessions of two species of *Dioscorea* were evaluated in thescreening exercise. These included 49 accessions of *D. rotundata* (5 improved IITA lines and 44 landraces) and 32 accessions of *D. alata* (26 improved IITAlines

and 6 landraces). These accessions were of varied maturation period; *D. alata* for example were mostly late maturing while *D. rotundata* were either early (Abi, Tabene), intermediate (99/02562, Laboko) or late (Aloshi, Amula, Pepa) accessions (IITA, *pers. com*). The list of the accessions used in this study is shown in Table 3.1. Thirty setts (each of 40 g weight) were prepared from each accession. The yam setts were planted in sterile growth medium (carbonized rice husk) for two weeks to sprout before transplanting into the pots. Sprouted yam setts were selected based on their vigour (about 10 cm high), in order to harmonize the state of the planting materials. Soil in each pot was watered to field capacity and allowed to equilibrate for 24 hrs; sprouted yam sett was then planted into each pot. Each vine was passed through a short Polyvinyl Chloride (PVC) tube and wrapped with a transparent polyethylene bag. The plastic bagging was to minimize water loss from soil surface. Three pots with no sett planted were also watered and sealed as control. The polyethylene bags were fixed at the tip of the PVC tubes using twines, and thereafter fixed onto the pots using masking tape (Plate 3.1). The tubes were then insulated using cotton wool to minimize moisture loss. The initial pot weights were determined. The experimental materials were arranged in a randomized complete block design with three blocks. Five pots constituted one plot. The experiment was maintained within a glasshouse for four months (June to September, 2009) without further watering.

3.1.3 Data collection

Data were collected as follows: Fortnightly, plant vigour was assessed by scoring as: 1-Poor, 2-Weak, 3-moderate, 4- Good, and 5- Excellent (Table 3.2). Number of leaves per plant was determined along with vine lengths every two weeks. Plant biomass was determined at harvest. Total leaf area (cm^2)/ pot were also measured at harvest, using Leaf Area Meter (Model LI-3000, LI-COR, Nebraska, USA).

3.1.4 Harvesting

Each plant was cut at soil level, separated into leaves and vines and their weight recorded. Root weight was also recorded. Prior to this, roots were collected after soils in pots were emptied onto a wire mesh of 4 mm size and washed off under running tap water.

Table 3.1. Yam accessions evaluated for drought tolerance

*D. alata*accessions (TDa)				*D. rotundata*accessions (TDr)					
Serial No.	Accessions	Serial No.	Accessions	Serial No.	Accessions	Serial No.	Accessions	Serial No.	Accessions
1	291	18	00/00194	1	00/00365	17	Tabene	33	Danacha
2	00/00103	19	03/00090	2	Agumaga	18	Kpako	34	Kinterererekon
3	02/00151	20	Kesofunfun	3	Bukki	19	Mapaa	35	Mulkakwusa
4	98/01166	21	00/00066	4	Giwagaratu	20	Saminaka	36	PanicomKore Lagos
5	00/00060	22	02/00088	5	Kratsi	21	99/02562	37	Yason-baganon
6	02/00006	23	05/00141	6	Suba	22	Alago	38	PanicomKore Gwari
7	05/00048	24	Sagbe	7	Talibe	23	Chindo	39	Tabannin sokka
8	Olesunle	25	00/00046	8	Abi	24	Huvakwase	40	OloshiAggaabi
9	297	26	01/00015	9	Akwuki	25	Lemu	41	99/02789
10	00/00104	27	03/00185	10	Ekpeigbo	26	Gwagwa	42	Aloshi
11	02/00246	28	Lotosson	11	97/00812	27	Mumuye	43	Didio
12	98/01176	29	02/00092	12	Agahnmiri	28	Aggah	44	Kpakogi
13	00/00064	30	93-36	13	Ameh	29	Amula	45	Maisaki
14	02/00012	31	Sharm - bagada	14	Heobalo	30	Gbamgo	46	Pepa
15	05/00086	32	Agara white	15	Laboko	31	99/02626	47	Yangode
16	Agara red			16	Pounche	32	Boni yakpa	48	Manwouri
17	00/00045							49	Singor

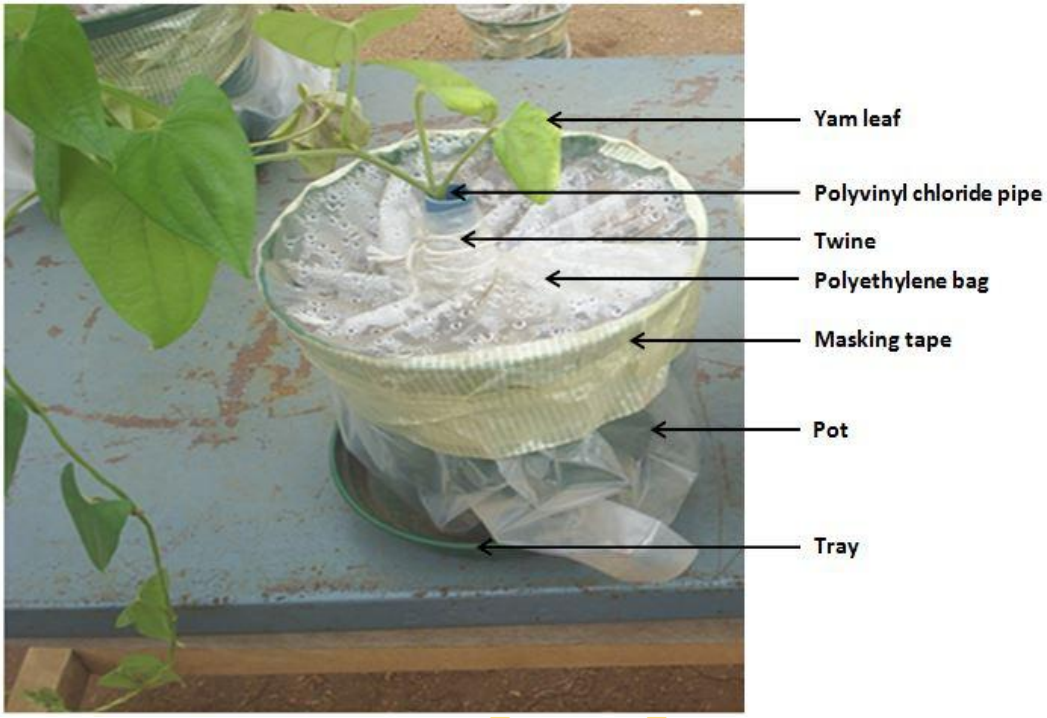


Plate 3.1: Growing yam plant in plastic- covered pot to prevent soil water loss.

Table 3.2. Scores and description of yam accessions response to imposed water stress

Scores	Meaning	Description
1	Poor	Plants completely dried, vines and leaves have completely turned brown
2	Weak	Leaf number reduced by 80%, more than 75% of the remaining leaves wilted and young leaves had reduced greenness
3	Moderate	Leaf number reduced by 50%, about 50% of the older leaves were droopy, wilted and partially dry and most young leaves had reduced greenness
4	Good	About 30% of the leaves have dropped, less than 50% of the remaining leaves were droopy, partially wilted or dry and the young leaves had reduced greenness
5	Excellent	Plants had full canopy, majority of the leaves retained were green and photo synthetically active

3.1.5 Statistical analysis

All data collected were analyzed using analysis of variance (ANOVA) with SAS package (SAS 9.2) and significantly different means were separated using standard error.*Scored plant vigour* was*transformed*using the square root*transformation*scale. Furthermore, multivariate cluster analysis was used to group the means based on the studied characters. The canonical analysis was then used to display the clusters in two -dimensional graphics.

3.2 EXPERIMENT 2: Influence of Arbuscular Mycorrhizal Fungi Inoculation on Drought Tolerance of Yam under Moisture Stress

3.2.1 Study location and soil preparation

The study was carried out to assess the response of moisture stressed yam to mycorrhizal inoculation. This was conducted in the glasshouse at IITA, Ibadan, Nigeria, from May to October, 2010. Bulk soil samples (oxic paleustalf) from 0 to 15 cm soil depth were collected from an experimental plot at IITA, Ibadan. After a thorough mixing, subsamples were taken and sieved using a 2 mm mesh sieve for the determination of the physico-chemical properties of the soil carried out at the Analytical Service Laboratory of the IITA, Ibadan. Soil was sterilized at 110°C for 2 hours and allowed to cool. Field capacity and soil moisture content were determined. Soil moisture content was determined by weighing soil before and after drying at 110°C to a constant weight according to Hillel (1982). Moisture content was calculated as explained in 3.1.1 of experiment 1. Sterilized dry soils of 5 kg weight were filled into plastic pots.

3.2.2 Experimental design and treatments

Twelve accessions each of *D. rotundata* and *D. alata* selected from the first experiment (based on their responses to imposed stress) were used for this study. The selected accessions are listed in Table 4.10. Yam tubers were cut into minisetts of 50 g weight, using a sterile knife. Head and tail parts of yam tubers were used as planting materials due to the existence of a positive sprouting gradient for them over the mid part of the tuber. This was to ensure homogeneous sprouting in all treatments. The setts were soaked in a mixture of 600 g diazinon L-1 (insecticide), 240 g oxamyl L-1 (nematicide) and mancozebe 80% (fungicide) and air-dried for 24 hours beforeplanting (IITA, *pers. com*). This was done to protect the yam setts from pests and nematodes.

Soil inoculation method was used for the mycorrhizae application in which two levels of AMF treatment (with and without inoculum) were imposed. Soil-root inoculum of 10 g was added to each of the planting hole just before planting the yam sett. The inoculum was provided by IITA Soil Microbiology unit and it included a mixture of AM species of *Glomus*, *Scutelospora*, *Aculospora*, *Entorphospora and Gigaspora*. Watering was done at 48 hours interval for all pots till 11 weeks after planting when stress was imposed at 3 levels of moisture stress: 75% Field capacity (FC) at 11 weeks after planting (WAP), 25% FC at 15 WAP and 25% FC at 11 WAP. These moisture levels were maintained till the end of the experiment. Imposition of stress at 11 and 15 WAP was to target the tuber initiation and bulking stages of yam respectively. The factors and their levels were yam (12 accessions of each species), mycorrhizal (two levels) and moisture stress (three levels) each for *D. rotundata* and *D. alata.* Experiment was laid out in factorial arrangement in a randomized complete block design (RCBD) with three replicates. This trial was monitored for 20 weeks.

Each of the two species had treatment combinations as follows:

CL_{1---12} M+ W_1

CL_{1---12} M+ W_2

CL_{1---12} M+ W_3

CL_{1---12} M- W_1

CL_{1---12} M- W_2

CL_{1---12} M- W_3

where W_1, W_2 and W_3 are moisture stress levels at 75% FC at 11 WAP, 25% FC at 15 WAP and 25% FC at 11 WAP; M+ and M- are with and without mycorrhizal inoculation; CL_{1---12} represent 12 selected accessions for each of *D. alata* and *D. rotundata.*

3.2.3 Data collection

The responses of these accessions to moisture stress were assessed through growth parameter measurements such as vine length (measured with a metre rule), counting of fully developed leaves and measurement of chlorophyll content with Minolta SPAD-502 chlorophyll meter (Model 2900 DL, Spectrum Technologies Inc.). These assessments were done at 4 weeks interval (10, 14 and 18 WAP). The chlorophyll content reading was taken on 3 leaves per plant, between the 4^{th} and 7^{th} newly developed leaves, at the middle portion of the leaves midway between the

central vein and the leaf edge. Leaf area (cm^2) was determined at harvest by using a portable Leaf Area Meter (Model LI-3000, LI-COR, Nebraska, USA).

Prior to root collection, the pots with soils were emptied on to wire mesh of 4 mm size and washed off under a running tap water. Sub-samples of roots were taken for mycorrhizal assessment. For biomass yield determination, the tubers, fibrous roots and shoot components (vines and leaves) were weighed fresh and then oven-dried to a constant weight at a temperature of 80°C and weight recorded. Prior to oven drying, tubers were cut into chips for effective drying.

Harvest index (HI), which is the weight of a harvested product as a ratio of the total weight of crop, was estimated per pot.

HI= Dry tuber weight / Total dry weight of plant (leaves + vine + fibrous roots+ tuber)

3.2.4 AMF roots colonization assessment

Roots collected from each plant sample were cut into 1 cm length. Mycorrhizal staining was initiated by heating the roots in 10% KOH for 40 minutes at 80°C according to Philips and Hayman (1970). They were then washed in water and bleached in alkaline H_2O_2 for 10 minutes. Staining solution used contained methyl blue (0.05%), in acidic glycerol solution (500 mL of glycerol, 450 mL of water and 50 mL of HCl (1%)). Roots were de-stained with 50% glycerol. The degree of mycorrhizal colonization was assessed by spreading the root samples evenly on a grid plate in the laboratory and observing the roots under the dissecting microscope at low magnification. Total number of roots and infected roots intersecting the grids were counted according to Giovanetti and Mosse (1980). Percentage mycorrhizal colonization was calculated as C / (D + C) x 100 as suggested by Dautridge *et al*. (1986), where C = total number of mycorrhizal infected roots (scored positive) and D = total number of non-infected roots (scored negative).

3.2.5 Spore isolation and morphological identification

Soil samples of about 500 g for each treatment were air-dried and stored in sealed plastic bags at 4ºC until samples could be treated. Mycorrhizal spore assessment was done using the wet-sieving and decanting techniques as described by Gerdamann and Nicholson (1963). Soil of 100 g weight was suspended in 500 ml of water after which the suspension was thoroughly mixed with a stirrer. Supernatant was decanted through three sieves of 200 µm, 56 µm, 35 µm mesh sizes arranged in that order. This

process was repeated 3 times for each sample and the sieve content centrifuged at 3000 rmp for 3 minutes. Pellets were re-suspended in 40% sucrose solution and centrifuged again at 3000 rmp for 2 minutes. Spores in the suspension were filtered, counted and identified using stereomicroscope at magnification of × 40. Spore identification was done based on size, shape, colour and hyphal attachments. This was done according to the guideline provided by the International Collection of Vesicular-Arbuscular Mycorrhizal Fungi (INVAM, 1958).

3.2.6 Statistical analysis

Statistical analysis of all data obtained was carried out using SAS package (SAS, 9.2). Data were subjected to analysis of variance (ANOVA) and means were separated using Duncan multiple range test. Means of the measured variables under optimum and minimal water and mycorrhizae treatments were ranked and three stable accessions selected for field study from the highest moisture stressed treatment.

3.3 EXPERIMENT 3: Field evaluation of yam accessions for yield in drought-prone environment

3.3.1 Experimental site

This field experiment was carried out between July 2011 and April 2012 to evaluate drought influence on the growth and yield of different yam accessions. The experimental site was the IITA research farm at Minjibir, 40 km northwest of Kano; 500 m above sea level, in the Sudan Savanna agroecology of Kano State, Nigeria. The site is well drained with about 1% slope. Soil of the experimental site was hyperthermic typic ustipsamment, comprising of >80% sand, ≤ 10% silt, and ≤ 10% clay. The soil is characterized by high infiltration rates, with an overall mean of 17 cm hr^{-1} (Oluwasemire *et al.*, 2002).

3.3.2 Land preparation and soil analysis.

The field used was earlier cultivated to cassava and left to fallow for one year. The land was ploughed within one week prior to planting, then harrowed and ridged at 1m apart. A single composite was made from eight representative soil samples randomly taken from the field with a soil auger at a depth of 0 to 15 cm. The soils were thoroughly mixed, air dried, ground and passed through a 2 mm sieve for the determination of pH, particle size, exchangeable cations and available phosphorus. Subsamples for organic carbon and total nitrogen determination were passed through a

0.5 mm sieve. Soil physico-chemical analysis were carried out using IITA manual (1982) in the Analytical Service Laboratory at IITA, Ibadan. Particle size distribution was done using the hydrometer method (Bouyoucos, 1951) with sodium hexametaphosphate as the dispersant while soil pH was measured in a 1:1 soil: water ratio. Organic carbon was determined by chromic acid digestion method (Heanes, 1984). Phosphorus and exchangeable cations were estimated by Mehlich 3 extraction method (Mehlich, 1984). Soil was digested for Total N determination using acid mixture procedure (Novozamky *et al.*, 1983). Total N and available P were determined colorimetrically using the Technicon AAII Auto-analyser, while cations were determined using Atomic Absorption spectrophotometer (Model Buck 200A). Exchangeable acidity ($H^+ + Al^{3+}$ in cmol kg^{-1}) was measured after extraction with 1M KCl (Maclean, 1965). Effective cation exchange capacity (ECEC) expressed in cmol kg^{-1} soil is the sum of all exchangeable bases and acidity (Okalebo *et al.*, 1993). Climatic data of the site were assessed using an automated weather station (WS-GP2, Delta-T device, Ltd) installed at the experimental site.

3.3.3 Multiplication of mycorrhizae inoculum for field experiment.

Three months to the establishment of field trial, top soil was collected from an experimental field in IITA, sterilized and mixed with river sand in ratio of 2:1 (soil: sand). Each of ten pots were filled with 8 kg of this soil and mixed with inocula of *Glomus, Scutelospora, Aculospora, Entrophosphora and Gigaspora*. *Pearl millet* (*Pennisetum glaucum)* seeds were then planted and used for multiplication of mycorrhizae inoculum. Rorison's nutrient solution was added fortnightly throughout the growth period which lasted for 3 months. Nutrient addition was withdrawn and the plants stressed for 4 weeks to encourage sporulation. Pearl millet shoots were cut off at the base of the plant (soil surface level) while the roots were cut into pieces and mixed with soil to form soil-root inoculum.

3.3.4 Planting dates

Rainfall in Minjibir is unimodal, starts in June and stops in October. Considering the rainfall amounts and distribution, the three planting dates were spaced at 1 month intervals with the first date in July.

3.3.5 Experimental design and planting materials

Two separate experiments were set up for *D. alata* and *D. rotundata* accessions. They were laid out in a split-split-split plot design. Irrigation (well watered and water-stressed) constituted the main plot treatment; planting dates (three levels, separated by 1 month intervals) as subplot treatment; mycorrhizal levels (with and without) as the sub-sub plot; *D. alata* and *D. rotundata* accessions (3 each selected from experiment 2) as the sub-sub-sub plot.

The field was marked out into plots measuring 4 m x 4 m. Yam sett sizes of 120 g for *D. rotundata* and 150 g of *D. alata* were cut. Planting was done at about 10 to 15 cm depth on ridges at a spacing of 1 m x 1 m. Mycorrhizae inoculum of 50 g was added into each seed hole prior to planting. Each treatment had a total of 16 plants per plot and was replicated three times. Ten ridges were left between the two moisture stress levels to avoid spillage of water from the sprinklers.

For the irrigation treatment, stress imposition commenced at the same time irrespective of the differences in planting date, 14 weeks after planting (WAP) for the first planting, 10 WAP for the second and 6 WAP for the third. The unstressed treatment received 5 hours of irrigable water (12 mm of water) at 4 day- intervals while the stressed treatment received 5 hours of water monthly. Agronomic practices carried out include staking and weeding. Manual weeding was carried out every 4 weeks using hoe. Staking was done per stand using 2 m long stakes cut from *Leucaena leucocephala* trees. Twines were used to train the vines on the stakes.

Each of the two species had treatment combinations as follows:

$IR_{1-2}PD_{1-3}M+CL_1$

$IR_{1-2}PD_{1-3}M+CL_2$

$IR_{1-2}PD_{1-3}M+CL_3$

$IR_{1-2}PD_{1-3}M\text{-}CL_1$

$IR_{1-2}PD_{1-3}M\text{-}CL_2$

$IR_{1-2}PD_{1-3}M\text{-}CL_3$

where IR_1 and IR_2 are stressed and unstressed treatment , M+ and M- are with and without mycorrhizal inoculation; CL_{1---3} represent 3 selected accessions for each of *D. alata* and *D. rotundata.*

3.3.6 Data collection and analysis

Data collections were done at 14 and 18 WAP for each planting date for parameters such as chlorophyll content, stomata conductance and leaf area. Leaf area was determined using a portable leaf area meter (Model LI-3000, LI-COR, Nebraska, USA). Chlorophyll content was measured using Minolta SPAD-502 chlorophyll meter (Model 2900 DL Spectrum Technologies Inc.), while stomata conductance was measured using leaf Porometer (Model SC-1, Decagon Devices Inc., Pullman Washington, USA). These parameters were measured at four week intervals from the date of planting. Yam tubers were harvested at eight months after planting for each planting date. Fresh tuber weight (total yield per plot) and seed yam weight (tubers ≥ 100 < 1000g) as the subset of the total yield were recorded (Okwor *et al*., 2000). Statistical analysis was done using SAS package (SAS, 9.2); ANOVA was carried out and means were separated using least significant differences.

CHAPTER 4

RESULTS

4.1 Screening of 81 yam accessions for tolerance to moisture stress

4.1.1 Characteristics of soil used for screening

The soil used for experiment 1 (Table 4.1) was neutral (pH =7). The particle size distribution was predominantly sandy loam (790 g kg^{-1} sand, 90 g kg^{-1} silt and 120 g kg^{-1} clay). The organic carbon (7.6 g kg^{-1}), total nitrogen (0.9 g kg^{-1}), available P (8.3 mg kg^{-1}), Exchangeable bases: Ca (3.5 cmol kg^{-1}), Mg (0.7 cmol kg^{-1}), K (0.2 cmol kg^{-1}), Na (0.2 cmol kg^{-1}) and ECEC (4.6) of the soil were all below critical levels.

4.1.2 Variability among the 32 screened *D. alata* accessions

The 32 accessions differed significantly (P< 0.01) with respect to the six phenotypic traits considered viz. fresh shoot weight, fresh leaf weight, fresh root weight, plant vigour, vine length and total leaf area (Table 4.2). Five of the 32 accessions (00/00045, 03/00090, 03/00185, 93-36 and 02/00012) had means which were higher than the grand means for each of the traits. On the other hand, the performances of five other accessions (291, 00/00046, 02/00006, 05/00086 and 05/00141) were below the grand mean for each of the phenotypic traits.

4.1.3 Correlation among morphological traits of *D. alata* accessions

The relationships among the six traits are presented in Table 4.3. Fresh shoot weight was positively and significantly correlated with fresh leaf weight (r = 0.90**), vine length (r = 0.73**) and leaf area (r = 0.47**). The fresh leaf weight associated positively and significantly with the vine length (r = 0.59**). On the other hand, the plant vigour correlated with vine length (r = 0.45*) and leaf area (r = 0.43*).

Table 4.1. Chemical and physical characteristics of soil used for the first glasshouse study

Property	Value
pH (1:1 H_2O)	7.0
Organic Carbon (g kg^{-1})	7.6
Total N (g kg^{-1})	0.9
Available P (mg kg^{-1})	8.3
Exchangeable Cations (cmol kg^{-1})	
Ca^{++}	3.5
Mg^{++}	0.7
K^{+}	0.2
Na^{+}	0.2
Exchangeable Acidity (H^{+} + Al^{3+})	0.0
ECEC	4.6
Extractable micronutrients (mg kg^{-1})	
Zn	24.2
Cu	3.5
Mn	89.9
Fe	90.6
Bulk density (Mg m^{-3})	1.56
Particle size (g kg^{-1})	
Sand	790
Silt	90
Clay	120
Textural class (USDA)	Sandy loam

Table 4.2. Means of the morphological traits of the screened 32 *D. alata* accessions

Accessions	Fresh shoot weight	Fresh leaf weight	Fresh root weight	Plant vigour *	Vine length	Total leaf area
	g/pot				cm	cm^2
TDa 291	13.5	8.7	9.6	1.7	63.5	573.2
TDa 00/00046	11.5	8.6	10.9	2.7	53.5	597.0
TDa 00/00066	15.2	8.1	10.3	3.3	51.5	1003.6
TDa 01/00015	16.7	10.2	16.4	1.7	66.1	706.6
TDa 02/00006	17.4	10.7	6.6	3.3	50.5	712.5
TDa 02/00246	12.0	7.4	12.9	2.0	84.6	639.8
TDa 05/00086	13.4	8.9	6.6	1.7	66.2	467.5
TDa 05/00141	13.8	8.9	14.8	3.3	72.2	579.4
TDa 00/00103	16.1	11.2	10.2	1.7	60.1	890.2
TDa 02/00088	18.4	11.2	9.0	4.0	84.6	1056.6
TDa 02/00092	18.4	12.3	15.9	4.0	87.7	667.4
TDa 02/00151	18.5	12.2	9.3	1.3	79.0	673.2
TDa 05/00048	18.4	12.5	13.7	4.7	79.4	942.8
TDa 98/01176	18.8	11.6	12.5	2.0	72.3	1106.7
Kesofunfun	19.8	11.9	16.6	2.0	69.2	998.0
Lotosson	18.5	10.2	13.9	3.0	101.9	621.6
Agara white	19.2	12.2	9.6	2.7	98.6	960.8
TDa 00/00045	22.7	13.6	15.6	3.3	112.7	1180.2
TDa 00/00060	19.7	12.4	13.5	4.3	119.3	909.5
TDa 00/00064	22.9	13.4	13.1	2.7	116.6	958.1
TDa 00/00104	21.8	12.1	15.5	2.3	173	782.2
TDa 03/00090	18.9	11.5	24.2	2.3	101.7	1302.1
TDa 03/00185	24.7	13.4	13.2	4.7	144.2	1382.8
TDa 93-36	21.4	13.1	16.0	3.0	148.9	973.3
TDa 98/01166	22.2	13.1	13.3	2.3	111.1	921.7
Olesunle	19.0	10.4	19.3	1.7	95.1	1199.2
Sagbe	21.1	12.4	12.7	1.7	153.7	931.0
TDa 297	14.4	9.5	7.7	3.3	106.3	1113.2
TDa 00/00194	21.6	11.9	8.7	4.0	145.7	1187.9
TDa 02/00012	18.5	11.6	14.0	3.3	102.7	1164.8
Agara red	19.8	10.3	8.0	2.3	120.7	978.9
Sharm gbagada	15.7	8.5	12.9	3.0	72.7	1636.4
Range	11.5-24.7	7.4-13.6	6.6-24.2	1.3-4.7	52-149	468-1383
Grand mean	18.2	11.1	12.7	2.8	95.8	931.8
SE	1.89	1.13	1.25	0.34	22.37	192.93
P-value	<0.01	0.05	<0.01	<0.05	<0.05	0.01

SE: Standard error of the mean, * Values in the table are transformed (square root)data of scores 1-5, where 1 = poor, 2 = weak, 3 = moderate, 4 = good, 5 = excellent

Table 4.3. Correlation coefficients among six traits of *D. alata* accessions

	Fresh shoot weight	Fresh leaf weight	Fresh root weight	Plant vigour	Vine length
Fresh leaf weight	0.90**				
Fresh root weight	0.29ns	0.27ns			
Plant vigour	0.33ns	0.31ns	0.20ns		
Vine length	0.73**	0.59**	0.22ns	0.45*	
Leaf area	0.47**	0.30ns	0.27ns	0.43*	0.31ns

**: significant at *P*= 0.01, *: significant at *P*= 0.05, ns: not significant, n= 15

4.1.4 Grouping of the 32 *D.alata* accessions in a 2- dimensional plane

Figure 4.1 shows the 32 *D. alata* accessions in a 2-dimensional plane using the first 2 canonical axes (Canonical 1 and Canonical 2). From this analysis, four groups of accessions were identified based on their similarity for specific characteristics. Eightaccessions were found in Group 1. Group 2 was made up of 9 accessions, 10 accessions were in Group 3 while Group 4 contained five accessions. Canonical 1 clearly separated accessions in Group 1 from those in Group 3. Accessions in Group 2 and 4 were loosely dispersed. Group 4 were distinctly located northward of Canonical 2. The highest diversity exists between accessions in Groups 1 and 3 (Fig. 4.1).

4.1.5 Proportion of variation among *D. alata* accessions explained by each canonical axis

The first two canonical axes were mostly important in classifying the 32 *D. alata* accessions. Cumulatively, the two canonical axes (Can 1 and Can 2) accounted for 96% of the total variation among accessions (Table 4.4). The first accounted for 79% of the total variation while the contribution of the second to the total variation was 17%. The discriminatory role of each trait in the classification of the 32 accessions was equally revealed in Table 4.4. Traits of higher importance in Can 1 were fresh leaf weight, fresh shoot weight and vine length. Plant vigour and leaf area were the most important in their role discriminating the 32 accessions in Can 2. Only the role of fresh root weight appeared negligible in discriminating among the 32 *D. alata* accessions.

4.1.6. Descriptive statistics of the groups formed from the screening for moisture stress *in D. alata* accessions

The best performance for most of the traits was observed in Group 3 (Table 4.5) as observed in mean fresh shoot weight (21.4 g), fresh leaf weight (12.5 g), fresh root weight (15.6 g) and vine length (127.6 cm). The mean of the accessions in Group 4 however, was higher than those in Group 3 for plant vigour. Lowest mean values for fresh shoot weight (14.2 g), fresh leaf weight (8.9 g), vine length (63.5 cm) and total leaf area (660.0 cm^2) were observed in Group 1. Generally, the performances of accessions in Groups 2 and 4 for the six traits were intermediate as summarized in Table 4.6.

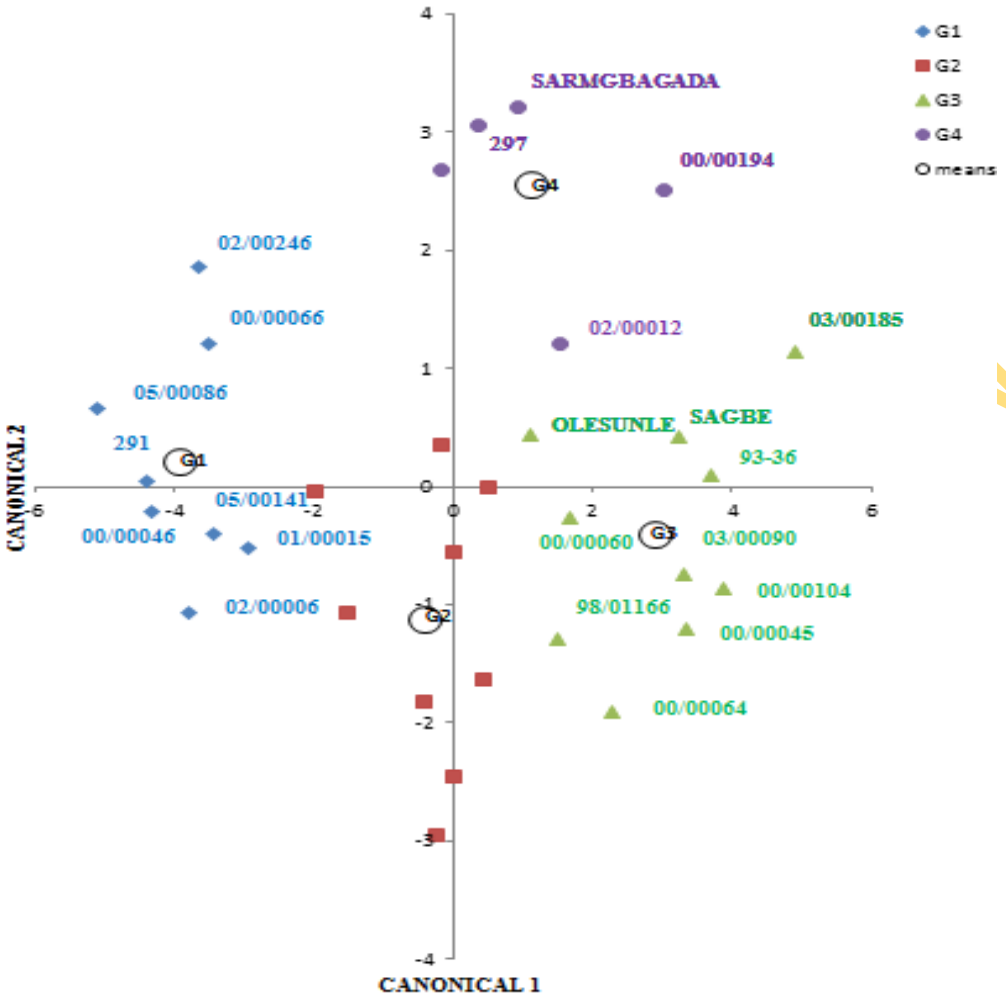


Fig. 4.1. Scatter diagram showing response to moisture stress by each of the 32 *D. alata* accessions

Table 4.4. Eigen values, proportion of variation and coefficients of correlation between original and canonical variables of *D. alata* accessions

Canonical Axes	Eigen value	Proportion of variance
		%
Can 1	7.57	79
Can 2	1.63	17
	Coefficient of correlation	
Variables	†Can 1	Can 2
Fresh leaf weight	0.47	0.53
Fresh root weight	0.18	0.28
Fresh shoot weight	0.53	0.29
Plant vigour	0.20	0.30
Vine length	0.48	0.15
Total leaf area	0.34	0.36

†Can= canonical

Table 4.5. Descriptive statistics of the four groups formed by cluster analysis for six phenotypic traits for the screening of *D. alata* accessions for moisture stress

Variable	Group	Minimum	Maximum	Mean	Sdev
Fresh leaf weight (g /pot)	1	7.4	10.7	8.9	1.1
	2	10.2	12.5	11.7	0.7
	3	10.4	13.6	12.5	1.0
	4	8.5	11.9	10.4	1.4
Fresh root weight (g /pot)	1	6.6	16.4	11.0	3.6
	2	9.0	16.6	12.3	2.9
	3	12.7	24.2	15.6	3.6
	4	7.7	14.0	10.3	2.9
Fresh shoot weight (g/ pot)	1	11.5	17.4	14.2	2.1
	2	16.1	19.8	18.5	1.0
	3	18.9	24.7	21.4	1.8
	4	14.4	21.6	18.0	2.9
Plant vigour *	1	1.3	4.0	2.2	0.9
	2	1.7	3.3	2.4	0.6
	3	1.7	4.7	3.2	0.9
	4	2.3	4.7	3.5	1.0
Total leaf area (cm^2)	1	467.5	1003.6	660.0	159.7
	2	621.6	1106.7	879.7	180.9
	3	782.2	1382.8	1054.0	197.1
	4	978.9	1636.4	1216.3	248.5
Vine length (cm)	1	50.5	84.6	63.5	11.7
	2	60.1	101.9	81.4	13.5
	3	95.1	173.0	127.6	25.6
	4	72.7	145.7	109.6	26.7

* Values in the table are means from transformed (square root) data of scores 1-5, where 1= poor, 2 = weak, 3 = moderate, 4 = good, 5 = excellent. Sdev= standard deviation

Table *4.6.* Means of the four groups of *D. alata* accessions generated by cluster analysis

Cluster	Fresh shoot weight	Fresh leaf Weight	Fresh root weight	Plant vigour *	Vine length	Total leaf area
	g/ pot				cm	cm^2
1	14.2	8.9	11.0	2.2	63.5	660.0
2	18.5	11.7	12.3	2.4	81.4	879.7
3	21.4	12.5	15.6	3.2	127.6	1054.0
4	18.0	10.4	10.3	3.5	109.6	1216.3
Mean	18.0	10.9	12.3	2.8	95.5	952.5
Sdev	3.0	1.6	2.4	0.6	28.6	238.6
Range	14.2-21.4	8.9-12.5	10.3-15.6	2.2-3.5	63.5-127.6	660.0-1216.3

* Values in the table are transformed (square root) data of scores 1-5, where 1 = poor, 2 = weak, 3 = moderate, 4 = good, 5 = excellent.
Sdev= standard deviation

4.1.7 Grouping of 49 *D. rotundata* accessions in a 2- dimensional plane

Forty- nine *D. rotundata* accessions were grouped into five clusters from the multivariate analysis carried out using four phenotypic traits and displayed in a 2-dimensional plane (Fig 4.2). Eleven accessions fell within Group 1, thirteen fell withinGroup 2, Group 3 had seven, Group 4 with twelve and Group 5 had six accessions. The highest diversity exists between accessions in Group 1 and 5.

4.1.8 Proportion of variation among *D. rotundata* accessions explained by each canonical axis

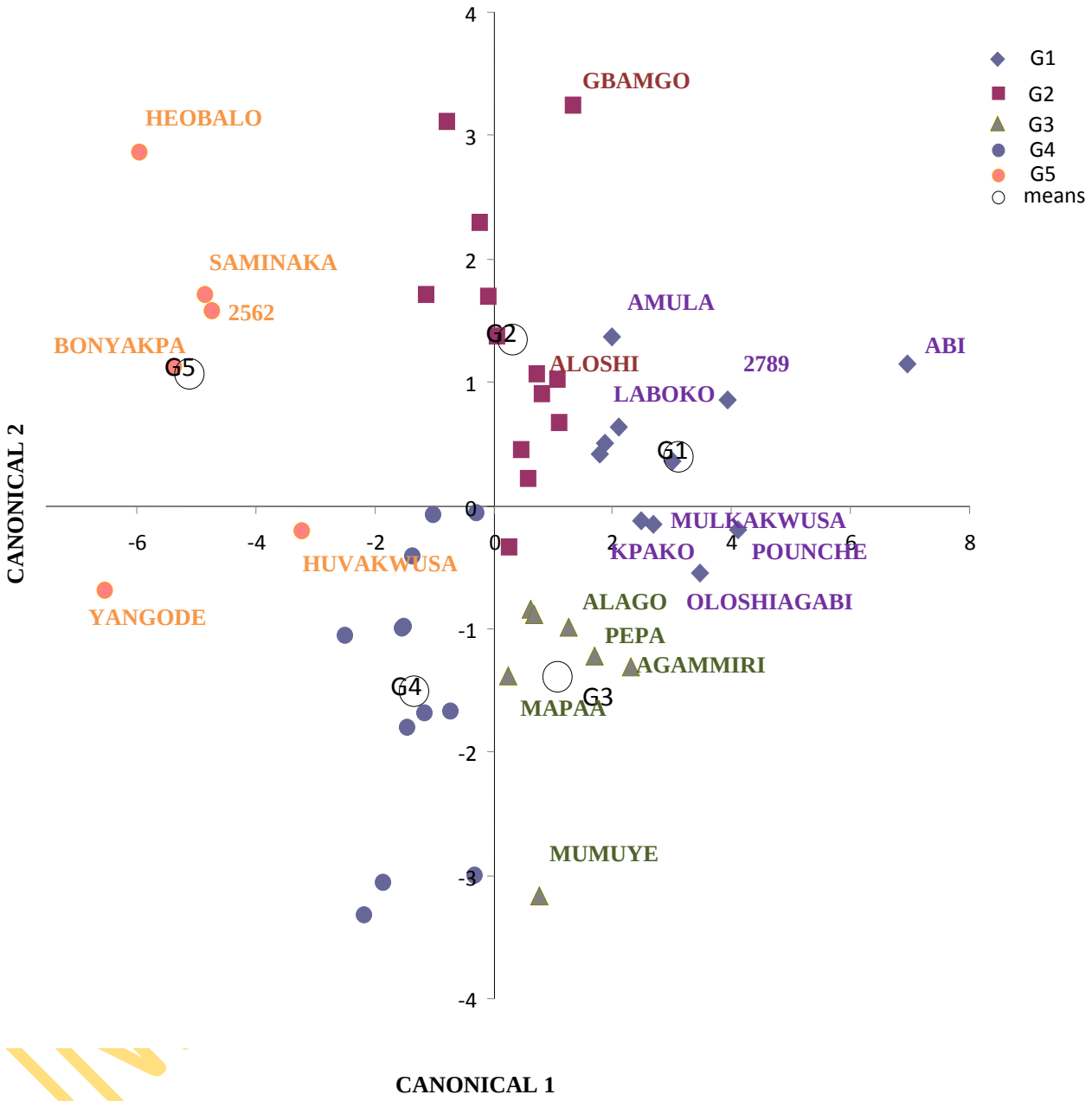
The 49 *D. rotundata* accessions were classified using the first 2 canonical axes, which cumulatively explained about 95% of the total variation among the *D. rotundata* accessions (Table 4.7). The first canonical axis explained 76%, while the second accounted for 19% of the total variation among these accessions. Fresh leaf, root, and shoot weight were shown to be the most important traits in Can 1 while plant vigour was the most important in their discriminatory role in Can 2 for the 49 *D. rotundata* accessions (Table 4.7).

4.1.9 Descriptive statistics of the groups formed from screening for moisture stressin *D. rotundata* accessions

Table 4.8 showed the range of mean values, and their standard deviation for the measured traits within each group. Accessions in Group 1 had the highest mean weight for fresh leaf weight, fresh root weight and shoot weight. Plant vigour was however highest among accessions in Group 4, while those Group 1 ranked second. With the exception of plant vigour, accessions within Groups 5 maintained plant weight below the main value for all traits (Table 4.9).

4.1.10. Selection of superior *D. alata* and *D. rotundata* accessions for further screening

Following the general screening of 81 yam (49 *D. rotundata* and 32 *D. alata*)accessions in Experiment 1, 12 best performing accessions of each species were selected


G1
G2
G3
G4
G5
means
GBAMGO
HEOBALO
SAMINAKA
2562
BONYAKPA
AMULA
ABI
ALOSHI
2789
LABOKO
G2
G5
G1
MULKAKWUSA
KPAKO
POUNCHE
HUVAKWUSA
YANGODE
ALAGO
OLOSHIAGABI
PEPA
AGAMMIRI
G4
G3
MAPAA
MUMUYE
CANONICAL 2
CANONICAL 1
4
3
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0
-1
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-4
-6
-4
-2
0
2
4
6
8

Fig. 4.2. Scatter diagram showing response to moisture stress by each of the 49 *D. rotundata* accessions

Table4.7.Eigen values, proportion of variation and coefficients of correlation between original and canonical variables of *D. rotundata* accessions

Canonical Axes	Eigen value	Proportion of variance
		%
Can 1	6.68	76
Can 2	1.65	19
	Coefficient of correlation	
Variables	†Can 1	Can 2
Fresh leaf weight	0.64	0.04
Fresh root weight	0.43	0.03
Fresh shoot weight	0.83	0.05
Plant vigour	0.12	0.86

†Can= canonical

Canonical 1 (76%) high fresh leaf, fresh root and fresh shoot

Table4.8. Five groups formed by cluster analysis for four phenotypic traits for the screening of *D. rotundata* accessions for moisture stress

Variable	Cluster	Minimum	Maximum	Mean	Sdev
Fresh leaf weight (g/pot)	1	7.7	15.3	10.7	2.1
	2	8.3	10.3	9.5	0.7
	3	7.8	10.9	9.8	1.0
	4	5.5	9.7	7.6	1.2
	5	2.3	5.2	3.5	1.4
Fresh root weight (g/pot)	1	6.5	15.8	10.3	2.6
	2	3.9	7.4	5.6	1.1
	3	4.9	8.9	7.0	1.3
	4	3.0	8.2	5.1	1.6
	5	1.7	6.7	3.9	2.2
Fresh shoot weight (g/pot)	1	16.7	25.3	20.4	2.4
	2	12.8	20.9	16.7	1.9
	3	14.3	19.1	17.5	1.8
	4	10.9	16.1	13.2	1.7
	5	3.6	10.1	6.5	2.5
Plant vigour *	1	2.0	3.0	2.4	0.3
	2	2.3	3.7	2.8	0.4

3	1.0	2.0	1.7	0.4
4	1.0	2.3	1.6	0.5
5	1.7	4.0	2.3	1.1

*Values in the table are transformed (square root) data of scores 1-5, where 1 = poor, 2 = weak, 3 = moderate, 4 = good, 5 = excellent. Sdev= standard deviation

Table4.9. Means of the five groups of *D. rotundata* accessions generated by cluster analysis

Cluster	Fresh leaf weight	fresh root weight	Fresh shoot weight	Plant vigour*
		g/plant		
1	10.7	10.3	20.4	2.4
2	9.5	5.6	16.7	2.8
3	9.8	7.0	17.5	1.7
4	7.6	5.1	13.2	1.6
5	3.5	3.9	6.5	2.3
Mean	8.2	6.4	14.9	2.2
Sdev.	1.3	1.8	2.1	0.5
Range	6.3-10.3	4.0-9.4	11.7-18.3	1.6-2.8

* Values in the table are transformed (square root) data of scores 1-5, where 1 = poor, 2 = weak, 3 = moderate, 4 = good, 5 = excellent. Sdev= standard deviation

from the groups and used for further studies. The selected accessions and their corresponding groups within each species are as shown in Table 4.10.

4.2 Influence of arbuscular mycorrhizal fungi inoculation on drought tolerance of yam under moisture stress

4.2.1 Chemical and physical characteristics of soils used for the second glasshouse experiment

The physico-chemical characteristics of soil used in experiment 2 is shown in Table 4. 11. The soil was sandy loam (790 g kg^{-1}) and alkaline (pH = 8.1). It had a high available P of 46.2 mg kg^{-1}, Ca content of 7.3 cmol kg^{-1} and ECEC was 9.8 cmol $kg^{-1.}$

4.2.2 Variation in morphological traits among 12 *D. alata* accessions

The mean values and *P*-values of the 14 parameters of the 12 accessions of *D. alata* considered are in Table 4.12. Significant ($P \leq 0.01$) variations were observed among these accessions for all the characteristics measured. Fresh below ground weight varied ranging from 57.1g (in TDa 93-36) to 112.2 g (in TDa 02/00012). Fresh tuber weight varied within the range of 24.0 g (TDa 02/00012) to 53.7 g (TDa 297). Dry tuber weight was highest in TDa 297 (139 g) while the least tuber weight of 4.9 g was observed in TDa 02/00151. Harvest index ranged between 9.3% (in TDa 02/00012) and 24.6% (TDa 297 and Kesofunfun). AMF spore number ranged from 104.2 spore/100 g soil (TDa 02/00246)

to 164 spore/100 g soil (TDa 00/00064). AMF colonization was within the range of 11.9% in TDa 03/00185 and 29.7% in TDa 297.

4.2.3 Correlation among agronomic traits in 12 *D. alata* accessions

The correlation coefficient of the 13 parameters for the 12 *D. alata* accessions is presented in Table 4.13. Fresh below ground weight had a positive and significant correlation with parameters such as fresh tuber weight (r = 0.78**), fresh leaf weight (r = 0.55**), dry below ground weight (r = 0.86**), dry tuber weight (r = 0.77**), number of tubers, harvest index (r = 0.60**), total leaf area (r = 0.47**) and AMF colonization (r = 0.33**). There were also significant (P = 0.01) correlation between fresh tuber weight and other parameters which includes dry below ground (r = 0.77**) and tuber (r = 0.89**) weight, number of tubers (r = 0.52**), harvest index (r = 0.80**), fresh vine weight (r =0.23**),

Table 4.10. Twelve selected accessions each of *D. alata* and *D. rotundata* from Experiment 1

S/N	*D. alata* (TDa)	Group (in Fig. 4.1)	*D. rotundata* (TDr)	Group (in Fig 4.2)
1	TDa 02/00012	4	TDr 99/02562	5
2	TDa 03/00185	3	TDr Agumaga	2
3	TDa 00/00060	3	TDr Abi	1
4	TDa 02/00151	2	TDr 99/02626	2
5	TDa 02/00092	2	TDr 99/02789	1
6	TDa 00/00064	3	TDr Didio	4
7	TDa 297	4	TDr Aloshi	2
8	TDa 00/00194	4	TDr 00/00365	2
9	TDa 02/00246	1	TDr 97/00812	3
10	TDa Kesofunfun	2	TDr Tabene	2

11	TDa 02/00006	1	TDr Saminaka	5
12	TDa 93-36	3	TDr Amula	1

fresh leaf weight (r = 0.47**), dry vine (r = 0.24**)and dry leaf weight (r = 0.46**),total leaf area (r = 0.41**), number of leaves(r = 0.46**) and AMF colonization (r = 0.46**).

4.2.4 Influence of mycorrhizal inoculation on *D. alata* accessions

Mycorrhizal inoculation treatment significantly (P= 0.01) enhanced the performance of *D. alata* accessions. Fresh and dry tuber weights were increased by 58% and 112% respectively while total leaf area, harvest index, AMF spore number and colonization increased by 24%, 74%, 145% and 100%, respectively (Table 4.14).

4.2.5 Effects of moisture stress on *D. alata* accessions

Highly significant variations (P = 0.01) were observed among the different levels of moisture stress imposed on *D. alata* accessions. Across the measured parameters, stress imposed at 75% FC at 11 WAP recorded the highest mean values of parameters. This was followed by stress imposed at 25% FC at 15 WAP (bulking stage) and the least mean values were observed in stress imposed at 25% FC at 11 WAP. At 15 WAP, stress imposed at 25% FC reduced fresh tuber weight by 67.8%, while stress imposed at 25% at FC 11 WAP (tuber initiation stage) further reduced fresh tuber weight by 83.2%. Moisture stress at 25% FC at 15 WAP reduced dry tuber weight by 69.7% while at 25% FC 11 WAP, dry tuber weight was further reduced by 86.5 %. Total leaf area decreased by 27% when moisture stress was imposed at 25% FC at 15 WAP, but at 25% FC at 11 WAP, total leaf area was further reduced by 39.5%. Harvest index declined by 46% at 25% FC 15

WAP and 65.4% at 25% FC 11 WAP, respectively. Moisture stress impact decreased in this order 75% FC 11 WAP < 25% 15 WAP < 2 5% FC 11 WAP (Table 4.15).

4.2.6 Influence of mycorrhizal treatment on tuber biomass, AMF spores and colonization of 12 *D. alata* accessions

Mycorrhizal inoculation significantly influenced the 12 *D. alata*accessions used in this study as shown in increased fresh tuber weight (P = 0.01), AMF colonization (P = 0.05) and number of spores (P= 0.01) (Table 4.16). Dry tuber weight of *D. alata* had a similar trend to that of fresh tuber weight under mycorrhizal inoculated treatment. Within mycorrhizal inoculated treatment, fresh tuber weight of*D. alata* accessions ranged from 25.0 g (TDa 02/00151) to 63.9 g (TDa00/00064) whilefortreatmentwithout mycorrhizae, fresh tuber weightwithout mycorrhizae, freshtuber weight ranged between 13.6 g

Table 4.11. Chemical and physical characteristics of soil used for the second glasshouse study

Property	Value
pH (1:1 H_2O)	8.1
Organic Carbon (g kg^{-1})	10.5
Total N (g kg^{-1})	1.3
Available P (mg kg^{-1})	46.2
Exchangeable Cations (cmol kg^{-1})	
Ca^{++}	7.3
Mg^{++}	1.9
K^{+}	0.5
Na^{+}	0.2
Exchangeable Acidity (H^{+} + Al^{3+})	0.0
ECEC	9.8
Extractable micronutrients (mg kg^{-1})	
Zn	25.0
Cu	5.0
Mn	89.0
Fe	96.0
Bulk density (Mg m^{-3})	1.6
Particle size (g kg^{-1})	
Sand	790
Silt	90
Clay	120
Textural class (USDA)	Sandy loam

Table 4.12. Variations among 12 *D. alata* accessions for growth and yield traits and for mycorrhizae characteristics.

Accessions (TDa)	Fresh below ground weight	Dry below ground weight	Fresh tuber weight	Dry tuber weight	Fresh leaf weight	Dry leaf weight	Fresh vine weight	Leaf area at 20WAP	Harvest index	AMF colonization	No. of AMF spores
				g/plant				cm^2		%	no./100g soil
02/00012	112.2a	22.1a	24.0e	5.9d	50.9a	9.1a	32.2ab	2545a	9.3e	14.4cd	116.6e
03/00185	70.1de	11.5d	29.8de	5.8d	43.4bc	7.6bc	34.9a	2402ab	10.5de	11.9d	122.3e
00/00060	78.5cd	14.4cd	32.4cde	7.4cd	47.4ab	8.0ab	31.3abc	2177abc	14.1cde	19.6cd	136.3c
02/00151	97.7ab	15.4cd	30.0de	4.9d	37.7cd	6.4cde	32.6ab	1913cd	10.8de	13.8d	109.6e
02/00092	95.0abc	17.8cd	30.2de	9.2bc	40.4c	7.8b	35.3a	2212abc	14.7cd	20.8c	143.6c
00/00064	91.5bc	15.2cd	51.5a	9.8bc	42.9bc	7.3bcd	30.6abc	2418ab	19.9bc	20.9c	164.0a
297	90.7bc	19.3ab	53.7a	13.9a	30.0ef	6.3cde	18.7e	1952cd	24.6a	29.7a	157.8a
00/00194	68.5de	13.2d	36.8cd	8.2cd	36.7cd	8.1ab	27.4bcd	2024bcd	18.1bc	21.4c	123.2e
02/00246	102.1ab	20.8ab	39.5bcd	9.8bc	38.0cd	7.1bcd	25.2cd	1821cd	15.6c	18.8cd	104.2e
Kesofunfun	89.6bc	15.4cd	46.3ab	11.3ab	25.5f	5.3e	18.1e	1379e	24.6a	29.6a	135.1c
02/00006	71.5de	13.4d	42.0bc	7.7cd	41.7bc	7.5bcd	28.7abcd	1871cd	18.2bc	29.2a	118.6e
93-36	57.1e	12.3d	37.8bcd	8.3cd	32.5de	6.1de	22.3de	1631de	21.6ab	23.1a	114.1e

Means with the same letter within a column are not significantly different at $P< 0.01$

Table 4.13. Correlation coefficients among agronomic traits of 12 *D. alata* accessions

	Fresh tuber weight	Fresh vine weight	Fresh leaf weight	No. of tubers	Dry below ground weight	Dry tuber weight	Dry vine weight	Dry leaf weight	Harvest index	Total leaf area	No. of leaves	AMF colonization
Fresh below ground weight	0.78**	0.36**	0.55**	0.44**	0.86**	0.77**	0.33**	0.50**	0.60**	0.47**	0.48**	0.33**
Fresh tuber weight		0.23**	0.47**	0.52**	0.77**	0.89**	0.24**	0.46**	0.80**	0.41**	0.46**	0.46**
Fresh vine weight			0.58**	0.09ns	0.29**	0.21**	0.65**	0.50**	0.07ns	0.48**	0.39**	0.06ns
Fresh leaf weight				0.19**	0.51**	0.46**	0.68**	0.84**	0.27**	0.78**	0.70**	0.17*
No. of tubers					0.47**	0.51**	0.13*	0.22**	0.51**	0.17*	0.28**	0.26**
Dry below ground weight						0.76**	0.26**	0.50**	0.53**	0.45**	0.48**	0.34**
Dry tuber weight							0.22**	0.49**	0.90**	0.40**	0.47**	0.48**
Dry vine weight								0.62**	0.06ns	0.62**	0.56**	0.01ns
Dry leaf weight									0.28**	0.68**	0.66**	0.22**
Harvest index										0.21**	0.30**	0.47**
Total leaf rea											0.71**	0.24**
No. of leaves												0.24**

**: significant at 0.01, *: significant at 0.05, ns: not significant, n = 18

Table 4.14. Influence of mycorrhizal inoculation on selected characters of *D. alata* accessions

Mycorrhizal inoculation	Fresh below ground weight	Dry below ground weight	Fresh tuber weight	Dry tuber weight	Fresh leaf weight	Dry Leaf weight	Dry vine weight	No. of leaves 20 WAP	Leaf area at 20 WAP	Harvest index	AMF colonization	No. of AMF spores
	———			g/plant	———			no./plant	cm^2	———%	———	no./100g soil
With mycorrhizae	97.8a	18.2a	46.3a	11.7a	41.1a	7.6a	7.9a	61.2a	2250a	21.4a	28.0a	183.0a
Without mycorrhizae	72.9b	13.6b	29.3b	5.5b	36.8b	6.9b	7.8a	55.0b	1808b	12.3b	14.0b	74.6b

Values represent means of 12 *D. alata* accessions**.** Means with the same letter in a column are not significantly different at $P< 0.01$

Table 4.15. Effects of moisture stress on some characters of *D. alata* accessions

Water application	Fresh below ground weight	Dry below ground weight	Fresh tuber weight	Dry tuber weight	Fresh leaf weight	Dry leaf weight	Fresh vine weight	Leaf area	Harvest index	AMF colonization	No. of AMF spores
	———			g/plant	———			cm^2	———	% ———	no./100g soil
75% FC at 11 WAP	134.3a	26.7a	76.2a	17.8a	53.0a	9.5a	33.5a	2607a	26.9a	26.9a	164.9a
25% FC at 15 WAP	75.7b	13.1b	24.5b	5.4b	34.7b	6.6b	28.3b	1903b	14.4b	20.1b	127.9b
25% FC at 11 WAP	46.2c	7.9c	12.8c	2.4c	29.1c	5.5c	22.5c	1577c	9.3c	16.3c	93.6c

Values represent means of 12 *D. alata* accessions**.** Means with the same letter in a column are not significantly different at *P*< 0.01

Table 4.16. Influence of mycorrhizal inoculation on AMF characterization and the mean tuber weight of 12 *D. alata* accessions

Accessions	Fresh tuber weight			Dry tuber weight			AMF colonization			AMF spores		
	M0	M1	PD	M0	M1	PD	M0	M1	PD	M0	M1	PD
	— g/plant —		%	— g/plant —		%	%			no. /100 g soil		%
TDa 02/00012	13.6b	34.3a	60.3	2.5b	9.5a	73.7	15.4b	27.4a	43.8	53.7b	179.4a	70.1
TDa 03/00185	27.0b	32.6a	17.2	3.3b	8.3a	60.2	9.4b	26.0a	63.8	73.0b	171.6a	57.5
TDa 00/00060	22.0b	42.8a	48.6	4.3b	10.6a	59.4	19.9b	31.2a	36.2	78.2b	194.3a	59.8
TDa 02/00151	34.9a	25.0a	-39.6	3.7a	6.2a	40.3	17.2a	23.1a	25.5	60.7b	158.6a	61.7
TDa 02/00092	22.6b	37.9a	40.4	4.7b	13.7a	65.7	13.9b	34.6a	59.8	84.0b	203.1a	58.6
TDa 00/00064	39.1b	63.9a	38.8	6.6b	13.0a	49.2	14.6b	34.5a	57.7	126.1b	201.9a	37.5
TDa 297	47.4b	60.0a	21.0	10.3b	17.5a	41.1	28.3b	36.8a	23.1	82.7b	232.9a	64.5
TDa 00/00194	24.2b	49.4a	51.0	4.8b	11.6a	58.6	18.4b	32.4a	43.2	61.7b	184.8a	66.6
TDa 02/00246	28.9b	50.0a	42.2	6.4b	13.2a	51.5	16.7b	30.3a	44.9	71.2b	137.2a	48.1
Kesofunfun	36.2b	56.3a	35.7	8.1b	13.9a	41.7	29.8a	35a	14.9	66.9b	203.3a	67.1
TDa 02/00006	33.2b	50.8a	34.6	4.9b	10.5a	53.3	30.8a	33.9a	9.1	74.6b	162.6a	54.1
TDa 93-36	25.2b	53.0a	57.4	4.6b	10.3a	38.8	22.6a	30.4a	25.7	62.6b	165.4a	62.2

M0: Without mycorrhizae, M1: with mycorrhizae, PD: percentage difference due to mycorrhizal inoculation, means with the same letter in a row for each character are not significantly different at $P \leq 0.05$

(TDa 02/00012) and47.4 g (TDa 297).A significant reduction was observed in fresh tuber weight of TDa 02/00151 with mycorrhizal application but this trend was however not observed in dry tuber weight. TDa 297 had a significant performance irrespective of mycorrhizal treatment although the fresh tuber weight for this accession under mycorrhizal application was still significantly higher than where mycorrhizae was not applied. Percentage increase in fresh tuber weight due to mycorrhizae inoculation ranged between -39.6% and 60.3%.

Inoculation of mycorrhizal significantly (P = 0.05) influenced AMF colonization among the 12 *D. alata*accessions. Under mycorrhizal treatment, AMF colonized accessions ranged from 23.1% (in TDa 02/00151) to 36.8 % (in TDa 297). For non-mycorrhizal treatment, AMF colonization was between 9.35 % (in TDa 03/00185) and 28.3% (TDa 297). There were also significant (P= 0.01) differences among accessions within mycorrhizal treatments. Under mycorrhizae applied treatment, number of spores was in the range of 137.2 spores/ 100 g soil (in TDa 02/00246) and 232.9 spores/ 100 g soil (in TDa 297) while in the treatment without mycorrhizae, number of spore ranged between 53.7 spores/ 100 g soil (in TDa 02/00012) and 126.1 spores/ 100 g soil (in TDa 00/00064) (Table 4.16).

4.2.7 Influence of mycorrhizal inoculation on the below and above ground biomass, total leaf area and number of AMF spores under moisture stress.

Mycorrhizal inoculation increased the biomass, total leaf area and number of AMF spores of *D. alata*accession (Table 4.17). With reference to the dry tuber weight, mycorrhizae treatment resulted in an increase of 88.6% at the least water-stressed condition (75% FC at 11WAP). For stress imposed at 25% FC, 15 WAP; mycorrhizal inoculation caused a 196% increase in dry tuber weight while stress imposition at the 25% FC, 11 WAP caused an increase of 127%.

4.2.8 Below ground biomass production of *12 D. alata* accessions under moisture stress condition

A general trend of stress impact was maintained within accession and moisture stress levels, across accessions for all measured parameters (Table 4.18). Stress impact was highest at 25% FC 11WAP and least when stress was imposed at 75% FC 11 WAP. The highest dry below ground weight was observed in TDa 02/00012 acrosswater levels. TDa 93-36 had the least dry below ground weight at the least stress level

Table 4.17. Influence of mycorrhizal inoculation on biomass, total leaf area and number of AMF spores under moisture stress

Mycorrhizal inoculation	Water level	Fresh below ground weight	Dry Below ground weight	Fresh tuber weight	Dry tuber weight	Fresh leaf weight	Total leaf area	No. of AMF Spores
		g/plant					cm^2	no. / 100 g soil
MC1	WL1	154.3a	31.5a	91.3a	23.2a	57.2a	2909a	245.6a
MC1	WL2	85.0b	14.6b	31.0b	8.0b	36.8b	2210b	177.9b
MC1	WL3	54.1c	8.5c	16.8c	3.4c	29.3c	1631c	125.3c
MC0	WL1	114.2a	21.9a	61.1a	12.3a	48.8a	2305a	84.2a
MC0	WL2	66.3b	11.6b	18.0b	2.7b	32.5b	1597b	77.8a
MC0	WL3	38.4c	7.3c	8.9c	1.5b	29.0b	1522b	61.9b

MC1-with mycorrhizae, MC0-without mycorrhizae, WL1- water applied at 75% Field Capacity (FC) 11 WAP, WL2-water applied at 25% FC 15 WAP, and WL3- at 25% FC 11 WAP. Means with the same letter in a column within a mycorrhizal inoculation level are not significantly different at $P \leq 0.05$.

Table4.18. Below ground biomass of 12 *D. alata* accessions under to moisture stress

Accessions	Dry below ground weight				Fresh tuber weight				Dry tuber weight			
	WL1	WL2	WL3	PD	WL1	WL2	WL3	PD	WL1	WL2	WL3	PD
	g/plant											
TDa 02/00012	38.3a	16.9b	11.2b	70.8	61.9a	8.7b	1.4b	97.7	14.8a	2.1b	0.8b	94.6
TDa 03/00185	21.7a	8.6b	4.2c	80.6	65.7a	23.1b	0.6c	99.1	15.5a	1.9b	0.0b	100.0
TDa 00/00060	25.3a	12b	5.9c	76.7	73.3a	21.2b	2.6c	96.5	17.2a	4.5b	0.6b	96.5
TDa 02/00151	22.8a	16.4b	6.9c	69.7	54.4a	25.9b	9.6c	82.4	9.5a	4.7b	0.7c	92.6
TDa 02/00092	29.1a	14.8b	9.7b	66.7	69.7a	13.1b	7.8b	88.8	22.3a	3.8b	1.5b	93.3
TDa 00/00064	24.6a	13.6b	7.3b	70.3	100.2a	31.6b	22.8b	77.2	19.3a	6.2b	3.9b	79.8
TDa 297	34.9a	15.3b	7.7c	77.9	104.4a	38. 3b	18.4b	82.4	27.4a	11.2b	3.0c	89.1
TDa 00/00194	22.3a	10.8b	6.5b	70.9	66.7a	29.5b	14.1c	78.9	15.7a	5.9b	3.0b	80.9
TDa 02/00246	37.0a	14.7b	10.8b	70.8	89.9a	19.2b	9.35b	89.6	22.9a	4.5b	1.9b	91.7
Kesofunfun	22.8a	14.3b	9.2b	59.6	86.9a	38.4b	13.4c	84.6	19.8a	9.9b	3.4b	82.8
TDa 02/00006	22.3a	10.3b	7.7b	65.5	77.3a	24.1b	24.6c	68.2	14.5a	5.0b	3.7b	74.5
TDa 93-36	19.4a	9.5b	7.9b	59.3	67.8a	20.5b	29b	54.6	11.6a	4.6b	6.1b	57.3

WL1- water applied at 75% Field capacity (FC) 11 WAP, WL2-water applied at 25% FC 15 WAP, and WL3-at 25% FC 11 WAP, PD: percentage difference between the highest and least moisture stress levels. Means with the same letter in a row for a parameter are not significantly different at *P* =0.01

of 75% FC 11 WAP, while TDa 03/00185 had the least fresh and dry below ground weight at intermediate and highest stress level.

Dry tuber weight significantly ($P < 0.01$) differed among the 12 *D. alata*accessions under varied moisture stress conditions. Under the least stress condition, dry tuber weight ranged from 9.5g (TDa 02/00151) to 27.4 g (TDa 297). At the intermediate stress level, dry tuber weight ranged from 1.9 g in TDa 03/00185 to 11.2 g (TDa 297). However under the highest stress level, TDa 03/00185 showed the highest response to water stress with respect to dry below ground weight (80.6%), fresh tuber weight (99.1%) and dry tuber weight (100%). On the other hand, kesufunfun had the lowest response to stress with respect to dry below ground weight (59.6%) while TDa 93-36 had the least fresh tuber (54.6%) and dry tuber (57.3%) weight (Table 4.18).

4.2.9 Influence of moisture stress on harvest index, AMF colonization and spores on 12 *D. alata* accessions

Harvest index (HI) significantly ($P < 0.05$) differed among the accessions across the imposed moisture stress levels. Under the least stress condition, HI ranged between 17.3% (TDa 02/00151) and 35.4% (TDa 297). At the highest stress level, TDa 93-36 ranked the best with HI of 24.1% while TDa 03/00185 had the least HI of 0.1% (Table 4.19).

Mycorrhizae colonization of the accessions under least stress condition was in the range of 22.4 (TDa 03/00185) and 39.7% (TDa 297) while at the highest imposed stress condition, it ranged from 14.1 (TDa 02/00151) to 29.3% (TDa 02/00006).
There were significant ($P = 0.05$) differences in the number of AMF spores for the 12 *D. alata* accessions under varied moisture stress conditions. Under the highest stress condition, the number varied between 73 spores /100 g soil (TDa 02/000006) and 128 spores /100 g soil (TDa 00/00064).

4.2.10 Influence of mycorrhizal inoculation on tuber weight of 12 *D. alata* accessions under moisture stress

*D. alata*accessions differed significantly ($P < 0.01$) in fresh tuber weight with mycorrhizal inoculation under moisture stress (Table 4.20). TDa 00/00064 maintained the highest mean weights of 116.6 g and 37.3 g/plant at the least and highest stress

Table 4.19. Influence of moisture stress on the harvest index, AMF colonization and spores of 12 *D. alata* accessions

Accessions	Harvest index (%)				AMF colonization (%)				No. of AMF spores (no./100 g soil)			
	WL1	WL2	WL3	PD	WL1	WL2	WL3	PD	WL1	WL2	WL3	PD
TDa 02/00012	18.5a	5.7b	3.6b	80.5	24.0a	20.2a	20.0a	16.7	151.7a	115.5b	82.5c	45.6
TDa 03/00185	24.6a	6.7b	0.1b	99.6	22.4a	12.0b	18.8ab	16.1	150.8a	126.5b	89.5c	40.6
TDa 00/00060	26.7a	13.0b	2.5b	90.6	30.6a	23.5b	22.5b	26.5	178.2a	138.7b	92.0c	48.4
TDa 02/00151	17.3a	12.1ab	2.9b	83.2	26.5a	19.8b	14.1b	46.8	130.2a	120.7a	78.0b	40.1
TDa 02/00092	28.7a	10.1b	5.3b	81.5	22.9a	26.2a	23.7a	-3.5	180.2a	143.3b	107.2c	40.5
TDa 00/00064	30.1a	17.2b	12.6b	58.1	22.3a	31.3a	20.1a	9.9	202.0a	161.7b	128.3c	36.5
TDa 297	35.4a	26.3b	12.1c	65.8	39.7a	30.5b	27.4b	31.0	210.5a	157.2b	105.7c	49.8
TDa 00/00194	24.0a	17.6b	12.8b	46.7	28.5a	22.3a	25.5a	10.5	164.7a	123.0b	82.0c	50.2
TDa 02/00246	29.5a	10.5b	6.7b	77.3	29.9a	23.5a	17.1a	42.8	138.3a	76.3ab	98.0b	29.1
TDa Kesofunfun	34.7a	26.1b	12.9c	62.8	39.6a	32.0b	25.5b	35.6	171.8a	128.2b	105.3b	38.7
TDa 02/00006	26.0a	13.2b	15.3b	41.2	33.8a	34.0a	29.3a	13.3	151.5a	131.0a	73.2b	51.7
TDa 93-36	26.8a	13.9a	24.1a	10.1	37.1a	23.9ab	18.4b	50.4	148.7a	112.3b	81.3c	45.3

WL1: water applied at 75% field capacity (FC) 11 WAP, WL2: water applied at 25% FC 15 WAP and WL3: water applied at 25% FC 11 WAP, PD: percentage difference between the highest and least moisture stress levels. Means with the same letter in a row for a parameter are not significantly different at $P \leq 0.05$

levels, respectively. With mycorrhizal inoculation under the highest stress level, fresh tuber weight ranged between 1.3 g (TDa 03/00185) and 37.3 g (TDa 00/00064).With no mycorrhizal inoculation, TDa 93-36 had a significantly highest fresh tuber weight under the highest stress level, a trend which was maintained for dry tuber weight.

4.2.11 Variations among 12 *D. rotundata* accessions for some parameters under controlled moisture condition

A highly significant variation was observed across these accessions for parameters assessed (Table 4.21). Fresh below ground biomass weight varied among the accessions, ranged from 37.9 g/plant (Agumaga) to 83.3 g/plant (Abi). Fresh tuber weight varied between 13.4 g/plant (TDr 2789) and 56.5 g/plant (Abi). Dry below ground weight ranged between 7.8 g/plant (Agumaga) and 18.0 g/plant (Abi). Dry tuber weight ranged from 3.6 (TDr 2789) to 14.1 g/plant (Saminaka). However, dry tuber weight in Saminaka did not differ significantly with that of Abi (13.2 g/plant). Harvest index varied among accessions ranging from 10.8% (TDr 2789) to 32.0% (Saminaka). Aloshi had the highest total leaf area, fresh vine weight, number of leaves, but its economic traits such as tuber weight and harvest index were low.

4.2.12 Relationships among agronomic traits of 12 *D. rotundata* accessions

The correlation coefficients of the parameters measured for *D. rotundata* accessions are shown in Table 4.22. Fresh tuber weight was positively and significantly related to fresh below ground weight (r = 0.91**), dry below ground weight (r = 0.90**), dry tuber weight (r = 0.91**) and harvest index (r = 0.78**). It was also positively related with dry leaf weight (r = 0.31**) and total leaf area (r = 0.23**). Dry vine weight was negatively and significantly correlated with harvest index (r = - 0.34**). Dry vine weight was however positively correlated with dry leaf weight (r = 0.52**) and total leaf area (r = 0.42**). Fresh leaf weight had a significant but negative correlation with number of tubers (r = -0.19) but was highly significant and positively in agreement with dry leaf weight (r = 0.84) and total leaf area (r = 0.78). Dry below ground weight was positively and significantly correlated with dry tuber weight (r = 0.92) harvest index (r = 0.73), dry leaf weight (r = 0.36) and total leaf area (r = 0.29).

Table 4.20. Influence of mycorrhizal inoculation on fresh tuber weight of 12 *D. alata* accessions under moisture stressed condition

Accession	Fresh tuber weight (g/plant)					
	With mycorrhizae			Without mycorrhizae		
	WL1	WL2	WL3	WL1	WL2	WL3
TDa 02/00012	87.6a	12.6b	2.8b	36.1a	4.8b	2.0b
TDa 03/00185	80.8a	16.9b	1.3b	50.6a	29.4a	2.5b
TDa 00/00060	93.2a	30.8b	5.4b	53.4a	11.6b	2.4b
TDa 02/00151	49.2a	25.8ab	7.5b	59.6a	25.9b	19.3b
TDa 02/00092	80.4a	17.6b	15.7b	59.0a	8.7b	6.6b
TDa 00/00064	116.6a	37.9b	37.3b	83.8a	25.3b	11.6b
TDa 297	113.2a	38.3b	28.6b	95.5a	38.4b	8.2c
TDa 00/00194	88.1a	38.1b	21.9c	45.4a	20.8ab	6.4b
TDa 02/00246	104.5a	29.3b	16.3b	75.3a	9.0b	2.4b
TDa Kesofunfun	93.4a	52.3b	23.2b	80.5a	24.6b	10.5b
TDa 02/00006	79.1a	39.1b	34.3b	75.5a	9.2b	15.0b
TDa 93-36	109.1a	33.0b	16.9c	26.4ab	8.1b	41.0a

WL1- water applied at 75% Field capacity (FC) 11 WAP, WL2- water applied at 25% FC 15 WAP, and WL3- at 25% FC 11 WAP. Means with the same letter in a row within mycorrhizae level are not significantly different at P <0.01.

Table 4.21. Variations in selected characters of 12 *D. rotundata* accessions

Accession (TDr)	Fresh below ground weight	Dry below ground weight	Fresh tuber weight	Dry tuber weight	Fresh leaf weight	Dry leaf weight	Fresh vine weight	Total leaf area	Harvest index	AMF colonization	No. of AMF spores
	g/ plant							cm^2	%		no./100g soil
99/2562	44.2def	9.1d	22.3de	5.6def	26.6cde	5.2cd	34.3a	1166ef	18.4cd	6.6ef	92.0f
Agumaga	37.9f	7.8d	23.5de	4.8f	21.8e	4.8d	30.9ab	1073f	16.2d	7.1def	97.0ef
Abi	83.3a	18.0a	56.5a	13.2a	46.4a	8.9a	26.0bc	1832b	24.3b	13.2abc	185.0a
99/2626	43.1ef	9.6d	26.3cd	5.8def	31.0bcd	5.8cd	31.1ab	1359cdef	17.7cd	2.7f	109.0e
99/2789	38.9f	9.5d	13.4e	3.6f	35.7b	6.4bc	31.0ab	1583bcde	10.8e	8.4cde	89.0f
Didio	59.5bcd	15.2ab	45.7ab	11.9ab	33.4bc	7.5b	24.6c	1680bcd	24.0b	9.4bcde	143.0bc
Aloshi	61.7bc	13.4bc	37.1bc	8.8bcd	43.1a	8.8a	36.6a	2321a	17.5d	12.4abcd	140.0bcd
00/365	64.1b	15.4ab	49.1a	10.9abc	23.4e	5.0d	30.8ab	1096f	24.1b	13.7ab	128.0d
97/812	72.9ab	15.5ab	50.2a	10.4abc	35.8b	6.5bc	22.2c	1770bc	24.6b	13.9ab	149.0bc
Tabene	57.4bcde	17.2a	48.9a	12.3ab	25.4de	5.3cd	21.8c	1207ef	22.5b	7.8def	150.0bc
Saminaka	64.4b	16.7ab	55.6a	14.1a	21.0e	4.5d	16.4d	1275def	32.0a	15.1a	151.0b
Amula	47.4cdef	11.0cd	33.0cd	7.9cde	22.8e	5.0d	26.0bc	1089f	22.5bc	7.4def	135.0cd

Values represent means of 12 *D. rotundata* accessions**.** Means with the same letter in the column are not significantly different at $P = 0.01$.

Table 4 .22. Correlation among agronomic traits in 12 *D. rotundata* accessions

	Fresh tuber weight	Fresh vine weight	Fresh Leaf weight	No. of tubers	Dry below ground weight	Dry tuber weight	Dry vine weight	Dry leaf weight	Harvest Index	Total leaf area	No. of leaves	No. of spores
Fresh below ground weight	0.91**	0.14*	0.48**	0.06ns	0.90**	0.85**	0.08ns	0.41**	0.67**	0.31**	0.39**	0.55**
Fresh tuber weight		0.03ns	0.35**	0.11ns	0.90**	0.91**	-0.02ns	0.31**	0.78**	0.23**	0.32**	0.60**
Fresh vine weight			0.60**	-0.15*	0.08ns	0.02ns	0.84**	0.52**	-0.26**	0.46**	0.46**	0.04ns
Fresh leaf weight				-0.19**	0.41**	0.32**	0.49**	0.84**	0.03ns	0.78**	0.62**	0.36**
No. of tubers					0.08ns	0.14*	-0.13ns	-0.17*	0.21**	-0.1ns	-0.00ns	0.09ns
Dry below ground weight						0.92**	0.04ns	0.36**	0.73**	0.29**	0.35**	0.58**
Dry tuber weight							-0.04ns	0.28**	0.88**	0.23**	0.32**	0.57**
Dry vine weight								0.52**	-0.34**	0.42**	0.33**	0.01ns
Dry leaf weight									-0.03ns	0.70**	0.58**	0.29**
Harvest index										0.00ns	0.14*	0.44**
Total leaf area											0.71**	0.28**
No. of leaves												0.32**

**: significant at 0.01, *: significant at 0.05, ns: not significant at $P< 0.05$, n = 18

4.2.13 Influence of AMF inoculation on selected characters in 12 *D. rotundata* accessions

Mycorrhizal inoculation led to a highly significant increase ($P \leq 0.01$) in fresh and dry below ground weight, fresh and dry tuber weight, total leaf area, number of leaves, harvest index, AMF spore number and colonization as shown in Table 4.23. Mycorrhizal inoculation increased the dry below ground weight by 28.5%, fresh tuber weight by 33.3%, dry tuber weight by 37.7%, and total leaf area by 18%, HI by 19.2%, number of spores by 100% and AMF colonization by 222%.

4.2.14 Effects of moisture stress on selected parameters in *D. rotundata* accessions

The level of water application significantly ($P < 0.01$) influenced the performance of *D. rotundata* accessions at $P < 0.01$ as shown in Table 4.24. Water applied at 75% FC 11 WAP showed the best performance for all the parameters. At intermediate stress level (25% FC 15 WAP), a significant reduction in the mean values of the traits was observed.At the highest imposed stress level (25% FC 11 WAP), drastic fall in mean values of the assessed parameters were observed. Fresh tuber weight of *D. rotundata* for instance across the water levels, was within the range of 16.8 to 66.1 g/plant. Moisture stress imposition effect on *D. rotundata* accessions followed similar trend of 75% FC at 11WAP < 25% FC at 15 WAP < 25% FC at 11 WAP, the same trend was observed in *D. alata.*

4.2.15 Interactive effect of mycorrhizal and moisture stress on the total leaf area of *D. rotundata* accessions

Mycorrhizae inoculation significantly increased the total leaf area under varied moisture stress levels as clearly shown in Fig. 4.3. This significant effect of mycorrhizae inoculation led to a linear decrease in leaf area as water stress level progressed. Under water applied at 75% FC 11 WAP and mycorrhizal inoculation, leaf area of 2043 cm^2 was recorded while at the highest stress level, leaf area decreased to 1121cm^2. Besides stress level, the growth stage of *D. rotundata* at the time of stress imposition also influenced the effect of mycorrhizae treatment on the total leaf area. Inoculation of *D. rotundata*accessions under moisture stress condition at 25% FC 15 WAP led to a meaningful increase in the leaf area as compared to mycorrhizae inoculation at 25% FC 11 WAP. In treatment without mycorrhizae inoculation, significant difference in the values of leafarea was observed between theleast and

Table 4.23. Influence of AMF inoculation on selected characters in 12 *D. rotundata* accessions

Mycorrhizal treatment	Fresh below ground weight	Dry below ground weight	Fresh tuber weight	Dry tuber weight	Fresh leaf weight	Dry leaf weight	Fresh vine weight	Total leaf area	Harvest index	AMF colonization	No. of AMF spores
	g/plant							cm^2		%	no./100g soil
With mycorrhizae	62.4a	14.8a	43.9a	10.5a	32.3a	6.3	27.9	1576a	23.1a	15.0a	174.0a
Without mycorrhizae	50.0b	11.5b	32.9b	7.6b	28.9b	6	27.4	1336b	19.3b	4.7b	87.0b
						ns	ns				

Values represent means of 12 *D. rotundata* accessions. Within columns, means with the same letter are not significantly different at $P \leq 0.01$

Table 4.24. Effects of moisture stress on selected parameters in 12 *D. rotundata* accessions

Water application	Fresh below ground weight	Dry below ground weight	Fresh tuber weight	Dry tuber weight	Fresh leaf weight	Dry leaf weight	Fresh vine weight	Total leaf	Harvest Index	AMF colonization	No. of AMF spores
				g/plant				cm^2		%	no/100g soil
75% FC at 11WAP	92.8a	21.8a	66.1a	15.8a	40.2a	7.7a	33.1a	1771a	27.3a	12.9a	160.9a
25% FC at 15WAP	47.8b	11.4b	32.0b	7.7b	28.5b	5.8b	26.6b	1431b	20.8b	8.3b	122.2b
25% FC at 11WAP	27.7c	6.2c	16.8c	3.7c	22.9c	4.9c	23.3c	1160c	15.5c	8.3c	109.0c

Values represent means of 12 *D. rotundata* accessions**.** Means with the same letter in a column are not significantly different at $P< 0.01$

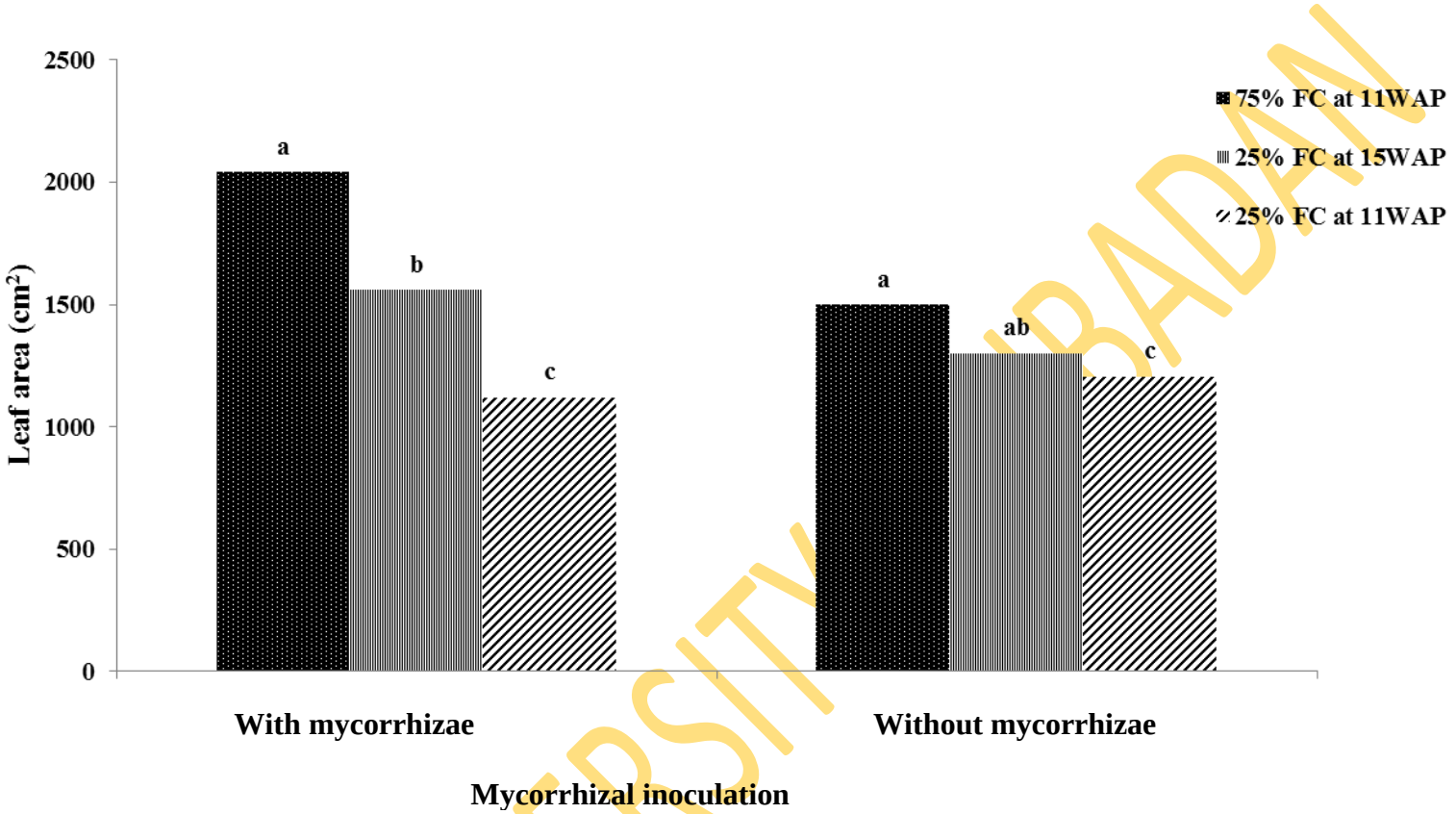

Fig. 4.3. Influence of mycorrhizal treatment on the leaf area of *D. rotundata* under moisture stress.

(Within mycorrhizal inoculation level, bars with the same letter are not significantly different at $P \leq 0.01$)

highest stressed condition while no difference was noted between the intermediate and least stressed conditions.

4.2.16 Influence of mycorrhizal inoculation on fresh leaf and vine weight, AMF colonization and number of spores of *D. rotundata* under moisture stress condition

Effect of mycorrhizal inoculation differed significantly with moisture stress levels at $P \leq 0.01$ for fresh vine and leaf weight, AMF colonization and spore (Table 4.25). Under the least stress imposition (water applied at 75% FC at 11 WAP); mycorrhizal inoculation increased the fresh leaf and vine weight, AMF colonization and spore count appreciably compared to treatments without mycorrhizae application. Mycorrhizae inoculation effect decreased with an increase in moisture stress imposition (Table 4.25). At the highest moisture stress level (water applied at 25% FC at 11 WAP); mycorrhizal inoculation did not cause an increase in the fresh vine and leaf weight. It however, led to increased number of AMF spores in the soil as well as AMF colonization of the root.

4.2.17 Influence of mycorrhizal inoculation on root colonization and AMF spores of 12 *D. rotundata* accessions

Interactive effect of mycorrhizae inoculation and accession on the number of AMF spores and AMF colonization were significant at P =0.01 (Table 4:26). With mycorrhizal inoculation, accessions showed a substantial increase in the number of AMF spores and AMF colonization. The number of AMF spores ranged from 111.3 (TDr 99/2789) to 280.3 (Abi) due to mycorrhizal inoculation, as against a lower range of 65.8 (TDr 99/2789) to 111.3 (Saminaka) for treatment without mycorrhizal inoculation. Similarly, AMF colonization of the root due to mycorrhizal inoculation ranged from 5.3% (TDr 99/2626) to 23.9% (Abi) while a lower range of 0.0% (TDr 99/2626 and TDr 99/2562) to 12.7% (TDr 97/812) were observed among accessions without mycorrhizal inoculation.

4.2.18 Effects of moisture stress on dry tuber weight in 12 *D. rotundata* accessions

Interactive effect of water level and accession on dry tuber weight was significant (Fig.4.4). At least stressed treatment (water applied at 75% FC at 11 WAP), *Abi* was thebest performed accession. It however did not differ substantially from *Didio*, TDr 00/365, and *Tabene*.In terms of dry tuber weight within this water level,

Table 4.25. Influence of mycorrhizal inoculation on AMF characterization, fresh vine and leaf weight of *D. rotundata* under moisture stress

Mycorrhizal Inoculation	Water level	Fresh vine weight	Fresh leaf weight	No. of AMF spores	AMF colonization
		—— g/ plant ——		no./ 100g soil	%
MC1	WL1	35.4a	43.7a	215.4a	17.6a
MC1	WL2	26.9b	30.7b	168.0b	12.9b
MC1	WL3	21.3c	22.2c	139.7c	14.4c
MC0	WL1	30.8a	36.7a	106.4a	8.1a
MC0	WL2	26.2b	26.3b	76.4b	3.7b
MC0	WL3	25.3b	23.5b	78.2b	2.2b

MC1: with mycorrhizae, MC0: without mycorrhizae, WL1-3: water applied 75% field capacity at 11WAP, 25% FC at 15 WAP and at 25% FC at 11 WAP. For each mycorrhizae inoculation level, means with the same letter are significantly different at $P \leq 0.05$

Table 4.26. Influence of mycorrhizal inoculation on AMF characterization in 12 *D. rotundata*accessions

Accessions	No. of AMF spores (no./ 100 g soil)			AMF colonization (%)		
	MC1	MC0	PD	MC1	MC0	PD
TDr 99/2562	114.2a	70.0b	38.7	13.1a	0.0b	100.0
TDr Agumaga	114.2a	80.4b	29.6	13.3a	0.9b	93.2
TDr Abi	280.3a	89.3b	68.1	23.9a	2.7b	88.7
TDr 99/2626	131.1a	87.1b	33.6	5.3a	0.0b	100.0
TDr 99/2789	111.3a	65.8b	40.9	12.7a	4.2b	66.9
TDr Didio	206.0a	79.6b	61.4	11.8a	7.1b	39.8
TDr Aloshi	181.3a	99.6b	45.1	12.9a	12.0b	7.0
TDr 00/365	160.9a	94.3b	41.4	22.0a	5.3b	75.9
TDr 97/812	199.0a	98.2b	50.7	15.1a	12.7b	15.9
TDr Tabene	218.7a	81.8b	62.6	13.8a	1.8b	87.0
TDr Saminaka	191.5a	111.3b	41.9	23.3a	6.9b	70.4
TDr Amula	183.5a	111.3b	52.6	12.7a	2.2b	82.7

MC1: with mycorrhizae, MC0: without mycorrhizae. PD: percentage difference between MC1 and MC0. Means with the same letter in a row within each parameter are not significantly different at $P \leq 0.01$.

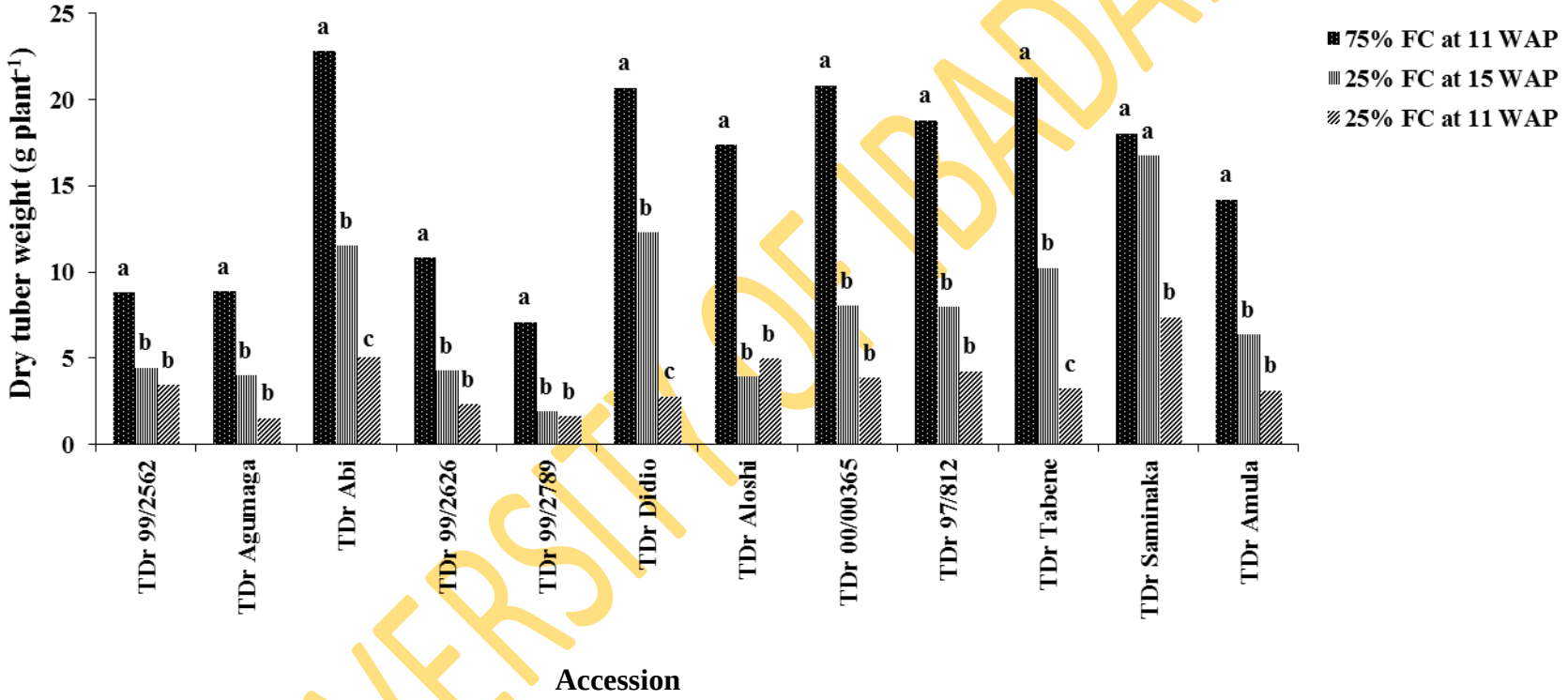

Fig. 4.4. Effect of moisture stress on the dry tuber weight of 12 *D. rotundata* accessions.
(Bars with the same letter for eachaccession are not significantly differentat $P = 0.01$)

least mean weight was recorded inTDr 99/2789, which was not substantially different (19.6%) from thoseof TDr 99/2562 and *Agumaga*. At moisture stress applied at 25% FC at 15 WAP and 25% FC at 11 WAP, *Saminaka* had the highest dry tuber weight. This weight was however, not significantly different from *Abi* and *Aloshi* at the highest stress level. TDr 99/2789 had the least dry tuber weight at 25% FC at 11 WAP; this was though not different from those of other accessions except *Abi*, *Aloshi* and *Saminaka*.

4.2.19. Effects of moisture stress on the below ground dry weight, harvest index, number of spores and colonization of AMF

Below ground dry weight differed significantly (P = 0.01) among the 12 *D. rotundata* accessions under moisture stress conditions (Table 4.27). Accession *Agumaga* maintained the least below ground dry weight across the 3 water levels. Under the least stress level (75% FC at 11 WAP), *Tabene* had the highest dry tuber weight, but under intermediate and highest stress condition, *Saminaka* had the highest dry tuber weight.

Harvest index was significantly influenced by water level and accession interaction at P < 0.01. Across moisture stress conditions, *Saminaka* had the highest harvest index while TDr 99/2789 was the least performed accession at the least and intermediate stress levels. Under the highest stress condition, *Agumaga* had the least harvest index though this was not significantly different from that of TDr 99/2789 (Table 4.27).

The highest mean number of AMF spores across moisture stress levels was observed in *Abi* 262.5, 158.7 and 133.3 respectively, while the least number of spores under the intermediate and highest stress levels were observed in TDr 99/2789 as 82.8 and 81.8 respectively.

4.2. 20. Selection of *D. rotundata* and *D. alata* accessions for field screening

Three accessions each of *D. rotundata* viz. TDr *Abi*, TDr *Aloshi* and TDr *Saminaka* and *D. alata* viz. TDa 02/00012, TDa 02/00151 and TDa 00/00064 were selected from 12 accessions of the respective species. This selection was based on their consistent performance under varied imposed moisture stress and mycorrhizae conditions (Table 4.28 and Table 4.29). *D. rotundata*, TDr *Aloshi* and TDr *Abi* maintained a stable performance irrespective of the moisture stress and mycorrhizae

Table 4.27. Effects of moisture stress on the dry below ground weight, harvest index and number of AMF spores of 12 *D. rotundata* accessions

	Dry below ground weight (g/plant)				Harvest index (%)				AMF spores (no. /100 g soil)			
Accession	WL1	WL2	WL3	PD	WL1	WL2	WL3	PD	WL1	WL2	WL3	PD
TDr 99/2562	15.4a	6.7b	5.2b	66.2	19.5a	19.4a	16.3a	16.4	98.7a	92.2a	85.5a	13.4
TDr Agumaga	12.8a	6.6b	4.1b	68.0	22.5a	16.9ab	9.1b	59.6	101.3a	95.5a	95.2a	6.0
TDr Abi	30.2a	15.7b	8.2c	72.8	30.5a	25.7ab	16.8b	44.9	262.5a	158.7b	133.3b	49.2
TDr 99/2626	16.1a	8.2b	4.4c	72.7	24.2a	14.6b	14.4b	40.5	114.2a	108.8b	104.3b	8.7
TDr 99/2789	15.8a	8.3b	4.3c	72.8	15.9a	7.2b	9.2b	42.1	101.0a	82.8b	81.8b	19.0
TDr Didio	25.1a	15.9b	4.6c	81.7	32.6a	26.6a	12.8b	60.7	187.2a	126.7b	114.5b	38.8
TDr Aloshi	22.0a	9.6b	8.6b	60.9	25.8a	11.4b	15.3b	40.7	162.7a	145.3ab	113.3b	30.4
TDr 00/365	25.1a	13.4b	7.5c	70.1	33.5a	22.6b	16.2c	51.6	151.3a	136.8b	94.7c	37.4
TDr 97/812	26.9a	12.4b	7.3b	72.9	30.0a	24.4ab	19.3b	35.7	183.2a	143.9b	118.6b	35.3
TDr Tabene	30.3a	12.8b	6.7b	77.9	31.4a	26.4a	9.7b	69.1	189.0a	135.2b	126.5b	33.1
TDr Saminaka	22.8a	17.5b	9.8b	57.0	33.6a	35.6a	26.9a	19.9	200.5a	120.5b	133.2b	33.6
TDr Amula	19.3a	9.6b	4.2b	78.2	28.5a	19.3a	19.7a	30.9	179.2a	120.b	106.5c	40.6

WL1: water applied at 75% Field Capacity (FC) 11WAP, WL2: 25% FC 15 WAP, and WL3: 25% FC 11 WAP, PD: percentage difference between the least and most stress levels. Means with the same letter in a row within each parameter are not significantly different at $P \leq 0.01$.

Table 4.28. Rank summation Index (RSI) of *D. alata* accessions under different moisture stress and mycorrhizae conditions

M0W1		M0W3		M1W1		M1W3	
Accession	RSI	Accession	RSI	Accession	RSI	Accession	RSI
TDa 00/00064	119	TDa 02/00012	119	TDa 02/00012	122	TDa 00/00064	144
TDa 00/00060	105	TDa 02/00151	104	TDa 02/00092	116	TDa 02/00092	120
TDa 02/00012	103	TDa 00/00064	104	TDa 02/00006	104	TDa 297	103
TDa 02/00092	99	TDa 02/00006	100	TDa 00/00064	100	TDa 02/00012	102
TDa 02/00151	97	TDa 02/00092	99	TDa 00/00194	98	TDa 00/00060	99
TDa 03/00185	95	TDa 03/00185	91	TDa 297	96	TDa 02/00246	98
TDa 02/00246	91	TDa 93-36	90	TDa 03/00185	94	TDa 02/00006	91
TDa Kesofunfun	89	TDa 297	82	TDa 00/00060	90	TDa Kesofunfun	82
TDa 00/00194	88	TDa 00/00194	81	TDa 02/00151	88	TDa 00/00194	74
TDa 297	82	TDa 00/00060	77	TDa 02/00246	73	TDa 02/00151	67
TDa 02/00006	75	TDa Kesofunfun	77	TDa 93-36	59	TDa 03/00185	62
TDa 93-36	49	TDa 02/00246	68	TDa Kesofunfun	52	TDa 93-36	50

M0W1= Without mycorrhizae applied and least stress condition
M0W3= Without mycorrhizae applied and highest stress condition
M1W1= With mycorrhizae applied and least stress condition
M1W3= With mycorrhizae applied and highest stress condition
RSI= Rank summation index

Table 4.29. Rank summation Index (RSI) of *D. rotundata* accessions under different moisture stress and mycorrhizae conditions

M0W1		M0W3		M1W1		M1W3	
Accession	RSI	Accession	RSI	Accession	RSI	Accession	RSI
TDr Aloshi	126	TDr Abi	129	TDr Abi	128	TDr Aloshi	117
TDr Abi	126	TDr Saminaka	120	TDr Aloshi	116	TDr Abi	114
Amula	111	TDr Aloshi	115	TDr 00/00365	107	TDr 00/00365	101
TDr 00/00365	101	TDr 00/00365	105	TDr 97/00812	101	TDr 97/00812	99
TDr Didio	99	TDr 99/02562	101	TDr Didio	96	TDr Tabene	89
TDr 97/00812	98	TDr Didio	94	TDr Tabene	96	TDr Saminaka	80
TDr Tabene	87	TDr 97/00812	87	TDr 99/02562	91	TDr 99/02562	68
TDr 99/02789	81	Amula	80	TDr 99/02626	86	TDr 99/02789	66
TDr 99/02562	76	TDr Agumaga	69	Amula	80	TDr Didio	60
TDr Saminaka	74	TDr 99/02789	69	TDr 99/02789	71	TDr Agumaga	50
TDr 99/02626	63	TDr 99/02626	63	TDr Agumaga	65	TDr 99/02626	46
TDr Agumaga	50	TDr Tabene	60	TDr Saminaka	55	Amula	46

M0W1= Without mycorrhizae applied and least stress condition

M0W3= Without mycorrhizae applied and highest stress condition

M1W1= With mycorrhizae applied and least stress condition

M1W3= With mycorrhizae applied and highest stress condition

RSI= Rank summation index

condition, while TDr*Saminaka* had a stable performance under stress condition compared to optimum water supply condition. *D. alata* accessions, TDa 02/00012 and TDa 00/00064 performances were stable irrespective of the moisture stress and mycorrhizae condition while TDa 02/00151 performed best under moisture stress condition. These accessions selected were observed to have promising drought characteristics under various levels of imposed moisture stress.

4.3 Development and yield of yam in drought-prone environment

4.3.1 Chemical and physical characteristics of soils used for the second glasshouse experiment

The physico-chemical characteristics of soil used in Experiment 3 is presented in Table 4.30. The soil was loamy sand (830.0 g kg^{-1}) and slightly acidic (pH = 6.3). It had a high available P of 40.0 mg kg^{-1} while its Ca content and ECEC were 2.4 cmol kg^{-1} and 3.8 cmol kg^{-1} respectively.

4.3.2 Effects of irrigation on chlorophyll content, AMF colonization and yield parameters of *D. alata* accessions

Irrigation significantly (P = 0.01) influenced the chlorophyll at 14 WAP; the stress treatment had a higher (33.5 nmol/cm^2) mean value. Tuber weight was significantly (P < 0.01) influenced by irrigation; the stressed treatment had a higher tuber weight (0.6 kg/m^2) compared to the non-stress treatment (0.5 kg/m^2). Stress and non-stress treatments could not be significantly differentiated among other traits (Table 4.31).

4.3.3 Planting date influence on AMF colonization and yield attributes of *D. alata* accessions

Planting date significantly affected all the measured parameters at P ≤ 0.05. The highest significant mean values for chlorophyll at 14 WAP (44.4 nmol /cm^2), AMF colonization (24.1 %), fresh tuber weight (1.0 kg/m^2) and dry matter (141.8 g/ plant) were observed in July, while the least mean values were recorded in September (Table 4.32).

Table 4.30. Chemical and physical characteristics of the soil at Minjibir field

Property	Value
pH (1:1 H_2O)	6.3
Organic Carbon (g kg^{-1})	0.4
Total N (g kg^{-1})	0.1
Available P (mg kg^{-1})	40.0
Exchangeable Cations (cmol kg^{-1})	
Ca^{++}	2.4
Mg^{++}	0.4
K^{+}	0.4
Na^{+}	0.4
Exchangeable Acidity (H^{+} + Al^{3+})	0.0
ECEC	3.8
Extractable micronutrients (mg kg^{-1})	
Zn	5.0
Cu	2.0
Mn	14.0
Fe	74.0
Bulk density (Mg m^{-3})	1.6
Particle size (g kg^{-1})	
Sand	812
Silt	88
Clay	100
Textural class (USDA)	Sandy loam

Table 4.31. Effects of irrigation on the chlorophyll content, AMF colonization and yield parameters of *D. alata* accessions

Irrigation	Chlorophyll content (WAP)		AMF colonization (WAP)		Fresh tuber weight	Dry matter	Seed yam weight
	14	18	14	18			
	nmol /cm^2		%		kg/m^2	g/plant	kg/m^2
Well watered	29.0b	25.9	19.5	17.6	0.5b	69.5	0.5
Stressed	33.5a	28.1	15.2	12.4	0.6a	82.3	0.5
		ns	ns	ns		ns	ns

WAP: weeks after planting. Means with the same letter in a column are not significantly different at $P \leq 0.01$, ns: not significant

Table 4.32. Effects of planting date on the chlorophyll content, AMF colonization and yield parameters of *D. alata* accessions

Planting date	Chlorophyll content (WAP)		AMF colonization (WAP)		Fresh tuber weight	Dry matter	Seed yam weight
	14	18	14	18			
	nmol /cm^2		%		kg/m^2	g/ plant	kg/m^2
July	44.4a	31.4a	24.1a	19.2a	1.0a	141.8a	0.6a
August	28.1b	23.6c	19.3b	10.9b	0.6b	59.7b	0.5a
September	21.1c	26.0b	8.5c	14.7b	0.3c	26.1c	0.3b

WAP: weeks after planting. Means with the same letter in a column are not significantly different at $P \leq 0.01$, ns: not significant

Table 4.33. Effects of mycorrhizal inoculation on chlorophyll content, AMF colonization and yield parameters of *D. alata* accessions

Mycorrhizal inoculation	Chlorophyll content (WAP)		AMF colonization (WAP)		Fresh tuber weight	Dry matter	Seed yam weight
	14	18	14	18			
	~~nmol~~ /cm^2	——	—— % ——		kgm^{-2}	g/plant	kgm^{-2}
With mycorrhizae	31.7a	28.2a	16.9	15.8	0.6	77.1	0.5
Without mycorrhizae	30.7b	25.8b	17.7	14.0	0.6	74.7	0.5
			ns	ns	ns	ns	ns

WAP: weeks after planting. Means with the same letter in a column are not significantly different at $P \leq 0.05$

4.3.4 Mycorrhizal inoculation influence on the chlorophyll content, AMF colonization and yield attributes of *D. alata* accessions

Chlorophyll content at weeks 14 and 18 were significantly ($P < 0.05$) different according to mycorrhizal inoculation (Table 4.33). Mycorrhizal treatment had higher mean values (31.7 nmol/ cm^2 and 28.2 nmol/ cm^2) at 14 and 18 WAP respectivelycompared to the un-inoculated treatment. Mycorrhizal inoculation did not affect the other growth and yield parameters.

4.3.5 Variation in the chlorophyll content, AMF colonization and yield parameters among *D. alata* accessions

The three *D. alata* accessions varied significantly ($P \leq 0.01$) in their responses under the various treatments (Table 4.34). TDa 02/00012 maintained the highest mean values for chlorophyll at 14 and 18 WAP (32.1 nmol/cm^2 and 31.4 nmol/cm^2 respectively), AMF colonization at 14 WAP (21.6%) and seed yam weight (0.5 kg/m^2).

4.3.6 Effects of planting date and irrigation on the chlorophyll content of *D. alata* accessions

The interaction effect of planting date and irrigation is presented in Fig. 4.5. Significant ($P< 0.01$) interaction existed between planting date and irrigation. In August and September, higher chlorophyll content was observed under stressed treatment compared to the well watered condition. However, the irrigation treatments were not significantly different in July.

4.3.7 Interactive effect of planting date andaccession on AMF colonization of *D. alata* roots

TDa 02/00012 and TDa 02/00151 had the highest and significant ($P <0.01$) AMF colonization in July and the least value for the same trait in September. However, TDa 00/00064 had a significantly highest performance in September compared to the other months. Each of the 3 accessions responded differently to the 3 planting dates (Fig. 4.6).

Table 4.34. Variation in the chlorophyll content, AMF colonization and yield parameters among *D. alata* accessions

Accession (TDa)	Chlorophyll content		AMF colonization		Fresh tuber weight	Dry matter	Seed yam weight
	14 WAP	18 WAP	14 WAP	18 WAP			
	~~nmol~~ /cm^2	——	——— % ———		kg/m^2	g/plant	kg/m^2
02/00012	32.1a	31.4a	21.6a	13.2	0.7a	74.0	0.5a
00/00064	29.0b	24.4b	13.8b	17.1	0.5b	71.8	0.3b
02/00151	31.1c	25.3b	16.5b	14.5	0.6ab	81.9	0.5a
				ns		ns	

WAP: weeks after planting. Means with the same letter in a column are not significantly different at $P \leq 0.01$, ns: not significant

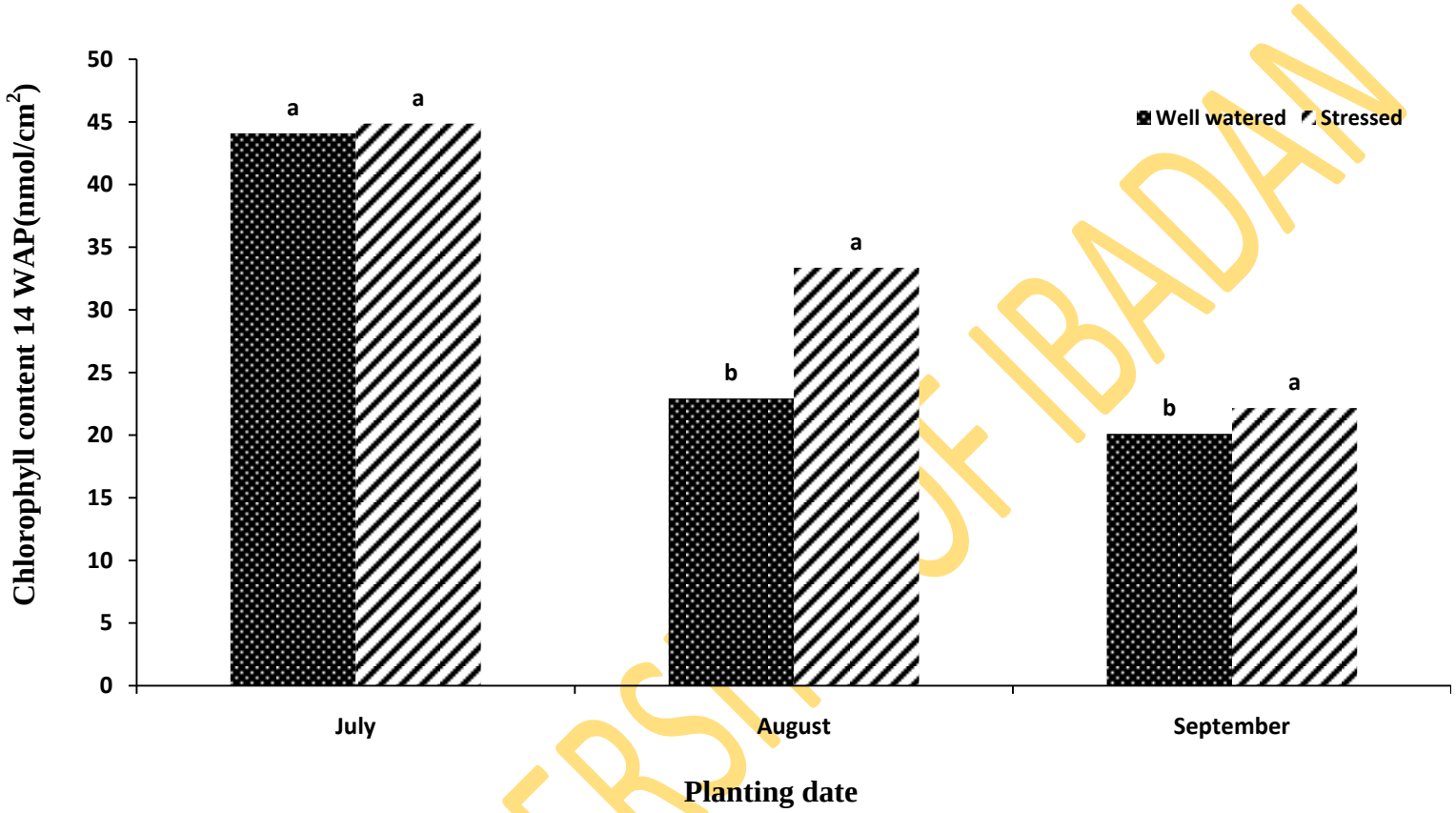

Fig. 4.5. Effects of planting date on the chlorophyll content under drought condition
(Bars with the same letter within a planting date are not significantly different at $P< 0.01$)

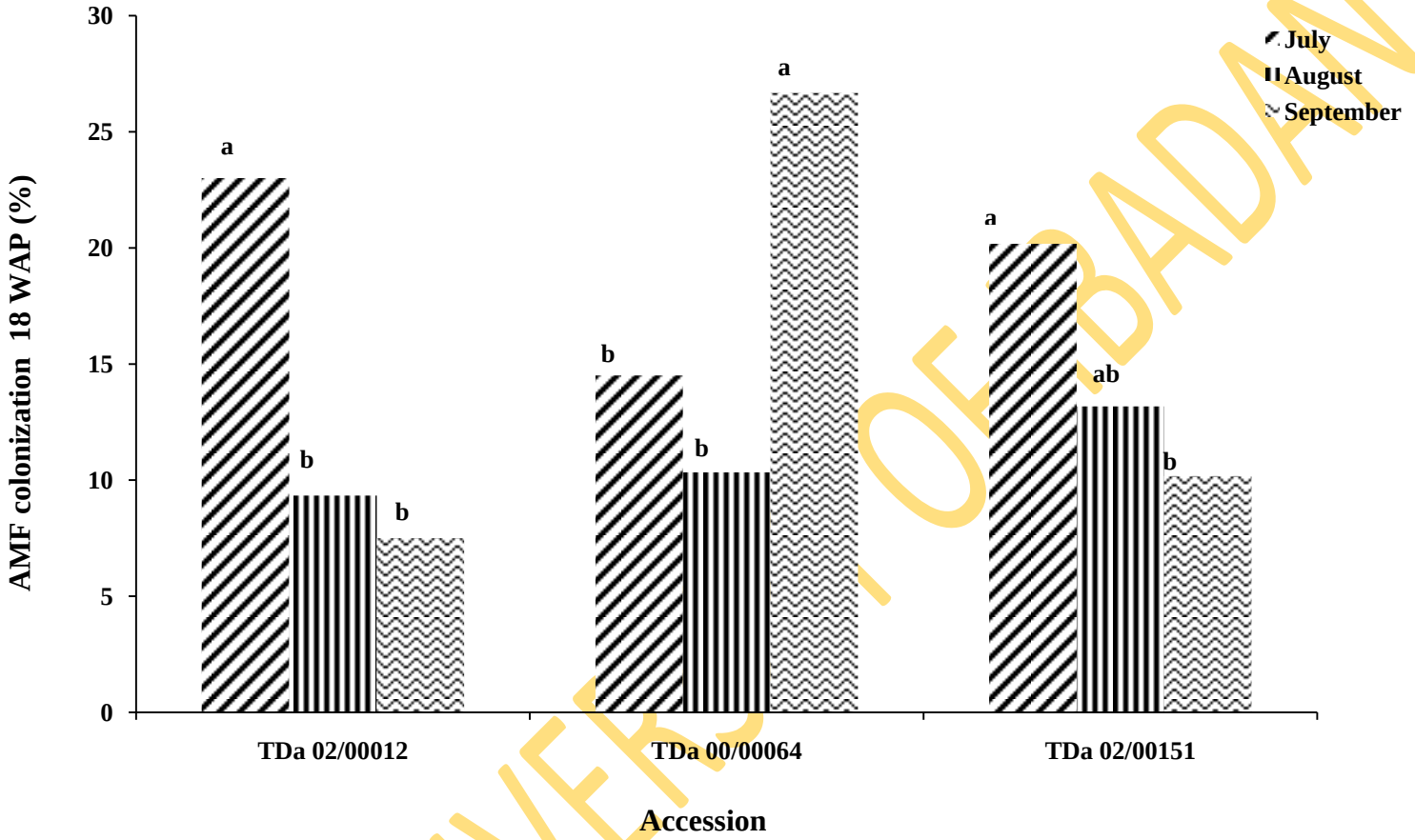

Fig. 4.6. Effects of planting date on AMF colonization of roots of three *D. alata* accessions.

(Bars with the same letter within an accession are not significantly different at $P< 0.01$)

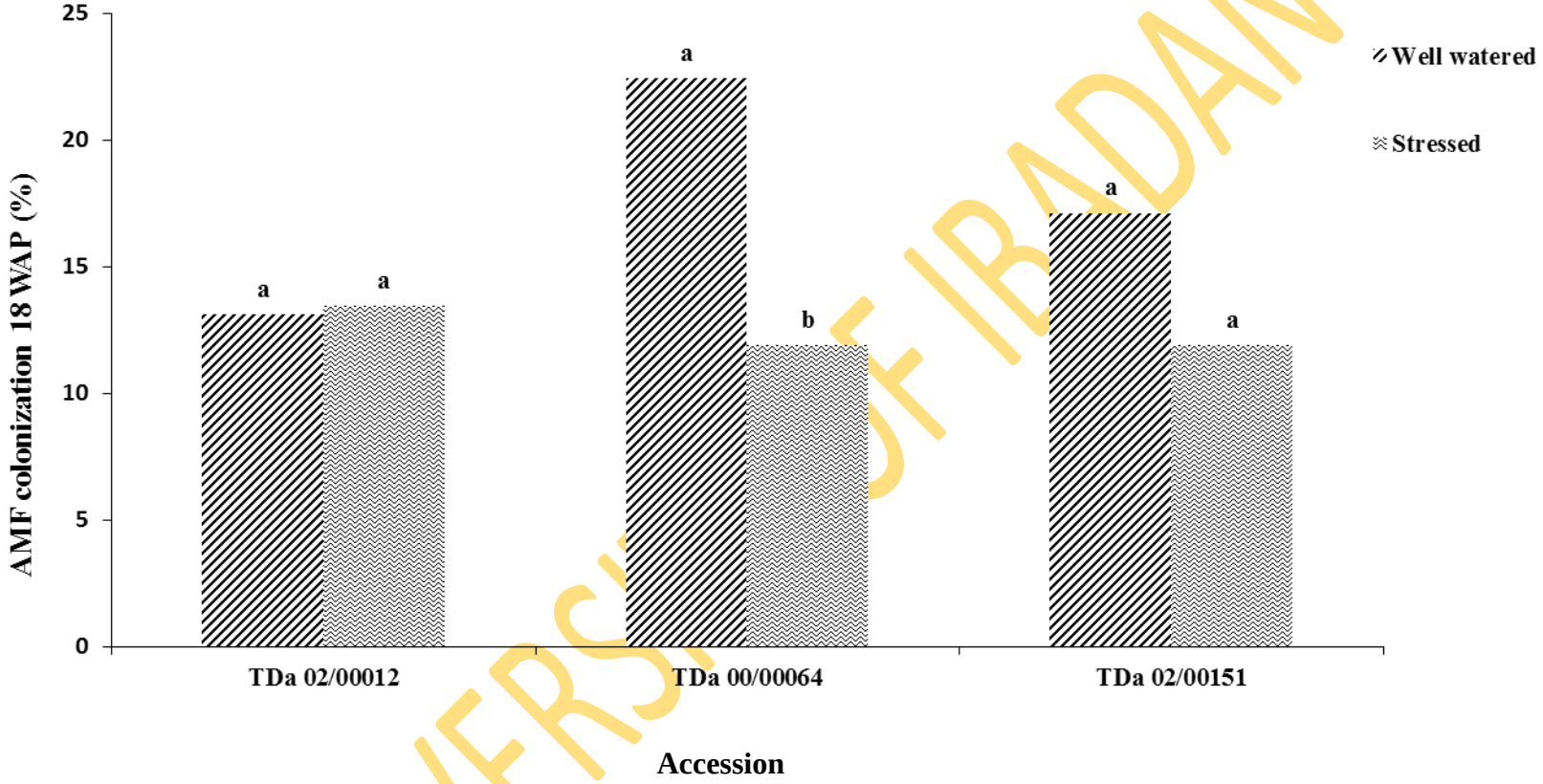

Fig. 4.7. Influence of irrigation on AMF colonization of the roots of three *D.alata* accessions. (Bars with the same letter are not significantly different at $P = 0.01$)

4.3.8 AMF root colonization of the three selected *D. alata* accessions as influence by irrigation at 18 WAP

The AMF root colonization of the accessions were significantly (P = 0.01) influenced by irrigation (Fig. 4.7).TDa 00/00064 recorded a highly significant AMF colonization under well watered as compared to stressed condition. There were however, no notable difference on the AMF colonization of TDa 02/00012 and TDa 02/00151 resulting from irrigation treatment.

4.3.9 Effects of irrigation on the dry matter yield of the three *D. alata* accessions under different planting date

In Fig. 4.8, the accessions differed significantly ($P \leq 0.05$) in their dry matter yield under irrigation and planting date treatments. TDa 02/00151 had a significantly higher dry matter yield than others in July under well watered condition. However, under stressed condition in July, TDa00/00064 significantly outperformed TDa 02/00151. In the well watered and stressed conditions, no significant differences were observed for dry matter among the accessions in August and September (Fig. 4.8).

4.3.10 Effects of irrigation on the yield of *D. alata* accessions

The accessions differed significantly ($P < 0.05$) in their responses to irrigation (Fig. 4.9). The highest yield (0.8 kg/m^2) was observed in TDa 02/00012 under the stress condition. TDa 00/00064 maintained lowest significant yield (0.5 kg/m^2) under stressed condition, while TDa 02/00151 was not affected by the two stress levels, TDa 02/00012 performed better under stress conditions. TDa 00/00064 maintained a significantly higher yield under well watered than water stress condition.

4.3.11 Effects of irrigation and mycorrhizal inoculation on the tuber yield of *D. alata* accessions

Accessions differed significantly in their response to mycorrhizae inoculation under irrigation treatment (Fig. 4.10). The highest fresh tuber weight was observed in TDa 02/00012 planted under stressed condition, irrespective of mycorrhizae inoculation. The least yield was observed in TDa 00/00064 under water stressed condition; thus, its performance was not influenced by mycorrhizal level.

Mycorrhizal inoculation however influenced the fresh tuber weight of TDa 02/00151 under irrigation treatment. Under well watered condition, mycorrhizae significantly increased the fresh tuber weight of TDa 02/00151 compared to non-mycorrhizae

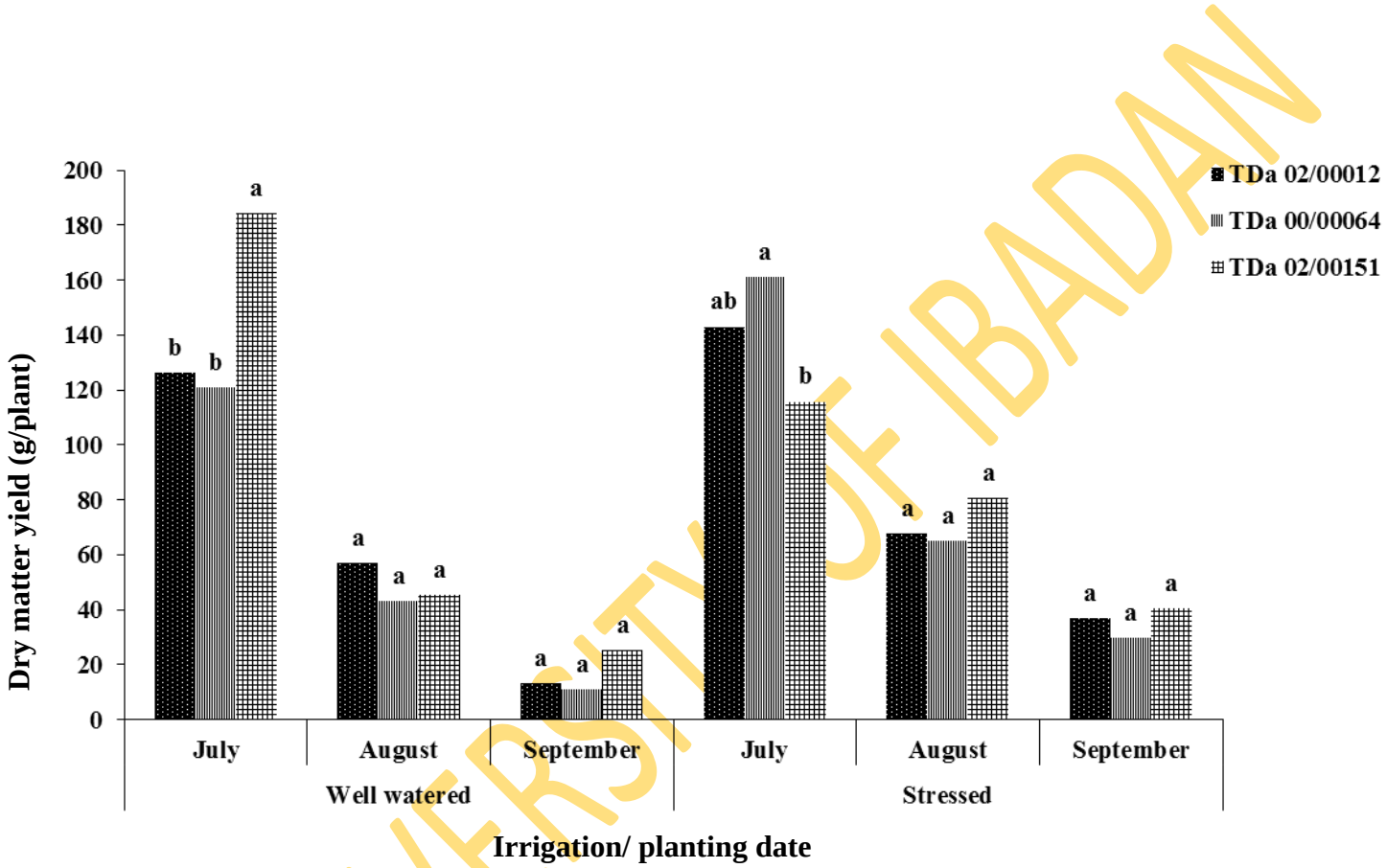

Fig. 4.8. Dry matter yield of three *D. alata* accessions under different planting date and moisture levels
(Bars with the same letter within a planting date, under irrigation treatment are not significantly different at $P< 0.01$)

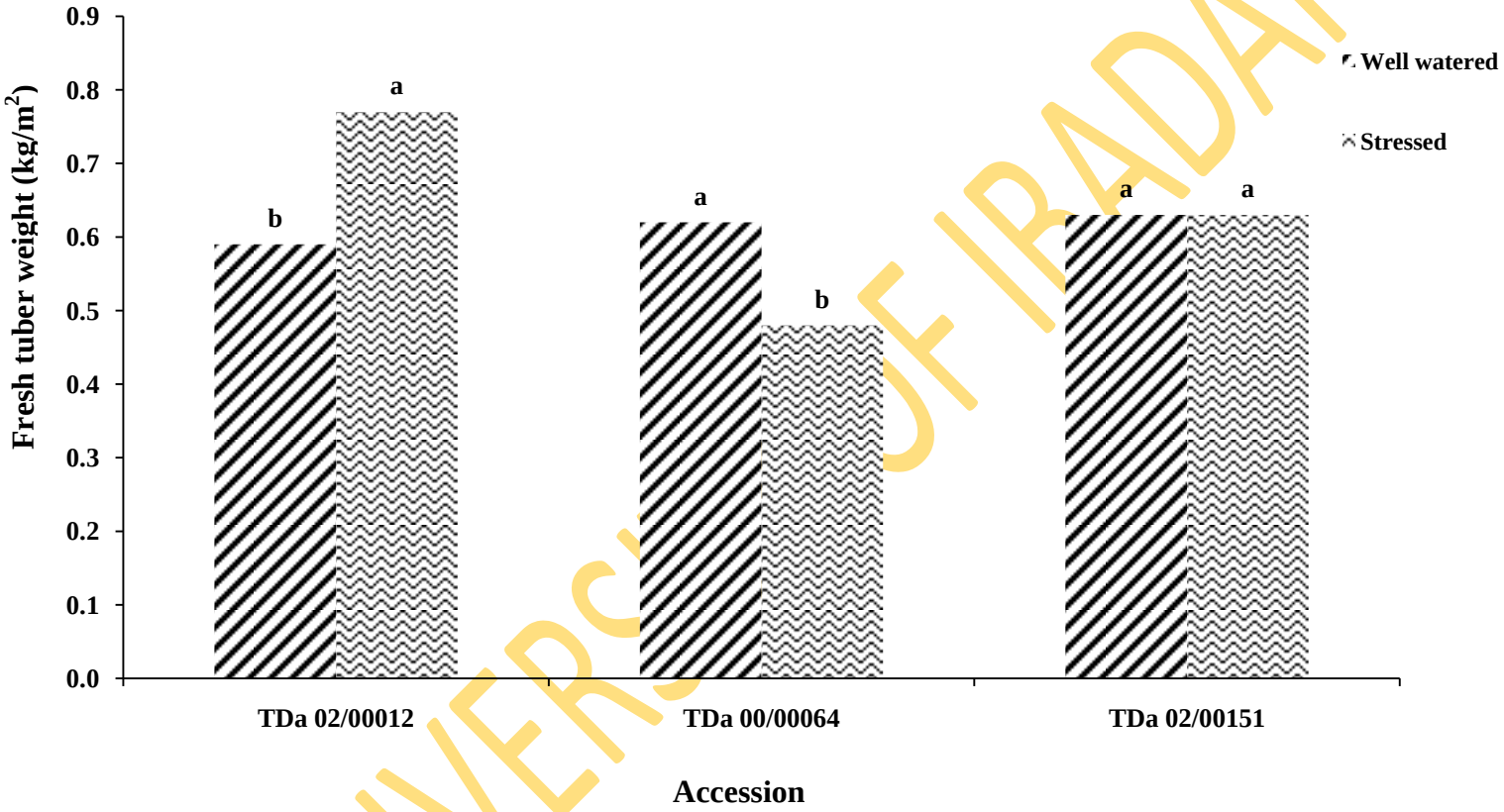

Fig. 4.9. Effects of irrigation on the yield of three *D. alata* accessions
(Bars with the same letter within an accession under irrigation treatment are not significantly different at $P< 0.01$)

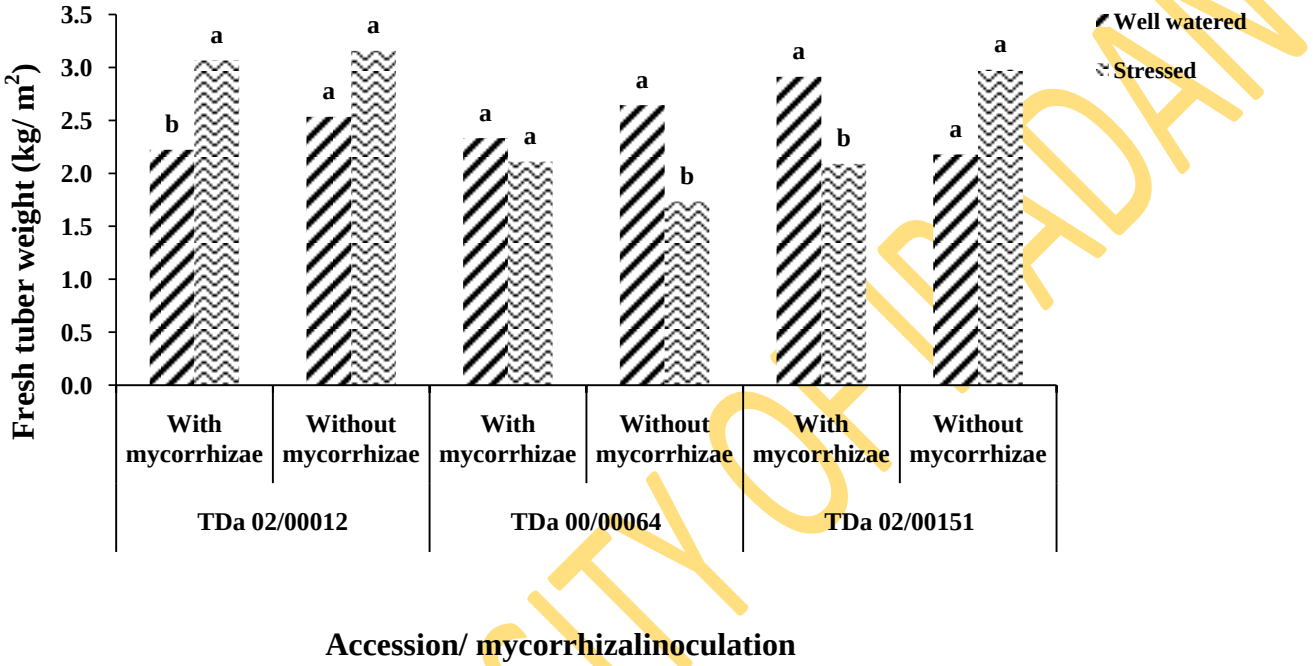

Fig. 4.10. Effects of irrigation and mycorrhizal inoculation on the yield of three *D. alata* accessions (Bars with the same letter within an accession are not significantly different at P <0.01)

Table 4.35. Effects of irrigation on the chlorophyll content, AMF colonization and yield of *D. rotundata* accessions

Irrigation	Chlorophyll content (WAP)		AMF colonization (WAP)		Dry matter	Fresh tuber weight	Seed yam weight
	14	18	14	18			
	nmol/cm^2	——	—— % ——		g/ plant	kg/ m^2	kg/ m^2
Well watered	42.3	35.8a	28.7	11.9	73.3	0.6a	0.5a
Stressed	41.9	31.3b	23.4	16.8	53.7	0.3b	0.3b
	ns		ns	ns	ns		

WAP: weeks after planting. Means with the same letter in a column are not significantly different at $P< 0.05$, ns: not significant

treatment. Mycorrhizal inoculation also significantly improved the fresh tuber weight of TDa 02/00151 under stressed condition (Fig. 4.10).

4.3.12 Irrigation effect on the chlorophyll content, AMF colonization and yield of *D. rotundata* accessions

Table 4.35 shows the significant ($P \leq 0.05$) effect of irrigation treatment on *D. rotundata* chlorophyll content at 18 WAP, tuber weight, and weight of seed yam. This significant higher performance was recorded under the well watered treatment. Chlorophyll content at 18 WAP fresh tuber weight and weight of seed yam (0.5 kg/m^2) were significantly higher than under stressed condition.

4.3.13 Effects of mycorrhizal inoculation on the chlorophyll content, AMF colonization and yield of *D. rotundata* accessions

Mycorrhizal inoculation showed no significant influence on the measured parameters of *D rotundata* in the field trial (Table 4.36).

4.3.14 Influence of genotypic variation among *D. rotundata* for the chlorophyll content, AMF colonization and yield

Variations were observed among the three *D. rotundata* accessions in some of the measured parameters at $P \leq 0.05$ (Table 4.37). Abi significantly ($P < 0.01$) maintained higher chlorophyll content of 50.6 nmol/cm^2 and 41.8 nmol/cm^2 at 14 and 18 WAP respectively. For yield assessment, TDa Saminaka maintained a significantly highest dry matter of 83.3 g/plant, fresh tuber weight of 2.2 kg/m^2 and weight of seed yam 2.1 kg/m^2. Aloshi had a significantly least fresh tuber weight and dry matter of 1.2 kg/m^2 and 1.0 kg/m^2 respectively.

4.3.15 Effects of irrigation on the harvest index of three *D. rotundata* accessions

Irrigation and accession interaction significantly influenced the harvest index at P= 0.01 (Fig. 4.11). A higher harvest index (34%) was observed in TDr Saminaka under stress condition as compared to 16.5% in the well watered treatment. TDr Abi and TDr Aloshi however were not influenced by irrigation in terms of harvest index.

4.3.16 Variation in harvest index as affected by mycorrhizal inoculation of the three *D. rotundata* accessions

Fig. 4.12 displayed effects of interaction between accession and mycorrhizal inoculation on harvest index at P = 0.01. TDr Saminaka had a significantly higher HI (33.4%) under non-inoculated treatment as compared to under AMF inoculated

Table 4.36. Effects of mycorrhizal inoculation on the chlorophyll content and AMF colonization and yield of *D. rotundata* accessions

Mycorrhizal inoculation	Chlorophyll content (WAP)		AMF colonization (WAP)		Dry matter	Fresh tuber weight	Seed yam weight
	14	18	14	18			
	~~nmol~~ /cm^2 ——		———% ———		g/ plant	kg/ m^2	kg/m^2
With mycorrhizae	42.1	33.7	30.2	12.4	66.8	0.5	0.4
Without mycorrhizae	42.1	33.4	21.9	16.3	60.2	0.4	0.4
	ns	ns	ns	ns	ns	ns	ns

WAP: weeks after planting. ns: not significant

Table 4.37. Effects of genotypic variation on the chlorophyll content, AMF colonization and yield of *D. rotundata* accessions

Accession (TDr)	Chlorophyll content (WAP)		AMF colonization (WAP)		Dry matter	Fresh tuber weight	Seed yam weight
	14	18	14	18			
	~~nmol~~/cm^2	——	—— % ——		g/ plant	kg/ m^2	kg/ m^2
Abi	50.6a	41.8a	24.5	11.0b	67.1a	1.9a	1.9ab
Saminaka	36.3b	29.9b	30.2	19.8a	83.3a	2.2a	2.1a
Aloshi	39.4b	28.8b	23.5	12.2b	40.0b	1.2b	1.0b
			ns				

WAP: weeks after planting. Means with the same letter in a column are not significantly different at $P \leq 0.05$

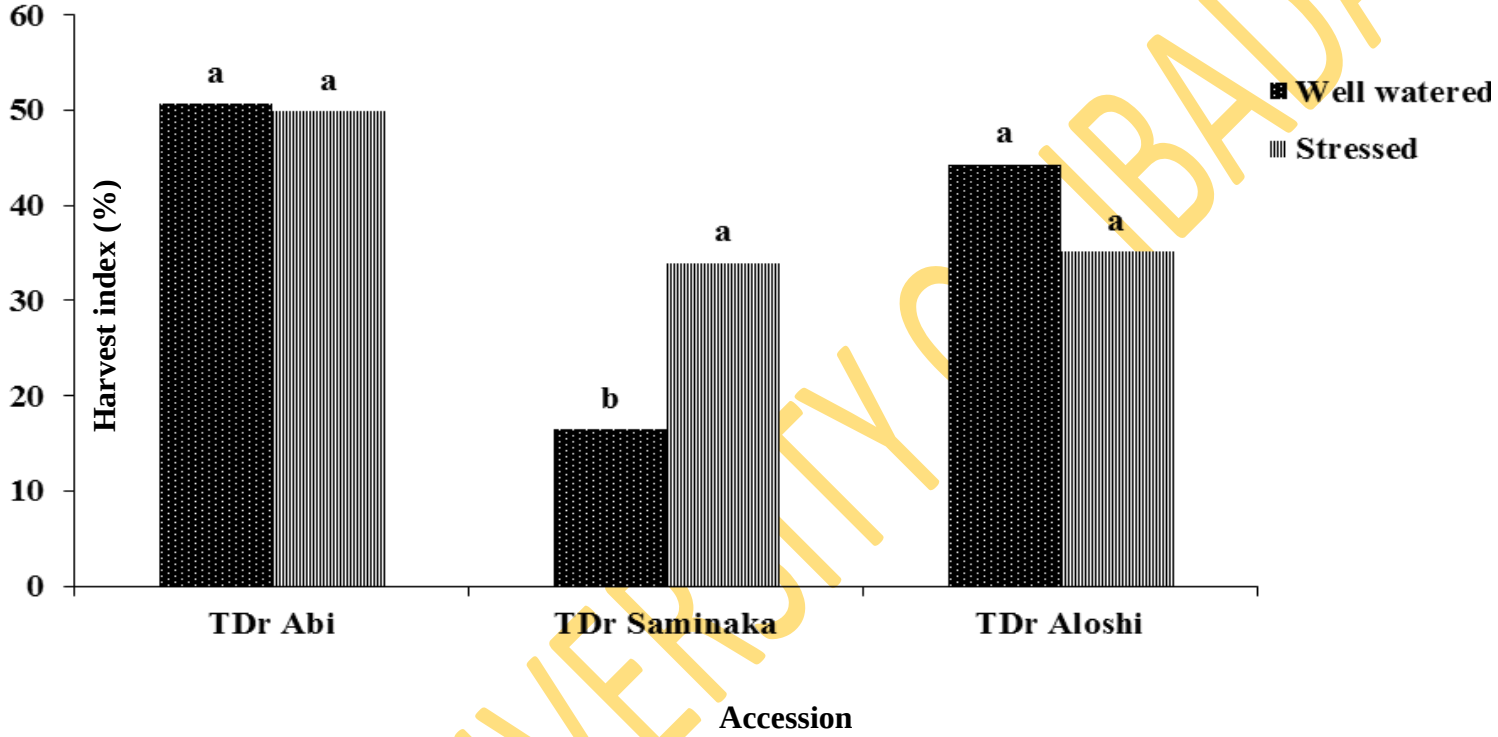

Fig.4.11. Effects of irrigation on the harvest index of three *D. rotundata*accessions
(Bars with the same letter within an accession are not significantly different at *P*= 0.01)

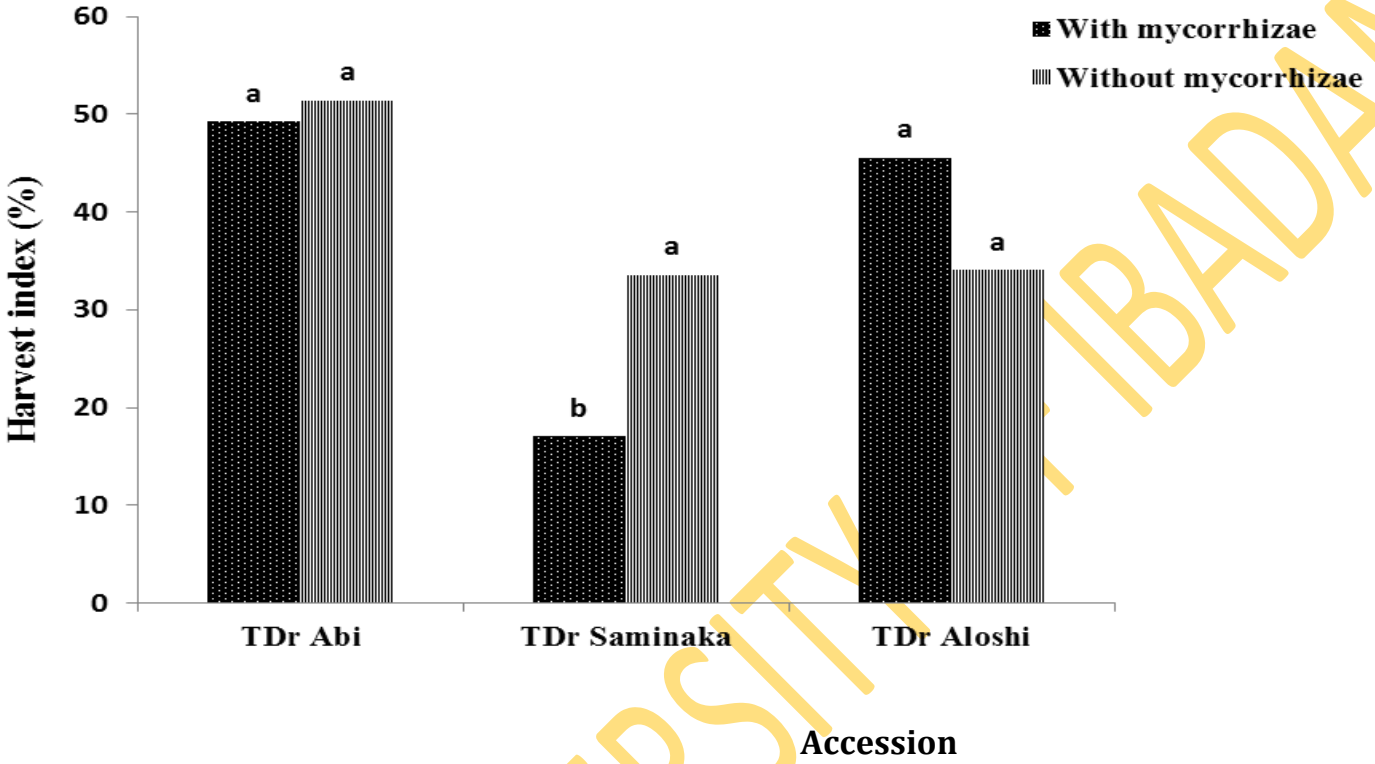

Fig. 4.12. Variation in harvest index as affected by mycorrhizal inoculation of the three *D. rotundata* accessions. Bars with the same letter within an accession are not significantly different at $P = 0.01$)

treatment. TDr Abi and TDr Aloshi however showed no significant response to mycorrhizal inoculation.

4.3.17 Effects of accessions and irrigation interaction on AMF spores production in the soil

Accessions varied significantly ($P<0.01$) in their responses to irrigation for the number of spores (Fig. 4.13). TDr Saminaka had a significantly higher number of spores (99.5) under well watered condition as compared to (37.8) under stressed condition. Abi had a higher and significant number of spores (65.3) under stressed than well watered condition. Spore production in Aloshi however, was not significantly influenced by irrigation treatment (Fig. 4.13).

4.3.18 Interactive effect of mycorrhizal inoculation and irrigation on AMF spores production in the soil

The interactive effect of mycorrhizal inoculation and irrigation on AMF spores production in the soil at $P = 0.01$ were displayed in Fig. 4.14. The effect of mycorrhizal inoculation on the number of spores differed with irrigation treatment. Under well- watered treatment and mycorrhizal inoculation 80.6 spores were recorded as against 53 recorded under stressed condition. Under no-mycorrhizal inoculated treatment, however, there was no significant difference in the number of spores for the 2 irrigation treatments.

4.3.19 Effects of mycorrhizal inoculation and irrigation on number of AMF spores of three *D. rotundata* accession

Figure 4.15 illustrates the significant three-factor interaction among mycorrhizae, accession and irrigation. Under mycorrhizal inoculated treatment, TDr Abi and TDr Aloshi were not significantly affected by irrigation treatment. TDr Saminaka had a significantly higher number of spores under well watered than stressed condition. In no-mycorrhizal inoculated treatment however, TDr Abi had a significantly higher number of spores under stressed than well watered condition. TDr Saminaka responded the same way as under well watered condition. Spore production TDr Aloshi was not significantly influenced by irrigation level (Fig. 4.15).

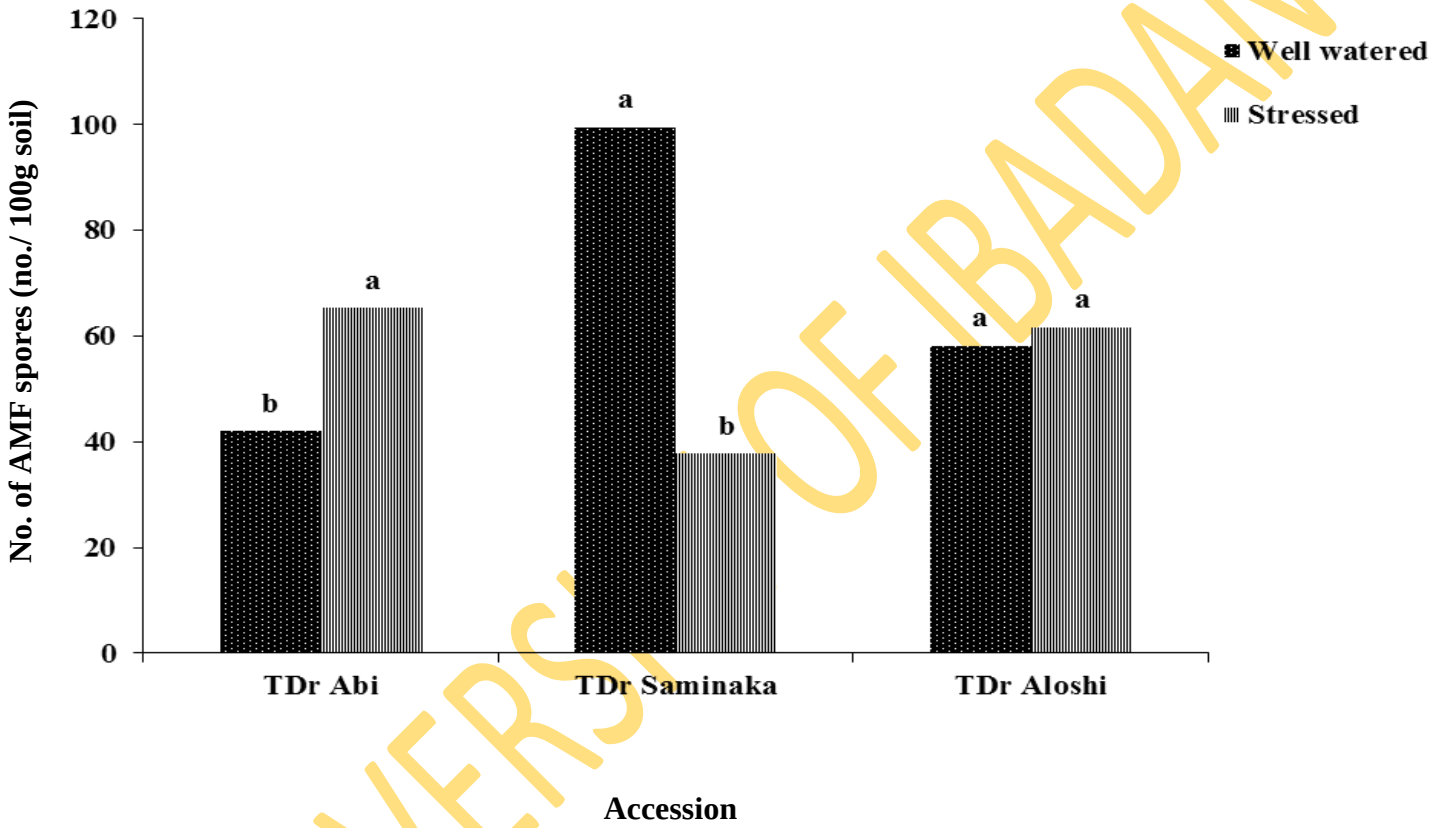

Fig. 4.13. Effects of accession andirrigation on AMF spores production in the soil.

(Bars with the same letter within a accession are not significantly different at $P< 0.01$)

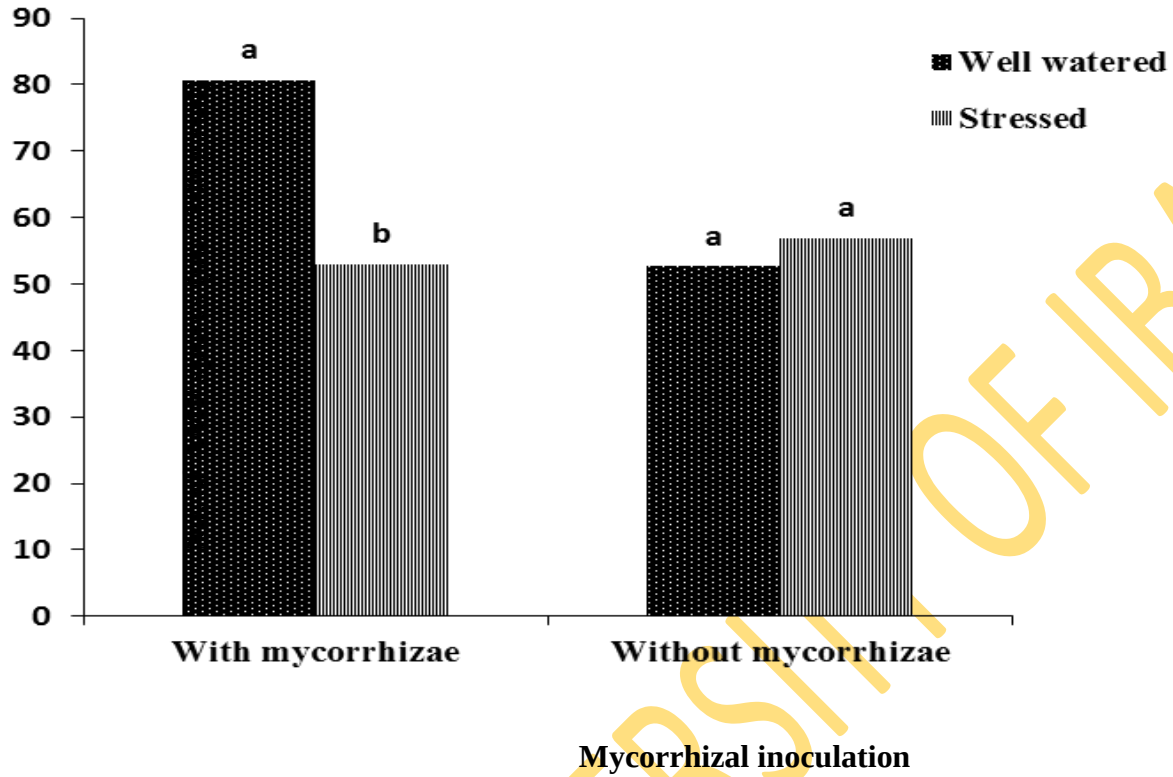

Fig. 4.14. Effects of mycorrhizal inoculation and irrigation on AMF spores production in the soil.
(Bars with the same letter within a mycorrhizal treatment are not significantly different at $P< 0.01$)

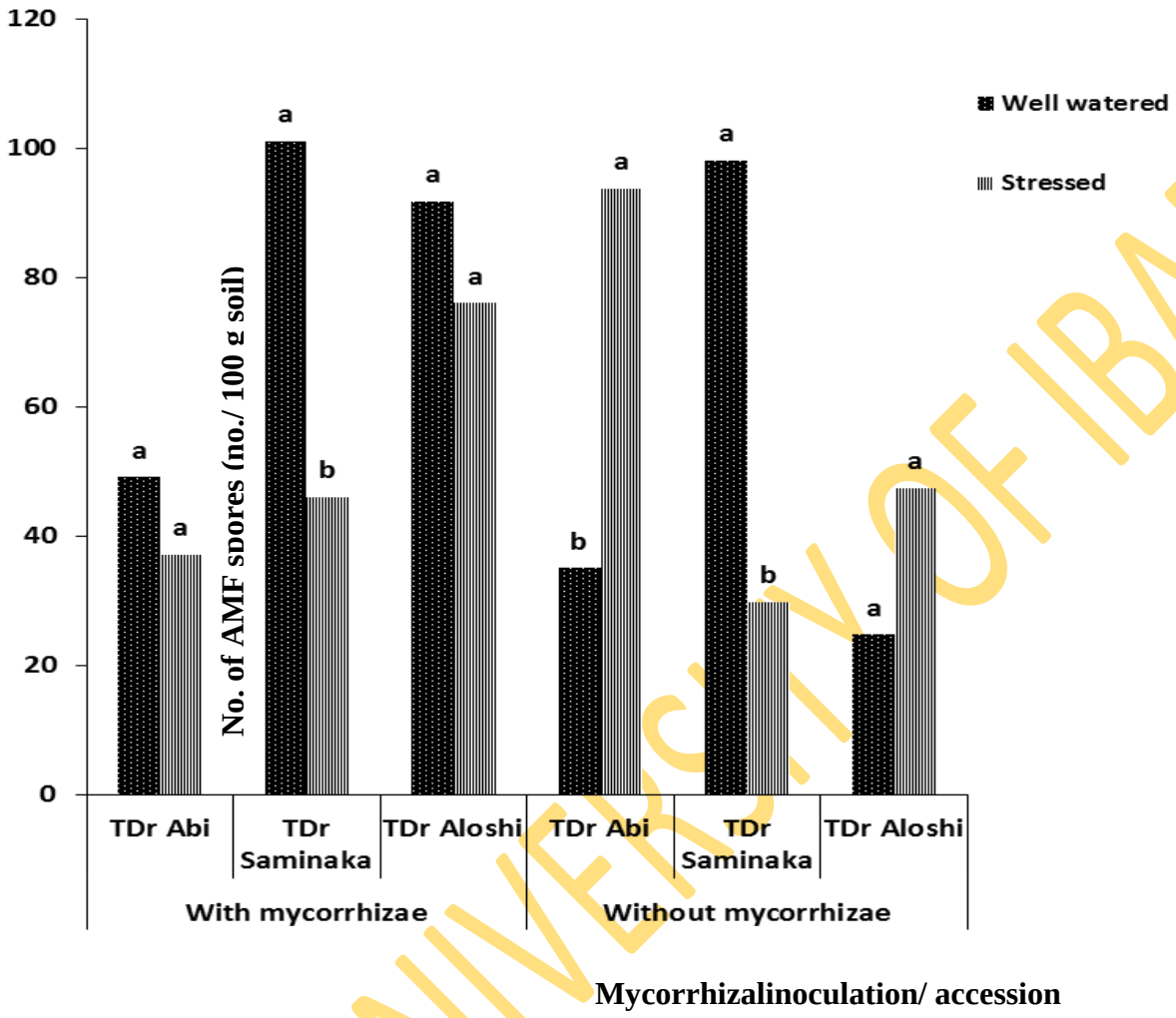

Fig 4.15. Effects of yam accession mycorrhizal inoculation and irrigation on AMF spores production in the soil.

(Bars with the same letter within mycorrhizal treatment and accession are not significantly different at *P*= 0.05)

CHAPTER 5

DISCUSSION

Amidst rainfall irregularities resulting from climate change coupled with the intensifying pressure on prime agricultural land, higher levels of food production can be achieved through the innovative cultivation and management of areas with not so favourable environmental conditions (El-Sharkawy, 1993). Moisture stress evaluation of yam under varied environmental conditions has become necessary in order to select suitable yam accessions for production in dry environments. Furthermore, selection of drought tolerant yam accessions will lead to increase in land area under yam cultivation.

Imposition of moisture stress resulted in significant variations in the performance of the 32 *D. alata* and 49 *D. rotundata* accessions in the present study. Most of the quantitative phenotypic traits measured differentially distinguished them, leading to the grouping of the accessions. Some accessions performed poorly compared to others under moisture stress. This is in agreement with the findings of El-Sharkawy (2007) that a range of cassava genotypes subjected to water stress, could be grouped into genotypes that had high levels of drought tolerance while others were highly susceptible. The observed genotypic variation in response to moisture stress is an indication of genetic diversity which is a pre-requisite for initiating breeding programmes for the selection of potentially drought tolerant accessions as noted by Keshava *et al*. (2010).

Discriminate analysis revealed that 96% and 95% of the total variations observed among *D. alata* and *D. rotundata* accessions respectively were accounted for by the first two canonical axes. The cumulative variance indicated that the identified descriptive traits within these axes exhibited greater influence on the phenotypic characters and could be used effectively to carry out selections among the accessions. The result from the present study conforms to a similar one by Tairo *et al.* (2008) in which significant variation among sweet potato genotypes was recorded. Thus the 32

D.alata and 49 *D. rotundata* accessions were observed to exhibit significant phenotypic diversity.

Accessions in group 1 for *D. alata* and accessions in group 5 for *D. rotundata* had lowest performance levels for most of the measured traits. This may have resulted from the cessation of the initiation of new leaves as well as non-expansion of existing leaves. Wiesz *et al*. (1994) noted that the cessation of initiation of new leaves is a typical indicator of moisture stress in plants. Thus, growth and yield of sweet potato were reduced under water stress conditions (Wiesz *et al*., 1994; Nadler and Heuer, 1995). Leaf growth is one of the first processes affected by water stress in plants (Vajrabhaya *et al.,* 2001). Plants with small leaf area exhibit reduced evapo-transpiration because stomata functions are lower in narrow leaves. In yam, the tuber yield is a function of photosynthetic efficiency, which is related to the leaf area spread for maximum light interception. Total leaf area was positively and significantly correlated with shoot weight (r = 0.46) and plant vigour (r = 0.42). Reduction in shoot growth among tuberous crops could be an adaptive response to drought (Carmo-Silva *et al.*, 2009). In addition to the drought tolerance mechanism used by plant shoots, root growth is also important in plant tolerance to drought as roots constitute the main component for meeting transpirational demand and also making water available to plants (Liu and Huang, 2000). The present study showed that accessions in Groups 3 and 4 of *D. alata* (TDa 00/00104, TDa 00/00064, TDa 96-36, *Sagbe*, TDa 03/00185, *Olesunle*, TDa 00/00045, TDa 00/00194, *Sharmgbagada*, TDa 297, TDa 02/00012) and those in group 1 of *D. rotundata* (TDr *Abi, Amula*, 2789, *Laboko, Mulkwusa, Pounche*, and *Kpako*) had appreciable higher performance for growth and yield parameters under moisture- stress conditions. The higher performance of the accessions in the groups above may be linked to their efficiency in accumulating assimilates for higher biomass production under moisture stress.

There were highly significant positive correlations among some growth and yield parameters in the present study. Dry tuber weight was highly correlated with fresh and dry below ground weight, fresh tuber weight, harvest index, leaf area, and yam root colonization by AMF. Thus, accessions can be assessed for their response to drought based on any of these parameters. A good index for predicting the corresponding change which occurs in one character at the expense of the proportionate change in the other can also be provided (Ahmad *et al*., 2008). Harvest index for instance, as a quantitative trait, is an indicator of plant's efficiency in

distributing photosynthetic materials into the economic components such as tubers in yam. Thus, accessions with important traits such as high harvest index would be of great value in terms of drought tolerance (Mutegi-Mutegi, 2009).

Moisture is a very significant factor for crop growth (Saraswati e*t al*., 2012). High significant variations were observed in the response to the different levels of moisture stress imposed on *D. alata and D. rotundata* accessions. In the present study, the best growth and yield performances among the accessions were observed when water stress was imposed at 11 WAP at 75% Field capacity (FC), while yield was poorest when applied moisture was lowest i.e 25% FC at the tuber initiation stage. This result agrees with the findings of Saraswati e*t al*. (2008) on sweet potato in which moisture stress reduced dry matter weight of 15 cultivars of sweet potatoes by 31 to 46% (Saraswati *et al*., 2008). Futhermore, in the present study, water stress decreased plant biomass, leaf area, leaf weight and ultimately, tuber yield. The result obtained in the present study agrees with the findings of Saraswati e*t al.* (2012), in which plant growth variables declined due to drought stress. It is however noteworthy that the respective responses of different variables to drought differ (Saraswati e*t al.*, 2012).

In the result of the present study, moisture stress imposition at 25% FC during tuber initiation and bulking stage resulted in general decline of the growth and yield parameters of the yam accessions evaluated. Reduction in dry tuber weight ranged from 69.7 to 86.5% for *D. alata*, and from 51.5 to 76.7% in *D. rotundata* at bulking and tuber initiation stages, respectively. The adverse effects of water stress on the growth and yield parameters were more pronounced when stress was imposed at 25% FC during tuber initiation (11 WAP) compared to the bulking stage (15 WAP). Thus, impact of water stress was dependent on the stage of growth and development of the plant to which it was imposed. The tuber initiation stage is a period of rapid cell division whereby most cells involved in tuber development are formed. Bulking stage is characterized by maximum canopy development, increased tuber bulking and rapid dry matter accumulation (Okwor and Ekanayake, 1998).

Stress imposition on *D. alata* accessions at the tuber initiation stage (25% FC at 11WAP) decreased the tuber fresh weight by 83.2%, dry tuber weight by 86.5%, total leaf area by 39.5% and harvest index by 65.4%. However, at 15 WAP (bulking stage), the impact of imposed stress was lower, causing a reduction of tuber fresh weight by 67.9%, dry tuber weight by 69.7%, total leaf area by 27% and harvest index by 45%. Similarly, in *D. rotundata*, imposed stress at 11 WAP decreased dry tuber weight, total

leaf area and harvest index 76.7%, 34.5% and 43.4%, respectively while imposition at 15 WAP also resulted in lower levels of decline of 51.5%, 19.2% and 27.3%, respectively. These observations show that the tuber initiation stage is the most critical period in respect of moisture stress effects on yam. Thus, this confirms the views of Okwor and Asadu (1998) as well as Okwor and Ekanayake (1998) on the high susceptibility of yam to moisture stress at tuberisation stage. Yam sensitivity to moisture stress is similar to that of potato (*Solanum tuberosum* L.), Shock and Feibert (2002) had also identified tuber initiation stage to be most critical for moisture stress in potatoes. Results of the present study also conform to that of Connor *et al*. (1981), whose work on cassava showed that root growth was inhibited by moisture stress as it affects root initiation and elongation.

Furthermore, the effect of moisture stress imposed at 25% FC during tuber initiation was severe compared to that imposed at 25% FC at bulking stage. The differences in the response to moisture stress was a reflection of genotypic differences, the plant developmental stage and severity of water stress, particularly the timing of stress in relation to tuber initiation as earlier reported by MacKerron and Jefferies (1986). The extent to which tuber yield and quality are adversely affected by drought depends on the severity, timing, duration of stress during the growing season and cultivar genetics (Jefferies, 1995). The findings in the present study corroborate the views of Jefferies (1995) who noted that severe and prolonged water stress from early growth stage has been found to adversely affect tuber initiation and subsequent partitioning to other organs whereas water stress after tuber initiation, may not adversely affect partitioning to tubers. Other corroborative findings include those of Wright and Stark (1990) which showed that some stress can be tolerated during early vegetative growth and late tuber bulking under water deficit conditions in potato. Also the study by Hassan *et al.* (2002) with potato showed tuberization stage to be more sensitive to water stress compared to bulking and tuber enlargement stage. Shock *et al.* (1992) had earlier reported that potato can tolerate water deficit before tuber set without reduction in tuber quality. Shock and Feibert (2002) confirmed that all growth stages of potato, especially tuber formation stage, are very sensitive to water deficit stress. However, the findings from the present study are contrary to that of van Loon (1981), in which it was stated that water shortage during the tuber bulking period decreases yield to a larger extent than drought during other growth stages of potato. This could be a reflection of genotypic differences.

The 12 *D. alata* and *D. rotundata* accessions selected from the first screening responded differently under varied moisture stress conditions as shown in data on the fresh and dry tuber weight, harvest index and AMF spore population and yam root colonization. With reference to dry tuber weight, Abi a *D. rotundata* accession recorded significantly highest mean weight at the least stress level of 75% FC, 11 WAP compared to Saminaka and Aloshi accessions. However at the highest stress level of 25% FC at 11 WAP, Saminaka maintained the highest tuber dry weight which was not significantly different from those of Abi and Aloshi. Similarly in *D. alata*, TDa 297 maintained the highest dry tuber weight under adequate moisture supply, but at the highest stress level of 25% FC at 11 WAP, a significant decline of 89.1% was observed in TDa 297 as compared with the best performing accession, TDa 93-36 with 47.4%.

The variability observed among these accessions for the measured morphological and agronomic traits in both yam species further confirms the presence of genetic diversity among the 12 selected accessions from both spp. The observed variability which revealed that accessions in both yam species differed from one another in their response under moisture stress conditions is suggestive of the potentials of the accessions for improvement in respect of drought tolerance through breeding.

Inoculation of AMF reinforced the potential of yam plants to adapt to drought stress. Significant differences were observed between AMF inoculated and non-inoculated treatments for most of the evaluated parameters. Fresh and dry tuber weights increased by 58% and 112%, respectively in *D. alata* and 33% and 38% in *D. rotundata* due to AMF inoculation. With the presence of active external hyphae, AMF could adhere to soil particles, thereby improving contact with soil moisture. The observed significant increase in tuber weight due to mycorrhizal inoculation may be linked to the presence of external hyphae on the roots of infected AMF plants which may help in water absorption in the soil micropores which normally would not be penetrated by roots or root hairs of uninoculated plants (Yusnaini *et al*., 1999; Smith and Smith,2011). Also, AMF root colonization could influence the root architecture under drought stress conditions, stimulating root proliferation in terms of rooting length and depth (Miransari *et al*. 2007) as well as surface area which results in better utilization of available water (Kothari *et al*., 1990). Symbiosis of AMF may, through an improved exploration of the soil pore space, improve uptake of plant nutrients

especially phosphorus. This could in turn bring about higher root hydraulic conductivity, increasing the ability of roots to absorb more water (Udaiyan *et al*, 1997), thereby playing an important role in increasing plant-water relationship in drought conditions and improving the drought tolerance of host plants (Kothari *et al*., 1990). This increase in growth and yield of *D. alata* and *D. rotundata* in the present study is in consonance with the findings of Al-Karaki *et al*. (2004) that biomass and grain yields in wheat, a cereal crop, were higher in mycorrhizal than in non-mycorrhizal plots irrespective of soil moisture. Furthermore, this positive effect of AMF colonization on the host plant may affect root exudation thereby affecting properties of the soil in the rhizosphere including soil structural stability which in turn increases soil water retention properties (Augé, 2001).

The 12 selected accessions differed significantly in their response to AMF root inoculation as reflected in AMF colonization, spore density in the soil and fresh tuber weight (of *D. alata*). This implies that some accessions are more responsive to AMF inoculation than others. Such accessions include TDa 297, TDa 00/00064, Kesofunfun, TDa 96-36 and TDa 00/00194 of *D. alata* along with TDr Abi, Didio, TDr 00/00365, Saminaka, Tabene and Aloshi of *D. rotundata*.

In line with the findings of Sarawati *et al*. (2012), regarding AMF interaction with drought stress on sweet potato, there were significant interactions between AMF inoculation and moisture stress in respect of fresh and dry biomass yield, total leaf area and number of AMF spores in the present study. The significantly higher leaf area in mycorrhizae- inoculated plants indicates that AMF contributes to maximizing photosynthesis in yam. This confirms the findings of Udaiyan *et al.* (1997) working on cowpea (*Vigna unguiculata*) a legume, that leaf area determines the efficiency of solar radiation interception, photosynthesis, biomass accumulation, transpiration and plants energy transfer. Thus, AMF can effectively enhance the growth of the yam plant in a moisture- stressed environment.

Yam grown under mycorrhizal inoculation had greater tolerance to drought than those without inoculation. In the present study, AMF root colonization occurred in non- AMF inoculated yam plants, although at a significantly lower level than those of inoculated plants. This non-inoculated colonization indicates that yam plants may normally be associated with AMFpresent in the soil.

Mycorrhizal inoculation effects were higher in well-watered plants than in water-stress plants. Thus, water regime at 30% FC significantly inhibited cassava

mycorrhizal root colonization thereby reducing the length and dry weight of mycorrhiza-infected roots (Agili and Pardales, 1997). Yano *et al*. (1996) reported that inoculation of AMF on roots of *Arachis hypogaea* L. and *Cajanus cajan* L., both legumes, led to a localized alteration in lateral root development. Thus, the root system in the fungus-inoculated part of the soil produced more lateral roots and greater root length than roots growing in the uninoculated part.

The percentage increase in the evaluated parameters due to mycorrhizal inoculation was however greater under stress conditions than under well-watered state. Thus, percentage increase in dry tuber weight ranged from 88.6% with optimum moisture level to 127% when stress was imposed at tuber initiation stage. Apart from the stress intensity, the timing of stress imposition influenced the mycorrhizal effects. Thus, water stress imposition at tuber initiation increased dry tuber weight of *D. alata* by 127% while an increase of 196% was obtained with water stress imposition at bulking stage. Tuber initiation stage, being the most sensitive and critical stage with regards to moisture stress, causes great reduction in tuber yield and quality relative to other growth stages (Shock and Feibert, 2002).

Growth and yield of crops under irrigation are dependent on crop type, its growth stage, duration of irrigation, soil and air temperatures, initial soil water content, initial soil nitrogen content and soil physical characteristics (Allen et al., 1998). The two species of yam evaluated in the field study at Minjibir differed in their response to irrigation. With the early planting i.e. first planting date, D. rotundata accessions had significantly higher tuber yields under well-watered conditions compared to moisture-stressed treatment. Lower tuber yield of D. alata at Minjibir could have resulted from leaching of nutrients from the shallow root zone. The soil of the study site at Minjibir, Kano state of Nigeria was predominantly sandy, hyperthermic typic ustipsamment, with a high infiltration rates and very low in organic matter content (Oluwasemire *et al.*, 2002). Consequently, owing to this soil characteristic coupled with the irrigation intervals, a rapid leaching of nutrients might have occurred.

In crop production, an appropriate sowing date is one of the most important factors. It was observed in the present study that planting date had a significant influence on the yield. The earliest planted *D. alata* accessionshad a significantly higher yield compared to yield from the second planting date, while the lowest yield was obtained with the last planting date. For *D. rotundata*, there was very poor sprouting and plant survival at second and third planting dates resulting in poor yield.

The reduction in vigour that occurred may be associated with long storage and the poor sprouting could also be partly due to the inadequate and poorly distributed amount of rainfall after planting, particularly for the late planted materials. When provided with desirable environmental conditions, particularly in respect to solar radiation and temperature, plants produce more assimilates and consequently, higher yields (Seghatoleslami *et al*., 2013). A significant relationship between plant dry weight and sowing date of sesame seeds was recorded by Bremner (1996), who observed a reduction in plant dry weight as the sowing date was delayed. Similar trends were observed for yam seed tuber weight. Planting date of yam in the tropics varies according to the onset of the rainy season (Marcos *et al.*, 2011). Yam is photoperiod-sensitive such that a change in the planting date will affect plant development and growth. Short daylength favours tuber initiation (Shiwachi *et al*., 2002; Vaillant *et al*., 2005). From the field study, a significant yield decline was observed as the planting date progressed from July to September. This observation was in agreement with the findings of Shiwachi *et al*. (2002). They noted that due to shortening of daylength after July, yield of yam is reduced because early tuber initiation with short days caused a considerable reduction in vegetative growth and a consequent poor tuber enlargement. The final biomass and yield decreased sharply because with late planting, short daylengths induced earlier tuber initiation (Marcos *et al*., 2009), thereby reducing the vegetative phase as early as two weeks after emergence.

CHAPTER 6

SUMMARY AND CONCLUSIONS

The area of yam cultivation in Nigeria is limited because of the crop's high moisture requirement coupled, in recent times, with the erratic and unreliable rainfall pattern resulting from climate change. Besides, its cultivation is mainly by resource-poor farmers who cannot afford irrigation costs. There is therefore a need to identify or develop yam varieties that are well adapted to marginal ecological areas, with special emphasis on drought tolerance. Arbuscular mycorrhizae fungi enable plants to absorb water from soils in dry/low rainfall environments. From 2009 to 2012, a study was conducted to:

a. assess the diversity of 81 yam accessions for tolerance to moisture stress,
b. identify drought tolerant yam (*D. alata* and *D. rotundata*) accessions and
c. determine the contributions of arbuscular mycorrhizae fungi to drought tolerance in the yam accessions.

The study included two glasshouse pot experiments and one field experiment. In the first glasshouse experiment, 32 *Dioscorea alata* and 49 *Dioscorea rotundata* accessions were evaluated for drought tolerance. The result of a canonical analysis showed that 96% and 95% of the total variation among the accessions of *D. alata* and *D. rotundata*, respectively were explained by the first two canonical axes. Multivariate cluster analysis grouped the *D. alata* accessions into four clusters with the best performing accessions being in Group 1. *Dioscorea rotundata* accessions formed five clusters, with the best performing accessions in group 3.

The contribution of moisture stress levels and AMF inoculation to drought tolerance of yam were assessed in the second glasshouse experiment using 12 representative accessions each of *D. alata* and *D. rotundata* selected from the first experiment. The environmental factors included two mycorrhizae levels (with and without) and three moisture stress levels viz. 75% FC at 11 WAP (control treatment), 25% FC at 15 WAP and 25% FC at 11 WAP. The results revealed that moisture stress

conditions significantly affected the evaluated yam growth factors. Thus, stress imposed at 25% FC at tuber initiation stage i.e. 11 WAP resulted in the reduction of the growth factors particularly fresh and dry tuber weight and leaf area as against stress imposition at the tuber bulking stage i.e. 15 WAP. Thus, with moisture stress imposed at 25% FC, at tuber initiation stage i.e. 11 WAP, the fresh and dry tuber weight declined by 83.2% and 86.5%, respectively compared to reductions of 67.8% in fresh tuber weight and 69.7% in dry tuber weight with moisture stress (25% FC) imposition at tuber bulking stage (15 WAP) in *D. alata*. For *D.rotundata*, reductions in dry tuber weight due to moisture stress were 51.3% with stress imposition at bulking stage and 76.6% with stress imposition at tuber initiation stage. Also, total leaf area decreased by 27% (*D.alata*) and 19.2% (*D.rotundata*) with moisture imposition at bulking stage and 39.5% (*D.alata*) and 34.5% (*D.rotundata*) at tuber initiation stage.

Mycorrhizae inoculation treatment significantly increased the fresh tuber weight of *D. alata* by 58% and dry weight by 112%while, increases of 33.3% in fresh tuber weight and 37.7% dry weight were recorded for *D. rotundata.* The 12 accessions of each of *D.alata* and *D. rotundata* differed significantly, in their response to AMF inoculation, confirming that some accessions to mycorrhizae were more responsive to AMF inoculation than others. The most responsive accessions to mycorrhizae were TDa 297, TDa 00/00064, Kesofunfun, TDa 96-36 and TDa 00/00194 (*D. alata*) and TDr Abi, Didio, TDr 00/00365, Saminaka, Tabene and Aloshi (*D. rotundata*).

In 2011, a field experiment was conducted in Minjibir to determine the growth and yield of three yam accessions each of *D. alata* and *D. rotundata* under drought conditions. The three *D. alata* accessions were TDa 02/00012, 00/00151, and 00/00064 along with TDr *Abi, Saminaka* and *Aloshi* for *D. rotundata*. The characters evaluated were fresh and dry biomass, total leaf area, spore density, percentage AMF colonization and tuber yield. Mycorrhizal inoculation in the field had no significant effects on the growth and yield of the accessions. This could have been due to the effect of unfavourable soil and environmental factors such as temperature, soil pH and nutrient status on the introduced inocula. There was a high level of phosphorus on the field soil. Irrigation had no favourable effects on *D. alata.* Planting date had a significant influence on the yield, with the earliest planted *D. alata* accessions having a significantly higher yield compared to the second and third planting dates. *D. rotundata* exhibited very poor sprouting in respect of the second and third planting

dates resulting in poor yield. This could partly be due to the inadequate and poorly distributed amount of rainfall after the first planting date.

The conclusions and recommendations from the various studies are as follows:

1. Diversity in drought tolerance existed among the evaluated *D. alata* and *D. rotundata* accessions. Efforts to meet the demand for yam through successful extension of its cultivation area particularly in the dry northern Guinea savannah, most consider the observed variability in the two yam species with respect to drought tolerance and the existence of genetic resources for utilization in breeding for drought tolerance in yam.
2. Tuber initiation stage was observed to be the most critical stage for moisture stress effects in yam. Thus, severe and prolonged moisture stress from early growth stage adversely affected tuber initiation and subsequent development.
3. Mycorrhizal inoculation could be used to improve yam production under moisture stress conditions.
4. The yam accessions varied in their response to mycorrhizal inoculation.
5. TDa 93-36, 02/00006, *Kesofunfun*, TDa 00/00064 and TDa 297 accessions of *D. alata*, and *Aloshi*, *Abi*, TDr 97/812, *Saminaka* and TDr 00/00365 accessions of *D. rotundata* were selected as accessions with promising genetic potentials for drought tolerance.
6. Relatively early planting is recommended for yam cultivation as late planting resulted in reduced tuber yields.

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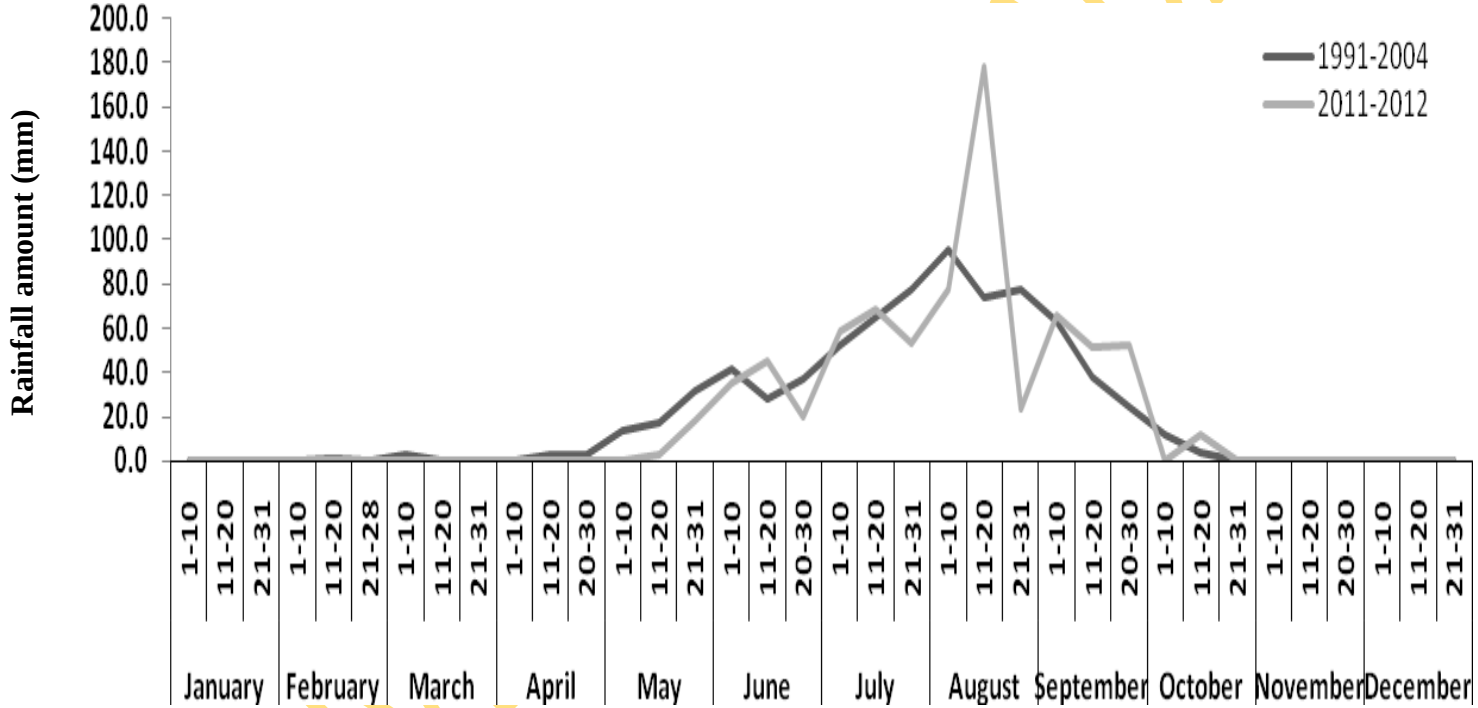
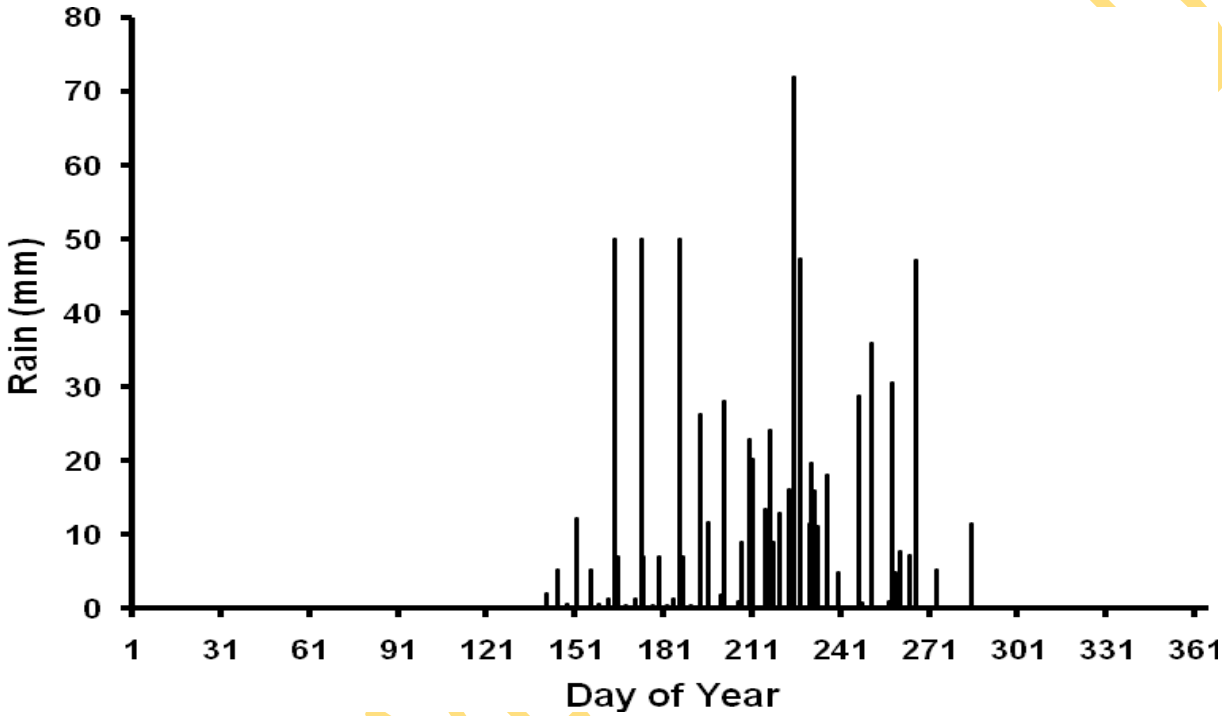
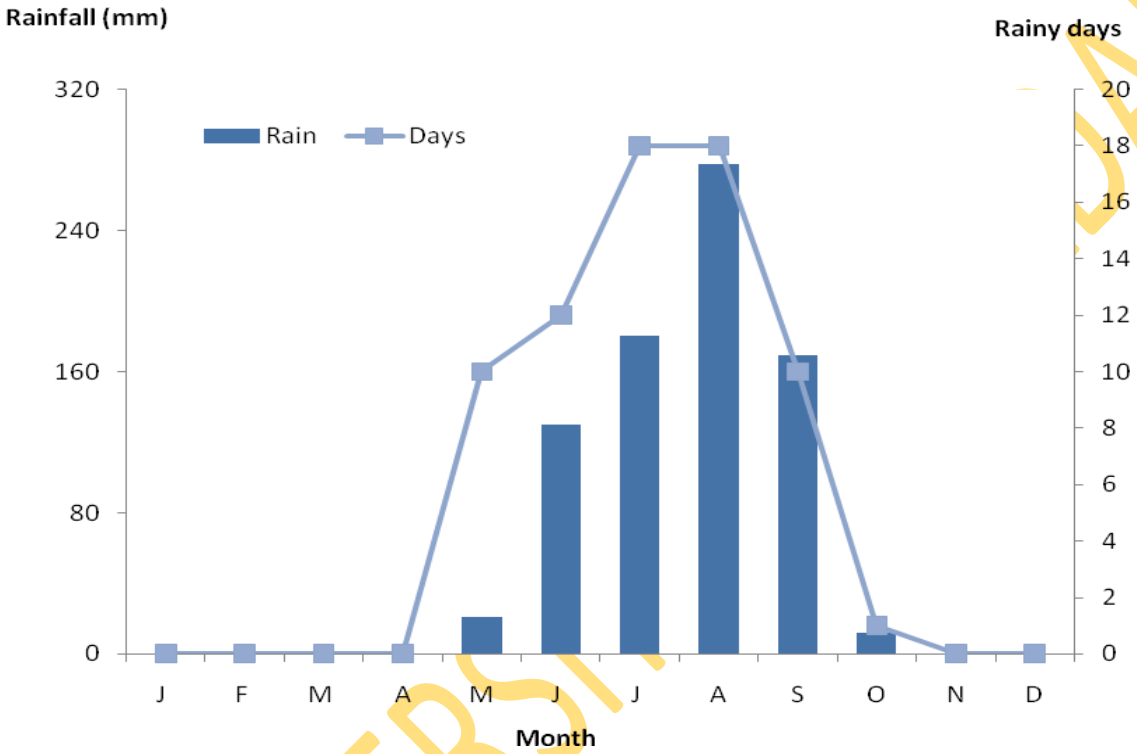
APPENDICES



Appendix 1. Comparison of Rainfall distribution in Minjbir-Kano State between 1991-2004 and 2011-2012



Appendix 2. Daily Rainfall distribution in Minjbir-Kano State during the field experiment, 2011



Appendix 3. Monthly rainfall distribution and rainy day in Minjbir-Kano State during the field experiment, 2011

Appendix 4. Summary of weather condition in Minjbir-Kano State during the field experiment, 2011

Month	Sunshine hrs	Tmax (°C)	Tmin (°C)	Rain (mm)	Rainy Days
January	8.7	30.6	14.3	0.0	0.0
February	8.2	35.9	19.2	0.0	0.0
March	7.6	39.6	23.8	0.0	0.0
April	7.7	41.3	26.2	0.0	0.0
May	9.2	39.4	26.2	20.4	10.0
June	9.1	34.1	23.2	130.7	13.0
July	8.6	32.2	22.6	179.9	17.0
August	7.1	30.7	21.6	277.6	18.0
September	8.7	33.4	22.3	169.1	10.0
October	8.8	34.7	21.9	11.5	1.0
November	10.4	34.1	16.4	0.0	0.0
December	8.0	29.8	14.8	0.0	0.0
Av./Total	8.5	34.7	21.0	789.2	69.0

Appendix 5. Summary of the analysis of variance for the 12 *D. alata* accessions

Source of variation	DF	Fresh below ground weight	Fresh tuber weight	Fresh vine weight	Fresh leaves weight	Dry below ground weight	Dry tuber weight	Dry vine weight	Dry leaves weight	Root: shoot ratio	Harvest index	Total leaf area	No. of spores	AMF colonization
					g/plant						%	cm^2	no./100 g soil	%
Accessions (G)	11	4715.3***	1534.1***	629.0***	929.***	208.0***	109.1***	27.1***	25.7**	4.3***	497***	2097207.6***	0.1***	421.8***
Mycorrhizae treatment (MC)	1	33351.4***	15662.7***	252.9ns	1018.6***	1139.1***	1966.0***	0.4ns	300.8***	14.5**	4483.3***	10544862.0***	8.0***	7217.4***
Water level (WL)	2	144611.4***	81941.1***	2146.5***	11206.2***	6791.3***	4769.4***	94.8***	9.6ns	48.5***	5905.6***	19962170.7***	0.8***	1147.7***
MC* WL	2	3185.61**	2448.71***	178.62ns	297.42*	351.50***	377.37***	3.4ns	19.0***	3.5**	62ns	1499290.77**	0.12***	30.91ns
MC*G	11	569.96ns	507.14**	79.30ns	96.63ns	41.80ns	12.28ns	1.5ns	6.1ns	0.26ns	39.3ns	426241.40ns	0.04***	146.06**
WL * G	22	421.88ns	492.45***	78.13ns	110.34ns	58.37**	47.31***	3.3ns	4.6ns	1.69***	113.8***	430979.04ns	0.01**	97.30*
MC* WL* G	22	1153.43**	559.44***	75.38ns	118.39ns	42.35ns	24.06ns	1.8ns	4.1ns	0.8ns	69.8*	352383.04ns	0.007ns	88.00ns
Means		85.37	37.82	28.11	38.93	15.89	8.51	7.83	7.22	1.07	25.66	2028.92	2.04	25.51

*and ** represents significant at $P \leq 0.05$, 0.01; ns' not significant

Appendix 6. Summary of the analysis of variance for the *12 D. rotundata* accessions

Source of variation (*D. rotundata*)	DF	Fresh below ground weight	Fresh tuber weight	Fresh vine weight	Fresh leaf weight	Dry below ground weight	Dry tuber weight	Dry vine weight	Dry leaf weight	Root: shoot	Harvest index	Total leaf area	No. of spores	AMF colonization
Accession (G)	11	3619.8***	3737.8***	616.5***	1296.4***	224.0***	217.7***	43.7***	41.5***	5.7***	626.5***	2725087.3***	0.1***	409.6***
Mycorrhizae treatment (MC)	1	8519.4***	6651.2***	14.1ns	613.3**	606.4***	469.8***	0.6ns	3.5ns	2.3ns	898.5***	3294647.1***	4.6***	8798.0***
Water level (WL)	2	79600.9***	45585.8***	1818.1***	5585.6***	4520.4***	2751.4***	79.2***	152.0***	17.3***	3224.9***	6851003.2***	0.5***	880.4***
MC* WL	2	0.37ns	292.13ns	298.9**	296.50*	9.74ns	9.53ns	10.3ns	1.4ns	1.39ns	161.53ns	1594216.20**	0.03***	22.19ns
MC * G	11	459.98ns	405.68ns	99.6ns	81.85ns	32.00ns	18.83ns	8.7ns	1.6ns	0.38ns	78.35ns	574553.82*	0.05***	153.76***
WL* G	22	689.20ns	920.52***	76.7ns	97.31ns	47.35**	49.48**	8.3ns	3.2ns	1.21ns	100.21**	284784.2ns	0.02***	257.33***
MC*WL* G	22	280.33ns	220.66ns	45.7ns	71.81ns	16.18ns	14.47ns	4.6ns	2.7ns	0.81ns	62.58ns	438542.09ns	0.01***	189.53***
Means		56.22	38.41	27.68	30.57	13.18	9.08	8.25	6.14	1.05	21.20	1453.63	2.07	14.35

*and **,represents significant at $P \leq 0.05$, 0.01ns' not significant

Appendix 7. Mean square of ANOVA for growth and physiological parameters at 14 and 18 weeks after planting (WAP) of *Dioscorea alata* accessions

Source of variation		Chlorophyll content (nmol /cm^2)		Stomata conductance (µmol.m-2.s-1)		Harvest index	
	d.f.	14WAP	18WAP	14WAP	18WAP	14wap	18wap
REP stratum	2	5.12	34.54	166	179.6	69.23	20.98
REP.IRR stratum							
IRRGATION (IRR)	1	528.01**	126.71ns	12193.4ns	35752.1*	17.25ns	68.77**
Residual	2	1.27	7.69	1913.6	1254.8	43.4	0.23**
REP.IRR.PD stratum							
PLANTING DATE (PD)	2	5165.3***	561.28***	1968.2ns	12038.3***	569.2***	8922.9***
IRR.PD	2	247.41***	10.32ns	3330.1*	3499.3*	129.6**	374.41***
Residual	8	9.25	15.25	548.6	730.7	16.56	15.76
REP.IRR.PD.MC stratum							
MYCORRHIZAE (MC)	1	26.21*	162.91*	173.6ns	257.8ns	5.17ns	51.91ns
IRR.MC	1	7.47ns	88.73ns	51.9ns	38.7ns	2.85ns	1.24ns
PD.MC	2	0.7ns	126.31**	87.8ns	1359.3ns	138.61ns	157.56*
IRR.PD.MC	2	3.98ns	122.53**	827.6**	54.3ns	68.64ns	80.24ns
Residual	12	4.1	24.86	131.3	472.3	46.64	31.48
REP.IRR.PD.MC.*Units*	stratum						
ACCESSION (G)	2	97.18***	511.59***	1283.4***	4812.5**	138.64*	92.77*
IRR.G	2	7.05ns	71.7*	613.2*	1315.2ns	28.14ns	29.53*
PD.G	4	68.34***	199.57***	820.5***	1186.5ns	69.42ns	228***
MC.G	2	7.07ns	148.46**	384.5ns	1770.3ns	1.23ns	184.72***
IRR.PD.G	4	17.17ns	137.77***	143.5ns	822.6ns	16.27ns	62.72*
IRR.MC.G	2	0.51ns	160.39***	30ns	162.6ns	9.41ns	28.01ns
PD.MC.G	4	9.26ns	152.79***	127.4ns	1060.2ns	15.46ns	66.39*
IRR.PD.MC.G	4	17.94ns	202.26***	496.7*	796.9ns	59.93ns	73.65*

Residual	48	10.48	21.11	141.2	849.7		30.83	23.58
Total	107							

**: significant at 0.01, *: significant at 0.05, ns: no significant difference

Appendix 8. Mean square of ANOVA for AMF root colonization of *Dioscorea alata* accessions and number of AMF spores in the soil

Source of variation	d.f.	% AMF colonization 14WAP	%AMF colonization 18WAP	*Entrophosphora*	*Glomus*	*Aculospora*	*Gigaspora*	No. of Spores
REP stratum	2	0.02	0.01	6.6184	4.24	14.9601	1.24	846
REP.IRR stratum								
IRRIGATION (IRR)	1	0.22ns	0.63	0.02ns	0.19ns	0.42ns	0.89ns	52.1ns
Residual	2	0.1	0.21	0.17	0.49	0.3305	0.06	123
REP.IRR.PD stratum								
PLANTING DATE (PD)	2	2.62***	1.46***	14.85***	29.68**	12.01**	3.18***	5676.7***
IRR.PD	2	0.12ns	0.27ns	2.08ns	2.05ns	3.27ns	0.63**	283ns
Residual	8	0.05	0.114	0.85	1.92	1.3471	0.07	302
REP.IRR.PD.MC stratum								
MYCORRHIZAE (MC)	1	0.004ns	0.20ns	8.05**	9.88***	7.20***	0.03ns	2089.1***
IRR.MC	1	0.01ns	0.44ns	10.97**	33.83***	9.38***	7.56***	8060.1***
PD.MC	2	0.05ns	0.05ns	0.93ns	0.03ns	0.53ns	1.12**	350.3**
IRR.PD.MC	2	0.17**	0.17ns	0.57ns	2.17*	1.06ns	0.64*	856.3***
Residual	12	0.02315	0.13	0.79	0.42	0.37	0.14	46.3
REP.IRR.PD.MC.*Units* stratum								
ACCESSION (G)	2	0.35**	0.19ns	0.13ns	0.42	3.26**	0.67ns	384ns
IRR.G	2	0.09ns	0.45**	0.45ns	0.66ns	5.23***	2.47**	116.6ns
PD.G	4	0.18**	0.59ns	0.98*	1.06ns	1.48*	4.05***	527**
MC.G	2	0.80***	0.68**	1.93***	6.29***	1.30ns	1.76*	1418.5***
IRR.PD.G	4	0.8***	0.13ns	0.83*	2.89***	0.51ns	2.13***	275.3ns
IRR.MC.G	2	0.04ns	1.21***	2.59***	0.16ns	8.17***	1.16ns	310ns
PD.MC.G	4	0.12ns	1.18***	1.13**	1.48*	0.95ns	2.12***	617.5***
IRR.PD.MC.G	4	0.29***	0.64***	1.18**	0.79ns	1.75*	1.11*	164.9ns
Residual	48	0.05	0.09	0.29	0.54	0.54	0.4	147

Total	107

**: significant at 0.01, *: significant at 0.05, ns: no significant difference

Appendix 9. Mean square of ANOVA for yield parameters of *Dioscorea alata*accessions

Source of variation	d.f.	Ware yam weight (kg/Plot)	Net weight (kg/Plot)	No. of seed yam	No. of ware yam	Plot weight (kg/plot)	Seed tuber weight (kg/plot)	Dry matter (g/plot)
REP stratum	2	2.47	0.0781	9.93	1.23	8.36	0.7078	1071.4
REP.IRR stratum								
IRRIGATION (IRR)	1	0.02ns	0.07**	7.26ns	0.33ns	0.005ns	0.11ns	4382.8ns
Residual	2	0.5	0.0004	25.15	0.86	2.3	0.64	1556.6
REP.IRR.PD stratum								
PLANTING DATE (PD)	2	15.89**	54.23***	64.03*	8.90**	944.77***	11.86***	127581.4***
IRR.PD	2	2.22	3.82ns	2.82ns	0.69ns	51.05**	0.42ns	1893.4ns
Residual	8	1.22	1.27	12.29	0.91	4.21	0.72	583.4
REP.IRR.PD.MC stratum								
MYCORRHIZAE (MC)	1	0.05ns	0.18ns	6.26ns	0.59ns	0.26ns	0.01ns	156.5ns
IRR.MC	1	0.18ns	0.38ns	2.37ns	0.33ns	35.94*	0.01ns	960ns
PD.MC	2	0.48ns	1.26ns	28.04*	0.18ns	3.17ns	0.24ns	424.1ns
IRR.PD.MC	2	0.58ns	0.56ns	1.93ns	0.53ns	10.25ns	0.06ns	779.7ns
Residual	12	1.14	1	4.87	0.69	7.33	0.55	729.4ns
REP.IRR.PD.MC.*Units* stratum								
ACCESSION (G)	2	0.36ns	2.66ns	34.48*	0.26ns	126.87***	3.10***	1034.5ns
IRR.G	2	3.02**	3.83*	3.59ns	2.11**	0.99ns	0.47ns	2567.7**
PD.G	4	0.16ns	1.72ns	25.55*	0.07ns	33.90**	1.00ns	224.3ns
MC.G	2	0.26ns	0.12ns	2.37ns	0.70ns	0.37ns	0.16ns	388.9ns
IRR.PD.G	4	1.06ns	1.30ns	36.94**	0.59ns	12.84ns	0.62ns	3909.3***
IRR.MC.G	2	0.68ns	3.36*	11.14ns	0.11ns	0.77ns	2.03**	1597.2ns
PD.MC.G	4	0.59ns	0.69ns	2.69ns	0.07ns	5.60ns	0.03ns	92ns
IRR.PD.MC.G	4	0.26ns	0.24ns	13.079ns	0.09ns	6.41ns	0.42ns	1759.4**

Residual	48	0.51	0.89	9.88	0.36	9.14	0.41	506.9
Total	107							

**: significant at 0.01, *: significant at 0.05, ns: no significant difference

Appendix 10. Mean square of ANOVA for growth parameters of *Dioscorea rotundata*

		Chlorophyll content (nmol /cm^2)			Stomata conductance (µmol.m-^{2}.s^{-1})			Dry leaf weight (g/plant)	
Source of variation	d.f.	14WAP	18WAP	22WAP	14WAP	18WAP	22WAP	14wap	18wap
REP stratum	2	10.72	50.85	23.84	79.3	1259.4	103.28	15.9	528.9
REP.WL stratum									
WATER LEVEL (WL)	1	1.04ns	186.78*	49.23ns	58358.6**	108243.7**	552.64*	328.2ns	485ns
Residual	2	0.96	7.79	14.27	166.6	388.6	20.74	115.9	178.7
REP.WL.MC stratum									
MYCORRHIZEA (MC)	1	0ns	0.79ns	0ns	1233.5*	45.2ns	3.6ns	44.2ns	1404.4ns
WL*MC	1	7.17ns	0.43ns	0.67ns	912.8ns	517.2ns	88.1ns	84.6ns	330.2ns
Residual	4	13.18	9.32	10.22	152.8	281.9	891.4	284.6	301.4
REP.WL.MC.G stratum									
ACCESSION (G)	2	675.49***	623.8***	285.49***	1065.7*	10919.1***	228.81ns	876.2*	788.7ns
WL* G	2	4.49ns	21.11ns	15.98ns	509.8ns	9341.6***	180.59ns	340.5ns	14.3ns
MC*G	2	3.4ns	3.86ns	2.42ns	155.1ns	69.2ns	1915.17***	253.7ns	1064.4ns
WL*MC*G	2	8.28ns	14.03ns	4.97ns	61.5ns	1307.3ns	358.51ns	295.7ns	419.1ns
Residual	16	13.6	14.43	16.76	238.3	876.5	99.76	232.3	508

Total	35

**: significant at 0.01, *: significant at 0.05, ns: no significant difference

Appendix 11. Mean square of ANOVA for AMF root colonization of *Dioscorea rotundata* and number of AMF spores in the soil

Source of variation	D.f.	%Colonization 14WAP	%Colonization 18WAP	*Entrophosphora*	*Glomus*	*Scutelospora*	*Aculospora*	*Gigaspora*	No Spores
REP stratum	2	1.38	3.64	0.84	0.1	0.24	0.4	0.06	0.029
REP.WL stratum									
WATER LEVEL (WL)	1	4.52ns	9.62ns	0.21ns	0.003ns	0.29ns	0.28ns	0.03ns	0.026ns
Residual	2	0.58	1.73	0.04	0.006	0.22	0.09	0.04	0.027
REP.WL.MC stratum									
MYCORRHIZAE (MC)	1	7.98ns	0.03ns	0ns	0.255*	0.02ns	0.01ns	0.16**	0.174*
WL*MC	1	0.12ns	5.66ns	0.01ns	0.304*	0.003ns	0.49**	0.07*	0.136*
Residual	4	2.08	2.29	0.07	0.03177	0.03	0.01ns	0.008	0.015
REP.WL.MC.G stratum									
ACCESSION (G)	2	0.88ns	8.73**	0.22ns	0.149*	0.507***	0.09ns	0.06ns	0.013ns
WL*G	2	5.63ns	4.94ns	0.62**	0.26**	0.096ns	0.49**	0.43**	0.317***
MC*G	2	7.78ns	0.61ns	0.10ns	0.222**	0.184*	0.11ns	0.21*	0.219***
WL.MC.G	2	2.23ns	7.14*	0.01ns	0.178*	0.071ns	0.23*	0.08ns	0.112*
Residual	16	2.34	1.38	0.08	0.03171	0.037	0.05	0.05	0.02
Total	35								

**: significant at 0.01, *: significant at 0.05, ns: no significant difference

Appendix 12. Mean square of ANOVA for Yield of *Dioscorea rotundata* in a drought environment

Source of variation	D.f.	Netweight (kg/plot)	Number of seed yam	Seed weight (kg/plot)	Plot weight (kg/plot)	Dry Matter (g/plot)
REP stratum	2	0.8611	12.69	0.25	2.96	639.7
REP.WL stratum						
WATER LEVEL (WL)	1	7.47*	25ns	7.47***	162.14***	3461.4ns
Residual	2	0.1	1.58	0.001	0.19	753.5
REP.WL.MC stratum						
MYCORRHIZAE (MC)	1	0.11ns	5.44ns	0.11ns	12.48ns	393.4ns
WL.MC	1	0.28ns	2.78ns	0.28ns	32.87ns	272.2ns
Residual	4	1.51	13.19	1.11	8.9	1102.4
REP.WL.MC.G stratum						
ACCESSION	2	3.63***	62.19**	4.05***	25.65ns	5750.7***
WL*G	2	0.44ns	3.58ns	0.44ns	1.55ns	843.7ns
MC*G	2	0.72ns	11.36ns	0.32ns	0.62ns	1008.4ns
WL*MC*G	2	0.08ns	0.86ns	0.08ns	4.96ns	923.6ns

Residual	16	0.36	7.96	0.21	8.23	499.2
Total	35					

**: significant at 0.01, *: significant at 0.05, ns: no significant difference