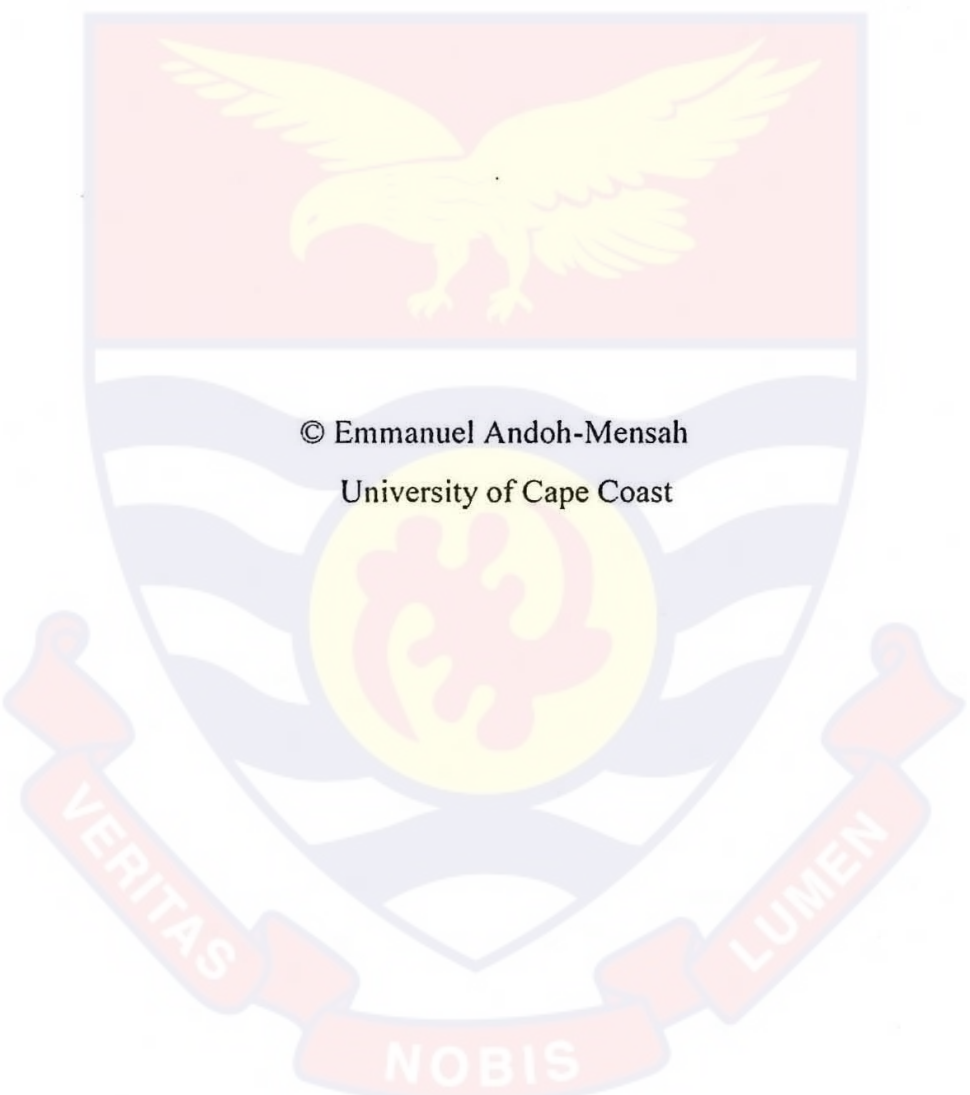

UNIVERSITY OF CAPE COAST

NURSERY AND TREE MANAGEMENT PRACTICES FOR IMPROVED GERMINATION, SEEDLING QUALITY AND FRUIT CHARACTERISTICS OF CAPE ST. PAUL WILT DISEASE TOLERANT COCONUT VARIETIES

BY

EMMANUEL ANDOH-MENSAH

Thesis submitted to the Department of Crop Science of the School of Agriculture, College of Agriculture and Natural Sciences, University of Cape Coast, in partial fulfilment of the requirements for the award of Doctor of Philosophy Degree in Crop Science

MARCH, 2022

DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the results of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature.....Date..30/09/2022

Name: Emmanuel Andoh-Mensah

Supervisor's Declaration

I hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature:..... Date: 30/09/2022

Name: Prof. Kingsley Joseph Taah

Co-Supervisor's Signature:.....Date30/09/2022

Name: Prof. Michael Osei Adu

ABSTRACT

To meet the increasing demand for Cape St. Paul Wilt Disease (CSPWD) tolerant coconut seedlings, this research was carried out to develop interventions for improving seed nut germination and vigour, seedling quality and vigour and Sri Lanka Green Dwarf (SGD) fruit characteristics. Seven (7) different experiments were carried out to assess pre-nursery practices, seedling spacing and fertilizer application, ablation and fruit thinning towards addressing deficiencies in coconut nursery and tree management practices. Fully burying Sri Lanka Green Dwarf crossed Vanuatu Tall (SGD x VTT) coconut hybrid seed nut in decomposed sawdust at pre-nursery stage improved germination rate, speed of germination and germination index respectively by 33%, 30% and 98% relative to the control. A treatment combination of 60-cm triangular spacing and fertilizer application of 47.3:96.6:126.0:28.4 g seedling^{-1} $N:P_2O_5:K_2O:MgO$ produced good quality SGD x VTT coconut hybrid seedlings with averagely 34% higher vigour, 12% bigger collar girth, 11% wider canopy diameter and 5% increase in height relative to the control. Thinning of SGD coconut variety to 10 fruits per bunch increased crude protein and Vitamin C contents of fresh fruits by 31% and 42% respectively; and average fresh fruit weight by 32% and its components: husk, shell, kernel and water averagely by 42%, 61%, 42% and 65% respectively. Findings of pre-nursery studies are recommended for dissemination to appropriate entities to improve seed nut germination rate and increase supply of SGD x VTT coconut hybrid seedlings to farmers. Further research is recommended for assessing field performance of SGD x VTT coconut hybrid seedlings as affected by potassium nitrate soaking treatment, planting depth or nut size.

KEY WORDS

Cape St. Paul Wilt Disease

Coconut nursery,

Germination,

Seedling vigour,

Fruit thinning,

Fruit characteristics.

ACKNOWLEDGEMENTS

I am sincerely grateful to my supervisor, Prof. Kingsley Joseph Taah, for his advice, encouragement and guidance. I also acknowledge the invaluable contributions made by my co-supervisor, Prof. Michael Osei Adu. I sincerely thank Dr. Josiah Wilson Tachie-Menson for enhancing my capacity in the use of the Genstat Statistical Software for data analysis.

I thank staff of the Coconut Programme of the CSIR-Oil Palm Research Institute particularly, Miss Elizabeth Adjei, Messrs Obed Kwabena Owusu, Peter Kuupiel Nalasco, Richard Nkrumah, Jacob Taylor and Mr. John Baido for their immense assistance in the experimental set-ups, treatment application and data collection.

I appreciate the cooperation I enjoyed from my family during the PhD programme.

DEDICATION

To Prof. Victor Kwame Agyeman, Director-General of CSIR; Dr. Eric Cornelius, Senior Lecturer, University of Ghana; and my family.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

LIST OF TABLES

LIST OF TABLES (CONTINUED)

LIST OF TABLES (CONTINUED)

LIST OF FIGURES

LIST OF FIGURES (CONTINUED)

LIST OF ABBREVIATIONS

AOAC	Association of Official Agricultural Chemists
AOSA	Association of Official Seed Analysts
APCC	Asian and Pacific Coconut Community
APO	Asian Productivity Organization
CSPWD	Cape St. Paul Wilt Disease
FCA	Fruit Component Analysis
GEPA	Ghana Export Promotion Authority
IPGRI	International Plant Genetic Resources Institute
MoFA	Ministry of Food and Agriculture
PCRDF	Philippine Coconut Research and Development Foundation
PERD	Planting for Export and Rural Development
SGD	Sri Lanka Green Dwarf
SRID	Statistics, Research and Information Directorate
TCDA	Tree Crops Development Authority
VCO	Virgin Coconut Oil
VTT	Vanuatu Tall
SGD x VTT	SGD crossed VTT

CHAPTER ONE

1.0 INTRODUCTION

In recent years, demand for Cape St. Paul Wilt Disease (CSPWD) tolerant coconut seedlings has been on the ascendency and the inability to meet increasing demand has become a limiting factor to the growth of Ghana's coconut subsector (MoFA, 2018). Early research aimed at making CSPWD tolerant planting materials available to farmers led to the identification of two coconut varieties namely; Sri Lanka Green Dwarf (SGD) and Vanuatu Tall (VTT), which have high tolerance to the CSPWD (Dery *et al.*, 2008). The SGD and VTT on their own merits suffer low preference for commercial planting by farmers due to agronomic and fruit characteristic reasons. Consequently, hybridization of the two tolerant varieties to produce early bearing SGD x VTT coconut hybrid with improved fruit characteristics has been the way forward (Dare *et al.*, 2010).

However, the relatively low output of the hybridization process has become a matter of great concern as the low output does not keep pace with the high demand for CSPWD tolerant coconut seedlings (GEPA, 2020; MoFA, 2011). The situation is compounded by an annual loss of 30-40% of potential SGD x VTT hybrid seedlings (Owusu, 2014) and poor quality coconut seedlings for field planting (MoFA, 2018). The present study assesses nursery and tree management practices to develop agronomic interventions for improving seed nut germination, seedling quality and vigour and SGD fruit characteristics.

1.1 Background to the Study

The agricultural sector was a driving force behind the socio-economic growth of Ghana generating about 40% of the country's Gross Domestic Product (GDP) until 2011 when the sector's contribution to GDP took a nosedive. Despite the decline, the agricultural sector has a huge potential duly acknowledged as a strong stimulus for a sustained economic growth and development of Ghana. Consequently, six agricultural commodities including coconut have been selected to serve as drivers of economic growth and development under the ''Tree Crops Development Authority'' established by Act 1010 of Parliament in 2019.

The coconut palm, affectionately described as a "Tree of Life" by Rangaswani (1977), Ohler (1984) and Bourdeix *et al.* (2005), is an important economic crop in the coastal areas of Western, Central and Volta Regions of Ghana where it faces little or no competition with other tree crops due to edaphic reasons; though potentially it can be grown successfully in the hinterland areas across 10 regions namely; Western, Western North, Central, Eastern, Volta, Oti, Ashanti Ahafo, Bono and Bono East (Issaka *et al.*, 2012). According to MoFA (2018), approximately 80% of the total land area under coconut cultivation, estimated at 44,000 ha is found in the coastal areas. Dery *et al.* (1997) estimated that well over 50,000 households in the coastal belt depend on the coconut value-chain considering men and women engaged in its production, transportation, processing, marketing and utilization of by-products.

About 90% of coconut produced in Ghana is consumed as fresh nuts (MoFA, 2018). Its ability to enhance national food security lies in the tasty meat

and refreshing sweet water of fresh fruit coconuts which provide good satisfaction to both urban and rural consumers who take it either as snack or whole meal. In terms of nutritional value coconut provides a good source of energy; contains protein, fibre, vitamins and minerals. It is rich in health giving medium-chain fatty acids including lauric acid which is known to boost the body's immune system (Van Die, 1974; Rumulo, 2003; Floresca, 2004).

Ghana's export of non-traditional products amounted to USD 2.5 billion in 2016 (MoFA, 2017) of which coconut holds a high promise as non-traditional foreign exchange earner. Currently, less than 10% of coconut produced in Ghana is exported (MoFA 2018). An annual average of 12 million tonnes of coconut oil is traded globally (APCC, 2017). The demand for virgin coconut oil (VCO) is growing for its nutritional and health benefits and also for its applicability as a beauty product (Floresca, 2004). Its medium-chain fatty acid content with high lauric acid component has resulted in VCO growing demand as health supplement (nutriceutical) and healthy premium food and oil for cooking and salad dressing (Rumulo, 2003). The global market for nutriceuticals is growing rapidly and its value is estimated at US$504 billion for US, Europe and Japan markets (Carandang, 2005). The Ghana Export Promotion Authority (GEPA) is poised to take advantage of this growing market and invest in coconut production and export to enhance its non-traditional foreign exchange earnings (GEPA, 2020).

The government policy of "one-district-one factory" expects the coconut subsector to provide coconut raw material for coconut-based factories. Coconut as a raw material is used to produce a wide range of commercial and industrial

products. The kernel/copra is used to produce edible and non-edible oils for making margarine, moisturizer, liniment, cosmetics, medicines, soaps, detergents, paints and bio-fuel (Bazon &Velasco, 1985). The shell is utilized for production of activated carbon, charcoal briquettes, shell powder and novelty items. Coconut husk is used to produce husk fibre for making ropes, bristles and mats; coco-coir for making mattress fibres, carpets, geotextiles, upholstery and insulation materials; coconut pith for use as potting medium (Arboleda, 1997). The water is harnessed for producing vinegar, intravenous fluid, electrolyte, wine and alcohol. Coconut timber is used to manufacture wood for furniture making.

The coconut palm in Ghana is however under a devastating threat by a phytoplasma disease known locally as "Cape St. Paul Wilt Disease". The disease is caused by a related strain of *'Candidatus palmicola'* (Harrison *et al.*, 2014). It has typical symptoms of pre-mature nut drop, blackening of inflorescence, yellowing/ browning of leaves and tipping over of crown. As at 2001 the CSPWD had devastated about 11,000 ha of coconut farms in the Western and Central Regions and over 5,500 ha in the Volta Region (Anonymous, 2002). Until 2015, the Jomoro district of the Western Region was the only coconut growing district without the CSPWD and was the heartbeat of Ghana's Coconut Industry due to its tremendous contribution to the national coconut output. As at 2020, the CSPWD has devastated over 2,000 ha of coconut plantations in the Jomoro district.

The expected rapid expansion of the coconut subsector into the hinterland regions in recent years, as a result of increased demand for coconut and its value-added products globally and the favourable political climate created for its

planting through the government flagship programme of "Planting for Export and Rural Development (PERD)," has been slowed down drastically by limited availability of recommended coconut planting materials. The devastating nature of the disease puts the cultivation of coconut in the country at high risk without CSPWD tolerant seedlings (Dery *et al.*, 1997). The CSPWD tolerant planting materials are therefore critical for the sustenance and expansion of the coconut subsector in Ghana.

Research up to date has identified two coconut ecotypes: Sri Lanka Green Dwarf (SGD) and Vanuatu Tall (VTT) as tolerant to CSPWD (Dery *et al.*, 2008). Notwithstanding, famers' interest in the SGD and VTT coconut varieties for commercial planting has been low due to reasons bordering on agronomic and fruit characteristics. The SGD is constrained by its small fruit size and poor weight of the fruit components while the VTT suffer low preference for commercial planting due to its tall architecture and prolonged time lag from planting to fruiting (Dare *et al.*, 2010). Consequently, hybridization of the two tolerant varieties to produce early bearing SGD x VTT coconut hybrid with improved fruit and agronomic characteristics has been the way forward.

However, the hybridization process faces the problem of high fruit drop leading to low output of hybrid seed nut; a situation that has become an issue of concern to the coconut subsector due to its inability to keep pace with the increasing demand for CSPWD tolerant coconut seedlings (MoFA, 2011; GEPA, 2020). The situation is compounded by an annual loss of 30-40% of potential SGD x VTT coconut hybrid seedlings due to poor germination at the nursery (Owusu, 2014) and

poor quality seedling identified as one of the major causes of low productivity and poor financial viability of plantations in the coconut subsector (MoFA, 2011; MoFA 2018).

The situation therefore places a huge responsibility on research to develop agronomic interventions for improving seed nut germination and vigour, seedling quality and vigour and fruit characteristics of the SGD coconut variety.

1.2 Statement of the Problem

Research has identified two coconut varieties: SGD and VTT, which are tolerant to the CSPWD (Dery *et al.*, 2008). The SGD coconut variety, though most tolerant to the devastating CSPWD, has not been officially recommended for commercial planting by farmers due to its poor fruit characteristics. The poor fruit attributes originate from the fact that the dwarf variety produces inflorescence at an early age of 2-3 years at the time that its vegetative capacity has not fully developed, expressed particularly in its weak/ small stem. Intrinsically, the SGD variety carries a high fruit set which when developed into a heavy nut load in the context of a limited vegetative capacity triggers an assimilate availability crisis leading to relatively small fruit size and poor weight of the fruit components.

The VTT coconut variety is also not of commercial interest to farmers due to its tall architecture and prolonged time lag from planting to fruiting averaged at 6 years (Dare *et al.*, 2010). Consequently, the way forward has been the hybridization of the two tolerant varieties to produce early bearing SGD x VTT

coconut hybrid with improved fruit size and weight of fruit components for commercial planting (Dare *et al.*, 2010).

Apart from being expensive, time-consuming and labour intensive, the hybridization process generates relatively low seed nut output ranging from 25-45% of fruit set due to high fruit drop. The low hybrid seed nut output is unable to keep pace with the high demand for CSPWD tolerant coconut seedlings (GEPA, 2020; MoFA, 2011) making it a great concern. This situation is compounded by a relatively low germination rate of SGD x VTT hybrid seed nuts estimated at 60 -70% (Owusu, 2014) leading to an annual loss of 30 - 40% potential SGD x VTT seedlings in face of high demand.

In the Tree Crops Sector, poor quality seedlings has been identified as a contributory factor to low productivity and poor financial viability of plantations (MoFA, 2011). Consequently, poor quality seedlings for field planting has been flagged as a major problem facing the coconut subsector (MoFA, 2018). Ghana's research in coconut has focused largely on the devastating CSPWD to the detriment of some aspects including agronomic studies in coconut nursery. Therefore scanty scientific knowledge has been generated locally in support of coconut nursery management leading to adoption of unrecommended practices identified as a contributory factor to poor quality coconut seedlings (MoFA, 2011).

These problems of the coconut subsector have a compelling effect on Research Institutions to intervene with solutions especially those mandated officially to research into coconut.

1.3 Purpose of the Study

The study assesses nursery and tree management practices with the purpose of developing interventions with capacity to increase the supply of good quality coconut seedlings that are tolerant to CSPWD for commercial planting.

1.4 Research Objectives

Research objectives were identified to address issues mentioned in the problem statement (Section 1.2) with the purpose of the study (Section 1.3) in view.

In order to get the best out of the SGD coconut variety, it is believed that agronomic interventions involving tree management practices particularly; fruit thinning (Jackson & Frederich, 1999; Bourdeix *et al.*, 2005) and inflorescence removal (ablation) for a period (Datuluri & Misra, 2002; Corley & Tinker, 2003) could be used to improve the fruit characteristics of the SGD variety.

It is also believed that pre-nursery studies into seed treatment, planting medium, planting depth and nut size could be useful for improving seed nut germination in coconut (Wuidart, 1981a; Bewley & Black, 1994). Even though a number of studies are required to develop best nursery practices, it is important to begin with studies into spacing and nutrition at the main nursery to improve seedling quality and vigour (Nelliat, 1972; Thomas *et al.*, 2018).

Research objectives were therefore formulated to assess the effects of:

1. Pre-nursery practices (planting medium, seed nut soaking, planting depth and seed nut size) on germination and vigour of SGD x VTT coconut hybrid seed nut.

2. Fertilizer application and spacing on seedling growth and vigour of SGD x VTT coconut hybrid.
3. Agronomic tree management practices (ablation and fruit thinning) on fruit characteristics of SGD coconut variety.

1.5 Significance of the Study

The increasing demand for coconut and its value-added products globally (Rumulo, 2003; Floresca, 2004; Carandang, 2005) and the favourable political climate created for its planting through the government flagship programme of "Planting for Export and Rural Development (PERD)," should have led to a rapid expansion of the coconut subsector into the hinterland across the 10 coconut growing regions of Ghana (Issaka *et al.*, 2012) but for limited availability of recommended coconut planting material. The expansion of the coconut subsector holds a high promise as non-traditional foreign exchange earner to increase Ghana's export of non-traditional products which amounted to USD 2.5 billion in 2016 (MoFA, 2017).

The expansion is also critical to provide raw materials for government policy of "one-district-one factory" which is meant to create employment and livelihood for the rural people. Coconut raw material can be used to produce a wide range of commercial and industrial products including mattress, carpets, geotextiles, activated carbon, charcoal briquettes, shell powder, ropes, margarine, moisturizer, liniment, cosmetics, medicines, soaps, detergents, paints, vinegar,

intravenous fluid, electrolyte, wine and alcohol (Bazon &Velasco, 1985; Arboleda, 1997).

In this study, developing interventions with capacity to increase the supply of CSPWD tolerant seedlings will have a direct bearing on the expansion of the coconut subsector. Improved seed nut germination of SGD x VTT coconut hybrid will curtail the 30-40% annual loss of potential seedlings and improve the supply of SGD x VTT coconut hybrid seedlings for commercial planting by farmers.

Improving on the acceptability of the CSPWD tolerant SGD and VTT coconut varieties for commercial planting, the way forward has been the hybridization of the two varieties to produce SGD x VTT coconut hybrid with improved fruit and agronomic characteristics. However, the low hybrid seed nut production efficiency of hybridization contributing to the coconut subsector's inability to meet increasing demand for CSPWD tolerant seedlings has been a source of great concern (MoFA, 2011; GEPA, 2020).

It is believed that agronomic tree management (ablation and fruit thinning) is the alternative option to improve on the fruit characteristics of the SGD coconut variety without going through hybridization. Agronomic tree management will pave the way for official recommendation of SGD coconut variety as planting material for commercial planting together with fruit thinning or ablation as a package. This will greatly improve access to disease tolerant coconut planting material closing the gap between the existing demand and supply towards rapid expansion of the coconut subsector.

The study also comes with an intervention to improve on the quality of coconut seedlings. Improved quality of seedlings will lead to high productivity on the field and improved financial viability of plantations (MoFA, 2011) and make investment in coconut cultivation more profitable for farmers. The scientific information and techniques generated by the study could be disseminated through training workshops to enable Agricultural Extension Officers to upgrade their knowledge in coconut production for onward transfer to farmers. Coconut Nursery Operators could also benefit from such workshops to strengthen their knowledge capacity in coconut nursery management to turn out high quality coconut seedlings for premium price. Government Agencies particularly, the Tree Crops Development Authority and the Ministry of Food & Agriculture, leveraging on the improved availability of CSPWD tolerant planting materials could draw agricultural policies and programmes to distribute free coconut planting materials to resource-poor farmers.

1.6 Organization of the Study

The thesis is organized into seven chapters beginning with chapter one, which presents an introduction to the study under the subheadings: background to the study, statement of the problem, purpose of the study, research objectives, significance of the study and organization of the study. Chapter two presents the literature review covering the important subject areas of the study including botany, nursery practices, tree management practices and hybridization in coconut. Chapter three presents materials & methods used for the study describing the study area,

experimental set-up and designs, field maintenance, data collection and data analysis.

The write-up on the various studies are presented using the manuscript format in the subsequent chapters which cover: germination of SGD x VTT coconut hybrid seed nut (chapter four) involving four experiments, fertilizer application and spacing of SGD x VTT coconut hybrid seedlings (chapter five) and agronomic tree management practices in Sri Lanka Green Dwarf coconut variety (Chapter 6). Finally, chapter seven gives a general summary, conclusion and recommendations for agricultural extension, government policy and future research work.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

This chapter has been compiled to cover all the important areas of the study, which assesses nursery and tree management practices to develop interventions for improving seed nut germination and seedling quality and enhancing fruit weight/size and its components in coconut. Relevant refereed journal papers, conference proceedings, review papers, manuals, books and book chapters available online through library resources or in hard copies at institutional or university libraries were accessed for the compilation, having in mind plagiarism issues as a guide.

The chapter begins with the botany of coconut under which the taxonomy of coconut and its classification are presented alongside the various part of coconut including the stem, root, leaf, inflorescence and the fruit followed by a vivid description of germination in coconut. The chapter continues with a review of nursery practices covering the relevant subject matter under seed preparation, pre-nursery and main nursery. Tree management practices in coconut are also reviewed touching on relevant areas under leaf pruning, inflorescence ablation, inflorescence tapping, fruit thinning and ends with hybridization explaining the various steps

involved in the hybridization process under parental selection, pollen collection, isolation of the female flower, pollination and harvesting.

2.2 Botany of Coconut

2.2.1 Taxonomy

Coconut is a monocotyledon and belongs to the palm family Arecaceae (previously Palmae), subfamily Arecoideae (formerly Cocoideae), genus *Cocos* and species *Cocos nucifera* L. The Palm family comprises of an estimated 2,800 species in about 190 genera. Coconut (*Cocos nucifera* L.) is the only species of the genus *Cocos* (Tomlinson, 1990; Perera *et al.*, 2010).

2.2.2 Classification

Coconut is classified as tall or dwarf based on its stature. Baugal & Bourdeix (1995) indicated that tall palms are distinguished by robust stems and fast growth in height. They grow to a height of 20-30 metres, come into bearing at 5-7 years after planting and enjoy economic life span of about 60-70 years. On the contrary, as pointed out by Taffin (1998), dwarf palms have less robust stems and relatively short stature growing to a height of 8-10 metres midway their economic life span of about 30-40 years. They come into bearing relatively early at 3-4 years after planting. According to Santos *et al.* (1996), a cross between the two types (tall and dwarf) results in a hybrid whose basic characteristics are intermediate between the tall and the dwarf.

2.2.3 Coconut stem

The trunk of coconut is the stem. Tomlinson (1990) explained that the stem develops from the only terminal bud of the palm known as the 'cabbage' which serves as a sole vegetative growing point. The stem has no cambial tissues and hence cannot repair damage done to it. Notwithstanding, it is composed of primary vascular bundles which are enclosed with fibrous tissues which impact strength to the trunk to withstand physical damage.

Botanically, the coconut stem is not a tree due to lack of cambial cells for secondary growth. Santos *et al.* (1996), indicated that increase in the stem diameter is attributable to growth in the size of the individual cells since there is no secondary growth. Under suitable conditions, the foundation of the stem of a young coconut attains a full development from 3 - 4 years. Any change in stem diameter after its full development is attributable to climatic conditions and crop management.

2.2.4 Coconut root

According to Child (1974) confirmed by Thampan (1981) the stem ends underneath the soil in a bulbous shape known as the 'bole' from which adventitious roots constantly develop. The root system develops from the surface of the bole located within soil depth 0 - 40 cm. It is made up of fairly uniform adventitious roots numbering about 3,000 to 5,000 in an adult palm, measuring about 1 cm in diameter and may grow more or less horizontally in the top soil up to 10 m in length. Pham (2016) pointed out that absorption of water and nutrients occur mainly at the tips of the adventitious roots through fibrous rootlets. The anchor roots grow

vertically deeper; the depth of which is influenced by the type of soil. In a favourable soil, the penetration of the anchor roots could reach up to 5 m or more. Taffin (1998) explained that during the most active stage of growth from year two to five, the root system develops more slowly than the shoot system leading to a temporary mismatch between the roots and foliage with increased susceptibility to nutrient deficiency and wind effect. Comparatively, dwarf palms have less developed root system than the tall palms with the hybrid palms being intermediate.

2.2.5 Coconut leaf

For coconut seedlings, juvenile (first) leaves show up as entire leaves with the pinnae fused together (Figure 2.1) but after emitting up to 10 leaves in about 6-8 months after germination, subsequent leaves differentiate into leaflets (Figure 2.2). According to Thampan (1981) the crown of an adult palm carries about 30-40 leaves surrounding a sole terminal bud from which leaves (also known as fronds) are continuously produced.

Taffin, (1998) indicated that a fully grown leaf is 3-4 m long with a robust petiole for attachment to the stem. The petiole extends into a rachis with 200-300 leaflets. The leaflets have different lengths ranging from 90-135 cm depending on its location on the rachis. The lower surface of the leaflets are more populated with stomata than the upper surface. Santos *et al*., (1996) described the general shape of a crown of coconut leaves as spherical, semi-spherical, X-shaped or V-shaped depending on the genotype.

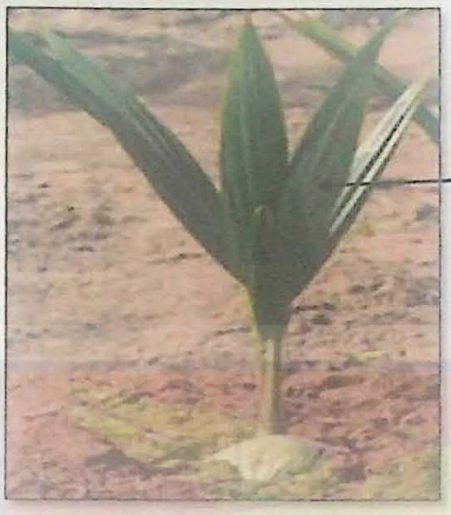

Figure 2.1 Coconut seedling with entire leaves

Figure 2.2 Coconut seedling with differentiated leaves

Coconut leaves grow in 5 spirals turning either left or right with two successive leaves apart making an angle of about 145° (Child, 1974; Thampan, 1981). Under favourable conditions, an adult palm produces 12-15 new leaves annually with each of them subtending an inflorescence (Perera *et al.*, 2010). Each leaf enjoys a life span of 2-3 years before drying up and falling off.

2.2.6 Coconut inflorescence

The inflorescence is enclosed in a spadix (Figure 2.3) made up of a double sheath known as the spathe and an axis called the rachis to which numerous spikelets (also called rachillas) are attached. Both male and female flowers are borne on the same spikelet with male flowers at the top and female flowers (also called button) at the bottom of the spikelet (Figure 2.4). Taffin (1998) indicated that emergence of inflorescence in coconut palms begins from year 2 to 7 after planting depending on coconut ecotype and crop management. The dwarf ecotypes come into flowering earlier than the tall ecotypes. According to Tomlinson (1990) annual inflorescence production and female flower population per inflorescence is greatly influenced by ecotype and environmental factors.

After ripening, the spathe split opens to release the inflorescence enclosed in it. The male flowers open first to shed its pollen systematically from the top to down of each spikelet (Bourdeix *et al.*, 2005). According Bourdeix *et al.* (2005) and Perera *et al.* (2010), the male phase lasts for about 20 days but this could vary depending on coconut ecotype and environmental conditions. The female phase may either begin few days before or few days after the spathe has opened and persists for 3-5 days in the tall ecotypes and 8-15 days in the dwarf ecotypes. In the tall ecotypes, the male and female phases quite often do not overlap resulting in a high level of cross pollination as against self-pollination in the dwarf ecotypes where the two phases usually overlap. According to Santos *et al.*, (1996) the female flower population per inflorescence vary widely from 10-50 across coconut ecotypes and environmental conditions. Fruit set takes place after successful

pollination and fertilization. Open pollination results in 30-50% fruit set with immature fruits aborting and falling off within the first month after pollination. Successful fruit set and development leads to mature fruit in about 12 months.

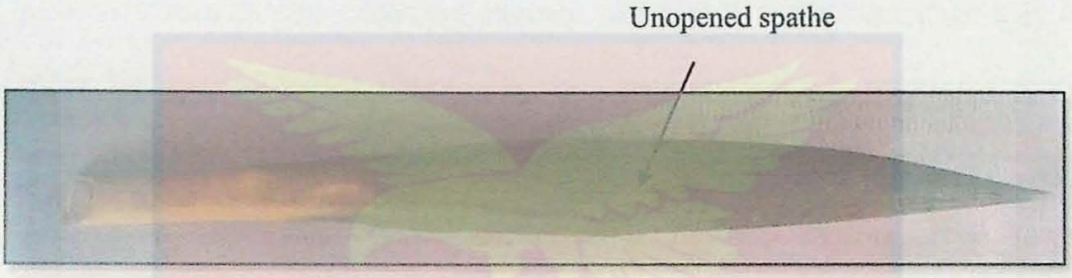

Figure 2.3 Coconut Spadix

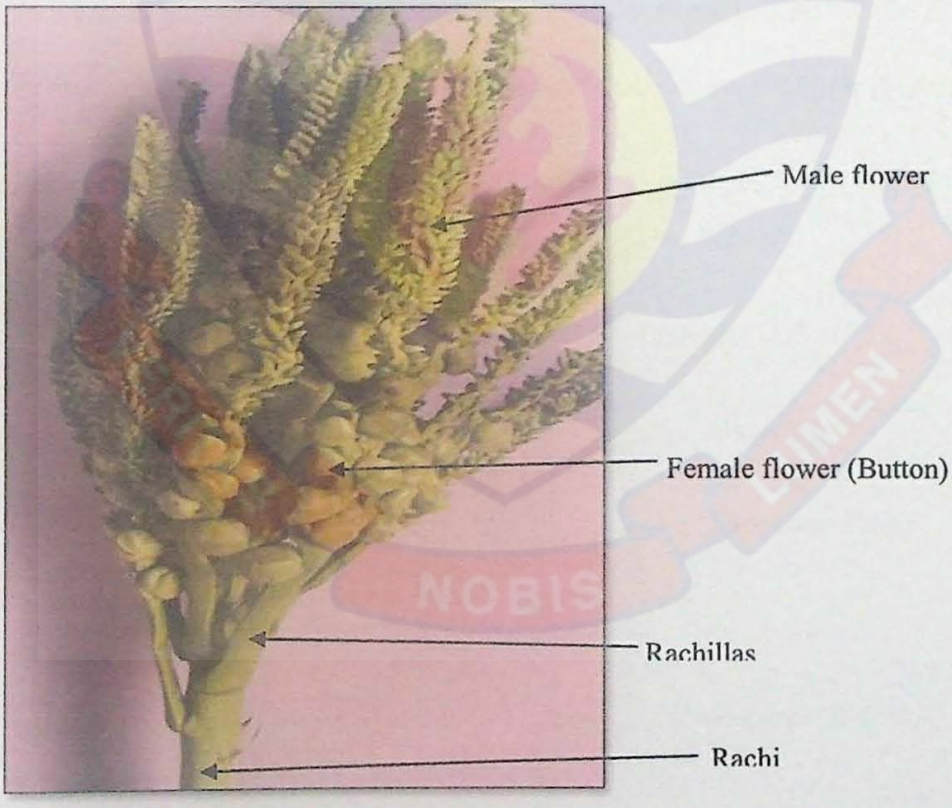

Figure 2.4 Coconut inflorescence

2.2.7 Coconut fruit

Botanically, the fruit is a drupe but loosely referred to as a nut (Thampan, 1981). The diversity in coconut germplasm is morphologically expressed in the fruit which vary widely in colour, shape and size (Taffin, 1998). The fruit has a protective smooth skin called the exocarp which at the immature stage may be green, yellow, red, brown or bronze but become greyish at full maturity. A cross-section of a mature fruit shows an outer firm and fibrous husk called the mesocarp followed by a woody dark brown shell known as the endocarp; then a white fleshy meat or kernel called the endosperm which lines internal cavity that contains a liquid referred to as coconut water. Inside the endosperm, towards the basal end of the fruit, is embedded a tiny embryo beneath the germ pore of the shell. This germinates under favourable conditions to produce a new seedling (Figure 2.5).

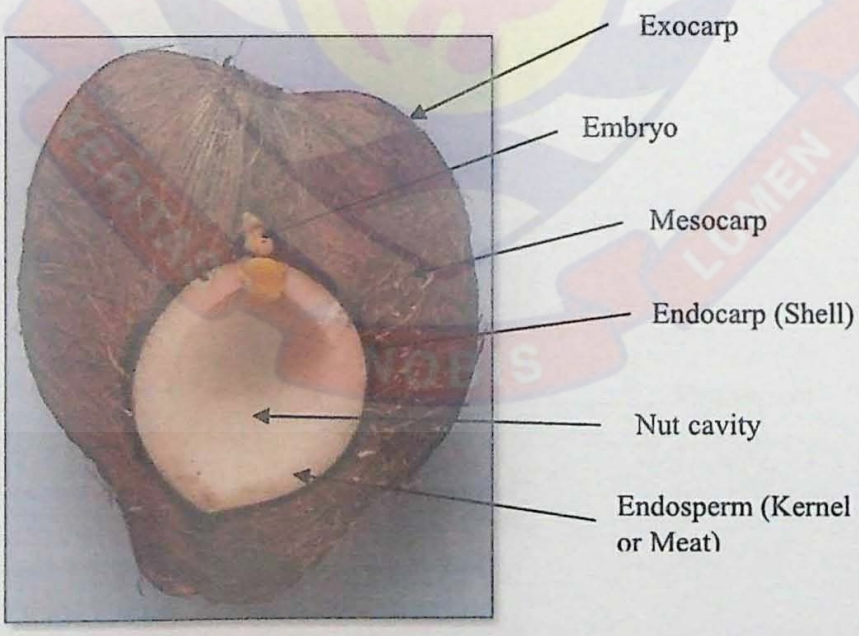

Figure 2.5 Longitudinal section of a matured coconut fruit

2.2.8 Germination

Coconut is known to germinate easily in a warm and humid environment. The embryo of coconut never really undergo dormancy, since as tiny as a peg, it does grow continuously (Chin & Roberts, 1980). However, the fibrous mesocarp constitutes a considerable barrier to rapid germination (Ugbah & Akpan, 2003). Sugimura (1998) indicated that germination begins with the enlargement of the embryo which fills the coconut cavity with a yellowish sponge-like growth known as haustorium. Balachandran & Arumughan (1995) explained that the haustorium (Figure 2.6) produces enzymes which breaks down the endosperm and releases nutrients to support growth of the plumule and radicle as they emerge through the mesocarp to begin photosynthesis (the plumule) and nutrient absorption from soil (the radicle).

Figure 2.6 Developing haustorium of coconut seed nut

Kartha (1981) pointed out that germination through the germ pore is not visible to the naked eye until emergence takes place. Consequently, the date of germination is taken from the day the young shoot (sometimes described as the 'crow's beak') emerges (Figure 2.7).

Figure 2.7 Germinated seed nut of SGD x VTT coconut hybrid

The time interval between sowing and germination is greatly influenced by the ecotype and may vary from 12-24 weeks. Germination of seed nuts in the tall ecotypes usually begins from 11 to 12 weeks after sowing and reaches a peak from 17 to 18 weeks, and then declines. Generally, dwarf ecotypes germinate relatively faster than the tall ecotype. Rapid sprouting is linked with high leaf production, early flowering and high yield (Thomas *et al.*, 2018).

2.3 Nursery Practices

Straight planting of coconut seed nuts in the field is not a recommended agricultural practice (Harries, 2012b). According to Thomas *et al.* (2018), nursery practices are meant to provide favourable environment for germination of seed nuts and subsequent growth of seedlings resulting in high quality seedlings. The nursery environment also facilitates watering, pest and disease control and selection of true-to-type, healthy and vigourous seedlings for field planting. The three phases of coconut nursery are seed preparation, pre-nursery and main nursery.

2.3.1 Seed preparation

Seed preparation involves sorting, curing and treatment. It is a standard practice to sort seed nuts that are received at the nursery into physiologically matured nuts (aged 9-10 months) and fully matured nuts (aged 11-12 months). Taffin (1998) observed that physiologically matured nuts appear relatively fresh and have their original fruit colour intact whilst the fully matured nuts are dried up and turned brown in colour.

Depending on ecotype, seeds at physiological maturity are stored for 1-3 weeks in the open air to cure. It is a recommended practice to subject all nuts to paring treatment before setting in the nursery (Taffin, 1998; Thomas *et al.*, 2018). Paring or notching involves removal of a portion of the husk at the broadest side of the nut towards the anterior (Figure 2.8). Paring enhances infiltration of water into nuts and reduces the time taken by a sprout to grow through the husk before

emergence. Ugbah & Akpan (2003) pointed out that the practice began in coconut growing communities whose nuts are thick shelled and slow in germination.

Shaking of nut is done to check for water content before paring. Matured nuts produce a sloshing sound when shaken. Harries (1981) explained that physiologically matured nuts that do not produce a sloshing sound are immature whilst fully matured nuts that do not produce a sloshing sound must be having a haustorium in the nut. Seed nuts with developed haustorium usually results in twisted seedlings.

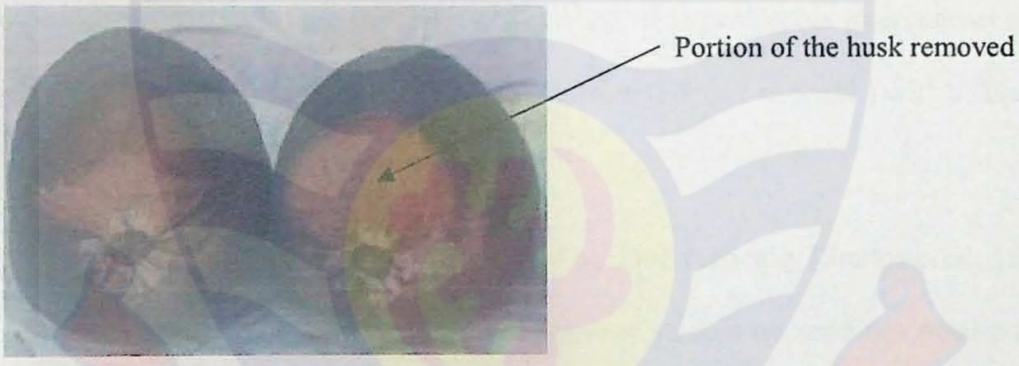

Figure 2.8 Pared seed nuts of SGD x VTT coconut hybrid

Bewley & Black (1994) indicated that soaking treatment either in water or nutrient solution is believed to enhance germination since the process starts with imbibition of water and uptake of nutrient by the embryo. Soaking of seed nuts can be done using sprinkler irrigation after seeding in the nursery or by floating in tank or pond (Marar & Shambhu, 1961).

2.3.2 Pre-nursery

The practice of pre-nursery is meant to provide optimum conditions for rapid germination of seed nuts. The practice enhances the selection of good quality sprouts for the main nursery (Wuidart, 1981a). Soil medium is commonly used for pre-nursery germination. Site selected must have fairly loose-textured soil to ensure good percolation of water and must have a reliable source of water for irrigation. Land preparation involves making seed beds. Taffin (1998) indicated that in loose-textured soils, flat seed beds with fine tilth could be prepared instead of raised seed beds. Digging should be done to sufficient depth (about 15 cm deep) to enable nuts to penetrate easily into the topsoil when pushed. It is preferable to construct seed beds that are long (as long as possible) and narrow (about 1 m width) with adequate inter-bed spacing (about 50 cm width).

Planting of nuts in the seed bed could be done vertically (Santos *et al.*, 1996) or horizontally (Taffin, 1998). However, various studies on seed nut positioning have shown that, planting horizontally on the broadest side with the pared area facing upwards but tilted towards the anterior, give best results (Wickramaratne & Padmasiri, 1986; Kenmen, 1973; Remison & Mgbeze, 1988; Chattopadhyay *et al.*, 2004). The seed bed should be deep enough to enable at least two-thirds of the pared nut (Taffin, 1998) or not more than half of the pared nut (Harries, 2012a) to be easily buried at planting. The buried portion absorbs soil moisture while the remaining part absorbs solar energy. Spacing of nuts could be closer (5 cm within rows and 20 cm between rows) than in the main nursery to cut down on space, water usage and labour (Thomas *et al.*, 2018).

According to Taffin (1998), seedbed should be watered regularly to receive 4 -5 mm of water per day. The pared portion can be pressed with the thumb to check water adequacy. If water squeezes out after pressing it suggests the nuts are adequately watered. Watering is best done in early morning or late afternoon. It should not be too little or too much. Over watering could create favourable conditions for fungal infection, which causes sprout rot. As regular watering promotes rapid growth of weeds, maintenance of weeds should be done as frequent as necessary.

Santos *et al.* (1996), indicated that all viable nuts are expected to sprout and pricked out for planting into main nursery by week 16 after seeding. However, Harries (1983) and Taffin (1998) suggested 20 weeks for slow germinating ecotypes beyond which seed nuts that did not sprout must be discarded. Pricking out is done when the crow's beak sprouts (4-6 cm high) emerge. Roots that get damaged during pricking-out are trimmed to stimulate production of more roots after planting in the main nursery. Pricking out is done in batches to take advantage of the speed of germination which tend to influence earliness of fruiting (Harries, 2012a). Abnormal sprouts and off-types are rouged out to ensure high purity.

2.3.3 Alternative medium for pre-nursery

Apart from soil medium, sawdust and cocoa bean shell could possibly provide suitable medium for pre-nursery germination of coconut seed nuts. Sawdust is a by-product of sawmills. It is basically composed of ligno-cellulose material which takes time to be biodegraded and produces no remarkable odour

during biodegradation (Terazawa *et al.*, 1999). It has good physical properties including low bulk density, good porosity and water retention ability and slow biodegradability (Horisawa *et al.*, 1999). These physical properties render sawdust suitable for use as a planting medium since the basic requirement for seed germination including water and oxygen (Dwiyono & Djauhari, 2021) are readily met using sawdust.

Cocoa bean shell (Figure 2.9a) is separated from the cotyledons during processing before or after the roasting process (Mylsalmy, 2012). According to Rojo-Poveda *et al.* (2020), cocoa bean shell (CBS) has a high fibre content (39.3-66.3g/ 100g CBS), rich in potassium (1.3-1.8g/ 100g CBS) and has good amount of phosphorus (0.58-1.0g/100 g CBS), magnesium (0.48-1.29g/100 g CBS) and calcium (0.23-0.44g/100g CBS). It is usually used as mulch (Billeaud *et al.*, 1989; Bond & Grundy, 2001) but when semi-decomposed (Figure 2.9b) it presents physical properties that make it satisfactory for use as planting medium. Its chemical composition could possibly be an advantage as a planting medium (Dwiyono & Djauhari, 2021).

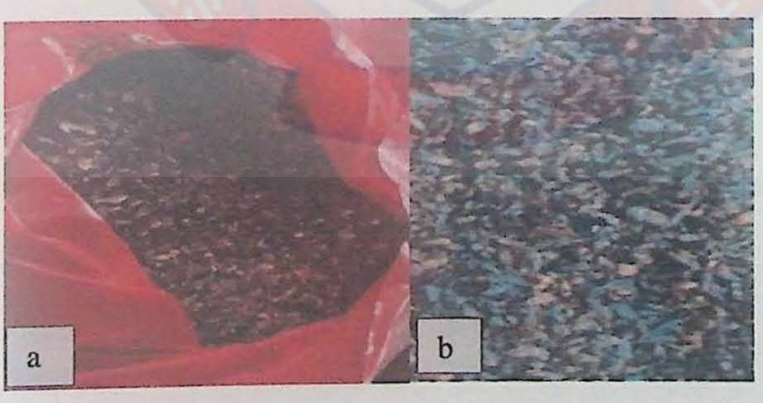

Figure 2.9 Fresh cocoa bean shell (a) Semi-decomposed cocoa bean shell (b)

2.4 Main Nursery

The main nursery is intended to provide favourable environment characterized by watering, weeding, fertilizer application and plant protection for prick-outs to grow optimally till they are transplanted into the field (Thomas *et al.*, 2018).

2.4.1 Types of nursery

There are two types of nursery namely; field nursery and polybag nursery. Field nursery produce bare root seedlings whilst the polybag nursery turn out polybag seedlings. The key advantage of bare root seedling has to do with easiness of transportation to the field and that of polybag seedling borders on minimal transplanting shock leading to early establishment of seedlings (Sunbak, 1970). Land preparation depends on whether bare root or polybag seedlings are to be produced (Harries, 2012a).

2.4.1.1 Field Nursery

Field nursery involves making of nursery beds. A nursery bed can measure 10-20 cm high, 1 m wide and as long as possible. Planting is done at 60-100 cm triangular spacing depending on ecotype and expected duration of seedlings at the nursery. Pre-germinated seed nut is buried leaving the pared portion of the husk with the sprout intact (Santos *et al.*, 1996).

2.4.1.2 Polybag Nursery

Polybag nursery involves the use of black polyethylene bags measuring 40 cm x 40 cm x 500 micron for the nursery. The lower half of the bag is perforated with holes and filled with topsoil leaving enough space (about one-third of the bag) at the top to provide space for the germinated nut. The nursery area is marked out and pegged at 60 cm triangular for arrangement of the polybags (Santos *et al.*, 1996). According to Taffin (1998) spacing of polybags depends on how long the seedlings are to be kept in the nursery. A spacing of 60 cm x 60 cm is recommended for up to 6 months; 80 cm x 80 cm for 6-9 months and 100 cm x 100 cm for 9-12 months. Each bag is supplied with one pre-germinated seed nut. The nut is placed such that the seedling will be at the centre of the bag. The bag is then topped with soil to a level that after firmly pressed around the nut there will be 1 cm space within the top of the bag with the pared portion exposed (Figure 2.10).

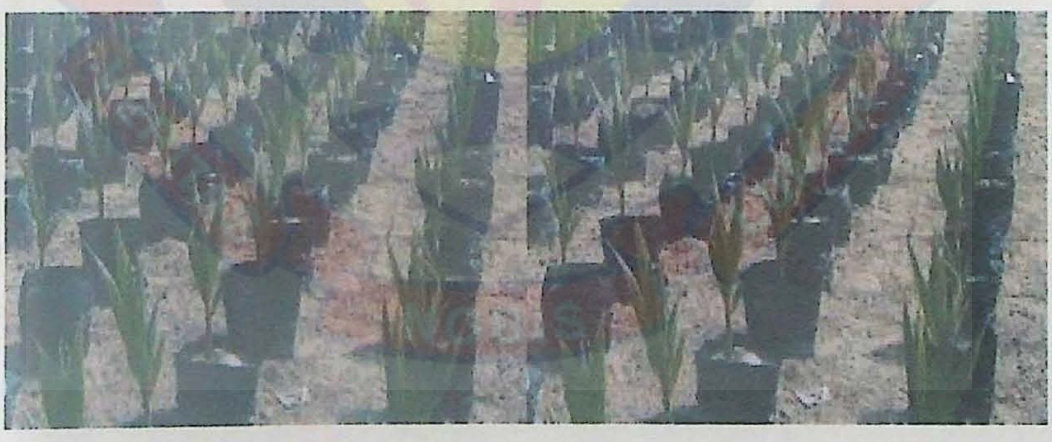

Figure 2.10 Coconut polybag nursery

2.4.2 Irrigation

Effective irrigation, whether manual or mechanized, has been identified as a key in input for attaining optimum nursery performance (Wuidart, 1981a). Peries & Everard (1995) reported that seedling vigour was improved by adequate moisture availability at early stages of nursery especially when combined with sufficient solar radiation. Wuidart (1981b) recommended a 2-day interval application of irrigation water at 8 mm for 0-2 month's old seedlings, 10 mm for 2-4 month's old seedlings, 12 mm for 4-6 month's old seedlings and 15 mm for seedlings older than 6 months.

2.4.3 Weed maintenance

Weed maintenance is a critical intervention to basically forestall competition between seedlings and weeds for growth resources such as air, water, nutrients and solar radiation. The nursery as well as the nursery beds must, as much as possible, be free from weeds since some weeds, especially grass species, are known to harbor insect vectors for diseases like blast and dry bud rot (Taffin, 1998). For coconut nurseries, the manual method of weeding is most popular and more appropriate despite its labour intensiveness (Remison & Mgbeze, 1987).

2.4.4 Fertilizer application

Fertilizer application to coconut seedlings at the nursery has been pointed out to be crucial to turning out healthy and vigourous seedlings for field planting to enhance establishment, rapid growth and early bearing (Nelliat, 1972). The

inability of coconut seedlings to respond to fertilizer application in the early stages after germination could be attributed to adequate levels of endosperm nutrients for growth of seedlings. However, as the nutrient reserve diminishes they become responsive to fertilizer treatment.

Some of the early studies on fertilizer treatments in coconut nurseries have shown that Cl treatment increased collar girth of seedlings whilst KCl and Nacl application did not only improved growth but increased resistance to leaf spot (Magat & Prudente, 1974; Magat *et al*., 1977; Abad *et al*., 1978). As observed by Ho *et al*. (1978), monthly application of Sulphur and NPK fertilizer starting from month 2 after germination enhanced seedling growth whilst S increased seedling height. N and K fertilizers produced taller seedlings and larger collar girth and greater vigour (Almaden & Satiago, 1980). According to Taffin (1998), within one month of planting pre-germinated nuts in polybags, coconut seedlings can benefit from a standard mixture of urea, triple superphosphate, potassium chloride and magnesium sulphate in the ratio 1:2:2:1 applied in a ring around the nuts at different rates based on age of seedlings as 30, 60, 75, 75 and 75 g/plant respectively at 1, 3, 5, 7 and 9 months after germination.

2.4.5 Protection against pest and diseases

Protection of coconut seedlings against pest and diseases must be of a great concern since seedlings are prone to pests and diseases particularly; leaf spot disease caused by *Curvularia Pseudobrachyspora* (Lekete, 2019 b) and damping off disease caused by Phytophthora sp. (Lekete, 2019a). The first outbreak of fall

army worm in coconut nursery in Ghana was reported in 2021. Phytosanitary inspection and routine spraying using recommended pesticides and fungicides are necessary to protect seedlings. Two or more recommended fungicides should be alternated to prevent pathogens from developing resistance to one fungicide.

2.4.6 Transplanting

Transplanting is the last most important exercise towards achieving the nursery objective to produce healthy and vigourous seedlings for field planting. The popular transplanting age in the major coconut producing countries varies from 4-5 months to 6-9 months after germination. According to Thampan (1981), transplanting between 6-9 months is more appropriate since at this age leaf differentiation would have commenced giving an indication of readiness for the field. Taffin (1998) also pointed out that the appropriate age for transplanting is between 6-8 months. At this age a hybrid seedling would have developed a collar girth of 18-20 cm and a height of 110-120 cm with 7 or 8 leaves, the youngest of which would have differentiated into leaflets. Abnormal and illegitimate seedlings must be discarded.

2.5 Tree Management Practices in Coconut

The tree management practices in coconut (TMPC) refer to the deliberate handling of any part of the palm (leaves, spadix, flowers, etc.) towards influencing growth or generating desirable products or minimizing the negative effect of palm-

crop interactions (Chavan, *et al.*, 2018). The TMPC include leaf pruning, inflorescence ablation, inflorescence tapping, fruit thinning and hybridization.

2.5.1 Coconut leaf pruning

Leaf pruning in coconut refer to the practice of removing the lower and old leaves in the crown to enable adequate penetration of solar radiation for normal growth of associated perennial and annual intercrops (Lwakuba *et al.*, 2003). Early work by Bailey *et al.* (1977) indicated that leaf pruning of the crown beyond 40% has negative implications for palm health. Later on, Magat *et al.* (1994) reported that retention of 18 functional leaves in the crown was adequate for optimal yield performance of coconut. Investigating further, Padrones *et al.* (2000) and Ronsefield (2009) noticed increased rate of leaf production due to leaf pruning but decreased size of new leaves at increasing levels of pruning. Also, Magat *et al.* (2002) and Canjan *et al.* (2003) observed marginal (2.3 - 2.8%) gain in copra weight per nut due to leaf pruning even though nut and copra yield per palm saw a decrease. Pointing out the compensation for the decrease in nut and copra yield per palm due to leaf pruning, Magat *et al.* (2002) explained that the better growth and yield observed in the associated peanut and corn intercrops due to improved penetration of solar radiation led to higher total farm productivity and maximized net income.

It has been suggested that instead of lower coconut density with wider inter-row spacing for the purposes of intercropping, pruning could be adopted to manage solar radiation penetration for the benefit of associated intercrops while maintaining higher densities. Also, mitigation of certain pests and diseases in

coconut could be achieved by pruning in cases where lower and old leaves tend to aggravate damage (Anon. 2000).

2.5.2 Inflorescence ablation

Inflorescence ablation in coconut refers to the complete removal of the inflorescence either before or after the opening of the spathe (Taffin, 1998). The inflorescence is the reproductive organ of coconut and the other parts (roots, stem and leaves) constitute the vegetative organs. In all plants including coconut, photosynthetic assimilates are partitioned between the reproductive and vegetative organs (Saravitz *et al.* 1994; Noggle & Fritz, 2006).

Noggle & Fritz (2006) described producers (e.g. leaves) and consumers (e.g. inflorescence, stem and roots) of assimilates as 'source' and 'sink' respectively. Using the concept of 'sink strength' Wareing & Patrick (1975) suggested that, at the reproductive stage of any plant, the floral structures become more dominant and major consumers of assimilates thereby deprive the other organs including the vegetative organs of the needed photosynthate for growth and development. Removal of the floral structures minimizes the reproductive sink size leading to re-allocation of assimilates to vegetative and other organs for growth and development (Wang & Breen 1986; Corley & Tinker, 2003).

Literature is available on ablation studies carried out in many crops such as oil palm (*Elaeis guineensis*), waterleaf (*Talinum triangulare*), Asiatic lily (*Lilium candidum* L.) and Easter lily (*Lilium longiflorum* Thunb.) (Wang & Breen, 1986; Datuluri & Misra, 2002; Corley & Tinker, 2003; Etebom & Chimezie, 2016).

Growers of these crops adopt inflorescence ablation to influence allocation of assimilates to economically important vegetative organs for growth and development (Datuluri & Misra, 2002; Etebom & Chimezie, 2016).

However, in coconut, studies on inflorescence ablation is very scarce. Locally, coconut farmers do not take advantage of inflorescence ablation, even though some coconut ecotypes particularly, the Sri Lanka Green Dwarf (SGD), produce inflorescence at an early age (from 2-3 years) at the time that the vegetative capacity is not adequately developed; the effect being that the SGD which intrinsically takes on high nut numbers per bunch suffer small fruit size and poor fruit characteristics (Bourdeix *et al*., 2005).

Earlier work carried out in soybean (*Glycine max*) by Heitholt & Egli (1985) showed that flower removal impacted positively on total dry matter content of the plant. Working further on soybean, Saravitz *et al.* (1994) reported that during reproductive development, seeds become a dominant sink for nitrogen and carbon. Subsequent removal of newly formed soybean pods led to dry matter partitioning being diverted to vegetative development resulting in increased number of leaves with higher total area. Earlier studies in lily plant by Wang & Breen (1986) using Easter lily indicated that removal of flower buds augmented the supply of carbon to the bulb. Further work by Datuluri & Misra (2002) using Asiatic lily buttressed the point that removal of floral structures in lily augmented the supply of carbon to economically important yield components.

Pace *et al.* (1999) and Binnie & Clifford (1999) reported on photosynthate and dry matter partitioning in cotton (*Gosyypium hirsutum*) and dwarf bean

(*Phaseolus vulgaris*) respectively. Using the 14C labelling technique, Pace *et al.* (1999) showed that main stem leaves were the key source of photosynthate to the dominant bolls whilst Binnie & Clifford (1999) observed that pods that successfully grew to maturity enjoyed high sink activity and those that abscised suffered low sink activity. Using the 13C labelling technique in rice (*Oryza sativa*), Mohapatra *et al.* (2004) noticed that partitioning of photosynthate did not only vary along the growth stages but with panicle size. They found that uptake of 13C by the three leaves at the post-heading stage was translocated mainly to grains and hull of the panicle. Etebom & Chimezie (2016) assessed source - sink relationship in Waterleaf (*Talinum triangulare*) based on farmers' belief that removal of inflorescence which emerges very early in less than one month after germination will boost edible leaf yield and concluded that weekly removal of inflorescence was labour cost-effective and resulted in higher leaf vegetable yield. Corley & Tinker (2003) observed that removal of early inflorescence in oil palm enhanced better palm growth through better stem girth and root development.

2.5.3 Inflorescence tapping

Inflorescence tapping is the practice of stimulating the spadix of palms to produce sap. The process of stimulating the spadix is known as tapping. Earlier observation made by Mathes (1984) suggested that inflorescence tapping was not lethal to coconut but a tree management practice for enhancing coconut yield performance.

Sap is a mild alcoholic beverage with different local names in different producing countries such as India (Toddy), Sri Lanka (Neera) and Ghana (Adoka). According to Sudha *et al.* (2019), inflorescence sap is the most lucrative item for farmers among the products of coconut. It is rich in minerals, amino acids and vitamins and used as nutritive drink. It can be processed into honey and coconut sugar and many other value-added products. Export of sap and its value-added products is seeing an increasing trend in Philippines, Indonesia and Thailand. The authors think that promoting the production of coconut inflorescence sap will create employment and provide coconut farmers with regular income thereby sustaining the rural economy and contributing to GDP of producing countries involved.

Selection of palm for profitable sap production has to meet a certain minimum criteria. Earlier studies carried out by Nathanael (1955) and relatively recent work done by Magat (1966) recommended a well-sited (location with low moisture deficit) middle-aged tree (around 40 years) with a well-developed crown of leaves (robust and short petioles) and a good annual production of spadix whose inflorescence has high female flower to male flower ratio. Sap yield vary from 200 ml to 1500 ml/palm/day depending on how well the criteria is met.

The method of tapping follow similar principles in the various coconut sap producing countries. According to Sudha *et al.* (2019) a selected palm for tapping is monitored for its spadix (unopened spathe) production. When the base of an unopened spathe reaches it maximum swelling (due to developing inflorescence), the spadix is selected and trained to respond to tapping by gentle beating with an appropriate tool uniformly across its length in the morning and repeated in the

evening. This done, the spadix is tied across its length to hinder it from opening. After 7 days, a piece (7-10 cm in length) of the spadix is cut off at the top and the handle of the tapping knife is used to pound the exposed surface. The operation is continued and repeated either once or twice a day, with a cut of a thin slice at the end of the spadix each time, till the sap starts to trickle. The sap is collected using a treated earthen pot hung to the spadix. A thin slice of the spadix is cut off during collection of sap, morning and evening till the spadix reduces to a piece (about 10 -15 cm) after which tapping ceases for the selected spadix. The flow of the sap ranges from 10 - 25 days.

An 'ancient' work carried out by Patel (1938) showed that a continuous tapping of the inflorescence of a palm for 6 -12 months resulted in a significant increase in nut yield especially in palms with yield less that 70 nuts per year. He indicated that the yield impact of tapping lasted for four years. Mathes (1984) reporting on a relatively recent study in which low yielding palms (tapped) were compared with high yielding palms (untapped) and very high yielding palms (untapped) concluded that female to male flower ratio and fruit set percentage improved tremendously for low yielding palms which were tapped leading to a potential nut yield which was twice the nut yield potential of very high yielding palms (untapped) and thrice that of high yielding palms (untapped). The tree management technique applied by farmer tappers is to tap poor-yielding palms for a season or two and then allow those palms to produce nuts. Tapping is again resumed in such palms when the yield begins to dwindle.

2.5.4 Coconut fruit thinning

Fruit thinning refers to the removal of excess fruits after fruit set and natural fruit drop (Valenzuela, 1992; Falivene & Hardy, 2008). Under favourable conditions most fruit trees tend to set more fruit than necessary (Ouma, 2012). Depending on the crop, fruit thinning is done to improve fruit set, increase fruit size, enhance fruit quality, forestall damage due to breakage of branches or stimulate flower initiation (Chacko *et al.*, 1982; Westwood, 1993; Jackson & Frederich, 1999).

Fruit thinning is a common practice with well-documented studies carried out in many tree crops including citrus, grapes, mango, pear and apple. However in coconut, literature on fruit thinning is quite limited even though in Philippines, fruit thinning is used to ensure good development of seed nuts in Catigan Green Dwarf coconut seed gardens (Bourdeix *et al.*, 2005). Locally, neither farmers nor the Coconut Stations of the CSIR-Oil Palm Research Institute leverage on the benefits of fruit thinning even though some coconut ecotypes, typically the Sri Lanka Green Dwarf, take on high nut numbers per bunch but nut sizes are small with poor fruit component characteristics.

The general methods of thinning could be categorized as manual, mechanical and chemical method. Ouma (2012) indicated that the manual involves the use of the hand for thinning whilst the mechanical engages machinery in the thinning and the chemical requires the application nitrogen fertilizers (e.g. urea and calcium nitrate) or plant hormones (e.g. cytokinins, auxins and gibberellins). The nitrogen fertilizers are applied at high concentrations and spray volume at the pre-

blossom stage to cause thinning effect on blossoms by scorching (Ouma, 2012). Cytokinins initiate fruit thinning through reduction of net carbon dioxide assimilation rate leading to a decrease of energy available for developing fruit thereby promoting abscission (Stopar *et al.*, 1997). Gibberellins trigger fruit thinning through inhibition of flower initiation (Valenzuela, 1992). Auxins and Ethylene act through formation of abscission layers to cause fruit thinning (Smith & Hall, 1993; Bangerth, 2000).

2.6 Coconut Hybridization

Coconut hybridization is a tree management practice which involves the use of an artificial process to cross a dwarf palm with a tall palm to produce a new variety called coconut hybrid. The dwarf and the tall varieties selected for hybridization usually possess desirable characteristics, such as early bearing, high yielding and pest & disease tolerance, which are strongly expressed in the new variety as hybrid vigour (Harries, 1976). The hybridization process goes through five stages namely; parental selection, pollen collection, isolation of female flowers, pollination and harvesting.

2.6.1 Parental selection

According to Taffin (1998) a dwarf and a tall ecotypes are carefully selected based on phenotypic expressions, desirable characteristics, vegetative and reproductive performance, among others. The dwarf ecotype is most of the time

used as the female or 'mother' palm whilst the tall ecotype is usually engaged as the male or 'father' palm.

2.6.2 Pollen collection

The pollen is collected exclusively from the male palm. The inflorescence of the male palm is isolated by bagging with a recommended collection bag. The timely bagging (a day before or after spathe opening) forestalls possible pollen contamination. The inflorescence is isolated for 6 days after which the male flowers are harvested from the spikelets. At the pollen laboratory, the male flowers are subjected to recommended treatments to enable viable pollen to be extracted. The extracted pollen is then prepared and conditioned under a high vacuum for storage in a freezer (Santos *et al.*, 1996).

2.6.3 Isolation of female flowers

Harries (1976) indicated that emasculation, which refers to the removal of male inflorescence, is carried out on the mother palms as the first step to isolating the female flowers. This is followed by bagging of the emasculated inflorescence using a recommended isolation bag. The bagging is done not later than 6 days before any of the female flowers on the emasculated inflorescence become receptive.

2.6.4 Pollination

According to Santos *et al.* (1996) the isolated female flowers must be inspected daily after bagging to determine the exact date the female flowers become

receptive so that pollination can be done. Receptivity is confirmed when splitting of stigma and secretion of nectar are observed. The pollen in storage is removed from the deep freezer and prepared for pollination after isolated flowers have become receptive. After successful pollination, the stigma of the female flowers wither within six days after the last pollination. The isolation bag is then removed following the withering of the stigmas of the flowers.

2.6.5 Harvesting

Fruits that set successfully become fully mature after 11 to 12 months. Harvesting therefore is done after 11 months and sent to the nursery to raise hybrid seedlings for farmers (Taffin, 1998).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Introduction

This chapter describes materials and methods used in carrying out the study to achieve identified research objectives. The study assesses nursery and tree management practices to develop interventions for improving seed nut germination and vigour and seedling quality and vigour of the SGD x VTT coconut hybrid and fruit characteristics of the SGD coconut variety. Materials and methods applied generally in the study are recounted here but procedures that are peculiar to specific experiments are reported under the appropriate chapters.

3.2 Description of Study Area

The study was carried out at two locations within the Rain Forest Zone of South-Western Ghana namely; Agona-Nkwanta (4°52`N 1°58`W) and Badukrom (5°00`N 1°37`W) in the Western Region. The climatic environment of the Rain Forest Zone is characterized by bi-modal rainfall distribution from April-July (major rainy season) and September-December (minor rainy season) with a mean above 1,700 mm per annum. The relative humidity of the area is high with a mean range of 75%-85% in the rainy season and 70%-80% in the dry season. The maximum mean temperature is around 34°C which falls between March and April whilst the least mean temperature is around 20°C observed in August. Its soils are

highly leached and acidic and classified as Utisols in the USDA (1960, 1967) soil classification.

3.3 Soil Sampling and Analysis

The experimental sites were zoned into replicates, where field conditions are uniform, for sampling. Sampling was done randomly within replicates at two depth levels: 0 - 20 cm and 21- 40 cm with a 10-cm soil augur. Samples of the same replicate and depth were bulked together and mixed thoroughly to obtain composite samples. About 200 g of each composite sample was fetched, air-dried, packaged and labeled for analysis at the Soil Science Laboratory of University of Cape Coast. Parameters determined were particle size, pH, organic carbon (%), total nitrogen (%), exchangeable bases (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) and available phosphorus (Magat, 2003).

3.3.1 Determination of particle size

The pipette method as described by Rowell (1994) was used to carry out the soil particle size analysis. Ten grams (10 g) of soil sample was weighed into a 500 ml beaker followed by 20 ml of hydrogen peroxide and then allowed to stand until frothing was over. The suspension was heated to destroy the organic matter completely, and then allowed to cool. The peroxide-treated soil was transferred into a 500 ml plastic bottle followed by 10 ml of dispersing agent and a top up with distilled water to 200 ml and then put in a mechanical shaker overnight. The

contents were then transferred into a 500 ml measuring cylinder and topped up with distilled water to 500 ml.

A plunger was used to stir the suspension to ensure thorough mixing. The suspension was allowed to settle for 40 seconds and a pipet was used to draw 25 ml of the suspension from 10 cm below the surface into a weighed beaker. This first pipetted suspension was supposed to contain silt and clay. The suspension was allowed to settle for 5 hours and 25 ml of the suspension was drawn off at 10 cm depth. This second pipetted suspension was supposed to contain clay only. The pipetted suspensions were dried at 105°C till constant weight was achieved. The supernatant liquid of the remaining suspension in the 500 ml measuring cylinder was gently poured off and the sediment was transferred into a beaker. The sediment was repeatedly washed through dilution with distilled water, stirring, settling and decanting till a clear supernatant was obtained. The sand was transferred to a weighed beaker and dried at 105°C till constant weight was achieved.

The proportions of silt, clay and sand in the soil were estimated using the various formulae listed below:

1. $$\% \text{ Sand} = \frac{\text{Mass of sand x 100}}{\text{Mass of oven dried soil}}$$

2. $$\text{Total mass of silt} = \frac{\text{Mass of silt in 25ml x 500}}{25}$$

3. $$\% \text{ Silt} = \frac{\text{Mass of silt x 100}}{\text{Mass of oven dried soil}}$$

4. Total mass of clay = $\frac{\text{Mass of clay in 25ml x 500}}{25}$

5. % Clay = $\frac{\text{Mass of clay x 100}}{\text{Mass of oven dried soil}}$

The USDA textural triangle (Rowell, 1994) was used to determine the textural classes of the soil samples.

3.3.2 Determination of soil pH

Ten grams (10 g) of soil sample was weighed into a test tube and 25 ml of distilled water was added then put in a mechanical shaker for 15 minutes after which a pH meter was used to determine the pH (Rowell, 1994).

3.3.3 Determination of organic carbon

One gram (1 g) of soil sample was weighed into a 500 ml conical flask and 10 ml of 0.1667 M potassium dichromate solution was added followed by 20 ml of concentrated sulphuric acid. The mixture was thoroughly shaken and then allowed 30 minutes for reaction to complete. The reaction mixture was diluted with 200 ml of distilled water and 10 ml of phosphoric acid was added followed by 10 ml of sodium fluoride solution and 1ml of diphenylamine indicator. This was titrated against 0.5 M ammonium ferrous sulphate solution to a green colour. A blank was ran alongside the samples. The formula below was used to determine the percent organic carbon (FAO, 2008).

$$\% \text{ Organic carbon} = \frac{(S-B) \times \text{Molarity of } Fe2^{+} \times 0.003 \times 100}{\text{Weight of sample} \times 77}$$

% Organic matter = % Organic carbon × 1.724

Where;

B = Blank titre

S = Sample titre

3.3.4 Determination of total nitrogen

One gram (1.0 g) of soil sample was weighed into a digestion flask and 0.2 g of catalyst was added followed by 3 ml of concentrated sulphuric acid. The digestion flask and its contents were put in a bloc digester at 380°C for 2 hours. The digest, after the digestion, was allowed to cool and after which it was diluted with distilled water to a volume of 50 ml. An aliquot of 20 ml of the digest was pipetted into the reaction chamber of a steam distillation apparatus followed by 10 ml of alkali mixture to begin the distillation. About 40 ml of the distillate was collected in a boric acid indicator. The distillate was titrated against 1/140 HCl until there was a colour change from green to a wine. Blank determination was done alongside. The formula below was used to determine the nitrogen percentage.

$$\% \text{ Nitrogen} = \frac{(S - B) \times \text{Solution volume}}{\text{Aliquot volume} \times \text{Sample weight} \times 10^2}$$

Where;

S = Sample titre

B= blank titre

3.3.5 Determination of exchangeable bases (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+})

The determination of the exchangeable bases were done by the method described by Rowell (1994). Five grams (5 g) of sieved soil sample was weighed into 50 ml centrifuge tubes followed by 20 ml of ammonium acetate solution and then shaken for 1 hour and allowed to stand overnight. The suspension was transferred into 100 ml conical flask fitted with Whatman filter paper. The soil trapped on the filter paper was successively leached with 20 ml of the ammonium acetate solution until 100 ml of the filtrate was obtained. The collected filtrate was used for the determination of calcium, magnesium, sodium and potassium.

An aliquot of 25 ml of the filtrate was pipetted in a 250 ml conical flask and the filtrate was diluted to 150 ml with distilled water. Fifteen (15) ml of buffer solution and 1 ml each of potassium cyanide, hydroxylamine hydrochloride, potassium ferro-cyanide and triethanolamine (TEA) were added followed by 5 drops of erichrome black T (EBT). The solution was titrated against 0.005 M ethylene diamine tetra-acetic acid (EDTA) to enable the concentration of calcium and magnesium together to be calculated.

Another aliquot of 25 ml of the filtrate was pipetted in a 250 ml conical flask and the filtrate was diluted to 150 ml with distilled water. One (1) ml each of potassium cyanide, hydroxylamine hydrochloride, potassium ferro-cyanide and triethanolamine were added followed by 5 drops of calcon indicator. The solution

was titrated with 0.005 M EDTA to enable the concentration of calcium only to be calculated.

The potassium and sodium concentrations were determined using a flame photometer. The concentrations of the exchangeable bases were calculated using the various formulae below:

$$\text{Exchangeable Mg} = \frac{4 \text{ x titre volume}}{\text{Weight of soil (g)}}$$

$$\text{Exchangeable Ca} = \frac{4 \text{ x titre volume}}{\text{Weight of soil (g)}}$$

$$\text{Cmol}_c\, K^+ kg^{-1} \text{ soil} = \frac{C \text{ x } 0.256}{\text{Weight of soil (g)}}$$

$$\text{Cmol}_c\, Na^+ kg^{-1} \text{ soil} = \frac{C \text{ x } 0.44}{\text{Weight of soil (g)}}$$

Where;

C = concentration from calibration curve

3.3.6 Determination of available phosphorus

Bray 1 method was used to determine the available phosphorus in the soil samples. One gram (1 g) of the air-dried soil sample was weighed into a 50 ml centrifuge tube and 10 ml of Bray 1 extraction solution was added. Bray 1 solution was prepared using 15 ml of 1.0 N ammonium fluoride and 25 ml of 0.5 N hydrochloric acid. The tube was placed in a mechanical shaker for 5 minutes and

the contents transferred into a 50 ml conical flask fitted with Whatman filter paper to leach the soil solution. Two (2) ml aliquot of the filtrate was pipetted into a 25 ml round bottom test tube followed by 4 ml colour forming reagent called reagent B. Reagent B is a solution of ammonium molybdate and potassium antimony tartrate in ascorbic acid. The final solution was topped up with distilled water to 25 ml and allowed to stand for 10 minutes for colour development. The absorbance of the solution was read using spectrophotometer (CE 1000 series) at 882 nm.

Standard working solutions of phosphorus (0, 0.1, 0.2, 0.4, 0.6, 0.8 and 1.0 µg/ml) were prepared from 5 µg P/ml stock solution. The standard solutions were allowed to stand for 15 minutes for the colour to develop and their absorbance read using the spectrophotometer at 882 nm. A calibration curve was obtained by plotting absorbance against concentration for the standard solution. Concentration of phosphorus in soil sample aliquot was calculated using the calibration curve from the formula below:

$$\mu g\ P\ g^{-1}\ soil = \frac{C \times dilution\ factor}{Weight\ of\ soil\ (g)}$$

Where;

C = concentration of P obtained from calibration curve (µg ml^{-1})

3.4 Leaf Sampling and Analysis

Reference leaves were selected for sampling. Leaf rank 4 or 9 was selected as reference for young palms whilst 2 and 14 were selected for seedlings and adult

palms respectively (Magat, 2003; Andoh-Mensah *et al.*, 2005). Sampling was done from the reference leaf by detaching 6 leaflets from the middle of the rachis, 3 each on both sides. Leaf samples of the same treatment were bulked to obtain composite samples. The samples were trimmed at both ends and cleaned using distilled water and cotton wool after midribs have been removed. The cleaned samples were oven-dried at 40°C for 72 hours, allowed to cool, packaged and appropriately labelled. Analysis was done at the Soil Science Laboratory of University of Cape Coast. At the laboratory, the samples were homogenized into powdery form and analyzed for leaf nitrogen, phosphorus, potassium, calcium and magnesium.

3.4.1 Determination of leaf nitrogen

The nitrogen content of the leaf samples was determined by using the Micro-Kjedahl method (Rowell, 1994). The procedure involves digestion, distillation and titration.

3.4.1.1 Digestion

The digestion, which aimed at breaking down organically bonded nitrogen in the sample and convert them into ammonium ions, was carried out as outlined in Stewarte *et al.*, (1974). A quantity of the sample weighing 200 mg was placed in a 100 ml Kjedahl flask followed by 4.4 ml of mixed digestion reagent. The mixed digestion reagent was made up of 350 ml of hydrogen peroxide, 0.42 g of selenium powder, 14 g of lithium sulphate and 420 ml sulphuric acid. The sample was digested using Tecator Digester 2012 by heating for 2 hours at 360°C. After the

digestion was complete, the clear digest was allowed to cool to room temperature after which it was transferred into a 100 ml volumetric flask and made up to volume. Blank digests were also prepared using the same procedure.

3.4.1.2 Distillation

A distillation apparatus was set up and steam was passed through it for about 20 minutes. A 100 ml conical flask containing 5 ml of 2% boric acid indicator solution was placed under the condenser of the distillation apparatus. An aliquot of the sample digest was transferred into the reaction chamber through the trap funnel and 10 ml of alkali mixture was added. Distillation was commenced and 50 ml of the distillate was collected.

3.4.1.3 Titration

The distillate was titrated against a 0.0071 M HCI and a colour change was noted from green to red wine end point. The blank digests were also treated same way. The titre values were recorded. The formula below was used for the estimation of nitrogen.

$$N\ (\%) = \frac{(S-B) \times M \times A \times D \times 100}{W}$$

Where;

S = volume of 0.0071 M HCl used for sample titration

B = volume of 0.0071 M HCl used for blank titration

M = molarity of HCl

A = atomic weight of nitrogen

D = sample dilution factor

100 = factor for converting N to %

3.4.2 Determination of leaf phosphorus

Total phosphorus in leaf was determined using Ammonium Molybdate-Ascorbic Acid method. The method requires preparation of P standard solutions and colour forming reagents A and B. Reagent A was prepared by mixing together three solutions in a 2 litre volumetric flask and making up to the mark with distilled water. The three solutions were: 12 g of ammonium molybdate contained in 20 ml distilled water, 0.2908 g of potassium antimony tartrate contained in 100 ml distilled water and 1,000 ml of 2.5 M sulphuric acid. Reagent B was prepared by dissolving 1.56 g of ascorbic acid in every 200 ml of reagent A. Five (5) µg P ml^{-1} (ppm) of standard solution was prepared from a 100 ppm P stock solution. Phosphorus concentrations of 0, 0.1, 0.2, 0.4, 0.6, 0.8 and 1.0 ppm (working standard solutions) were prepared from 5 ppm standard solution. Then, two (2) sets of working standard solutions contained in 25 ml volumetric flasks were formed. Two (2) ml aliquots of both the sample digest and the blank digest were pipetted into each set of working standards to give the samples and the standards the same background solution. Ten (10) ml of distilled water was added to the standards as well as the samples after which 4 ml of reagent B was added and their volumes

made up to 25 ml with distilled water and mixed thoroughly. The flasks were allowed to stand for 15 minutes for colour development.

Spectrophotometer (CECIL CE1021, 1000 SERIES) was made ready by warming it up for 20 minutes followed by calibration using 0 ppm blank standard. The readings (absorbances) of the concentrations of phosphorus in both the working standards and samples were done on the spectrophotometer at 880 nm wavelength. A standard curve was plotted using their concentrations and absorbances of the working standards. The concentrations of P in the sample solutions were extrapolated from the standard curve. The concentration of P in the various leaf samples were estimated using the following equation:

$$P\ (\%) = \frac{C \times D \times 100}{W}$$

P = Concentration of P in the leaf

C = Concentration of P as obtained from the standard curve

D = Dilution factor

W = Sample weight (mg)

100 = Factor for converting P to %

3.4.3 Determination of leaf calcium and magnesium

Determination of leaf calcium and magnesium was done using the EDTA Titration Method. An aliquot of 10 ml of sample solution was pipetted in a 250 ml conical flask and solution diluted to 150 ml with distilled water. Fifteen (15) ml of

buffer solution and 1 ml each of potassium cyanide, hydroxylamine hydrochloride, potassium ferro-cyanide and triethanolamine (TEA) were added followed by 5 drops of erichrome black T (EBT). The solution was titrated against 0.005 M ethylene diamine tetra-acetic acid (EDTA) to enable the concentration magnesium together to be calculated.

Another aliquot of 10 ml of sample solution was pipetted in a 250 ml conical flask and solution diluted to 150 ml with distilled water. 1 ml each of potassium cyanide, hydroxylamine hydrochloride, potassium ferro-cyanide and triethanolamine were added followed by 5 drops of calcon indicator. The solution was titrated with 0.005 M EDTA to enable the concentration of calcium to be calculated. The concentrations of elemental calcium and magnesium in leaf were calculated using the formulae below:

$$\text{Leaf element (\%)} = \frac{M \times Mwt \times T \times 100}{Swt}$$

Where;

M = Molarity of EDTA

Mwt = Molecular weight of element

T = Titre value

Swt = Sample weight (mg)

100 = Factor for converting element to %

3.4.4 Determination of leaf potassium and sodium

Flame photometer was used to determine the concentrations of potassium and sodium in the leaf sample digests. Working standards of 0, 2, 4, 6, 8 and 10 μg ml^{-1} (ppm) were prepared for both potassium and sodium. The working standards and the sample solutions were introduced into the flame photometer one after the other and their emissions recorded. A standard curve was plotted using the concentrations and emissions of the working standards. The concentrations of the sample solutions were extrapolated from the standard curve using their emission readings. The concentrations of elemental potassium and sodium in leaf were calculated using the formulae below:

$$\text{Leaf element } (\mu g ml^{-1}) = \frac{C \times Svol}{Swt}$$

C= Concentration of element as obtained from the standard curve

Svol = Solution volume

Swt = Sample weight

3.4.5 Determination of leaf sulphur

Leaf sample was subjected to di-acid digestion involving nitric acid and perchloric acid (2:1). A quantity of leaf sample (0.5 g) was weighed into the digestion flask and 10 ml of di-acid mixture was added. The content of the flask was mixed by swirling after which it was placed in a digester. Heating was started at a temperature of 90°C and then adjusted upwards to 200°C. Heating was

continued until release of red nitrogen oxide fumes ceased and then continued further till the content turned colourless. The digest was allowed to cool and then diluted with 100 ml of distilled water.

Sulphur in the digest was measured by turbidimetric method. A 10 ml aliquot of the digest was pipetted into a 25 ml volumetric flask followed by 10ml of distilled water. One (1) ml of gelatin-barium chloride reagent was added and mixed thoroughly after which it was allowed to stand for 30 minutes. Standard sulphur solutions of 0, 1, 2, 3, 4 and 5 μg ml^{-1} were prepared followed by addition of 1 ml gelatin-barium chloride reagent and 10 ml of blank digest and then made up to the volume with distilled water. The absorbances of the standard and sample solutions were determined on a spectrophotometer at a wavelength of 420 nm. A standard curve was plotted using the concentrations and absorbances of the working standards. The concentrations of the sample solutions were extrapolated from the standard curve using their absorbance readings. The concentrations of elemental sulphur in leaf were calculated using the formula below:

$$\text{Leaf element } (\mu\text{gml}^{-1}) = \frac{\text{C x Svol}}{\text{Swt}}$$

C = Concentration of element as obtained from the standard curve

Svol = Solution volume

Swt = Sample weight

3.5 Data Management and Statistical Analysis

Data collected were entered into a database created with Microsoft Excel 2013 and cross-checked with general field observations to remove errors. The boxplot graphical technique was used to test the data for normal distribution. Generally, data collected did not pass the normality test. Hence, appropriate regression analyses which are less stringent to normality, were used to model the data since scale transformation is often not suitable especially for count data generated within a specified period of days. Such data followed Poisson distribution making the application of Poisson regression analysis more appropriate.

Data analysis was done using Genstat Statistical Software (Version 12.1, Lawes Agricultural Trust, VSN International). Predictions from the regression models were used as estimates of mean values and separation of means was done at 5% least significant difference of predictions. Tables of least significant differences for separation of mean estimates are presented in the appropriate appendix.

CHAPTER FOUR

4.0 GERMINATION OF SGD x VTT COCONUT HYBRID SEED NUTS

4.1 Introduction

The increase in demand for coconut and its value-added products globally (Floresca, 2004; Carandang, 2005) and the favourable political climate created for its cultivation locally through Government of Ghana flagship programmes such as "Planting for Export and Rural Development" should have led to a rapid expansion of the coconut subsector into the hinterland across ten potential coconut growing regions of Ghana but for limited availability of recommended coconut seedlings. The SGD x VTT coconut hybrid is officially recommended by research for commercial planting in CSPWD endemic and potentially endemic areas due to its high tolerance to the disease and good agronomic characteristics (Dery *et al.*, 2008; Dare *et al.*, 2010).

However, the coconut hybrid has a seed nut germination rate of 60-70% (Owusu, 2014) resulting in 30-40% of potential SGD x VTT coconut hybrid seedlings produced annually being lost at the nursery stage. In the face of high demand for CSPWD tolerant coconut seedlings, this loss is a major concern. Efforts to improve germination of SGD x VTT coconut hybrid seed nut necessitated the need to investigate pre-nursery practices involving planting medium, soaking treatment, planting depth and seed nut size.

Four experiments were carried out to investigate planting medium, soaking treatment, planting depth, seed nut size and their interactions. The four experiments have been appropriately reported under their respective subsections in this chapter.

4.2 Experiment 1: Effect of Soaking Treatment and Medium on Germination and Vigour of SGD x VTT Coconut Hybrid Seed Nut

4.2.1 Introduction

In coconut, there is little scientific information on how seed nut germination is influenced by planting medium and soaking treatment. The soaking of seed either in water or nutrient solution, according to Bewley & Black (1994), is believed to enhance germination since the process begins with absorption of water and nutrients by the embryo. Copeland & McDonald (1999) indicated that soaking of pine walnut in 0.15% potassium nitrate solution improved germination. Also, Bian *et al.* (2013) reported 65.3% seed germination rate in red palm when seeds are soaked in 0.6% potassium nitrate solution for 24 hours as compared with 36% in the control.

The superiority of potassium nitrate solution as a soaking medium lies in its ability to make oxygen, potassium ions and nitric acid available after decomposition. The oxygen is required for seed respiration which stimulates the breakdown of seed carbohydrate into simple sugars for energy generation to support

germination (Poljakoff-Mayber, 1989; Bewley & Black, 1994). The nitric acid makes the seed shell more porous to dissolved oxygen uptake and the potassium ions facilitate water absorption (Dwiyono & Djauhari, 2021).

Planting medium is known to influence germination of all types of seeds (Abad *et al.*, 2002; Agbo & Omaliko, 2006; Bhardwaj, 2002) since physical and chemical properties of a medium affect availability of nutrients, water and oxygen required for germination (Dwiyono & Djauhari, 2021). In the coconut belt of South Western Ghana, there is a good availability of sawdust and cocoa bean shell as a result of activities of sawmill and cocoa processing factories in the belt. Sawdust and cocoa bean shell, as reviewed in Chapter 2, Section 2.3.3, could provide effective options for coconut germination besides soil medium.

Experiment 1 assesses the effect of soaking treatment and medium on germination and vigour of SGD x VTT coconut hybrid seed nut.

4.2.2 Materials and methods

4.2.2.1 Description of the Study Area

Experiment 1 was carried out at Agona-Nkwanta, at the Coconut Station of the CSIR- Oil Palm Research Institute. The station was located close to the source of the planting material for the study and had adequate space and watering facilities for nursery. The description of the study area is presented in Chapter 3.

4.2.2.2 Experimental Design and Treatments

A split-plot design with 3 replicates was used to assess 3 types of planting media (topsoil, semi-decomposed cocoa bean shell and decomposed sawdust) assigned to main plots and 3 different soaking treatments (soaking in water, soaking in 1% KNO_3 solution and control) assigned to subplots. Bottomless wooden boxes (Figure 4.1) of dimension 2.4 m x 1.0 m x 0.2 m each were filled to the brim with topsoil, decomposed sawdust or semi-decomposed cocoa bean shell. The main plots were partitioned into 3 subplots of dimension 0.8 m x 1.0 m x 0.2 m each to contain 20 seed nuts/plot.

Figure 4.1 Bottomless wooden boxes

4.2.2.3 Seed Nut Harvesting and Preparation

Matured seed nuts of SGD x VTT coconut hybrid were harvested at the Bamiankor Seed Garden of CSIR - Oil Palm Research Institute and transported to the Agona Nkwanta Station. After curing for one week, 540 seed nuts were selected randomly for paring. One hundred and eighty (180) each were soaked in water and 1% KNO_3 solution respectively. The remaining 180 served as control.

4.2.2.4 Soaking Treatment

A 200-litre capacity aluminum basins with dimensions 2 m x 1m x 0.1 m were constructed for the soaking treatment. Potassium nitrate solution was prepared by measuring 99 litres of water, using a measuring container, into the aluminum basin and dissolving 1 kg of potassium nitrate 13-0-46 in the water to obtain 1% (w/v) solution of KNO_3. Seed nuts were arranged in the soaking medium (potassium nitrate solution or water) contained in the basin (Marar & Shambhu, 1961) with the pared portion of the seed nuts submerged in the soaking medium. Soaking was done for 48 hours but the soaking medium was renewed after 24 hours to keep availability of oxygen in soaking medium at satisfactory level for seed nut germination initiation.

4.2.2.5 Seed Nut Planting

The bottomless wooden boxes were filled to the brim with topsoil, decomposed sawdust or semi-decomposed cocoa bean shell and then seed nuts were planted by fully burying them in their respective media (Figure 4.2). The main plot

with dimension 2.4 m x 1.0 m x 0.2 m were planted with 60 seed nuts whilst the subplot with dimension 0.8 m x 1.0 m x 0.2 m was planted with 20 seed nuts arranged in 4 rows with 5 seed nuts in a row.

Figure 4.2 Bottomless wooden boxes filled with planting media

4.2.2.6 Maintenance Culture

Hand picking was used to keep the planting medium free from weeds whilst hand weeding with cutlass was used to control weeds in the spaces within the experimental layout. Water from a dug-out well was used for hand watering through a rubber hose fitted to a pipe stand connected to a pump in the well. Watering was done every other day in absence of rains for 2 hours 15 minutes between 2-5 pm. Each block (replicate) was watered for 45 minutes. Termite infestation was controlled by treating planting medium with Dursban*Pro pesticide which contains chlorpyrifos as active ingredient.

4.2.2.7 Data Collection

Days to germination (primary data) were collected within a period of 90 days (Santos *et al.*, 1996). Secondary data derived from the primary data were final germination percentage, time to 50% germination and germination index. Final germination percentage gives a measure of germination rate whilst time to 50% germination measures speed of germination. Germination index and speed of germination give an indication of seed nut vigour (Santos *et al.*, 1996).

Other relevant data taken were temperature and moisture content of planting medium. Temperature of planting medium impacts on the activity level of enzymes such as lipase, α-amylase and protease, which facilitate the hydrolysis of stored food in seeds for uptake by developing embryo during germination (Ahmadi *et al.*, 2007). The moisture content of planting medium influences seed access to moisture critical for germination. Measurements of temperature and moisture content could provide further insight into physical properties of planting medium.

4.2.2.7.1 Moisture content of planting medium

Planting media were watered adequately and then allowed to drain for 8 hours. Samples of 100 g each of topsoil, decomposed sawdust and semi-decomposed cocoa bean shell were taken and oven dried at 80°C for 72 hours. The percentage moisture content (MC %) was calculated from the formula:

$$\text{MC \%} = \frac{\text{Loss in sample weight x 100}}{\text{Dry weight of sample}}$$

4.2.2.7.2 Temperature of planting medium

Soil thermometer was used to measure temperature of planting medium in the morning between 9-10 am and in the afternoon between 3-4 pm. At each measurement, the thermometer bulb was inserted gently up to 15 cm depth of planting medium. Temperature reading was taken after 10 minutes following insertion.

4.2.2.7.3 Final germination percentage

Final germination percentage (FGP) gives an estimate of final germination obtained from a seed lot after a defined period. The higher the FGP estimate the greater the germination obtained from a seed lot after a given period of time. It is a measure of germination rate. The formula of Scott *et al.*, (1984) was used to calculate FGP.

$$FGP = \frac{\text{Number of germinated seeds x 100}}{\text{Number of seeds sown}}$$

4.2.2.7.4 Time to 50% germination

Time to 50% germination (T_{50}) refers to time taken to reach 50% of the maximum germination obtained. It is a measure of speed of germination and for coconut, this parameter was recommended by Santos *et al.*, (1996) for estimation of speed of germination which gives an indication of seed nut vigour. T_{50} was calculated using the formula of Coolbear *et al.*, (1984) which was modified by Farooq *et al.*, (2005).

$$T_{50} = \frac{ti + [(\frac{N}{2} - ni)(ti - tj)]}{ni - nj}$$

Where;

N is the final number of seeds germinated and n_i, n_j cumulative number of seeds germinated by adjacent counts at times t_i and t_j respectively, when $n_i < \frac{N}{2} < n_j$.

4.2.2.7.5 Germination index

Germination index (GI) has been identified as the single most precise measure of seed germination. It gives maximum weight to seeds that germinate early and less to those that germinate later (Bench *et al.*, 1991). It is a good measure of germination rate and indication of seed nut vigour as it takes into account germination percentage, speed and spread (Kader, 2005). GI was calculated using the formula of Association of Official Seed Analysts (AOSA, 1983).

$$GI = \frac{G1}{T1} + \frac{G2}{T2} + \ldots\ldots + \frac{Gn}{Tn}$$

Where G1, G2, … , Gn refer to the number of germinated seed on the first count, second count and so on until the last count (n), respectively, and T1, T2 ,..., Tn: number of days between sowing and the first count, between the sowing and the second count, and so on until the last count (n), respectively.

4.2.2.8 Data Management and Statistical Analysis

The data management and statistical analysis were carried out as described in Chapter 3, Section 3.5.

4.2.3 Results

4.2.3.1 Moisture Content of Planting Medium

The moisture content of the planting media was highest for cocoa bean shell (mean of 144.4% ± 6.70) followed by sawdust (mean of 87.3% ± 6.70) and topsoil (mean of 34.4 ± 2.45). The cocoa bean shell capacity to hold water was 4.2 - fold higher than the topsoil medium and 1.5 - fold more than sawdust medium.

4.2.3.2 Temperature of Planting Medium

Morning and afternoon mean temperatures of planting medium from February - May 2020 are presented in Table 4.1. Temperatures of planting media were not significantly ($P>0.05$) different at 10.00 a.m. but at 3.00 pm, differences were significant ($P< 0.05$) (Appendix 1). The mean temperature of the topsoil at 3.00 pm was significantly ($P<0.05$) higher than that of cocoa bean shell and sawdust media by 2.4°C and 2.0°C respectively.

Table 4.1 Morning and afternoon mean temperatures of planting medium from February-May 2020

Planting medium	Temp °C 10.00 am	Temp °C 3.00 pm
Cocoa Bean Shell	30.50 ± 0.592a	31.86 ± 0.605b
Top soil	30.89 ± 0.593a	34.23 ± 0.627c
Sawdust	30.54 ± 0.590a	32.25 ± 0.609b

Mean estimates ± S.E. with the same letters within columns are not significantly different at P<0.05. LSD (0.05) of mean estimates is presented in Appendix 2.

4.2.3.3 Final Germination Percentage

The final germination percentage of SGD x VTT coconut hybrid seed nuts as influenced by soaking treatment and planting medium is presented in Table 4.2. Data analysis showed significant ($P<0.001$) treatments effect on final germination percentage (Appendix 3) which is a measure of germination rate. Germination rate averaged 84.2%, 83.2% and 36.4% respectively for topsoil, sawdust and cocoa bean shell media. The soaking treatment interaction with cocoa bean shell medium significantly ($P<0.05$) reduced germination rate by 44.4% as compared with the control. The difference in germination rate between topsoil and sawdust media was not significant ($P>0.05$).

Table 4.2 Final germination percentage of SGD x VTT coconut hybrid seed nuts as influenced by soaking treatment and planting medium

	Final Germination %		
Planting Medium	**Soaking treatment**		
	Control	1% KNO_3 solution	Water
Cocoa bean shell	51.7 ± 2.93aA	27.5 ± 2.14bB	30.0 ± 2.24bB
Top soil	82.5 ± 3.71cC	85.2 ± 3.78cC	85.0 ± 3.76cC
Sawdust	84.2 ± 3.75cD	82.2 ± 3.70cD	83.3 ± 3.73cD

Mean estimates ± S.E. with the same capital letters within rows or same small letters within columns are not significantly different, P>0.05. LSD (0.05) of mean estimates is presented in Appendix 4.

4.2.3.4 Time to 50% Germination

Time to 50% germination of SGD x VTT coconut hybrid seed nuts as influenced by soaking treatment and planting medium is presented in Table 4.3. Data analysis indicated significant ($P<0.028$) treatment effect on time to 50% germination (Appendix 5) which measures speed of germination and gives an indication of seed nut vigour. Sawdust medium interacted significantly ($P<0.05$) with soaking treatment in 1% potassium nitrate solution to increase speed of germination by 18.2% relative to the control and 16.4% as compared with topsoil. Cocoa bean shell and topsoil media interaction with soaking treatment did not influence speed of germination significantly ($P>0.05$) relative to the control.

Table 4.3 Time to 50% germination of SGD x VTT coconut hybrid seed nuts as influenced by soaking treatment and planting medium

	Time to 50% Germination		
Planting Medium	**Soaking treatment**		
	Control	1% KNO_3 solution	Water
Cocoa bean shell	44.0 ± 2.71aA	40.0 ± 2.58aA	42.3 ± 2.66aA
Top soil	49.3 ± 2.87abB	51.2 ± 2.92cB	50.5 ± 2.87bB
Sawdust	52.3 ± 2.93bC	42.8 ±2.73aD	48.0 ± 2.83abCD

Mean estimates ± S.E. with the same capital letters within rows or same small letters within columns are not significantly different, P> 0.05. LSD (0.05) of mean estimates is presented in Appendix 6.

4.2.3.5 Germination Index

Germination index of SGD x VTT coconut hybrid seed nuts as influenced by soaking treatment and planting medium is presented in Table 4.5. Data analysis showed significant ($P<0.01$) treatments effect on germination index (Appendix 7), which gives an indication of seed nut vigour. Germination index was averagely 3.84, 3.81 and 1.45 respectively for sawdust, topsoil and cocoa bean shell media. The interaction effect between soaking treatment and planting medium (except cocoa bean shell) was not significant ($P>0.05$) on germination index. The cocoa bean shell medium and soaking treatment interaction significantly ($P<0.05$) reduced germination index by 55.8% relative to the control. The difference ($P>0.05$) in germination index between topsoil and sawdust media was not significant ($P>0.05$).

Table 4.4 Germination index of SGD x VTT coconut hybrid seed nuts as influenced by soaking treatment and planting medium

Planting Medium	Germination Index		
	Soaking treatment		
	Control	1% KNO_3 solution	Water
Cocoa bean shell	2.31 ± 0.62aA	1.02 ±0.49aB	1.01 ± 0.48aB
Top soil	3.86 ± 0.78bC	3.91 ±0.80bC	3.67 ± 0.78bC
Sawdust	3.87 ± 0.79bD	3.93 ±0.81bD	3.71 ± 0.79bD

Mean estimates ± S.E. with the same capital letters within rows or same small letters within columns are not significantly different, P> 0.05. LSD (0.05) of mean estimates is presented in Appendix 8.

4.2.4 Discussion

4.2.4.1 Final Germination Percentage

In coconut nursery, soil medium is commonly used for pre-nursery germination to the neglect of commonly available industrial by-products that could possibly provide comparable or even better medium for pre-nursery germination of coconut seed nuts. The final germination of 83.2% in decomposed sawdust medium compared very well 84.2% obtained in topsoil indicating high suitability of decomposed sawdust as planting medium for coconut seed nut. The excellent performance of the decomposed sawdust could be attributed to its good physical properties such as low bulk density, good porosity and water retention ability and slow biodegradability (Horisawa *et al.*, 1999). These physical properties might have enabled the supply of basic factors required for seed germination including water and oxygen (Dwiyono & Djauhari, 2021). Working on the effect of growing media on seed germination of papaya, Bhardwaj (2014) attributed the best performing medium to suitable physical properties that support germination of papaya seeds.

On the other hand, the final germination percentage or rate of 36.4% in the semi-decomposed cocoa bean shell indicates its low suitability as planting medium for coconut seed nut. The poor performance of semi-decomposed cocoa bean shell could be attributed to its excessive water holding property (moisture content of 144% at 8 hours after watering). The excessive moisture content might have filled most of the air pores in the semi-decomposed cocoa bean shell thereby cutting off

adequate supply of oxygen required for optimum respiration and germination of seed nuts (Poljakoff-Mayber, 1989; Bewley & Black, 1994; Finch-Savage *et al.*, 2004). The seed nut might have also taken in excess water that might have led to physiological seed damage (Murungu, 2011).

The negative interaction effect between cocoa bean shell medium and soaking treatment on final germination percentage could be attributed to excessive moisture environment for seed nut due to soaking treatment and excessive water holding property of cocoa bean shell as indicated earlier in this discussion.

4.2.4.2 Time to 50% Germination

Time to 50% germination gives an indication of the speed of germination; and that the shorter the time the higher the speed. Santos *et al.* (1996) recommended time to 50% germination as the standard measure for assessing speed of germination in coconut. In this experiment, sawdust medium interacted significantly ($P<0.05$) with soaking of seed nuts in 1% (w/v) potassium nitrate solution to increase the speed of germination by 18.2% relative to the control and 16.4% as compared with topsoil medium.

This was in accordance with Basra *et al.* (2005) who observed that soaking treatment during the early stages of priming activates the internal metabolism required to trigger germination process thereby improving speed of germination relative to control. Dwiyono & Djauhari (2021) established that soaking with potassium nitrate solution increased the speed of germination for Indonesian Konjac. Varier *et al.* (2010) observed that even though soaking treatment in general

activates physiological processes including protein and mitochondria synthesis and ATP production required to trigger seed germination, potassium nitrate soaking treatment has additional ability to make oxygen, potassium ions and nitric acid available to facilitate germination process. Since sawdust has suitable physical properties able to meet oxygen and water requirement for germination (Horisawa *et al.*, 1999), there might be enhanced synergy between sawdust and potassium nitrate soaking treatment leading to faster speed of germination.

4.2.4.3 Germination Index

Germination index has been identified as an excellent measure of germination rate as it takes into account germination percentage, speed and spread (Kader, 2005). The relatively high germination index in topsoil and sawdust media could be explained to a large extent by the high germination percentage observed in the two planting media. The suitability of sawdust as planting medium for seed nut is confirmed by the high germination index comparable to that of topsoil. The low germination percentage caused by the negative interaction effect between cocoa bean shell and soaking treatment led to the observed reduction in germination index due to the interaction.

4.2.5 Conclusion

Decomposed sawdust was identified as an alternative planting medium to topsoil for SGD x VTT coconut hybrid seed nut germination. Interaction between sawdust medium and soaking in 1% (w/v) potassium nitrate solution increased the

speed of germination by 18.2% as compared with the control and 16.4% relative to topsoil medium. Cocoa bean shell and soaking treatment interaction reduced germination rate by 44.4% as compared with the control.

4.3 Experiment 2: Effect of Planting Depth and Medium on Germination and Vigour of SGD x VTT Coconut Hybrid Seed Nut

4. 3. 1 Introduction

Planting medium has been established as a factor influencing germination performance of seeds as reviewed in Section 4.2.1 of Chapter 4. Similarly, planting depth is also recognized as an important factor in seed germination as it influences seed temperature, seed-to-soil contact and access to moisture (Adeogun & Usman, 2012; Sharma *et al.*, 2019).

Proctor & Sullivan (2013) observed that in American ginseng (*Panax quinquefolius* L.), seed germination increased with increasing planting depth up to approximately 2.7 cm. In evaluating planting depth (2 cm, 4 cm and 6 cm) and seed size for germination of soursop (*Annona muricata* L.), Chima *et al.* (2017) reported that seed germination was optimum at 2 cm sowing depth for large seed size. Field observation indicates that under favourable moisture conditions, coconut germination occurs over a wide range of planting depth, beginning from surface placement to deep planting (Asgharipour, 2011; Adeogun & Usman, 2012).

Notwithstanding, there is scanty scientific information on the influence of planting depth and medium on coconut germination.

Experiment 2 assesses the effect of planting depth and medium on germination and vigour of SGD x VTT coconut hybrid seed nut.

4.3.2 Materials and methods

4.3.2.1 Description of the Study Area

The study area has been described in section 4.2.2.1

4.3.2.2 Experimental Design and Treatments

A split-plot design with 3 replicates was used to assess 2 types of planting media (topsoil and decomposed sawdust) assigned to main plots and 3 levels of planting depths (PD_0, PD_1 and PD_2) assigned to subplots. Bottomless wooden planters of dimension 2.4 m x 1 m x 0.2 m each were filled to the brim with topsoil or decomposed sawdust to serve as the main plots. The main plots were partitioned into 3 subplots of dimension 0.8 m x 1 m x 0.2 m each to contain 20 seed nuts/plot. Treatments were assigned randomly within the main plots and subplots.

PD_0 = Planting by burying a quarter of the seed nut in medium (Control)

PD_1 = Planting by burying half of the seed nut in medium

PD_2 = Planting by burying seed nut fully in medium

4.3.2.3 Seed Nut Harvesting and Preparation

Seed nut harvesting and preparation have been described in Section 4.2.2.

4.3.2.4 Seed Nut Planting, Maintenance Culture and Data Collection

Seed nut planting, maintenance culture and data collection have been described in Section 4.2.2

4.3.2.5 Data Management and Statistical Analysis

The data management and statistical analysis have been described in Chapter 3, Section 3.5.

4.3.3 Results

4.3.3.1 Final Germination Percentage

Final germination percentage of SGD x VTT coconut hybrid seed nuts as influenced by planting depth and medium is presented in Table 4.5. Data analysis indicated significant ($P<0.001$) treatment effect on final germination percentage (Appendix 9). Germination rate increased significantly ($P<0.05$) with increasing planting depth. The interaction between planting medium and planting depth impacted significantly ($P<0.05$) on germination rate. Fully buried seed nuts produced an averaged germination rate of 88.3% as compared to 63.2% for the control.

Table 4.5 Final germination percentage of SGD x VTT coconut hybrid seed nuts as influenced by planting depth and planting medium

Planting Medium	Final Germination %		
	Planting Depth		
	PD_0	PD_1	PD_2
Top soil	71.3 ± 4.94aA	81.7 ± 5.22aAB	88.2 ± 5.43aB
Sawdust	55.0 ± 4.28bC	78.3 ± 5.11aD	88.3 ± 5.42aD

Mean estimates ± S.E. with the same capital letters within rows or same small letters within columns are not significantly different, P> 0.05. LSD (0.05) of mean estimates is presented in Appendix 10. PD0 = Planting by burying a quarter of the seed nut in medium (Control); PD1= Planting by burying half of the seed nut in medium; PD2 = Planting by burying seed nut fully in medium

4.3.3.2 Time to 50% Germination

Time to 50% germination of SGD x VTT coconut hybrid seed nuts as influenced by planting depth and planting medium is presented in Table 4.6. Data analysis indicated significant (P<0.045) treatment effect on time to 50% germination (Appendix 11). Sawdust medium and planting depth interaction significantly (P<0.05) increased the speed of germination. The speed of germination of fully buried seed nuts in sawdust medium was 30% faster than the control. Also, the germination of fully buried seed nuts in sawdust medium was 22.9% quicker than in topsoil.

Table 4.6 Time to 50% germination of SGD x VTT coconut hybrid seed nuts as influenced by planting depth and planting medium

Planting Medium	Time to 50% Germination		
	Planting depth		
	PD_0	PD_1	PD_2
Top soil	56.13 ± 4.33aA	53.93 ± 4.24aA	53.53 ± 4.21aA
Sawdust	59.20 ± 4.44aB	53.43 ± 4.26aB	41.20 ± 3.71bC

Mean estimates ± S.E. with the same capital letters within rows or same small letters within columns are not significantly different, P>0.05. LSD (0.05) of mean estimates is presented in Appendix 12. PD0 = Planting by burying a quarter of the seed nut in medium (Control); PD1= Planting by burying half of the seed nut in medium; PD2 = Planting by burying seed nut fully in medium

4.3.3.3 Germination Index

Germination index of SGD x VTT coconut hybrid seed nuts as influenced by planting depth and medium is presented in Table 4.7. Data analysis showed significant (P<0.05) treatment effect on germination index (Appendix 13). The interaction effect between planting medium and planting depth was not significant (P<0.05) on germination index. Germination index of fully buried seed nuts was 98% higher than that of the control.

Table 4.7 Germination index of SGD x VTT coconut hybrid seed nuts as influenced by planting depth and planting medium

Planting Medium	Germination Index		
	Planting depth		
	PD_0	PD_1	PD_2
Top soil	2.23 ± 0.86aA	3.01 ± 1.00aAB	4.09 ± 1.17aB
Sawdust	2.01 ± 0.82aC	2.88 ± 0.98aC	4.31 ± 1.20aD

Mean estimates ± S.E. with the same capital letters within rows or same small letters within columns are not significantly different, P> 0.05. LSD (0.05) of mean estimates is presented in Appendix 14. PD0 = Planting by burying a quarter of the seed nut in medium (Control); PD1= Planting by burying half of the seed nut in medium; PD2 = Planting by burying seed nut fully in medium

4.3.4 Discussion

4.3.4.1 Final Germination Percentage

The increase in germination rate of SGD x VTT coconut hybrid seed nuts from an average of 63.2% to 88.3% with increased planting depth could be attributed to improved soil factors, such as moisture and temperature, influencing seed germination as planting went deep. Unlike small seeds which suffer the negative effect of planting depth (Kumar & Srivastava, 2010; Nabi *et al.*, 2011; Opande *et al.*, 2017), large type of seeds to which coconut seed nut belongs enjoy the positive effect of planting depth due to modified seed nut temperature, enhanced seed-to-soil contact and improved access to soil moisture (Adeogun & Usman, 2012; Sharma *et al.*, 2019).

The poor germination rate observed in the control seed nuts especially in sawdust medium might be accounted for by new sprout mortality since shallow

planting exposed newly emerged sprout to relatively harsh conditions causing death of sprouts in some cases before attaining 5 cm height required of germination in this study.

4.3.4.2 Time to 50% Germination

The reduction in time to 50% germination or increase in speed of germination with increased planting depth might be attributed to, as indicated earlier, the positive effect of planting depth on large seeds. Considering the 30% increase in speed of germination for fully buried seed nuts in sawdust medium, planting depth as a factor becomes more effective at enhancing the speed of coconut seed nut germination than soaking treatment which increased the speed of germination by 18.2% when seed nuts were soaked in 1% (w/v) KNO_3 solution as observed in Experiment 1.

4.3.4.3 Germination Index

The positive effect of planting depth resulting in improved germination percentage and speed might have led to increased germination index with increased planting depth of seed nuts. This strongly suggested that planting depth of seed nuts especially in sawdust medium could be used not only to ensure high germination percentage but to reduce the time of germination effectively.

4.3.5 Conclusion

At pre-nursery stage, fully burying of SGD x VTT coconut hybrid seed nuts in decomposed sawdust improved germination rate by 33% and germination index by 98% and produced a speed of germination, which was 30% faster as compared with the control. The speed of germination of fully buried seed nuts was 23% quicker in sawdust than in top soil even though final germination percentage was the same for both media.

4.4 Experiment 3: Effect of Nut Size and Medium on Germination and Vigour of SGD x VTT Coconut Hybrid Seed Nut

4.4.1 Introduction

Planting medium is known to affect seed emergence as reviewed in Section 4.2.1 of this chapter. It is also known that seed size is an important factor that influences germination performance. Earlier studies in several crops including soybean (*Glycine max* (L.) Merr.), rapeseed (*Brassica campestris* L.), white clover (*Trifolium repens* L.) and red clover ((*Trifolium pratense* L.) showed that germination performance was influenced by seed size (Ahmed & Zuberi, 1973; Burris *et al.*, 1973; Evans, 1973; Mytton, 1973; Haskins & Gorz, 1975).

In the case of soybean, earlier and recent studies have established inverse relationship between emergence and seed size with small seeds enjoying 10 - 11% higher germination rate than large seeds especially within cultivars (Adebisi *et al.* 2013; Kering & Zhang, 2015; Crawford & Williams, 2019). The inverse

relationship has been attributed to differences in moisture requirement for seed imbibition and mechanical resistance on emerging seed. Soybean requires an amount of imbibition equivalent to 50% of its weight to initiate germination. A small seed therefore require less amount of imbibition than a large seed to initiate germination (Kering & Zhang, 2015). Also, emerging small seed is subject to less mechanical resistance in the soil than emerging large seed (Burris *et al.*, 1973).

In coconut, there is little scientific information on seed nut germination as affected by nut size. Variation of nut size in coconut is found among both healthy and pest damaged seed nuts. The attack of coconut bug (*Pseudotheraptus wayi*, Brown) and infestation of coconut mite (*Eriophyes guerreonis*, Keifer) affect nut size; the extent of reduction being dependent on the severity of damage (Egonyu *et al.*, 2013; Nkansa-Poku *et al.*, 2015). Coconut bug feeds on young coconut fruits by sucking sap and in the process releases toxins into the fruits leading to lesions, pitting, gummosis, deformation, reduced nut size and sometimes fruit drop (Hill, 2008). Coconut mite feeds beneath the floral bracts of developing fruits causing scars on the fruit surface which turn brown and develop into longitudinal fissures on the nut. Affected nut surface does not develop normally leading to damage of the husk and reduction in size (Nkansa-Poku *et al.*, 2015).

Experiment 3 assesses the effect of nut size and medium on germination and vigour of SGD x VTT coconut hybrid seed nut.

4.4.2 Materials and methods

4.4.2.1 Description of the Study Area

The study area has been described in section 4.2.2.1

4.4.2.2 Experimental Design and Treatments

A split-plot design with 3 replicates was used to assess 2 types of planting media (topsoil and decomposed sawdust) assigned to main plots and 4 levels of nut size assigned to subplots. Nut weight increases with nut size consequently; nut size was classified as follows: extra-large (> 1,000g); large (800g ≤ nut ≤ 1,000g); medium (600g ≤ nut ≤ 800g) and small (< 600g). Treatments were assigned randomly within the main plots and subplots.

Bottomless wooden planters of dimension 3.2 m x 1 m x 0.2 m each were filled to the brim with topsoil or decomposed sawdust to serve as the main plots. The main plots were partitioned into 4 subplots of dimension 0.8 m x 1 m x 0.2 m each to contain 20 seed nuts per subplot. Treatments were assigned randomly within the main plots and subplots. Healthy seed nuts were used for the study.

4.4.2.4 Seed Nut harvesting and Preparation

Seed nut harvesting and preparation have been described in Section 4.2.2.4. Various nut sizes: extra-large, large, medium and small (Figures 4.3) were selected for paring. Four hundred and eighty (480) seed nuts were pared for planting.

Figure 4.3. Various sizes of SGD x VTT coconut hybrid seed nuts: Extra-large (XL), Large (L), Medium (M) and Small (S)

4.4.2.5 Seed Nut Planting, Maintenance Culture and Data Collection

Seed nut planting, maintenance culture and data collection have been described in Section 4.2.2. Seed nut planting was done by fully burying the nuts in planting medium.

4.4.2.6 Data Management and Statistical Analysis

The data management and statistical analysis have been described in Chapter 3, Section 3.5.

4.4.3 Results

4.4.3.1 Final Germination Percentage

Final germination percentage of SGD x VTT coconut hybrid seed nuts as influenced by seed nut size and planting medium is presented in Table 4.8. Data analysis did not indicate significant ($P<0.001$) treatment effect on final germination percentage (Appendix 15).

Interaction between planting medium and seed nut size did not impact significantly ($P>0.05$) on germination rate. Germination rate of seed nuts increased from 90.4% in small nuts to 96.8% in extra-large nuts. However, differences in germination rates between the various sizes of seed nuts were not significant ($P>0.05$).

Table 4.8 Final germination percentage of SGD x VTT coconut hybrid seed nuts as influenced by seed nut size and planting medium

Planting Medium	Final Germination %			
	Seed nut size			
	Small	Medium	Large	Extra Large
Top soil	88.3±3.8	90.0±4.0	94.1±3.9	93.5±4.0
Sawdust	92.4±4.3	93.1±4.3	93.4±3.9	100.0±4.1

Mean estimates ± S.E. with no letters within rows or columns are not significantly different.

4.4.3.2 Time to 50% Germination

Time to 50% germination of SGD x VTT coconut hybrid seed nuts as influenced by seed nut size and planting medium is presented in Table 4.9. Data analysis showed significant (P>0.05) treatment effect on time to 50% germination (Appendix 16).

Speed of germination increased with increasing seed nut size. Interaction between seed nut size and planting medium did not affect speed of germination significantly (P>0.05). However, main effect of seed nut size significantly (P<0.05) increased speed of germination in both sawdust and topsoil media resulting in 22.9% higher speed of germination for extra-large seed nut as compared to small or medium seed nut. Speed of germination for extra-large nuts was averagely 29.9% quicker than small or medium seed nuts. Difference in speed of germination between large and extra-large seed nuts was not significant (P>0.05).

Table 4.9 Time to 50% germination of SGD x VTT coconut hybrid seed nuts as influenced by seed nut size and planting medium

Planting Medium	Time (in days) to 50% Germination			
	Seed nut size			
	Small	Medium	Large	Extra Large
Top soil	53.9±3.8aA	52.7±3.5aA	47.4±3.4aAB	41.4±3.2aB
Sawdust	49.5±3.7aD	47.0±3.6aD	43.3±3.3aDE	36.9±3.1aE

Mean estimates ± S.E. with the same capital letters within rows or same small letters within columns are not significantly different, P>0.05. LSD (0.05) of mean estimates is presented in Appendix

4.4.3.3 Germination Index

Germination index of SGD x VTT coconut hybrid seed nuts as influenced by seed nut size and planting medium is presented in Table 4.10. Data analysis indicated significant ($P<0.01$) treatment effect on germination index (Appendix 18).

Germination index improved with increasing seed nut size. Interaction effect between seed nut size and planting medium on germination index was not significant ($P>0.05$). Main effect of seed nut size significantly ($P<0.05$) increased germination index in both sawdust and topsoil media resulting in 43.2% higher germination index for extra-large seed nut relative to small or medium seed nut. Difference in germination index between large and extra-large seed nuts was not significant ($P>0.05$).

Table 4.10 Germination index of SGD x VTT coconut hybrid seed nuts as influenced by seed nut size and planting medium

Planting Medium	Germination Index			
	Seed nut size			
	Small	Medium	Large	Extra Large
Top soil	2.71±0.53aAB	2.86±0.57aAB	3.21±0.56aAC	3.97±0.56aC
Sawdust	2.89±1.71aDE	2.99±0.66aDE	3.41±0.57aDF	4.18±0.56aF

Mean estimates ± S.E. with the same capital letters within rows or same small letters within columns are not significantly different, P>0.05. LSD (0.05) of mean estimates is presented in Appendix 19.

4.4.4 Discussion

4.4.4.1 Final Germination Percentage

Though not significant, the upward trend in germination rate due to increased seed nut size could be attributed to storage reserve, which increased with seed nut size. Storage reserve in the form of endosperm is broken down through the agency of enzymatic actions during germination for the release of nutrients to support growth of plumule and radicle as they emerge through the seed nut (Balachandran & Arumughan, 1995; Sugimura, 1998). A large seed size is widely thought to stand a high chance of germination and emergence. According to Copeland & McDonald (2001), a greater seed weight is associated with a larger storage reserve and higher seed vigour.

4.4.4.2 Time to 50% Germination

The decrease in time to 50% germination or the increase in speed of germination with increasing seed nut size might be attributed also to storage reserve which increases with nut size. As indicated in Section 4.4.4.1, storage reserve is the source of nutrients and energy for germination (Balachandran & Arumughan, 1995; Sugimura, 1998). The larger the storage reserve the more nutrients and energy made available for faster emergence (Copeland & McDonald, 2001).

4.4.4.3 Germination Index

Germination index is a function of germination percentage and speed of germination. The improved trend in germination index with increased nut size could therefore be attributed to increased trend in germination percentage and speed of germination with increased seed nut size. As indicated previously, storage reserve is the source of nutrients and energy for germination (Balachandran & Arumughan, 1995; Sugimura, 1998). The larger the storage reserve the more nutrients and energy made available for improved emergence in terms of numbers, speed and spread (Copeland & McDonald, 2001).

4.4.5 Conclusion

Speed of germination and germination index were 22.9% and 43.2% respectively higher in extra-large nuts relative to small or medium size nuts. Differences in speed of germination or germination index between large and extra-large nuts were not significant.

4.5 Experiment 4: Effect of Soaking Treatment and Medium on Germination and Vigour of SGD x VTT Coconut Hybrid Seed Nut using Different Concentrations of Potassium Nitrate Solution

4. 5. 1 Introduction

Planting medium has been identified as a factor affecting germination performance of seeds as reviewed in Section 4.2.1 of this chapter. Similarly, soaking treatment is known to be an enhancing factor in the germination performance of many seeds as reviewed in Section 4.2.1. Potassium nitrate solution, as soaking medium, has been identified as having additional enhancing properties and has also played an influencing role in seed nut germination performance of some palm species as reviewed in Section 4.2.1.

In experiment 1 of this study, interaction between sawdust medium and soaking treatment using 1% potassium nitrate solution increased the speed of germination by 16.4% relative to topsoil and by 18.2% as compared with the control. In this experiment, only one concentration of potassium nitrate solution was used. There was therefore the need to carry out a further study using varying concentrations of potassium nitrate solution.

Experiment 4 assesses the effect of soaking treatment and medium on germination and vigour of SGD x VTT coconut hybrid seed nut using different concentrations of potassium nitrate solution.

4.5.2 Materials and methods

4.5.2.1 Description of the Study Area

The study area has been described in section 4.2.2.1

4.5.2.2 Experimental Design and Treatments

A split-plot design with 3 replicates was used to assess 2 types of planting media (topsoil and decomposed sawdust) assigned to main plots and 5 levels of potassium nitrate concentrations: 0% (PN_0), 1% (PN_1), 2% (PN_2), 3% (PN_3) and 5% (PN_5) assigned to subplots. Bottomless wooden boxes of dimension 4.0 m x 1 m x 0.2 m each were filled to the brim with topsoil or decomposed sawdust to serve as the main plots. The main plots were partitioned into 5 subplots of dimension 0.8 m x 1m x 0.2 m each to contain 20 seed nuts per subplot. Treatments were assigned randomly within the main plots and subplots.

4.5.2.3 Seed Nut Harvesting and Preparation

Seed nut harvesting and preparation have been described in Section 4.2.2.4. Six hundred (600) seed nuts were pared for planting.

4.5.2.4 Soaking Treatment

Soaking treatment has been described in Section 4.2.2.5. For preparation of 1% (w/v), 2% (w/v), 3% (w/v) and 5% (w/v) potassium nitrate solution 1 kg, 2 kg,

3 kg and 5 kg of potassium nitrate were respectively dissolved in 99, 98, 97 and 95 litres of water.

4.5.2.5 Seed Nut Planting, Maintenance Culture and Data Collection

Seed nut planting, maintenance culture and data collection have been described in Section 4.2.2. Seed nut planting was done by fully burying the nuts in the planting medium.

4.5.2.6 Data Management and Statistical Analysis

The data management and statistical analysis have been described in Chapter 3, Section 3.5.

4.5.3 Results

4.5.3.1 Final Germination Percentage

Final germination percentage of SGD x VTT coconut hybrid seed nuts as influenced by potassium nitrate soaking treatment and planting medium is presented in Table 4.11. Data analysis did not indicate significant ($P>0.05$) treatment effect on final germination percentage (Appendix 20). Germination rate varied from 85 - 88% and 83 - 89% in the topsoil and sawdust media respectively across the potassium nitrate concentrations.

Table 4.11 Final germination percentage of SGD x VTT coconut hybrid seed nuts as influenced by KNO_3 soaking treatment and planting medium

Planting Medium	Final Germination %				
	KNO_3 concentration				
	PN_0	PN_1	PN_2	PN_3	PN_5
Top soil	86.1	88.3	87.5	85.7	86.0
	±5.48	±5.11	±5.43	±5.38	±6.52
Sawdust	87.7	89.0	86.7	86.3	83.4
	±5.22	±5.48	±5.38	±5.27	±5.43

Mean estimates ± S.E. with the same capital letters within rows or same small letters within columns are not significantly different, P> 0.05. PN_0 = 0% KNO3 solution; PN_1 = 1% (w/v) KNO3 solution; PN_2 = 2% (w/v) KNO3 solution; PN_3 = 3% (w/v) KNO3 solution; PN_5 = 5% (w/v) KNO3 solution.

4.5.3.2 Time to 50% Germination

Time to 50% germination of SGD x VTT coconut hybrid seed nuts as influenced by potassium nitrate soaking treatment and planting medium is presented in Table 4.12. Data analysis showed significant (P>0.05) treatment effect on time to 50% germination (Appendix 21).

Interaction between planting medium and potassium nitrate soaking treatment produced an upward trend in speed of germination as potassium nitrate concentration increased. It also produced a speed of germination which was significantly (P<0.05) greater in sawdust medium than in topsoil. Sawdust medium interacted significantly (P<0.05) with potassium nitrate soaking treatment to increase the speed of germination on the average by 23.4% as compared with the control.

Table 4.12 Time to 50% germination of SGD x VTT coconut hybrid seed nuts as influenced by KNO_3 soaking treatment and planting medium

Planting Medium	Time (in days) to 50% Germination				
	KNO_3 concentration				
	PN_0	PN_1	PN_2	PN_3	PN_5
Top soil	55.9	53.2	51.5	50.9	51.7
	±4.16aA	±4.25aA	±4.04aA	±4.14aA	±4.89aA
Sawdust	54.4	43.1	42.6	42.2	40.3
	±4.05aB	±3.92bC	±4.03bC	±3.88bC	±4.84bC

Mean estimates ± S.E. with the same capital letters within rows or same small letters within columns are not significantly different, P> 0.05. LSD (0.05) of mean estimates is presented in Appendix 22. PN_0 = 0% KNO3 solution; PN_1 = 1% (w/v) KNO3 solution; PN_2 = 2% (w/v) KNO3 solution; PN_3 = 3% (w/v) KNO3 solution; PN_5 = 5% (w/v) KNO3 solution.

4.5.3.3 Germination Index

Germination index of SGD x VTT coconut hybrid seed nuts as influenced by potassium nitrate soaking treatment and planting medium is presented in Table 4.13. Data analysis indicated significant (P>0.05) treatment effect on germination index (Appendix 23). Interaction between planting medium and potassium nitrate soaking treatment resulted in an increased germination index with increasing potassium nitrate concentration. Over the range of potassium nitrate concentrations studied, germination index increased significantly (P<0.05) by 25.6% on the average in the sawdust medium relative to the control and marginally by 8.3% in the topsoil medium.

Table 4.13 Germination index of SGD x VTT coconut hybrid seed nuts as influenced by potassium nitrate soaking treatment and planting medium

Planting Medium	Germination Index				
	KNO_3 concentration				
	PN_0	PN_1	PN_2	PN_3	PN_5
Top soil	3.01	3.11	3.21	3.32	3.41
	±1.09aA	±1.02aA	±1.11aA	±1.09aA	±1.36aA
Sawdust	3.50	4.16	4.23	4.34	4.63
	±1.10aB	±1.14bBC	±1.15bC	±1.16bC	±1.19bC

Mean estimates ± S.E. with the same capital letters within rows or same small letters within columns are not significantly different, P>0.05. LSD (0.05) of mean estimates is presented in Appendix 24. PN_0 = 0% KNO3 solution; PN_1 = 1% (w/v) KNO3 solution; PN_2 = 2% (w/v) KNO3 solution; PN_3 = 3% (w/v) KNO3 solution; PN_5 = 5% (w/v) KNO3 solution.

4.5.4 Discussion

4.5.4.1 Final Germination Percentage

The inability of increased concentrations of potassium nitrate soaking treatments to affect seed nut germination rate was buttressed by the findings of Shim *et al.* (2008) in which soaking with different concentrations of potassium nitrate solution during priming did not influence seed germination rate of seashore paspalum (*Paspalum vaginatum*). On the contrary, Bian *et al.* (2013) reported that seeds of red palm (*Cyrtostachys renda*) soaked in 0.15% potassium nitrate solution, produced a germination rate of 65.3% as compared with 36% in the control. This impact of potassium nitrate soaking treatment on seed germination rate in red palm might be attributed to the breaking of dormancy in seeds of red palm; a situation

that does not exist in seed nuts of coconut which never suffer dormancy (Chin & Roberts, 1980). Rather, the fibrous mesocarp constitutes a considerable barrier to rapid germination (Ugbah & Akpan, 2003).

4.5.4.2 Time to 50% Germination

The increase in speed of germination of seed nuts with increasing concentration of potassium nitrate soaking treatment could be attributed to seed germination enhancing properties of potassium nitrate as reviewed in Section 4.2.1. Though in general, soaking treatment activates the internal metabolism required to trigger seed germination process (Basra *et al.* (2005), potassium nitrate soaking treatment has additional ability to make oxygen, potassium ions and nitric acid available after chemical decomposition. These chemicals released after the breakdown facilitate the germination process and enhance the speed of germination (Varier *et al.* 2010; Dwiyono & Djauhari, 2021). In the work carried out by Shim *et al.* (2008), the authors found out that even though potassium nitrate soaking treatment did not influence seed germination rate of seashore paspalum, it increased speed of germination.

For seed nut soaked in potassium nitrate solution, the higher speed of germination observed in sawdust medium relative to top soil could be attributed to enhanced synergy between sawdust medium and potassium nitrate soaking treatment. Sawdust medium has good physical properties highly suitable for seed nut germination (Horisawa *et al.*, 1999; Dwiyono & Djauhari, 2021). Similarly, as explained in Section 4.2.1, potassium nitrate soaking treatment has additional

germination enhancing properties. The interaction between sawdust medium and potassium nitrate soaking treatment therefore might have led to a synergy in seed germination enhancing properties.

4.5.4.3 Germination Index

The increased germination index due to potassium nitrate soaking treatment might be attributed to the seed germination enhancing properties of the soaking treatment (Basra *et al.*, 2005; Bian *et al.* 2013; Dwiyono & Djauhari, 2021) which improved the speed of germination, a key factor for enhancing germination index. The higher germination index observed in the sawdust medium relative to topsoil medium in the potassium nitrate soaking treatment might also be accounted for by the enhanced synergy between sawdust medium and potassium nitrate soaking treatment as explained earlier in Subsection 4.5.4.2 since enhanced speed of germination improves germination index.

4.5.5 Conclusion

Soaking of SGD x VTT coconut hybrid seed nuts in different concentrations of potassium nitrate solution did not influence seed nut germination rate; rather it enhanced speed of germination. Interaction between sawdust medium and potassium nitrate soaking treatment improved speed of germination by 23.4% and germination index by 25.6% relative to the control.

CHAPTER FIVE

5.0 FERTILIZER APPLICATION AND SPACING IN SGD x VTT COCONUT HYBRID SEEDLINGS

5.1 Introduction

Fertilizer application in coconut nursery is important for producing healthy and vigourous seedlings to enhance establishment, rapid growth and early bearing in the field (Nelliat, 1972; Almaden & Satiago, 1980). Report by some earlier workers (Magat & Prudente, 1974; Magat *et al*., 1977; Abad *et al*., 1978) showed that potassium chloride or sodium chloride treatment did not only improved coconut seedling growth but increased resistance to leaf spot disease. According to Almaden & Satiago (1980), nitrogen and potassium fertilizer treatments produced taller coconut seedlings with larger collar girth and greater vigour. Also, a standard mixture of urea, triple superphosphate, potassium chloride and magnesium sulphate in the ratio 1:2:2:1 applied to coconut seedlings aged 1, 3, 5, 7 and 9 months at 3 0, 60, 75, 75 and 75 g/plant respectively promoted healthy and vigourous growth (Taffin, 1998). The foregoing demonstrates the importance of mineral fertilizer application in the production of quality coconut seedlings and its relevance in the tropics, where most soils are depleted in soil nutrients (Child, 1974).

Besides nutrition, spacing is known to impact on growth and development of coconut seedlings through light interception (Almaden & Santiago, 1980). Closer spacing produce unhealthy seedlings due to mutual shading and enhanced

disease spread whilst larger spacing produces healthy and vigourous seedlings but requires greater land area and more labour to meet production target (Almaden & Santiago, 1980). Spacing recommendation made by Santos *et al.* (1996) for polybag nursery was 60 cm triangular. Taffin (1998) however, introduced variation in spacing linked with expected duration of seedlings at the nursery indicating 60 cm x 60 cm for up 6 months; 80 cm x 80 cm for 6-9 months and 100 cm x 100 cm for 9-12 months.

Poor quality coconut seedlings for field planting has been identified as one of the problems facing the coconut subsector in Ghana (MoFA, 2018). The devastating CSPWD, for a long time, had become the focus of coconut research in Ghana leading to a scanty study, locally, into coconut nursery management.

This study assesses the effect of spacing and fertilizer application regimes on growth and vigour of SGD x VTT coconut hybrid seedlings.

5.2 Experiment 5: Fertilizer Application and Spacing in SGD x VTT Coconut Hybrid Seedlings

5.2.1 Introduction

Introduction is presented under Section 5.1 of this chapter.

5.2.2 Materials and methods

5.2.2.1 Description of the Study Area

The study area has been described under Section 4.2.2.1

5.2.2.2 Experimental Design and Treatments

A split-plot design with 3 replicates was used to assess 2 levels of spacing (S1 and S2) assigned to main plots and 4 levels of fertilizer schedules (F0, F1, F2 and F3) assigned to subplots. Fertilizer schedules and spacing were formulated based on fertilizer rates and spacing described by Tafin, 1998 and Santos *et al.*, 1996 for coconut seedling production.

S1= Spacing at 60 cm triangular

S2= Spacing at 80 cm triangular

F0= control

F1= Fertilizer application at 28.4:58.0:75.6:17.0 g seedling^{-1} $N:P_2O_5:K_2O:MgO$

F2= Fertilizer application at 47.3:96.6:126.0:28.4 g seedling^{-1} $N:P_2O_5:K_2O:MgO$

F3= Fertilizer application at 66.2:135.2:176.4:39.7 g seedling^{-1} $N:P_2O_5:K_2O:MgO$

Six main plots of dimensions 9.6 m x 4.0 m each and 24 subplots of dimension 4.0 m x 2.4 m each were used for the study. Fifteen seedlings were planted to each subplot in 3 rows arranged in a triangular pattern using the appropriate treatment spacing. The four fertilizer schedules were split-applied 6 times at monthly intervals at 5%, 10%, 14%, 19%, 24% and 28% respectively.

Urea, Muriate of potash, Triple superphosphate and Kieserite were applied as source of N, P_2O_5, K_2O and MgO respectively. Treatments were assigned randomly within the main plots and subplots.

5.2.2.3 Seedling Planting

Lining and pegging was done in each plot in a triangular pattern using the appropriate treatment spacing. SGD x VTT coconut hybrid seed nuts with 5-cm high embryonic shoot (Figure 5.1) were roots pruned and pricked-out into the field nursery (Figure 5.2) for the study.

Figure 5.1. A technician measuring the height of embryonic shoot of SGD x VTT coconut hybrid seed nut

Figure 5.2. SGD x VTT coconut hybrid seedlings after one month of pricking-out seed nuts with 5cm-high embryonic shoot

5.2.2.4 Maintenance Culture

Weed maintenance in the seed beds and within experimental layout was done using hoe and cutlass. Water from a dug-out well was used for hand watering at every other day in absence of rains for 2 hours 15 minutes between 2 and 5 pm. Each replicate was watered for 45 minutes using a watering can. Seedlings were monitored for growth.

5.2.2.5 Data Collection

Soil sampling and analysis were carried out to assess initial soil nutrient status prior to fertilizer application. Leaf sampling and analysis were also done to

monitor fertilizer uptake by seedlings. Vegetative measurements were taken on collar girth, seedling height, leaf number and canopy diameter to evaluate seedling growth and vigour.

5.2.2.5.1 Soil sampling and analysis

Soil sampling and analysis were carried out based on the procedures detailed in Section 3.3 of Chapter 3.

5.2.2.5.2 Leaf sampling and analysis

Leaf sampling and analysis were done based on the procedures detailed in Section 3.4 of Chapter 3.

5.2.2.5.3 Collar girth

Collar girth was determined at monthly intervals with a measuring tape strapped around the base of seedlings (Santos *et al.*, 1996) as shown in Figure 5.3.

5.2.2.5.4 Seedling height

Seedling height was determined at monthly intervals by measuring the tallness of the seedling from the base to the tip of the tallest leaf (Santos *et al.*, 1996) as depicted in Figure 5.4.

5.2.2.5.5 Leaf number

Leaf number was determined at monthly intervals by count of functional leaves on the seedling (Santos *et al.*, 1996).

Figure 5.3. A technician measuring the collar girth of SGD x VTT coconut hybrid seedling

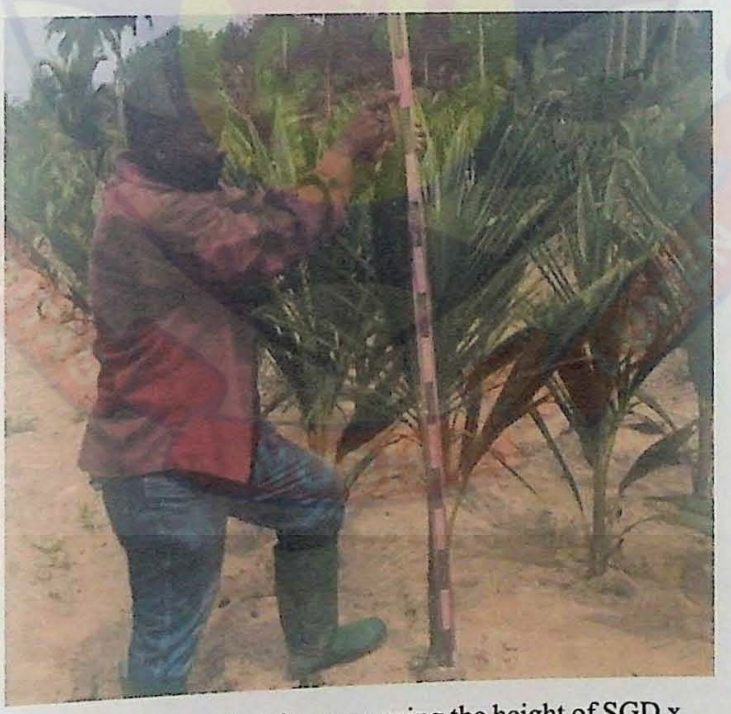

Figure 5.4. A technician measuring the height of SGD x VTT coconut hybrid seedling

5.2.2.5.6 Canopy diameter

Canopy diameter was determined at monthly intervals from the fourth month by measuring the canopy length (Figure 5.5) in the 2 directions: North-South and South-East and taking the average of the two lengths.

Figure 5.5. Technicians measuring the canopy diameter of SGD x VTT coconut hybrid seedling

5.2.2.5.7 Vigour index

Vigour index of seedlings was determined using the formula patterned after Child (1974) as follows:

$$VI = \frac{G^2}{2\pi\sqrt{H^2 + \frac{D^2}{4}}}$$

Where;

VI = Vigour index

G = Collar girth

H = Seedling height

D = Canopy diameter

5.2.2.6 Data Management and Statistical Analysis

The data management and statistical analysis were carried out as described Section 3.5 of Chapter 3.

5.3 Results

5.3.1 Soil analysis

Particle-size distribution of soil at the experimental site was representative of sandy loam texture (Table 5.1). Its chemical properties showed normal levels of P, Ca and Mg at top soil but low soil N and K. Also, its pH, organic matter content, level of exchangeable bases and cation exchange capacity were all low.

Table 5.1. Particle-size distribution and chemical properties of soil at the onset of experiment five

Soil Depth	Clay	Silt	Sand	OM	N	pH
	----------%----------					
0 -20	11.6	16.3	72.1	1.60	0.09	4.7
21- 40	11.2	16.2	72.6	1.12	0.06	4.6

	Ca	Mg	K	TEB	ECEC	P
	----------cmol kg^{-1}----------					ug g^{-1}
0 -20	2.58	0.61	0.24	2.49	2.50	13.8
21- 40	1.79	0.38	0.16	1.58	1.59	6.61

OM = Organic matter; TEB = Total exchangeable basis; ECEC = Effective cation exchange capacity

5.3.2 Leaf analysis

Leaf nutrients of SGD x VTT coconut hybrid seedlings as influenced by spacing and fertilizer treatment is presented in Table 5.2. Data analysis showed significant ($P<0.05$) treatment effect on N, P and K but not on Ca and Mg (Appendix 25).

Even though fertilizer application did not include Ca, leaf Ca content was moderately high across all treatments relative to a reference value of 0.6%. Differences in leaf Mg content between fertilizer-treated seedlings and the control were not significant ($P>0.05$). Leaf N, P and K increased with enhanced levels of fertilizer application schedules in the order F3>F2>F1>F0.

The interaction between fertilizer treatment and spacing resulted in a significant ($P<0.05$) reducing effect on leaf P and N with increase in spacing at F2 and F3 fertilizer levels. F3- and F2-treated seedlings had significantly ($P<0.05$) higher leaf N, P and K contents than the control and F1-treated seedlings at both S1

and S2 spacing levels. F3-treated seedlings had significantly ($P<0.05$) higher leaf P content than F2-teated seedlings but differences in leaf N and K between them were not significant ($P>0.05$).

Table 5.2. Leaf nutrient of SGD x VTT coconut hybrid seedlings as influenced by spacing and fertilizer treatment

LN	Spacing	Mean Leaf Nutrient (% dry matter, leaf rank # 2) Fertilizer Schedule			
		F0	F1	F2	F3
Mg	S1	0.236	0.236	0.238	0.239
	S2	0.234	0.234	0.235	0.236
Ca	S1	0.963	0.966	0.963	0.991
	S2	0.981	0.973	0.945	0.974
N	S1	2.251aA	2.291aA	2.778aB	2.897aB
	S2	2.141aC	2.166aC	2.474bD	2.639bD
P	S1	0.270aA	0.274aA	0.345aB	0.384aC
	S2	0.255aD	0.253aD	0.288bE	0.322bF
K	S1	0.907aA	0.970aA	1.158aB	1.166aB
	S2	0.897aC	0.976aC	1.148aD	1.164aD

For any particular leaf nutrient, mean estimates ± S.E. with no letters or the same capital letters within rows or same small letters within columns are not significantly different, $P>0.05$. LSD (0.05) of mean estimates is presented in Appendices 26, 27 and 28. LN = Leaf nutrient; S1 = Spacing at 60 cm triangular; S2 = Spacing at 80 cm triangular; F0 = control; F1 = Fertilizer application at 28.4:58.0:75.6:17.0 g seedling^{-1} $N:P_2O_5:K_2O:MgO$; F2 = Fertilizer application at 47.3:96.6:126.0:28.4 g seedling^{-1} $N:P_2O_5:K_2O:MgO$; F3 = Fertilizer application at 66.2:135.2:176.4:39.7 g seedling^{-1} $N:P_2O_5:K_2O:MgO$

5.3.3 Collar girth

Collar girth of SGD x VTT coconut hybrid seedlings as influenced by spacing and fertilizer treatment is presented in Table 5.3.

Table 5.3. Collar girth of SGD x VTT coconut hybrid seedlings as influenced by spacing and fertilizer treatment

MPO	Spacing	Mean Collar Girth (cm)			
		Fertilizer Schedule			
		F0	F1	F2	F3
1	S1	6.1 ± 0.11	6.0 ± 0.11	5.9 ± 0.12	5.9 ± 0.13
	S2	6.1 ± 0.12	5.9 ± 0.11	6.2 ± 0.12	6.0 ± 0.12
2	S1	7.1 ± 0.16	7.2 ± 0.16	7.2 ± 0.11	7.1 ± 0.16
	S2	7.3 ± 0.16	7.3 ± 0.17	7.4 ± 0.16	7.5 ± 0.16
3	S1	9.3 ± 0.22aA	9.5 ± 0.19aA	10.4 ± 0.21aB	10.5 ± 0.22aB
	S2	9.2 ± 0.20aC	9.4 ± 0.21aC	10.2 ± 0.23aD	10.3 ± 0.20aD
4	S1	12.7 ± 0.21aA	13.0 ± 0.24aA	13.8 ± 0.23aB	14.1 ± 0.26aB
	S2	12.3 ± 0.24aC	12.7 ± 0.25aC	13.5 ± 0.26aD	13.8 ± 0.25aD
5	S1	14.9 ± 0.34aA	15.7 ± 0.30aA	16.8 ± 0.34aB	17.1 ± 0.33aB
	S2	14.6 ± 0.34aC	15.2 ± 0.31aC	16.4 ± 0.33aD	16.7 ± 0.39aD
6	S1	17.8 ± 0.39aA	18.7 ± 0.43aA	20.5 ± 0.45aB	21.3 ± 0.47aB
	S2	17.3 ± 0.39aC	18.4 ± 0.45aC	19.8 ± 0.45aD	20.7 ± 0.44aD

For any particular month, mean estimates ± S.E. with no letters or the same capital letters within rows or same small letters within columns are not significantly different, P>0.05. LSD (0.05) of mean estimates is presented in Appendices 30, 31, 32 and 33. MPO =Month after pricking out; S1= Spacing at 60 cm triangular; S2 = Spacing at 80 cm triangular; F0 = control; F1= Fertilizer application at 28.4:58.0:75.6:17.0 g seedling^{-1} N:P_2O_5:K_2O: MgO; F2 = Fertilizer application at 47.3:96.6:126.0:28.4 g seedling^{-1} N:P_2O_5:K_2O:MgO; F3 = Fertilizer application at 66.2:135.2:176.4:39.7 g seedling^{-1} N:P_2O_5:K_2O:MgO

Data analysis showed significant ($P<0.05$) treatment effect on collar girth from 3-6 months after pricking-out (Appendix 29). Collar girth grew bigger with increased levels of fertilizer schedule in the order F3>F2>F1>F0 at S1 and S2 spacing levels. The interaction effect between fertilizer treatment and spacing on girth size was not significant ($P>0.05$). F3- and F2-treated seedlings had significantly ($P<0.05$) bigger girth size than the control and F1-treated seedlings. The average girth size for F3-treated seedlings from 3-6 months after prick-out was 10.5% and 15.2% bigger than F1- treated seedlings and the control respectively. Similarly over the same period, girth size for F2-treated seedlings was 7.8% and 12.4% respectively larger than F1-treated seedlings and the control.

5.3.4 Seedling height

Height of SGD x VTT coconut hybrid seedlings as influenced by spacing and fertilizer treatment is presented in Table 5.4. Data analysis indicated significant ($P<0.05$) treatment effect on seedling height from months 4 - 6 after pricking-out (Appendix 34).

Seedling height grew taller with increased levels of fertilizer schedule in the order F3>F2>F1>F0 at S1 and S2 spacing levels. The effect of interaction between fertilizer treatment and spacing not significant ($P>0.05$) on seedling height. F3-treated seedlings grew significantly ($P<0.05$) taller than the control seedlings after 4 months of pricking-out. The average height for F3-treated seedlings from 4-6 months after pricking-out was 7.6% taller than the control. Height of F1- and

F2-treated seedlings were not significantly (P>0.05) different from that of the control seedlings.

Table 5.4. Height of SGD x VTT coconut hybrid seedlings as influenced by spacing and fertilizer treatment

MPO	Spacing	Mean Seedling Height (cm)			
		Fertilizer Schedule			
		F0	F1	F2	F3
1	S1	42.0 ± 1.1	40.9 ± 1.1	39.9 ± 1.2	40.7 ± 1.2
	S2	40.9 ± 1.2	39.8 ± 1.1	40.0 ± 1.2	39.7 ± 1.2
2	S1	49.0 ± 1.6	52.8 ± 1.3	54.2 ± 1.5	51.2 ± 1.4
	S2	50.5 ± 1.6	51.8 ± 1.4	53.3 ± 1.4	52.5 ± 1.4
3	S1	68.7 ± 1.8	65.5 ± 1.6	65.7 ± 1.6	67.0 ± 1.8
	S2	67.6 ± 1.6	65.3 ± 1.6	64.0 ± 1.8	67.3 ± 1.6
4	S1	77.9 ± 1.8aA	81.2 ± 1.7aAB	81.9 ± 1.6aAB	85.3 ± 1.8aB
	S2	76.9 ± 1.7aC	80.6 ± 1.7aCD	81.1 ± 1.8aCD	84.4 ± 1.8aD
5	S1	96.2 ± 2.0aA	98.6 ± 1.6aAB	100.6 ± 1.8aAB	104.7 ± 1.7aB
	S2	95.4 ± 1.8aC	98.2 ± 1.6aCD	100.3 ± 1.7aCD	103.7 ± 1.6aD
6	S1	130.4 ± 2.3aA	131.7 ± 2.6aAB	136.5 ± 2.7aAB	137.7 ± 2.6aB
	S2	129.6 ± 2.3aC	130.4 ± 2.7aCD	135.8 ± 2.7aCD	136.9 ± 2.6aD

For any particular month, mean estimates ± S.E. with no letters or the same capital letters within rows or same small letters within columns are not significantly different, P>0.05. LSD (0.05) of mean estimates is presented in Appendices 35, 36 and 37. MPO = Month after pricking out; S1= Spacing at 60 cm triangular; S2= Spacing at 80 cm triangular; F0 = control; F1 = Fertilizer application at 28.4:58.0:75.6:17.0 g seedling^{-1} N:P_2O_5:K_2O:MgO; F2 = Fertilizer application at 47.3:96.6:126.0:28.4 g seedling^{-1} N:P_2O_5:K_2O:MgO; F3 = Fertilizer application at 66.2:135.2:176.4:39.7 g seedling^{-1} N:P_2O_5:K_2O:MgO

5.3.5 Leaf number

Leaf number of SGD x VTT coconut hybrid seedlings as affected by spacing and fertilizer treatment is presented in Table 5.5. Data analysis did not show significant (P>0.05) treatment effect on leaf number (Appendix 38). Differences in leaf numbers between fertilizer-treated seedlings and the control was not significant (P>0.05) over the 6-month period of the study. The average leaf number at 6-month after pricking-out varied from 7.6 to 7.8 for all the treatments under study.

Table 5.5. Leaf number of SGD x VTT coconut hybrid seedlings as influenced by spacing and fertilizer treatment

		Mean Leaf Number			
MPO	Spacing	Fertilizer Schedule			
		F0	F1	F2	F3
1	S1	2.4 ± 0.08	2.3 ± 0.08	2.3 ± 0.09	2.4 ± 0.09
	S2	2.3 ± 0.08	2.3 ± 0.08	2.5 ± 0.09	2.4 ± 0.09
2	S1	3.5 ± 0.09	3.5 ± 0.09	3.4 ± 0.10	3.4 ± 0.09
	S2	3.5 ± 0.09	3.4 ± 0.09	3.4 ± 0.09	3.4 ± 0.09
3	S1	5.0 ± 0.12	5.0 ± 0.11	5.0 ± 0.12	4.9 ± 0.12
	S2	5.0 ± 0.11	4.9 ± 0.11	5.1 ± 0.13	5.2 ± 0.11
4	S1	5.8 ± 0.12	5.9 ± 0.11	6.0 ± 0.11	6.0 ± 0.16
	S2	6.0 ± 0.11	6.0 ± 0.11	6.0 ± 0.12	6.0 ± 0.17
5	S1	7.2 ± 0.15	7.1 ± 0.15	7.2 ± 0.15	7.1 ± 0.15
	S2	7.2 ± 0.15	7.1 ± 0.14	7.0 ± 0.15	7.2 ± 0.15
6	S1	7.5 ± 0.13	7.7 ± 0.14	7.7 ± 0.15	7.7 ± 0.15
	S2	7.6 ± 0.13	7.5 ± 0.15	7.8 ± 0.14	7.7 ± 0.14

Mean estimates ± S.E. with no letters within rows or columns for any particular month are not significantly different, P>0.05. MPO=Month after pricking out; S1= Spacing at 60 cm triangular; S2= Spacing at 80 cm triangular; F0= control; F1 = Fertilizer application at 28.4:58.0:75.6:17.0 g seedling^{-1} N:P_2O_5:K_2O:MgO; F2 = Fertilizer application at 47.3:96.6:126.0:28.4 g seedling^{-1} N:P_2O_5:K_2O:MgO; F3 = Fertilizer application at 66.2:135.2:176.4:39.7 g seedling^{-1} N:P_2O_5:K_2O:MgO

5.3.6 Canopy diameter

Canopy diameter of SGD x VTT coconut hybrid seedlings as influenced by spacing and fertilizer treatment is presented in Table 5.6. Data analysis showed significant (P<0.05) treatment effect on canopy diameter from 4 - 6 months after pricking-out (Appendix 39). Canopy diameter grew wider with increased levels of fertilizer treatment in the order F3>F2>F1>F0 at S1 and S2 spacing levels.

Table 5.6. Canopy diameter of SGD x VTT coconut hybrid seedlings as influenced by spacing and fertilizer treatment

		Mean Canopy Diameter (cm)			
MPO	Spacing	Fertilizer Schedule			
		F0	F1	F2	F3
4	S1	50.3 ± 1.6aA	53.6 ± 1.4aAC	55.6 ± 1.4aBC	58.8 ± 1.5aB
	S2	50.5 ± 1.4aD	52.7 ± 1.5aDF	54.9 ± 1.5aEF	57.4 ± 1.5aE
5	S1	60.1 ± 1.5aA	64.8 ± 1.3aAB	68.5 ± 1.5aBC	72.6 ± 1.5aC
	S2	59.7 ± 1.5aD	64.1 ± 1.4aDE	67.3 ± 1.5aEF	69.2 ± 1.4aF
6	S1	80.4 ± 1.6aA	85.1 ± 1.8aAC	89.5 ± 1.9aBC	92.6 ± 1.9aB
	S2	82.5 ± 1.6aC	84.8 ± 1.9aCD	87.8 ± 1.9aDE	90.6 ± 1.8aE

For any particular month, mean estimates ± S.E. the same capital letters within rows or same small letters within columns are not significantly different, P>0.05. LSD (0.05) of mean estimates is presented in Appendices 40, 41, and 42. MPO=Month after pricking out; S1= Spacing at 60 cm triangular; S2 = Spacing at 80 cm triangular; F0 = control; F1= Fertilizer application at 28.4:58.0:75.6:17.0 g seedling^{-1} N:P_2O_5:K_2O:MgO; F2 = Fertilizer application at 47.3:96.6:126.0:28.4 g seedling^{-1} N:P_2O_5:K_2O:MgO; F3 = Fertilizer application at 66.2:135.2:176.4:39.7 g seedling^{-1} N:P_2O_5:K_2O: MgO

The interaction between fertilizer treatment and spacing did not impact significantly (P>0.05) on canopy diameter but the main effect of fertilizer was significant (P<0.05) on canopy diameter. F3- treated seedlings had significantly (P<0.05) wider canopy diameter than F1- treated seedlings and the control after 4

months of pricking-out. The average canopy diameter for F3- and F2-treated seedlings from 4-6 months after pricking-out were 15.0% and 10.5% respectively wider than that of the control. Differences in canopy diameter between F1-treated seedlings and the control and between F1- and F2-treated seedlings were not significant (P>0.05).

5.3.7 Vigour index

Vigour index of SGD x VTT coconut hybrid seedlings as influenced by spacing and fertilizer treatment is presented in Table 5.7. Data analysis showed significant (P<0.05) treatment effect on vigour index (Appendix 43). Vigour index increased with enhanced levels of fertilizer treatment in the order F3>F2>F1>F0 at S1 and S2 spacing levels.

The interaction effect between fertilizer treatment and spacing was not significant (P>0.05) on vigour index. Differences in vigour index between F3- and F2-treated seedlings were not significant (P>0.05) but these vigour indices were significantly (P<0.05) greater than that of F1-treated seedlings and the control after 4 months of pricking-out. The average vigour index for F3-, F2- and F1-treated seedlings from 4 - 6 months after pricking-out were 39.7%, 34.3% and 5.2% respectively higher than the control.

Table 5.7. Vigour index of SGD x VTT coconut hybrid seedlings as influenced by spacing and fertilizer treatment

MPO	Spacing	Mean Vigour Index			
		Fertilizer Schedule			
		F0	F1	F2	F3
4	S1	4.74 ± 0.20aA	4.86 ± 0.18aA	5.42 ± 0.18aB	5.92 ± 0.19aB
	S2	4.45 ± 0.18aC	4.80 ± 0.19aC	5.37 ± 0.19aD	5.53 ± 0.19aD
5	S1	4.59 ± 0.12aA	4.83 ± 0.10aA	6.38 ± 0.11aB	6.64 ± 0.11aB
	S2	4.31 ± 0.11aC	4.54 ± 0.10aC	6.36 ± 0.11aD	6.50 ± 0.10aD
6	S1	4.38 ± 0.14aA	4.62 ± 0.16aA	6.32 ± 0.16aB	6.53 ± 0.17aB
	S2	4.26 ± 0.14aC	4.48 ± 0.16aC	6.11 ± 0.16aD	6.26 ± 0.16aD

For any particular month, mean estimates ± S.E. with the same capital letters within rows or same small letters within columns are not significantly different, P>0.05. LSD (0.05) of mean estimates is presented in Appendices 44, 45, and 46. MPO=Month after pricking out; S1= Spacing at 60 cm triangular; S2 = Spacing at 80 cm triangular; F0 = control; F1= Fertilizer application at 28.4:58.0:75.6:17.0 g seedling^{-1} N:P_2O_5:K_2O:MgO; F2 = Fertilizer application at 47.3:96.6:126.0:28.4 g seedling^{-1} N:P_2O_5:K_2O:MgO; F3 = Fertilizer application at 66.2:135.2:176.4:39.7 g seedling^{-1} N: P_2O_5:K_2O:MgO

5.4 Discussion

5.4.1 Soil analysis

Soil at the experimental site was a representative of sandy loam texture and typical of most tropical soils where soil acidity, organic matter, cation exchange capacity and exchangeable bases are known to be limiting factors for soil productivity (Saikh *et al.*, 1998; Sombroek *et al.*, 1993). The well drained sandy loam texture could be partly accountable for the low organic matter and the deficiency in N and K could be largely attributed to the acidic soil conditions (Spargo *et al.*, 2013). The low cation exchange capacity and exchangeable bases

might be due to the interactive effect of the sandy loam texture, soil acidity and the low organic matter content.

5.4.2 Leaf analysis

Fertilizer application has been identified to be critical to the production of healthy and vigourous coconut seedlings for field planting (Santos *et al.*, 1996; Taffin 1998). However, soil factors among which soil acidity has been identified as key, regulate the availability of nutrients applied to plants (Shen *et al.*, 2010; Spargo *et al.*, 2013). Leaf sampling and analysis is therefore important for assessing uptake of fertilizers applied to plants.

The upward trend of leaf N, P and K with increased levels of fertilizer treatment was a clear indication of fertilizer uptake (Samuelson *et al.*, 2001). This expected to impact positively on seedling growth because of the various roles the nutrients play in plant growth.

N stimulates the synthesis of cytokinins which promote plant growth by influencing processes that lead to cell multiplication (Bloom *et al.*, 2006; Lawlor, 2012; Wei *et al.*, 2016). It also enhances photosynthesis by promoting green pigment formation and chloroplast development in leaf (Warmer *et al.*, 2004; Li *et al.*, 2012a). It is known to be associated with root growth and development (Costa et al., 2002; Tian *et al.*, 2005; Li *et al.*, 2012b).

P is involved in the utilization of photosynthate for plant metabolism (Spargo *et al.*, 2013) and plays a key role in growth and development of plant roots (Williamson, 2001). K is involved in the activation of several enzymes including

those that trigger protein and starch synthesis (Patil, 2011) and other biochemical processes resulting in cell growth and plant development (Van Brunt & Sultenfuss, 1998; Hepler *et al.*, 2001; Oosterhuis *et al.*, 2014). It plays an important role in the regulation of cell osmotic pressure which influences the opening and closure of stomata (Hu *et al.*, 2016; Thomas & Thomas, 2009) and regulates photosynthetic activity (Van Brunt & Sultenfuss, 1998).

5.4.3 Collar girth

Collar girth is a key parameter for assessing growth performance in coconut. The inability of collar girth to respond to fertilizer treatment until 3 months after pricking-out could be attributed to adequate reserve of endosperm nutrients of the seed nuts (Balachandran & Arumughan, 1995).

The upward trend in collar girth size in response to increased levels of fertilizer treatment could be attributed to the enhanced seedling uptake of N, P and K as shown by leaf analysis. The growth promoting functions of N, P and K as explained in Section 5.4.2 is clearly demonstrated in the increase in trend of collar girth size. Earlier work in coconut and other plants (e.g. *Populus spp.)* showed that N and P or N and K fertilizer application increased stem girth size (Almaden & Satiago, 1980; Brown & van den Driessche, 2005).

The inability of interaction effect between fertilizer treatment and spacing to impact positively on girth size strongly suggest that the increase in seedling spacing should not go beyond 60 cm triangular (S1 spacing level).

5.4.4 Seedling height

Like the collar girth, the no response of seedling height to treatment application until 4 months after pricking-out could be attributed to adequate reserve of endosperm nutrients in the seed nut (Balachandran & Arumughan, 1995). The increased trend in seedling height with enhanced levels of fertilizer treatment at the two spacing levels could be attributed to the increased uptake of N, P and K as explained earlier. In the work of Almaden & Satiago (1980), tallness in coconut seedlings produced was attributed to N and K fertilizers.

The absence of significant difference in height between the control and F1- and F2-treated seedlings and the meagre increase in height of F3-treated seedlings over the control was an indication of quality growth in the fertilizer-treated seedlings (Almaden & Satiago, 1980) since tallness can affect quality of seedling prduced (Child, 1974). Also, the absence of spacing effect on seedling height strongly indicated that there was no significant competition for light interception within the two levels of spacing.

5.4.5 Leaf number

The treatment effect of fertilizer and spacing could not influence leaf production in coconut seedlings in terms of numbers. This might be attributed to the predetermined nature of leaf emission in coconut fixed at the average rate of one leaf emission per month (Santos *et al.*, 1996) at the crop physiology level. Santiago (1978) and Almadem & Santiago (1980) reporting a similar result in their

work on coconut seedlings indicated that spacing and fertilizer levels did not have significant effect on the number of leaves emitted.

5.4.6 Canopy diameter

The increased trend in canopy diameter with enhanced levels of fertilizer treatment at the two spacing levels could be explained, as in the case of the collar girth and seedling height, by the increased seedling uptake of N, P and K since these major nutrients promote seedling growth and development (Spargo *et al.*, 2013; Oosterbius *et al.*, 2014; Wei *et al.*, 2016). The lack of significant difference in canopy diameter between F1- and F2-treated seedlings portrayed good growth in the F2-treated seedlings since increasingly large canopy diameter can affect quality of seedlings (Child, 1974). As in seedling height, the absence of spacing effect on canopy diameter suggested that there was no significant competition for light interception within the two levels of spacing.

5.4.7 Vigour index

The object of coconut nursery is to produce healthy and vigourous seedlings for field planting (Nelliat, 1972; Thomas *et al.*, 2018). Vigour index is therefore an important parameter in the determination of the best treatment combinations for the attainment of coconut nursery objective. The increased seedling vigour with enhanced levels of fertilizer treatment could be explained by increased seedling uptake of N, P and K as indicated in the earlier sections. Almaden & Satiago (1980)

reported that N and K fertilizer treatments produced coconut seedlings with greater vigour.

The lack of significant difference in vigour between F3- and F2-treated seedlings made F2 fertilizer regime a good choice over F3. The F2 fertilizer regime comes at a lower cost than F3. The average vigour of F2-treated seedlings which was 34.3% higher than the control and not significantly lower than the vigour of F3-treated seedlings, confirmed the F2-fertilizer treatment as the most suitable; more especially that the vigour of F1-treated seedlings was only 5.2% greater than the control. The absence of spacing effect on seedling vigour strongly confirmed the S1 spacing level of 60 cm triangular as suitable as it promotes land use intensification and cuts down land size for coconut nursery.

5.5 Conclusion

Seedling spacing of 60 cm triangular (19,264 seedlings ha^{-1}) and $N:P_2O_5:K_2O:MgO$ fertilizer application at the rate of 47.3:96.6:126.0:28.4 g $seedling^{-1}$ were identified as the most suitable treatment combination for coconut seedling production. This treatment combination, after 6 months of application, produced SGD x VTT coconut hybrid seedlings with averagely 34.3% higher vigour, 12.4% bigger collar girth, 10.5% wider canopy diameter and 4.7% increase in height relative to the control.

CHAPTER SIX

6.0 AGRONOMIC TREE MANAGEMENT PRACTICES IN SRI LANKA GREEN DWARF COCONUT VARIETY

6.1 Introduction

The Sri Lanka Green Dwarf (SGD) is currently the most tolerant coconut variety to the devastating Cape St Paul Wilt Disease (CSPWD) of Ghana (Dery *et al.*, 2008; Dare *et al.*, 2010). Notwithstanding, the SGD has not been officially recommended for commercial planting due to its poor fruit characteristics. The poor fruit characteristics of the SGD are attributed to the dwarf coconut type producing inflorescence at an early age of 2-3 years at the time that its vegetative capacity has not fully developed; evidenced particularly in its weak/ small stem at the time of first inflorescence emergence (Bourdeix *et al.*, 2005). Intrinsically, the SGD variety carries a high fruit set (averaging about 20 nuts per bunch) which when developed into a full bunch within the context of a limited vegetative capacity, triggers an assimilate availability crisis (Wareing & Patrick, 1975; Noggle & Fritz, 2006) leading to relatively small fruit size with attendant poor weight of its fruit components.

A solace to the poor fruit characteristic problem has been found in the hybridization of the SGD with Vanuatu Tall (VTT) coconut variety to produce the SGD x VTT coconut hybrid for commercial planting. However, it is believed that agronomic tree management practices particularly; fruit thinning (Jackson &

Frederich, 1999; Bourdeix *et al.*, 2005) and ablation involving inflorescence removal (Datuluri & Misra, 2002; Corley & Tinker, 2003) could be used to impact positively on SGD poor fruit characteristic (Ohler, 1984; Santos *et al.*, 1996) towards a more practical and efficient solution.

The current practice of SGD hybridization has been found to be inefficient considering the high demand for disease tolerant planting materials. In the assisted open pollinated method recommended for SGD hybridization, apart from being expensive in terms of initial investment and labour requirement for daily emasculation and pollination, the hybridization process generates a low turn-out of coconut hybrid seeds estimated at 5-8 nuts per bunch which is equivalent to 25-40% of fruit set. This low turn-out does not keep pace with the high demand for disease tolerant planting materials.

In order to get the best out of the SGD coconut variety, research needs to focus on low-cost agronomic tree management interventions involving ablation and fruit thinning for which there are adequate evidence in literature suggesting that they could be useful. This study evaluates agronomic tree management practices in the SGD coconut variety for improved fruit characteristics. Two separate experiments were set up under the study to investigate fruit thinning and ablation in the SGD coconut variety. These experiments have been appropriately reported under their respective subsections in this chapter.

6.2 Experiment 6: Fruit Thinning in Sri Lanka Green Dwarf Coconut Variety

6.2.1 Introduction

Under favourable conditions most fruit trees tend to set more fruit than necessary (Ouma, 2012) necessitating the removal of excess fruits after fruit set and natural fruit drop (Valenzuela, 1992; Falivene & Hardy, 2008). This is commonly referred to as fruit thinning. Depending on the crop, fruit thinning is done to increase fruit size, enhance fruit quality, forestall damage due to breakage of branches or stimulate flower initiation (Chacko *et al.*, 1982; Westwood, 1993, Jackson & Frederich, 1999). Fruit thinning could be carried out using manual, mechanical and chemical method. According to Ouma (2012), the manual method involves the use of the hand for thinning, the mechanical engages machinery in the thinning and the chemical requires the application of nitrogen fertilizers (e.g. urea and calcium nitrate) or plant hormones (e.g. cytokinins, auxins and gibberellins).

Fruit thinning studies are well-documented in many tree crops including citrus, peach, apple and pomegranate (Wheaton, 1981; Havis, 1992; Desai *et al.*, 1993; Guardiola & Carcia-Luis, 2000; Untied & Blacke, 2001; Fallali & Greens, 2010; Samara & Shalan, 2013; Mohsen & Osman, 2015). However, in coconut, scientific publication on fruit thinning is quite scanty even though in Philippines, fruit thinning is used to ensure good development of seed nuts in Catigan Green Dwarf coconut seed gardens (Bourdeix *et al.*, 2005).

Experiment 6 assesses the effect of fruit thinning on fruit characteristics in the SGD coconut variety.

6.2.2 Materials and methods

6.2.2.1 Description of the Study Area

The study area is the same as described in Chapter 3.

6.2.2.2 Experimental Design and Treatments

The experiment was set-up in a matured SGD coconut field aged 12 years old and planted at 7.5 m triangular spacing at a density of 205 trees ha^{-1}. A Randomized Complete Block Design with 3 replicates and 6 palms $plot^{-1}$ was used to evaluate the effect of 3 levels of fruit thinning treatments viz., Control (FT0), thinning to 15 nuts per bunch (FT15) and thinning to 10 nuts per bunch (FT10). The 3 levels of thinning were assigned randomly to treatments plots within the blocks.

6.2.2.3 Treatment Application

Experimental trees were inspected weekly for new inflorescence opening (Figure 6.1). Buttons that set into fruits are thinned 60 days after inflorescence opening. Thinning was done with a pair of secateurs sterilized in 95% alcohol starting from the lower fruits upwards (Figure 6.2).

Figure 6.1. A technician counting the buttons in a newly opened inflorescence of SGD coconut palm

Figure 6.2. A technician thinning coconut fruit set in a bunch of SGD coconut palm with a pair of secateurs

6.2.2.4 Maintenance Culture

Weed maintenance was achieved by integrating hand weeding with glyphosate 41% SL herbicide application. A uniform application of palm specific fertilizer with composition: 10:10:30 NPK + 2% MgO + 0.3% Boron was carried out at the rate of 2.5 kg tree^{-1} at six monthly intervals to improve soil fertility.

6.2.2.5 Data Collection

Soil and leaf sampling and analysis were carried out at the onset of the study to assess the initial nutrient status of soil and experimental palms before a uniform fertilizer application. The number of buttons (female flowers) and fruit set were counted after inflorescence opening. Mature and immature nuts were sampled for fruit component and proximate analyses.

6.2.2.5.1 Soil analysis

Soil sampling and analysis were carried out based on the procedures detailed in Section 3.3 of Chapter 3.

6.2.2.5.2 Leaf analysis

Leaf sampling and analysis were done based on the procedures detailed in Section 3.4 of Chapter 3.

6.2.2.5.3 Coconut button, fruit set and fruit drop count

Study palms were inspected every other day to identify new inflorescence opening for button count. Fruit set and fruit drop were determined 60 days after inflorescence opening.

6.2.2.5.4 Fruit component analysis

Fruit component analysis (FCA) was carried out for both immature (fresh) nuts and mature (dry) nuts. Fresh nuts were harvested from leaf rank 19 whilst dry nuts were harvested from leaf rank 24. A total of 54 nuts (2 per study palm) was sampled for FCA. Each fruit was weighed with a digital food scale to obtain fruit weight (Fwt). A machete was used to remove fruit husk completely and nut weight (Nwt) taken. The nut was split in the equatorial zone with a machete and the split nut weight (SNwt) measured. A coconut kernel remover was used to separate the kernel from the shell by hand. The kernel and shell weights (Kwt and Swt) were taken. The husk weight (Hwt) and Water weight (Wwt) were derived as follows:

a) Hwt = Fwt - Nwt

b) Wwt = Nwt - SNwt

6.2.2.5.5 Proximate analysis

Samples of fresh nuts harvested from leaf rank 19 were cleaned, de-husked and de-shelled after which the kernel was cut into 5 cm pieces using a ceramic knife. A high speed blender was used to grind the cut pieces and then stored in a

deep freezer at -20°C for analysis. Crude fat was estimated using continuous soxhlet extraction approach involving the use of petroleum ether at 60-80 °C for 18 hours. Kjeldahl's method and hot digestion approach were used to estimate crude protein and crude fibre respectively (AOAC, 1999). Sample of the kernel was incinerated in a furnace at 600°C for 6 hours and the ash content estimated by using the following formula:

$$Ash\ (\%) = \frac{final\ weight}{initial\ weight} \times 100$$

6.2.2.5.6 Physico-chemical analysis

A digital refractometer (DR-A1 1310) manufactured by Atago Co., Ltd, Japan, was used to measure total soluble solids. A pH meter (WTW 526 Germany) was used to take the pH reading. Titrimetric method with the chemical 2, 6-dichlorophenolindophenol was used to estimate ascorbic acid (AOAC, 1999).

6.2.2.7 Data Management and Statistical Analysis

The data management and statistical analysis were carried out as described in Chapter 3, Section 3.5.

6.2.3 Results

6.2.3.1 Soil Analysis

Particle-size distribution and chemical properties of soil at the onset of the experiment is presented in Table 6.1. Soil was acidic with sandy loam texture. Top soil organic matter, N, Ca and Mg contents were at normal levels relative to critical values of 2%, 0.1%, 2.5% and 0.5% respectively. Soil K and exchangeable bases/ cation exchange capacity were low with reference to critical values of 0.2 cmol kg^{-1} and 10 cmol kg^{-1} respectively.

Table 6.1. Particle-size distribution and chemical properties of soil at the onset of experiment six

Soil Depth	Clay	Silt	Sand	OM	N	pH
	----------	----------	%----------	----------	----------	
0-20	19.0	13.1	67.9	2.04	0.10	5.08
21-40	19.0	13.3	67.7	1.49	0.07	5.17
	Ca	Mg	K	TEB	ECEC	P
	----------	----------	cmol kg^{-1}----------	----------	----------	ug g^{-1}
0-20	2.73	0.61	0.12	3.58	3.75	8.81
21-40	2.38	0.28	0.13	3.08	3.08	5.89

OM = Organic matter; TEB = Total exchangeable basis; ECEC = Effective cation exchange capacity

6.2.3.2 Leaf Analysis

Leaf nutrients levels of experimental palms, 30 months after fruit thinning, are presented in Table 6.2.

Table 6.2. Leaf nutrient of SGD coconut variety 30 months after fruit thinning studies

Leaf Nutrient	Mean Leaf Nutrient (% dry matter, leaf rank # 14) Fruit thinning treatment		
	FT0	FT1	FT2
Mg	0.236 ± 0.013	0.236 ± 0.011	0.235± 0.012
Ca	1.121 ± 0.022	1.071 ± 0.021	1.121± 0.022
N	2.336 ± 0.054	2.330 ± 0.052	2.381± 0.054
P	0.234 ± 0.004	0.226 ± 0.003	0.219± 0.004
K	1.195 ± 0.023	1.105 ± 0.021	1.010± 0.022

Mean estimates ± S.E. with no letters within rows are not significantly different, P>0.05; MFT = Month after fruit thinning; FT0 = Control; FT1 = Thinning to 15 fruits in a bunch; FT2 = Thinning to 10 fruits in a bunch

The levels of leaf N, K and Mg were normal for all the experimental palms relative to critical values of 2.5%, 1.0% and 0.24% respectively. Leaf Ca and P contents were at moderate levels as compared with critical values of 0.6% and 0.15% respectively. Statistical analysis did not show significant (P>0.05) difference between treatment palms in the levels of nutrients (Appendix 47).

6.2.3.3 Coconut Button, Fruit Set and Fruit Drop Count

Count of coconut button, fruit set and fruit drop in the SGD fruit thinning experiment are presented in Table 6.3. Data analysis did not show significant (P>0.05) difference between fruit thinning treatments in the count levels of coconut button, fruit set and fruit drop (Appendix 48). Fruit set varied from 40.0-45.5% of coconut button whilst fruit drop ranged from 54.5-60.0%.

Table 6.3. Coconut button, fruit set and fruit drop count in SGD fruit thinning studies at Agona-Nkwanta

Fruit Count	Mean Count		
	Fruit thinning treatment		
	FT0	FT1	FT2
Coconut button	47.9 ± 7.5	43.3 ± 7.2	46.5 ± 6.8
Fruit set	21.8 ± 4.4	19.3 ± 4.1	18.6 ± 3.6
Fruit drop	26.1 ± 5.6	24.0 ± 4.9	27.9 ± 5.5

Mean estimates ± S.E. with no letters within rows are not significantly different, P>0.05; MFT = Month after fruit thinning; FT0 = Control; FT1 = Thinning to 15 fruits in a bunch; FT2 = Thinning to 10 fruits in a bunch

6.2.3.4 Fruit Component Analysis

6.2.3.4.1 Fruit weight

Fresh and dry fruit weights of SGD coconut variety as affected by fruit thinning are presented in Tables 6.4 and 6.5 respectively. Fruit weight increased with intensity of fruit thinning in the order FT2>FT1>FT0. Data analysis indicated significant (P<0.05) fruit thinning effect on fresh and dry fruit weight (Appendix 49).

In general, fresh fruits sampled from FT2 palms at 18, 24 and 30 months after fruit thinning were significantly (P<0.05) heavier than samples from FT1 and the control. However, at 18 months after fruit thinning fresh fruit weight differences between FT2 and FT1 were not significant (P>0.05). Also, differences in fresh fruit weight between FT1 and the control were not significant (P>0.05). FT2 treatment

improved fresh fruit weight averagely by 31.6% from 18-30 months after fruit thinning relative to the control.

Dry fruits sampled from FT2 palms at 18, 24 and 30 months after fruit thinning were significantly ($P<0.05$) weightier than the control and also weightier than samples from FT1 palms but only at 30 months after fruit thinning. Differences in dry fruit weight between FT1 and the control were not significant ($P>0.05$). FT2 treatment increased dry fruit weight on the average by 28.3% from 18-30 months after fruit thinning relative to the control.

Table 6.4. Fresh fruit weight of SGD coconut variety as influenced by thinning treatment

MFT	Mean Fruit Weight (g)		
	Fruit thinning treatment		
	FT0	FT1	FT2
6	575.4 ± 15.1	578.5 ± 20.2	582.5 ± 22.1
12	619.7 ± 27.5	636.3 ± 25.5	640.8 ± 30.5
18	694.9 ± 56.8a	750.2 ± 59.5ab	826.2 ± 64.5b
24	752.0 ± 62.9a	813.0 ± 64.6a	1,080.0 ± 68.0b
30	884.0 ± 58.9a	942.0 ± 64.1a	1,275.0 ± 60.7b

For any particular month, mean estimates ± S.E. with the same or no letters are not significantly different, P>0.05; MFT = Month after fruit thinning; FT0 = Control; FT1 = Thinning to 15 fruits in a bunch; FT2 = Thinning to 10 fruits in a bunch; LSD (0.05) of mean estimates is presented in Appendix 50.

Table 6.5. Dry fruit weight of SGD coconut variety as influenced by thinning treatment

MFT	Mean Fruit Weight (g)		
	Fruit thinning treatment		
	FT0	FT1	FT2
18	515.3 ± 17.4a	551.7 ± 19.1ab	612.3 ± 19.9b
24	710.9 ± 11.9a	809.8 ± 14.2ab	883.9 ± 16.4b
30	851.2 ± 36.8a	902.5 ± 35.1a	1,173.0 ± 32.2b

For any particular month, mean estimates ± S.E. with the same or no letters are not significantly different, P>0.05; MFT = Month after fruit thinning; FT0 = Control; FT1 = Thinning to 15 fruits in a bunch; FT2 = Thinning to 10 fruits in a bunch; LSD (0.05) of mean estimates is presented in Appendix 50.

6.2.3.4.2 Husk weight

Husk weight of fresh and dry fruits of SGD coconut variety as influenced by fruit thinning are presented in Tables 6.6 and 6.7 respectively. Generally, husk weight increased with intensity fruit thinning in the order FT2>FT1>FT0. Data analysis indicated significant (P<0.05) fruit thinning effect on dry and fresh husk weights (Appendix 51).

Husk weight of fresh fruits sampled from FT2 palms at 24 and 30 months after fruit thinning were significantly (P<0.05) greater than samples from FT1 and the control. Differences in fresh husk weight between FT0 and FT1 were not significant (P>0.05). On the average, FT2 treatment increased fresh husk weight by 41.6% from 24-30 months after fruit thinning as compared with the control.

Husk weight of dry fruits sampled from FT2 palms at 18, 24 and 30 months after fruit thinning were significantly (P<0.05) weightier than the control.

Differences in fresh husk weight between FT1 and the control were not significant (P>0.05). Averagely, FT2 treatment increased dry husk weight by 40.4% from 18-30 months after fruit thinning relative to the control.

Table 6.6. Fresh husk weight of SGD coconut variety as influenced by fruit thinning treatment

MFT	Mean Husk Weight (g) Fruit thinning treatment		
	FT0	FT1	FT2
6	405.6 ± 15.8	406.9 ± 14.8	405.8 ± 14.8
12	433.1 ± 22.2	447.5 ± 24.3	446.3 ± 21.9
18	467.4 ± 26.4	471.6 ± 21.0	466.4 ± 20.5
24	504.1 ± 27.6a	476.2 ± 29.9a	683.2 ± 29.9b
30	501.6 ± 21.1a	495.4 ± 27.4a	740.8 ± 14.7b

For any particular month, mean estimates ± S.E. with the same or no letters are not significantly different, P>0.05; MFT = Month after fruit thinning; FT0 = Control; FT1 = Thinning to 15 fruits in a bunch; FT2 = Thinning to 10 fruits in a bunch; LSD (0.05) of mean estimates is presented in Appendix 52.

Table 6.7. Dry husk weight of SGD coconut variety as influenced by fruit thinning treatment

MFT	Mean Husk Weight (g) Fruit thinning treatment		
	FT0	FT1	FT2
18	150.9 ± 10.7a	162.6 ± 11.7ab	184.5 ± 12.0b
24	215.9 ± 11.0a	236.6 ± 12.2ab	255.7 ± 10.9b
30	242.7 ± 32.4a	228.1 ± 30.9a	384.5 ± 28.5b

For any particular month, mean estimates ± S.E. with the same or no letters are not significantly different, P>0.05; MFT = Month after fruit thinning; FT0 = Control; FT1 = Thinning to 15 fruits in a bunch; FT2 = Thinning to 10 fruits in a bunch; LSD (0.05) of mean estimates is presented in Appendix 52.

6.2.3.4.3 Nut weight

Nut weight of fresh and dry fruits of SGD coconut variety as affected by fruit thinning are presented in Tables 6.8 and 6.9 respectively. Nut weight increased with intensity fruit thinning in the order FT2>FT1>FT0. Data analysis showed significant ($P<0.05$) fruit thinning effect on nut weight (Appendix 53).

Nut weight of fresh fruits sampled from FT2 palms at 18, 24 and 30 months after fruit thinning was significantly ($P<0.05$) greater than samples from FT1 palms and the control. FT1 palms in turn had significantly ($P<0.05$) higher fresh nut weight than the control. FT2 treatment improved nut weight of fresh fruits averagely by 55.2% from 18-30 months after fruit thinning as compared with the control. Similarly, FT1 treatment also increased nut weight of fresh nuts by 37.4% relative the control.

Nut weight of dry fruits sampled from FT2 palms at 18, 24 and 30 months after fruit thinning was significantly ($P<0.01$) greater than the control. In general dry nut weight differences between FT1 and the control or between FT2 and FT1 were not significant ($P>0.05$). However, at 30 months after fruit thinning dry nut weight of FT2 samples were significantly ($P<0.05$) heavier than FT1 samples. FT2 treatment improved nut weight of dry fruits on the average by 23.6% from 18-30 months after fruit thinning relative to the control.

Table 6.8. Fresh nut weight of SGD coconut variety as influenced by fruit thinning treatment

MFT	Mean Nut Weight (g)		
	Fruit thinning treatment		
	FT0	FT1	FT2
6	169.8 ± 6.7	171.6 ± 8.1	176.7 ± 7.9
12	186.6 ± 7.2	188.8 ± 8.3	194.5 ± 8.2
18	241.9 ± 8.8a	297.8 ± 7.8b	362.2 ± 7.8c
24	255.0 ± 7.1a	331.5 ± 7.8b	382.1 ± 8.1c
30	275.1 ± 8.2a	393.8 ± 8.9b	442.2 ± 8.5c

For any particular month, mean estimates ± S.E. with the same or no letters are not significantly different, P>0.05; MFT = Month after fruit thinning; FT0 = Control; FT1 = Thinning to 15 fruits in a bunch; FT2 = Thinning to 10 fruits in a bunch; LSD (0.05) of mean estimates is presented in Appendix 54.

Table 6.9. Dry nut weight of SGD coconut variety as influenced by fruit thinning treatment

MFT	Mean Nut Weight (g)		
	Fruit thinning treatment		
	FT0	FT1	FT2
18	364.4 ± 10.9a	389.1 ± 11.9ab	427.8 ± 12.4b
24	495.0 ± 12.5a	573.2 ± 16.8ab	588.2 ± 17.0b
30	608.5 ± 20.6a	674.4 ± 19.6ab	788.8 ± 18.1c

For any particular month, mean estimates ± S.E. with the same or no letters are not significantly different, P>0.05; MFT = Month after fruit thinning; FT0 = Control; FT1 = Thinning to 15 fruits in a bunch; FT2 = Thinning to 10 fruits in a bunch; LSD (0.05) of mean estimates is presented in Appendix 54

6.2.3.4.4 Shell weight

Shell weight of fresh and dry fruits of SGD coconut variety as influenced by fruit thinning are presented in Tables 6.10 and 6.11 respectively. Shell weight increased with intensity of fruit thinning in the order FT2>FT1>FT0. Data analysis indicated significant ($P<0.01$) fruit thinning effect on shell weight (Appendix 55).

Shell weight of fresh fruits sampled from FT2 palms at 18, 24 and 30 months after fruit thinning were significantly ($P<0.05$) greater than samples from FT1 palms and the control. Fresh fruits from FT1 palms had significantly ($P<0.05$) weightier shells than samples from the control. On the average, FT2 treatment increased fresh shell weight by 61.1% from 18-30 months after fruit thinning as compared with the control. Similarly, FT1 treatment also increased fresh shell weight significantly ($P<0.05$) by 29.0% from 18-30 months after fruit thinning.

Dry fruits sampled from FT2 palms at 18-30 months after fruit thinning had significantly ($P<0.05$) greater dry shell weight than the control. Differences in dry shell weight between FT1 and FT2 were not significant ($P>0.05$) except at 30 months after fruit thinning where shell weight of dry fruits from FT2 palms were significantly ($P<0.05$) heavier than that from FT1 palms. Averagely, FT2 treatment increased dry shell weight by 15.6% as compared with the control.

Table 6.10. Fresh shell weight of SGD coconut variety as influenced by fruit thinning treatment

MFT	Mean Shell Weight (g) Fruit thinning treatment		
	FT0	FT1	FT2
6	57.2 ± 3.8	58.6 ± 3.2	60.3 ± 3.3
12	63.0 ± 4.5	64.4 ± 4.6	66.3 ± 5.0
18	65.7 ± 5.4a	83.4 ± 4.9b	103.0 ± 6.0c
24	67.7 ± 5.2a	85.2 ± 5.6b	110.8 ± 6.9c
30	70.8 ± 5.5a	92.8 ± 6.5b	117.0 ± 6.1c

For any particular month, mean estimates ± S.E. with the same or no letters are not significantly different, P>0.05; MFT = Month after fruit thinning; FT0 = Control; FT1 = Thinning to 15 fruits in a bunch; FT2 = Thinning to 10 fruits in a bunch; LSD (0.05) of mean estimates is presented in Appendix 56

Table 6.11. Dry shell weight of SGD coconut variety as influenced by fruit thinning treatment

MFT	Mean Shell Weight (g) Fruit thinning treatment		
	FT0	FT1	FT2
18	165.2 ± 5.5a	172.5 ± 6.9ab	188.2 ± 6.9b
24	218.6 ± 6.1a	230.1 ± 8.9ab	252.2 ± 8.4b
30	258.5 ± 9.6a	262.2 ± 9.8ab	298.0 ± 9.3b

For any particular month, mean estimates ± S.E. with the same or no letters are not significantly different, P>0.05; MFT = Month after fruit thinning; FT0 = Control; FT1 = Thinning to 15 fruits in a bunch; FT2 = Thinning to 10 fruits in a bunch; LSD (0.05) of mean estimates is presented in Appendix 56.

6.2.3.4.5 Kernel weight

Kernel weight of fresh and dry fruits of SGD coconut variety as affected by fruit thinning are presented in Tables 6.12 and 6.13 respectively. Kernel weight increased with intensity of fruit thinning in the order FT2>FT1>FT0. Data analysis showed significant ($P<0.05$) fruit thinning effect on kernel weight (Appendix 57).

Fresh fruits sampled from FT2 palms at 18-30 months after fruit thinning had significantly ($P<0.05$) greater fresh kernel weight than the control. Differences in fresh kernel weight between FT1 and FT2 were not significant ($P>0.05$) except at 30 months after fruit thinning where fresh kernel weight of FT2 were significantly ($P<0.05$) higher than FT1 samples. FT2 treatment improved fresh kernel weight averagely by 42.1% from 18-30 months after fruit thinning as compared with the control. Similarly, FT1 treatment improved fresh kernel weight by 24.3% relative to the control.

Dry fruits sampled from FT2 palms at 24 and 30 months after fruit thinning had significantly ($P<0.05$) greater dry kernel weight than the control. Differences in dry kernel weight between FT1 and FT2 were not significant ($P>0.05$) at 24 months after fruit thinning but at 30 months dry kernel weight of FT2 palms were significantly ($P<0.05$) higher than that of FT1. FT2 treatment improved kernel weight from dry fruits on the average by 35.2% from 24-30 months after fruit thinning as compared with the control. Similarly, FT1 treatment also improved dry kernel weight by 18.1% at 30 months after fruit thinning relative to the control.

Table 6.12. Fresh kernel weight of SGD coconut variety as influenced by fruit thinning treatment

MFT	Mean Kernel Weight (g) Fruit thinning treatment		
	FT0	FT1	FT2
6	76.3 ± 3.7	76.6 ± 4.1	78.3 ± 4.9
12	83.9 ± 4.2	84.2 ± 4.3	86.1 ± 4.2
18	95.3 ± 12.8a	116.8 ± 14.8b	130.8 ± 15.8b
24	97.2 ± 12.7a	120.5 ± 13.8b	135.8 ± 13.1b
30	98.5 ± 11.2a	124.1 ± 12.9b	144.6 ± 12.5c

For any particular month, mean estimates ± S.E. with the same or no letters are not significantly different, P>0.05; MFT = Month after fruit thinning; FT0 = Control; FT1 = Thinning to 15 fruits in a bunch; FT2 = Thinning to 10 fruits in a bunch; LSD (0.05) of mean estimates is presented in Appendix 58.

Table 6.13. Dry kernel weight of SGD coconut variety as influenced by fruit thinning treatment

MFT	Mean Kernel Weight (g) Fruit thinning treatment		
	FT0	FT1	FT2
18	165.4 ± 6.9	181.0 ± 7.6	184.9 ± 7.6
24	196.2 ± 12.5a	208.3 ± 10.2ab	226.9 ± 10.9b
30	255.3 ± 11.7a	301.5 ± 11.2b	394.9 ± 10.3c

For any particular month, mean estimates ± S.E. with the same or no letters are not significantly different, P>0.05; MFT = Month after fruit thinning; FT0 = Control; FT1 = Thinning to 15 fruits in a bunch; FT2 = Thinning to 10 fruits in a bunch; LSD (0.05) of mean estimates is presented in Appendix 58.

6.2.3.4.6 Water weight

Weight of water in fresh and dry fruits of SGD coconut variety as influenced by fruit thinning are presented in Tables 6.14 and 6.15 respectively. Weight of water in the fruit increased with intensity of fruit thinning in the order FT2>FT1>FT0. Data analysis showed significant ($P<0.05$) fruit thinning effect on weight of water (Appendix 59).

Fresh fruits sampled from FT2 palms at 18-30 months after fruit thinning had significantly ($P<0.05$) higher water content by weight than the control. Differences in fresh fruit water content between FT1 and FT2 were not significant ($P>0.05$). However, at 18 months after fruit thinning water content of FT2 was significantly ($P<0.05$) higher than that of FT1. Fresh fruit water content of FT1 at 24 and 30 months after fruit thinning was significantly ($P<0.05$) higher than the control. FT2 treatment increased fresh fruit water content averagely by 65.0% from 18-30 months after fruit thinning as compared with the control. Similarly, FT1 treatment also increased water content by 43.9% relative to the control.

Dry fruits sampled from FT2 palms at 18-30 months after fruit thinning had significantly ($P<0.05$) more water content by weight than the control. Differences in dry fruit water content between FT1 and FT2 were not significant ($P>0.05$). However, at 18 months after fruit thinning water content of FT2 was significantly ($P<0.05$) higher than that of FT1. Water content of dry fruit from FT1 at 24 and 30 months after fruit thinning was significantly ($P<0.05$) higher than the control. FT2 treatment increased dry fruit water content on the average by 51.2% from 18-30

months after fruit thinning as compared with the control. Similarly, FT1 treatment improved dry fruit water content by 27.9% relative to the control.

Table 6.14. Weight of water in fresh fruit of SGD coconut variety as influenced by fruit thinning treatment

MFT	Mean Water Weight (g)		
	Fruit thinning treatment		
	FT0	FT1	FT2
6	56.3 ± 4.6	56.5± 4.7	58.2 ± 5.0
12	61.8 ± 4.5	62.2± 4.8	64.1 ± 4.9
18	80.9 ± 5.9ab	97.6± 6.0b	128.4 ± 6.9c
24	90.1 ± 5.4a	125.8± 6.3b	135.5 ± 6.9b
30	105.8 ± 4.5a	176.9± 4.8b	181.1 ± 4.9b

For any particular month, mean estimates ± S.E. with the same or no letters are not significantly different, P>0.05; MFT = Month after fruit thinning; FT0 = Control; FT1 = Thinning to 15 fruits in a bunch; FT2 = Thinning to 10 fruits in a bunch; LSD (0.05) of mean estimates is presented in Appendix 60.

Table 6.15. Weight of water in dry fruit of SGD coconut variety as influenced by fruit thinning treatment

MFT	Mean Water Weight (g)		
	Fruit thinning treatment		
	FT0	FT1	FT2
18	33.8 ± 3.2a	35.6 ± 3.5a	54.8 ± 3.5b
24	80.2 ± 5.4a	103.8 ± 6.3b	109.1 ± 6.8b
30	90.5 ± 9.7a	114.4 ± 9.3b	126.9 ± 8.5b

For any particular month, mean estimates ± S.E. with the same or no letters are not significantly different, P>0.05; MFT = Month after fruit thinning; FT0 = Control; FT1 = Thinning to 15 fruits in a bunch; FT2 = Thinning to 10 fruits in a bunch; LSD (0.05) of mean estimates is presented in Appendix 60.

6.2.3.5 Proximate Analysis

Proximate analysis of fresh fruits of SGD coconut variety as influenced by fruit thinning are presented in Table 6.16 Data analysis showed significant ($P<0.001$) fruit thinning effect on crude protein content (Appendix 61). Crude protein increased with intensity of fruit thinning in the order FT2>FT1>FT0. Fresh fruits sampled from FT2 palms had significantly ($P<0.001$) higher crude protein content than samples from FT1 and the control palms after 30 months of fruit thinning. Similarly, samples of fresh fruits from FT1 palms also had significantly ($P<0.001$) greater crude protein content than the control. FT2 and FT1 treatments improved crude protein contents of fresh fruits by 31.4% and 10.6% respectively over the study period. Crude fat, crude fibre and percent ash contents of fresh fruits were not affected significantly ($P>0.05$) by fruit thinning treatment.

Table 6.16. Proximate analysis of fresh fruit of SGD coconut variety after thirty months of fruit thinning treatment

Macromolecule	Mean Proximate Value (g kg^{-1} dry matter)		
	Fruit thinning treatment		
	FT0	FT1	FT2
Crude Protein	4.04 ± 0.13a	4.47 ± 0.13b	5.31 ± 0.12c
Crude fat	1.753 ± 0.01	1.710 ± 0.01	1.737 ± 0.01
Crude fibre	7.680 ± 0.17	7.733 ± 0.17	7.450 ± 0.18
Ash (%)	1.167 ± 0.02	1.047 ± 0.04	1.097 ± 0.05

Mean estimates ± S.E. with the same or no letters within rows are not significantly different, P>0.05; MFT = Month after fruit thinning; FT0 = Control; FT1 = Thinning to 15 fruits in a bunch; FT2 = Thinning to 10 fruits in a bunch; LSD (0.05) of mean estimates is presented in Appendix 62.

6.2.3.6 Physico-chemical Analysis

Physico-chemical analysis of fresh fruits of SGD coconut variety as affected by fruit thinning are presented in Table 6.17. Data analysis showed significant ($P<0.001$) fruit thinning effect on Vitamin C (Appendix 63). Vitamin C content of fresh fruits increased with intensity of fruit thinning in the order FT2>FT1>FT0. After 30 months of fruit thinning, fresh fruits of FT2 and FT1 palms had significantly ($P<0.001$) higher Vitamin C content than the control. Differences in Vitamin C contents between FT1 and FT2 was not significant ($P>0.05$). FT2 and FT1 treatments increased Vitamin C content of fresh fruits by 41.5% and 33.8% respectively over the period of the study. Total soluble solids and pH of fresh fruits were not affected significantly ($P>0.05$) by fruit thinning treatment.

Table 6.17 Physico-chemical analysis of fresh fruit of SGD coconut variety after 30 months of fruit thinning treatment

Parameter	Mean Proximate Value (g kg^{-1} dry matter)		
	Fruit thinning treatment		
	FT0	FT1	FT2
TSS	12.63 ± 0.17	11.90 ± 0.17	12.30 ± 0.17
Vitamin C	2.07 ± 0.14a	2.77 ± 0.14b	2.93 ± 0.14b
pH	5.97 ± 0.11	5.80 ± 0.11	5.97 ± 0.12

Mean estimates ± S.E. with the same or no letters within rows are not significantly different, P>0.05; MFT = Month after fruit thinning; FT0 = Control; FT1 = Thinning to 15 fruits in a bunch; FT2 = Thinning to 10 fruits in a bunch; LSD (0.05) of mean estimates is presented in Appendix 64.

6.2.4 Discussion

6.2.4.1 Soil Analysis

Soil fertility at the onset of the study left more room for improvement particularly the low soil K since K is required in relatively large quantities for good performance of bearing coconut (Magat, 2003). Application of palm specific Yara fertilizer 10:10:30 NPK + 2% MgO + 0.3% Boron was done to correct the K deficiency and improving soil fertility for the fruit thinning studies.

6.2.4.2 Leaf Analysis

The normal levels of leaf N, K and Mg coupled with moderate levels of leaf Ca and P for all the experimental palms was an indication of good uptake of soil nutrients and the palm specific fertilizer applied. The improved soil fertility was necessary to enhance good response to fruit thinning treatment (Patil, 2011; Spargo *et al.*, 2013; Wei *et al.*, 2016).

6.2.4.3 Coconut Button, Fruit Set and Fruit Drop Count

The count levels of coconut button, fruit set and fruit drop did not differ statistically among treatments therefore setting a common platform for fruit thinning evaluation. The average count of 45.6 buttons per inflorescence, fruit set of 42.5% and fruit drop of 57.5% of buttons were consistent with what was put forward by Santos *et al.* (1996) as indicated in Section 2.2.6 of Chapter 2. The relatively high fruit drop is attributable to natural factors particularly, pollination

failure, that tend to control nut load so that available resources could be re-allocated to the remaining fruits to develop into maturity (Ehrle'n, 1991; Dal Cin *et al.*, 2005) Notwithstanding, the fruit set observed in the SGD variety was relatively high therefore setting the basis for agronomic manipulation through fruit thinning to improve fruit size and quality (Heuvelink, 1997; Dennis, 2000).

6.2.4.4 Fruit Component Analysis

The fruit of coconut is made up of husk and nut; and the latter comprises shell, kernel and water (Santos *et al.*, 1996). The husk, shell, kernel and water constitute the fruit components (Perera *et al.*, 2014). It takes 6-8 months after pollination for the fruit to develop to a stage that can be consumed as fresh (immature) fruit whilst the dry (mature) fruit takes 10-12 months (Taffin, 1998). The non-observation of response to fruit thinning till 18 months after commencement of treatment was consistent with the development periods for mature and immature fruits and time interval of 6 months for fruit measurements.

The positive impact of fruit thinning on fruit weight of SGD coconut variety conforms to the report of Bourdeix *et al.*, (2005) indicating positive effect of fruit thinning on seed nut development of Catigan Green Dwarf coconut variety in seed gardens. Though published literature on coconut fruit thinning is limited, the increased fruit weight observed in SGD coconut variety with intensified level of fruit thinning conforms to results of fruit thinning in peach (*Prunus persica* L.), apple (*Malus domestica* Borkh.) and pomegranate (*Punica granatum* L.) (Havis, 1992; Fallali & Greens, 2010; Jafari *et al.*, 2014; Fattahia *et al.*, 2020).

Fruits and its structures present strong sinks for assimilates, nutrient and water. Consequently, maintaining a high fruit load triggers high competition among developing fruits for resources (Ge'nard *et al.* 2008; Rodrigues *et al.*, 2019) thereby affecting fruit development. Thinning treatment reduces fruit load and makes resources available to a desired number of fruits for improved fruit weight/ size and quality development (Westwood, 1993; Bourdeix *et al.*, 2005; Mohsen & Osman, 2015).

The positive impact of fruit thinning on all fruit components including husk, shell, kernel and water could possibly indicate the SGD coconut variety's unlimited partitioning ability of resources made available through fruit thinning in an attempt to compensate for losses (Obeso, 2002). The higher quantum of increase, generally, in weight of fresh fruit components relative to the dry fruit components might be attributed to fresh fruit having a stronger sink for water than dry fruit (Marsal *et al.*, 2008).

6.2.4.5 Proximate Analysis

Jafari *et al.*, (2014) reported the effectiveness of fruit thinning at enhancing not only fruit size but fruit quality attributes in pomegranate fruits. Proximates are also important for quality fruit attributes. The positive impact of fruit thinning on crude protein of fresh fruits of SGD coconut variety suggests that the treatment could be used to improve the proximate value of SGD fruits. The synthesis of crude protein increased with intensified fruit thinning probably due to re-allocation of photosynthetic materials made available by fruit thinning in favour of protein synthesis.

Fruit thinning did not affect crude fat, crude fibre and percent ash probably because the levels of these proximates are either independent of photosynthates or other factors (e.g. genetic) are involved in influencing their levels.

6.2.4.6 Physico-chemical Analysis

The positive effect of fruit thinning on ascorbic acid (Vitamin C) of fresh fruits of SGD coconut variety indicates that treatment could be used to enhance the physico-chemical value of SGD fruits. The formation of ascorbic acid increased with increased fruit thinning possibly due to re-allocation of assimilates made available by fruit thinning in favour of ascorbic acid formation.

In a similar study carried out using pomegranate fruits, the authors found out that fruit thinning increased TSS and ascorbic acid contents but reduced titratable acidity (Jemric *et al.*, 2003; Mohsen & Osman, 2015). In the current work however, TSS and pH were not affected by fruit thinning probably due to differences in the ability of crops to respond to fruit thinning.

6.2.5 Conclusion

SGD coconut variety showed significant improvement in fruit size expressed in weight and the contents of Crude Protein and Vitamin C with intensity of fruit thinning from 18-30 months after treatment.

Thinning to 10 fruits per bunch increased crude protein and Vitamin C contents of fresh fruits by 31.4% and 41.5% respectively; and weights of fresh fruits on the average by 31.6% and its components: husk, shell, kernel and water

averagely by 41.6%, 61.1%, 42.1% and 65.0% respectively. It also increased weights of dry fruit on the average by 28.3% and its components: husk, shell, kernel and water by 40.4%, 15.6%, 42.1% and 51.2% respectively.

Thinning to 15 fruits per bunch improved crude protein and Vitamin C contents of fresh fruits by 10.6% and 33.8% respectively; and weights of fresh fruits on the average by 6.6% and its components: shell, kernel and water averagely by 29.0%, 24.3% and 43.9% respectively. It also improved weights of dry fruit on the average by 6.6% and its components: kernel and water averagely by 12.2% and 27.9% respectively.

6.3 Experiment 7: Ablation in Sri Lanka Green Dwarf Coconut Variety

6. 3. 1 Introduction

Ablation in coconut refers to the complete removal of inflorescence either before or after the opening of the spathe. The inflorescence is the reproductive organ of coconut. Photosynthetic assimilates are partitioned between the reproductive and vegetative organs (Noggle & Fritz, 2006). In all plants including coconut, the reproductive parts become dominant and major consumers of assimilates as against vegetative organs (Wareing & Patrick, 1975; Ho, 1992; Génard *et al.*, 2008) thereby limiting vegetative growth and development. Removal of the floral structures reduces the reproductive sink size leading to re-allocation of

assimilates to vegetative and other organs for growth and development (Wang & Breen, 1986; Datuluri & Misra, 2002; Corley & Tinker, 2003).

Earlier work carried out in soybean (*Glycine max*) showed that removal of reproductive structures impacted positively on total dry matter content of the plant (Heitholt & Egli, 1985). Working further on soybean, Saravitz *et al.*, (1994) reported that during reproductive stage, seeds become a dominant sink for nitrogen and carbon. Subsequent removal of newly formed soybean pods led to dry matter partitioning being diverted to vegetative development resulting in increased number of leaves with higher total area. Etebom & Chimezie (2016) assessed source - sink relationship in Waterleaf (*Talinum triangulare*) and concluded that weekly removal of inflorescence resulted in a higher leaf yield.

In coconut, however, there is little or no published information on inflorescence ablation even though some coconut ecotypes for example, the Sri Lanka Green Dwarf (SGD), are good candidates for ablation. The SGD produce early inflorescence at the time that the vegetative capacity is not well developed. The dwarf coconut variety intrinsically takes on heavy fruit load but suffer small fruit size and poor weight of fruit components (Bourdeix *et al.*, 2005).

Experiment 7 assesses the effect of ablation on vegetative growth and fruit characteristics in the SGD coconut variety.

6.3.2 Materials and methods

6.3.2.1 Description of the Study Area

The experiment was set up on a farmer collaborator's land at Badukrom near Beposo in the Shama District. The description of the study area is presented in Chapter 3.

6.3.2.2 Experimental Design and Treatments

An experimental field for the ablation studies was established with SGD coconut variety at 7.5 m triangular spacing and at a density of 205 trees ha^{-1}. A Randomized Complete Block Design with 3 replicates and 9 palms $plot^{-1}$ are being used to evaluate the effect of 4 levels of ablation treatments viz., Control (A0), Ablation for 6 months (A1), Ablation for 12 months (A2) and Ablation for 18 months (A3). The 4 levels of ablation were assigned randomly to treatment plots within the blocks.

6.3.2.3 Treatment Application

Weekly inspection of experimental palms for inflorescence emergence began 2 years after planting and is ongoing. Inflorescence of control palms are left intact but that of treatment palms are ablated when fully emerged but before spathe opens (Figure 6.3). Ablation (Figure 6.4) is done with a sharp knife sterilized in 95% alcohol. During a given ablation period determined by treatment, any

inflorescence that emerge is ablated. After the duration, any inflorescence that emerge is allowed to develop to fruition.

Figure 6.3. SGD coconut palm with a fully emerged inflorescence

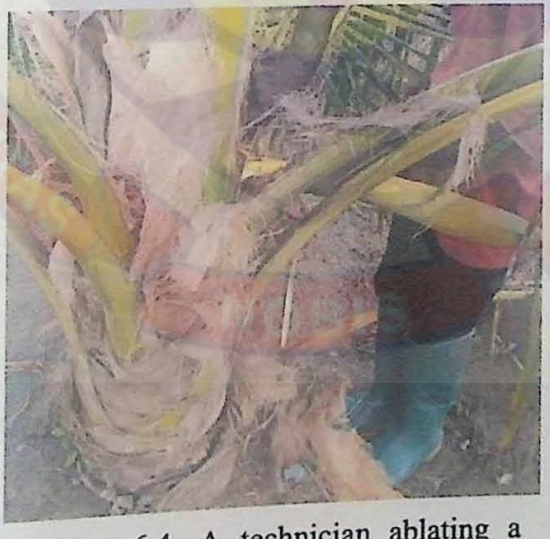

Figure 6.4. A technician ablating a fully emerged inflorescence of SGD coconut palm

6.3.2.4 Maintenance Culture

Weed maintenance is being achieved by integrating hand weeding with glyphosate 41% SL herbicide application. A uniform application of palm specific fertilizer with composition: 10:10:30 NPK + 2% MgO + 0.3% Boron is being carried out at the rate of 1.0 kg tree^{-1} at six monthly intervals to improve soil fertility. Oryctes traps with old fishing net technique are being used to prevent Oryctes attack.

6.3.2.5 Data Collection

6.3.2.5.1 Soil and leaf analysis

Soil and leaf sampling and analysis were carried out based on the procedures detailed in Section 3 of Chapter 3.

6.3.2.5.2 Collar girth measurement and leaf count

Collar girth measurement and leaf count are ongoing at 6-monthly intervals.

6.3.2.5.3 Coconut button, fruit set and fruit drop count

Palms selected for the study will be inspected every other day to identify new inflorescence opening for post-ablation button count. Fruit set and fruit drop will be determined 60 days after inflorescence opening.

6.3.2.5.4 Nut yield determination

Nut yield will be determined using the procedure described by Santos *et al.*, (1996) in ''Manual on standardized research techniques in coconut breeding''

6.3.2.5.5 Fruit component, proximate and physico-chemical analysis

Fruit component, proximate and physico-chemical analysis will done based on procedures described in Section 6.2.2.5 of Chapter 6.

6.3.2.6 Data Management and Statistical Analysis

The data management and statistical analysis will be carried out as described in Chapter 3, Section 3.5.

6.3.3 Results and Discussion

Data collection and treatment application are ongoing.

6.3.4 Conclusion/ Way forward

The experiment was not completed at the time of thesis submission in March 2022. It was however progressing steadily. The earliest time for completion will be 2024. The work will therefore continue after graduation. Final results will be communicated to the University.

CHAPTER SEVEN

7.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary

The study assessed nursery and tree management practices in coconut with the purpose of developing interventions with capacity to increase the supply of good quality coconut seedlings that are tolerant to Cape St Paul Wilt Disease for commercial planting. The research objectives were to assess the effects of:

1. Pre-nursery practices (planting medium, seed nut soaking, planting depth and seed nut size) on germination and vigour of SGD x VTT coconut hybrid seed nut.
2. Fertilizer application and spacing on seedling growth and vigour of SGD x VTT coconut hybrid.
3. Agronomic tree management practices (ablation and fruit thinning) on fruit characteristics of SGD coconut variety.

This chapter gives a recap of the study and summarizes the research findings thereof with recommendations for agricultural extension, government policy and future research work. Three (3) main studies were carried out involving seven (7) different experiments towards achieving the set objectives.

Experiment one was designed to assess the effect of soaking treatment and medium on germination and vigour of SGD x VTT coconut hybrid seed nut using a split-plot design with 3 replicates and 3 types of planting medium (top soil, semi-decomposed cocoa bean shell and decomposed sawdust) assigned to main plots and

3 different soaking treatments (soaking in water, soaking in 1% KNO_3 solution and no soaking) assigned to subplots.

Experiment two assessed the effect of planting depth and medium on germination and vigour of SGD x VTT coconut hybrid seed nut using a split-plot design with 3 replicates and 2 types of planting medium (top soil and decomposed sawdust) assigned to main plots and 3 levels of planting depth (PD_0, PD_1 and PD_2) assigned to subplots.

PD_0 = Planting by burying a quarter of the seed nut in medium (Control)
PD_1 = Planting by burying half of the seed nut in medium
PD_2 = Planting by fully burying seed nut in medium

Experiment three assessed the effect of nut size and medium on germination and vigour of SGD x VTT coconut hybrid seed nut using a split-plot design with 3 replicates and 2 types of planting medium (top soil and decomposed sawdust) assigned to main plots and 4 levels of nut size (extra-large, large, medium and small) assigned to subplots.

Experiment four assessed the effect of soaking in different concentrations of potassium nitrate solution and medium on germination and vigour of SGD x VTT coconut hybrid seed nut using a split-plot design with 3 replicates and 2 types of planting medium (top soil and decomposed sawdust) assigned to main plots and 5 levels of potassium nitrate concentrations (0%, 1%, 2%, 3% and 5%) assigned to subplots. Data collection in all the four experiments above included

final germination percentage or rate, time to 50% germination (speed of germination) and germination index.

Experiment five was designed to assess the effect of fertilizer application and spacing on growth and vigour of SGD x VTT coconut hybrid seedlings using a split-plot design with 3 replicates and 2 levels of spacing (S1 and S1) assigned to main plot and 4 levels of fertilizer schedules (F0, F1, F2 and F3) assigned to subplots.

F0 = No fertilizer treatment (Control)
F1 = Fertilizer application at 28.4:58.0:75.6:17.0 seedling g^{-1} N-P_2O_5-K_2O-MgO
F2 = Fertilizer application at 47.3:96.6:126.0:28.4 seedling g^{-1} N-P_2O_5-K_2O-MgO
F3 = Fertilizer application at 66.2:135.2:176.4:39.7 seedling g^{-1} N-P_2O_5-K_2O-MgO
S1 = Spacing at 60cm triangular (19,246 seedlings ha^{-1})
S2 = Spacing at 80cm triangular (14,434 seedlings ha^{-1})

Fertilizer treatment was split-applied six times at monthly intervals at 5%, 10%, 14%, 19%, 24% and 28% respectively. Urea, Muriate of potash, Triple superphosphate and Kieserite were applied as sources of N, P_2O_5, K_2O and MgO respectively. Data collection included soil and leaf sampling/analysis and measurement of collar girth, seedling height, leaf number, canopy diameter and vigour index.

Experiment six assessed the effect of fruit thinning on fruit characteristics in the Sri Lanka Green Dwarf (SGD) coconut variety using a Randomized Complete Block Design with 3 replicates and 3 levels of fruit thinning treatments viz., no thinning (control), thinning to 15 fruits per bunch and thinning to 10 fruits

per bunch. Data collected included soil and leaf sampling/ analysis, button and fruit set count, fruit component analysis, proximate analysis and physico-chemical analysis.

Experiment seven is currently ongoing. The experiment was designed to assess the effect of ablation on fruit characteristics of SGD coconut variety using a Randomized Complete Block Design with 3 replicates and 4 levels of ablation treatments namely; no ablation (control), ablation for 6 months, ablation for 12 months and ablation for 18 months. Treatment application and vegetative data collection have begun and are currently ongoing. Data to be collected include leaf sampling/ analysis, collar girth measurement, leaf count, button and fruit set count, nut yield determination, fruit component, proximate and physico-chemical analysis.

The experiment is progressing steadily but the earliest time for completion will be 2024. The work will therefore continue after graduation. Final results will be communicated to the University.

7.2 Conclusions

Based on the results of this study, the following conclusions are put forward;

1) Fully burying SGD x VTT coconut hybrid seed nuts in decomposed sawdust at pre-nursery stage improved germination rate, speed of germination and germination index respectively by 33%, 30% and 98% relative to the control.
2) Seed nut size increased speed of germination by 23% and germination index by 43% as compared to medium or small nuts.

3) Interaction effect between decomposed sawdust and potassium nitrate soaking treatment on SGD x VTT seed nut increased speed of germination by 23% and germination index by 26% as compared to control.
4) Seedling spacing of 60 cm triangular (19,264 seedlings ha^{-1}) and fertilizer application of 47.3:96.6:126.0:28.4 g $seedling^{-1}$ $N:P_2O_5:K_2O:MgO$ were identified as the most suitable treatment combination for SGD x VTT coconut seedling production.
5) Thinning of SGD coconut variety to 10 fruits per bunch increased crude protein and Vitamin C contents of fresh fruits by 31% and 42% respectively; and average fresh fruit weight by 32% and its components: husk, shell, kernel and water averagely by 42%, 61%, 42% and 65% respectively. It also increased average dry fruit weight by 28% and its components: husk, shell, kernel and water averagely by 40%, 16%, 42% and 51% respectively.

7.3 Recommendations

1) In the face of high demand for Cape St Wilt Disease tolerant planting material by farmers it is recommended that the findings of this research relating to pre-nursery practices should be urgently disseminated to relevant stakeholders through training workshops to improve SGD x VTT coconut hybrid seed nut germination rate up to 100% and increase turn-out of Cape St Paul Wilt Disease tolerant seedlings.
2) The CSIR-Oil Palm Research Institute by its mandate is recommended to pilot the fruit thinning technique on SGD coconut fields belonging to farmers for

validation, observation and adoption of the intervention towards official release of the SGD coconut variety together with fruit thinning technique as a package.

3) Nursery studies need to be replicated at different strategic locations for validation of results to enable dissemination of findings towards improving seedling quality and vigour of SGD x VTT coconut hybrid.

4) Further research is recommended to:

   a) Assess field performance of SGD x VTT coconut hybrid seedlings as affected by potassium nitrate soaking treatment, planting depth or nut size.

   b) Evaluate embryogenesis and tissue culture techniques for rapid multiplication of SGD x VTT coconut hybrid.

   c) Identify breeding and agronomic techniques to minimize high fruit drop in SGD x VTT coconut hybrid production.

REFERENCES

Abad, M., Noguera, P., Puchades, R., Maquieira A., & Noguera, V. (2002). Physico-chemical and chemical properties of some coconut dusts for use as a peat substrate for containerized ornamental plants. *Bioresource Technology*, *82*, 241-245.

Abad, R. G., Prudente, R. L., & Magat, S. S. (1978). Incidence of leaf spots in coconut fertilized with various combinations of N, P and K. *Philippine Journal of Coconut Studies, 3*(1), 37-44.

Adebisi, M. A., Kehinde, T. O., Salau, A. W., Okesola, L. A., Porbeni, J. B. O., Esuruoso, A. O., & Oyekale, K. O. (2013). Influence of different seed size fractions on seed germination, seedling emergence, and seed yield characters in tropical soybean (*Glycine max* L. Merrill). *International Journal of Agricultural Research, 8*, 26-33.

Adeogun, P. F., & Usman, J. J. A. (2012). *Sowing depth and seedling emergence of some Soudano-Sahelian tree species in a containerised experiment.* Paper presented at International Conference on Agriculture, Chemical and Environmental Sciences (ICACES' 2012), Dubai, UAE, October 6-7, 2012.

Agbo, C. U., & Omeliko, C. M. (2006). Initiation and growth of shoots of *Gongronema latifolia* Berth, stem cuttings in different rooting media. *African Journal of Biotechnology, 5*, 425-428.

Ahmadi, A., Mardeh, A. S., Poustini, K., & Jahromi, M. E. (2007). Influence of osmo and hydropriming on seed germination and seedling growth in wheat (*Triticum aestivum* L.) cultivars under different moisture and temperature conditions. *Pakistan Journal of Biological Sciences, 10* (22), 4043-4049.

Ahmed, S. U., & Zuberi, M. I. (1973). Effect of seed size on yield and its components in rapeseed (*Brassica campestris* L. var. Toria). *Crop Science, 13*, 119-120.

Ahmed, Z., Sheikh, M. A., Hameed, A., & Salah, U. D. (2012). Assessment of antioxidant enzymes and biochemical changes in the wheat seeds induced by different pre-sowing treatments. *World Applied Science Journal, 18* (1), 31-36.

Almaden, E. A., & Santiago, R. M. (1980). Response of coconut seedlings to spacing and application of nitrogen and potassium. *Annals of Tropical Research, 2* (2), 89-95.

Ali, S. A., & Idris, A. Y. (2015). Effect of seed size and sowing depth on germination and some growth parameters of faba bean (*Vicia faba* L.). *Agricultural and Biological Sciences Journal, 1*(1), 1-5.

Asian Pacific Coconut Community (APCC), (2017). *Yearbook 2017*. Jakarta, Indonesia, Asian Pacific Coconut Community.

Andoh-Mensah, E., Bonneau, X., Ollivier, J., Nuertey, B. N., & Dery, S. K. (2005). Evaluation of crop management options for replanting of coconut plantations devastated by lethal yellowing disease in Ghana. *Cord, 21* (2), 63-73.

Anonymous, (2000a). Coconut leaf pruning. A potential for higher farm productivity. *Techno Guide Sheet No. 3 series of 2000*. Department of Agriculture, Quezon City, Philippine Coconut Authority.

Anonymous (2002). *Annual Report 2001*. CSIR - Oil Palm Research Institute.

Asgharipour, M. A. (2011). Effect of planting depth on germination and emergence of field bindweed (*Convolvulus arvensis* L.). *Asia Journal of Agricultural Sciences, 3*(6), 459-461.

Association of Official Seed Analysts (AOSA), (1983). *Seed Vigor Testing*. Handbook of Association of Official Seed Analysts. Retrieved from https.//scholar.google.fr/scholar?q

Association of Official Analytical Chemists International (AOAC, I), (1999). *Methods of Analysis of Association of Official Analytical Chemists International*, Gaithersburg, USA, AOAC, I.

Arboleda, J. R. (1997). *Industrial application of coconut husk products- The development experience of a small-scale industry*. Technical Report. BUCA-Legaspi City.

Bailey, P., O'Sullivan D., & Perry, C. (1977). Effect of artificial defoliation on coconut yields in Papua New Guinea. *Papua New Guinea Agricultural Journal, 28* (2 - 4), 39-45.

Balachandran, C., & Arumughan, C. (1995). Biochemical and cytochemical transformations in germinating coconut (*Cocos nucifera* L.). *Journal of the American Oil Chemists' Society, 72*, 1385-1391.

Bangerth, F. (2000). Abscission and thinning of young fruit and their regulation by hormones. *Plant Growth Regulation, 31*, 43-59.

Basra, S. M. A., Farooq, M., & Tabassum, R. (2005). Physiological and biochemical aspects of seed vigour enhancement treatments in fine rice (*Oryza sativa* L.). *Seed Science Technology, 33*, 623-628.

Batugal, P., & Bourdeix, R. (2005). Conventional coconut breeding. In Batugal, P., Rao, R. V., Oliver, J. (Eds.), *Coconut Genetic Resources*. Serdang, Malaysia, IPGRI-APO.

Bazon, J. A., & Velasco (1985). *Coconut-Production and utilization.* Pasig, Metro Manila, PCRDF.

Bench A. R., Fenner, M., & Edwards, P. (1991). Changes in germinability, ABA content and ABA embryonic sensitivity in developing seeds of *Sorghum bicolor* (L.) Moench induced by water stress during grain filling. *New Phytologist, 118*, 339-347.

Bewley, J. D., & Black, M. (1994). *Seeds, Physiology of development and germination.* New York, Plenum Press.

Bhardwaj, R. L. (2014). Effect of growing media on seed germination and seedling growth of papaya cv. 'Red Lady'. *African Journal of Plant Science, 8* (4), 178-184.

Bloom, A. J., Frensch, J., & Taylor, A. R. (2006). Influence of inorganic nitrogen

and pH on the elongation of maize seminal roots. *Annals of Botany, 97* (5), 867-873.

Bian, L., Yang, L., An Wang, J., & Shen, H. L. (2013). Effect of KNO_3 pretreatment and temperature on seed germination of *Sorbus pohuashanensis. Journal of Forestry Research, 24* (2), 309-316.

Billeaud, L. A., Zajicek, J. M. (1989). Influence of mulches on weed control, soil pH, soil nitrogen content, and growth of *Ligustrum japonicum. Journal of Environmental Horticulture, 7*, 155-157.

Binnie, R. C., & Clifford, P. E. (1999). Sink characteristics of reproductive organs of dwarf bean in relation to likelihood of abscission. *Crop Science, 39* (4), 1077-1082.

Bond, B., Grundy, A. C. (2001). Non-chemical weed management in organic farming systems. *Weed Research, 41*, 383-405.

Bourdeix, R., Konan, J. L., & N'cho, Y. P. (2005). *Coconut, A guide to traditional and improved varieties*. Edition Diversiflora. Barcelona, Spain, Novoprint.

Brown, K. R., & Van Den Driessche, R. (2005). Effect of nitrogen and phosphorus fertilization on the growth and nutrition of hybrid poplars on Vancouver Island. *New Forests, 29* (1), 89-104.

Burris, J. S., Edje, T. O., & Wahab, A. H. (1973). Effect of seed size on seedling performance in soybeans, II. Seedling growth and photosynthesis and field performance. *Crop Science, 13*, 207-210.

Canja, L. H., Magat, S. S., & Margate, R. Z. (2003). Long term coconut leaf pruning (CLP) effect on CBFS, coconut-coffee agro-ecosystem. *Cord, 19* (2), 39-46.

Carandang, E. V. (2005). *Coconut oil, uses and issues on its health and nutraceutical benefits.* Retrieved from http.//www.coconut oil uses and issues.htm

Chacko, E. K., Reddy, Y. T. N., & Ananthanarayanan, T. V. (1982). Studies on the relationship between leaf number and area and fruit development in mango (*Mangifera indica* L.). *Journal of Horticultural Science, 57*, 483-492.

Chattopadhyay, N., Sharangi, A. B., & Hore, J. K. (2004). Effect of positioning and depth of planting on germination of coconut. *Haryana Journal of Horticultural Science, 33(1-2)*, 85-86.

Chavan, S. B., Naresh Kumar, A. R., Uthappa, A. K., Handa, K. B., Sridhar, M. S., Dhiraj, K., & Newaj, R. (2018). Tree management practices in agrofestry. Retrieved from https://www.researchgate.net/publication

Child, R. (1974). *Coconuts*. London, UK, Longman Green & Co.

Chima, U. D., Etuk, E. C., & Fredrick, C. (2017). Effect of sowing depths on the germination and early seedling growth of different seed sizes of *Annona muricata* L. *African Journal of Agriculture, Technology and Environment, 6* (2), 2346-7290.

Chin, H. F., & Roberts, E. H. (Eds.). (1980). *Recalcitrant crop seeds*. Kuala Lumpur, Malaysia, Timber Press.

Coolbear, P., Adele, F., & Grierson, D (1984). The effect of low temperature pre-sowing treatment on the germination performance and membrane integrity of artificially aged tomato seeds. *Journal of Experimental Botany, 35* (11), 1609-1617.

Copeland, L. O., & McDonald. M. B. (1999). *Principles of Seed Science and Technology*. Boston, MA, Kluwer Academic Publishers.

Copeland, L. O., & McDonald, M. B. (2001). Seed vigour and vigour Testing. In *Principles of Seed Science and Technology* (pp. 165-191). Boston, MA, Springer US.

Costa, C., Dwyer, L. M., Zhou, X., Dutilleul, P., Hamel, C., & Reid, L. M., (2002). Root morphology of contrasting maize genotypes. *Agronomy Journal, 94* (1), 96-101.

Corley, R. H. V., & Tinker, P. B. (2003). *The Oil Palm* (4th ed.). Singapore: Blackwell Science Ltd.

Crawford, E. L., & Williams, M. M. (2019). Planting depth and seed size affect Edamame emergence individually. *Horticultural Science, 54(1), 92-94.*

Dantuluri, V. S. R., & Misra, R. L. (2002). Response of Asiatic hybrid lily to flower bud removal. *Journal of Ornamental Horticulture New Series, 5*, 74-75.

Dare D., Andoh-Mensah, E., Owusu-Nipah, J., Yankey, N., Quaicoe, R. N., Nkansah-Poku, J., & Dery, S. K. (2010). Evaluation of some basic traits of a promising coconut hybrid, Sri Lankan Green Dwarf crossed to Vanuatu Tall (SGD x VTT). *Journal of Science and Technology*, *30* (3), 9-13

Dery, S. K., N'cho, Y. P., Sangare, A., & Arkhurst, E. D. (1997). Cape Saint Paul Wilt Disease, Resistance screening and prospects for rehabilitating the coconut industry in Ghana. In Eden-Green S. J. & Ofori, F. (Eds). *Proceedings of an International Workshop on Lethal Yellowing-Like Diseases of Coconut, Elmina, Ghana* (pp 147-151). Chatham, UK, NRI.

Dery, S. K., Philippe, R., Baudouin, L., Quaicoe, R. N., Nkansah Poku J., Owusu-Nipah, J., Arthur, R., Dare, D., Yankey, N., & Dollet, M. (2008). Genetic diversity among coconut varieties for susceptibility to CSPWD. *Euphytica, 164*, 1-11.

Desai, U. T., Ahire, G. Z., Masalkar, S. D. & Choudhari, S. M. (1993). Crop regulation in pomegranate, II. Effect of growth regulators on fruit set yield and fruit quality. *Annals of Arid Zone, 32* (3), 161-164.

Dwiyono, K., & Djauhari, M. A. (2021). Effect of potassium nitrate on Indonesian Konjac productivity. *Universal Journal of Agricultural Research, 9 (2),* 39-47.

Egonyu, J. P., Kabaru, J., Irungu, L., & Haas, F. (2013). Description of pre-adult stages of the coconut bug, *Pseudotheraptus wayi. Journal of Insect Science, 13,* 1-7.

Ehrle´n, L. (1991). Why do plants produce surplus flowers? A reserve-ovary model. *American Naturalists, 138*, 918-933.

Etebom, S. W., & Chimezie C. E. E. (2016). Effect of inflorescence on fresh vegetable yield in waterleaf [*Talinum triangulare* (Jacq.) Wild.]. *Journal of Agriculture and Veterinary Science, 9* (7), 1- 4.

Eufemia, A. A. & Santiago, M. R. (1980). Response of coconut seedlings to spacing and application of nitrogen and potassium. *Annals of Tropical Research, 2*, 89-95.

Evans, P. S. (1973). Effect of seed size and defoliation at three development stages on root and shoot growth of seedlings of some common pasture species. *New Zealand Journal of Agricultural Research, 16*, 389-394.

Fallahi, E., & Greens, D. V. (2010). The impact of blossom and post bloom thinning on fruit set and fruit quality in apples and stone fruits. *Acta Horticulturae, 884*, 179-187.

Falivane, S., & Hardy, S. (2008). Hand Thinning Citrus. New South Wales Department of Primary Industries. *Primefact, 789*, 1-3.

Farooq, M., Basra S. M. A., Hafeez, K., & Ahmad, N. (2005). Thermal hardening, a new seed vigour enhancement tool in rice. *Journal of Integrated Plant Biology, 47*, 187-193.

Food and Agricultural Organization (2008). *Guide for fertilizer and plant nutrient analysis.* Italy, Rome: FAO Communication Division.

Fattahia, E., Jafaria, A. & Fallahib, E. (2020). Hand thinning influence on fruit quality attributes of promegranate (*Punica granatum* L. cv.'Malase Yazdi'). *International Journal of Fruit Science, 20* (2), 77-86.

Finch-Savage, W. E., Dent, K.C., & Clark, L. J. (2004). Soak condition and temperature following sowing influence the response of maize (*Zea mays* L.) seeds to on-farm priming (pre-sowing seed soak). *Field Crops Res*earch, *90*, 361-374.

Floresca, F. R. (2004). Virgin coconut oil, An export winner in the making. *The Philippine STAR*. Retrieved from http.//www.searca.org/~bic.

Génard, M., Dauzat, J., Franck, N., Lescourret, F., Moitrier, N., Vaast, P., & Vercambre, G. (2008). Carbon allocation in fruit trees, from theory to modelling. *Trees, 22*, 269-282.

Ghana Export Promotion Authority (GEPA), (2020). Ghana Export and Promotion Authority distributes 400,000 coconut seedlings to farmers. *E-Newsletter, December 10, 2020*. Retrieved from https.//www.gepaghana.org/gepa-supports-coconut-sector-400,000 seedling.

Guardiola, J. L. & Carcia - Luis, A. (2000). Increasing fruit size in citrus-thinning and stimulation of fruit growth. *Plant Growth Regulation 31*, 121-132.

Harries, H. C. (2012a). Germination rate is the significant characteristic determining coconut palm diversity. *AoB PLANTS*, 1-10.

Harries, H. C. (2012b). Key to coconut cultivation on the Pacific coast of America, the Manila-Acapulco galleon route (1565-1815). *Journal of International Palm Society, 56*, 72-77.

Harries, H. C. (1976). Coconut Hybridization by the Policap and Mascopol Systems. *Principes, 20*, 136-147.

Harries, H. C. (1981). Germination and taxonomy of the coconut palm. *Annals of Botany, 48*, 873-883.

Harries, H. C. (1983). A ten point coconut nursery programme to avoid germination problems. *The Planter (Malaysia), 59*, 207-241.

Harrison, N. A., Davis R. E., Oropeza, C., Helmick, E., Narvaez, M., Eden-Green, S., Dollet, M., & Dickinson, M. (2014). '*Candidatus* Phytoplasma palmicola', a novel taxon associated with a lethal yellowing-type disease (LYD) of coconut (*Cocos nucifera* L.) in Mozambique. *International Journal of Systematic and Evolutionary Microbiology, 64*, 1890 -1899.

Haskins, F. A., & Gorz, H. J. (1975). Influence of seed size, planting depth, and companion crop on emergence and vigour of seedlings in sweet clover. *Agronomy Journal, 67*, 652-654.

Havis A. L. (1992). Effect of time of fruit thinning of 'Red Haven' Peach. *American Society of Horticultural Science, 80*, 172-176.

Hepler, P. K., Vidali, L., & Cheung, A. Y. (2001). Polarized cell growth in higher plants. *Annual Review of Cell and Developmental Biology, 17*, 159-187.

Heitholt, J. J., & Egli, D. B. (1985). Influence of deflowering on dry matter production of soybeans. *Field Crops Research, 12*, 163-173.

Heuvelink, E. (1997). Effect of fruit load on dry matter partitioning in tomato. *Horticultural Science, 69*, 51-59.

Hill, D. S. (2008). *Pest of crops in warmer climates and their control*. USA, New York, Springer Publishing Company.

Ho, L. C. (1992). Fruit growth and sink strength. In C. Marshall, & J. Grace (Eds.), *Fruit and seed production* (pp. 101-124) Cambridge, Cambridge University Press.

Ho, D. T., Loh, H. P., & Chan, E. (1978). Germination, nursery practices and field planting techniques for the MAWA hybrid coconut [in Malaysia]. In *International Conference on Cocoa and Coconuts, Kuala Lumpur (Malaysia), 21-24 Jun 1978*.

Horisawa, S. M., Sunagawa, Y., Tamai, Y., Matsuoka, T. M., & Terazawa, M. (1999). Biodegradation of nonlignocellulosic substances II, Physical and chemical properties of sawdust before and after use as artificial soil. *Journal of Wood Science 45*, 492-497.

Hu, W., Zhao, W., Yang, J., Oosterhuis, D. M., Loka, D. A., & Zhou, Z. (2016). Relationship between potassium fertilization and nitrogen metabolism in the leaf subtending the cotton (*Gossypium hirsutum* L.) boll during the boll development stage. *Plant Physiology and Biochemistry, 101*, 113-123.

Issaka, R. N., Senayah, J. K., Andoh-Mensah, E., & Ennin A. S. (2012). Assessment of fertility status of soils supporting coconut (*Cocus nucifera*) cultivation in Western and Central Regions of Ghana. *West African Journal of Applied Ecology*, 20 (1), 47-56.

Jackson, L. K., & Frederich, S. D. (1999). Citrus growing in Florida (4th ed.), pp 100-101. University press of Florida. Gainesville.

Jafari, A., Arzani, K., Fallahi, E., & Barzegar, M. (2014). Optimizing fruit yield, size, and quality attributes in 'Malase Torshe Saveh' pomegranate through hand thinning. *Journal of America Pomology Society, 68* (2), 89-96.

Jemric, T., Pavicici, N., Blaskovic, D., Krapak, M., & Pavicic, D. (2003). The effect of hand chemical fruit thinning on "Golden Delicious CL. B" apple fruit quality. *Current Research in Biotechnology, 3*, 193-198.

Kader, M. A. (2005). A comparison of seed germination calculation formulae and the associated interpretation of resulting data. *Journal and Proceedings of the Royal Society of New South Wales, 138*, 65-75.

Kartha, S. (1981). Embryo of coconut and its germination. *Journal of Plantation Crops, 9*, 125-127.

Kenman, E. T. (1973). Effect of seed nut trimming on the germination and growth of coconuts. *Papua New Guinea Agricultural Journal, 24(1)*, 269.

Kering, M. K., & Zhang, B (2015). Effect of priming and seed size on germination and emergence of six food-type soybean varieties. *International Journal of Agron*omy, Article 859212.

Kumar, R., & Srivastava, A. (2010). Effect of pre-sowing and depth on germination capacity of castor (*Ricinus communis*) seeds. *Advances in Bioresearch, 1*, 160-162.

Lawlor, D. W. (2012). Carbon and nitrogen assimilation in relation to yield mechanisms are the key to understanding production systems. *Journal of Experimental Botany, 53* (370), 773-787.

Lekete, E. (2019a). *New disease report (1), First report on damping-off disease caused by Phytophthora sp. on coconut (Cocos nucifera) seedlings in Ghana* (CSIR-OPRI/TR/E.L./2019/166). CSIR-Oil Palm Research Institute, Kusi.

Lekete, E. (2019b). *Leaf spot disease caused by Curvularia Pseudobrachyspora on Coconut (Cocos nucifera) seedlings in Ghana* (CSIR-OPRI/TR/E.L./2019/166). CSIR-Oil Palm Research Institute, Kusi.

Li, H., Li, M., Luo, J., Cao, X., Qu, L., Gai, Y., (2012). N fertilization has different effect on the growth, carbon and nitrogen physiology, and wood properties of slow and fast growing populous species. *Journal of Experimental Botany, 63* (17), 6173-6185.

Li, G., Zhang, Z. S., Gao, H. Y., Liu, P., Dong, S. T., & Zhang, J. W. (2012). Effect of nitrogen on photosynthetic characteristics of leaves from two different stay-green corn (*Zea mays* L.) varieties at the grain-filling stage. *Canadian Journal of Plant Science, 92*, 671-680.

Lwakuba, A., Kaudia, A. A., Okorio, J., Esegu, J. F., & Oluka-Akileng, I., (2003). *Agroforestry Handbook for the Montane Zone of Uganda*. Nairobi, Kenya, Swedish International Development Cooperation Agency.

Magat, S. S., Canja, L. H., & Margate, R. Z. (1994). Response of coconut to increasing levels of leaf pruning and its implication of farm productivity. *Coconut Research Development Journal, 10*(2), 16-32.

Magat, S. S., & Prudente, R. L. (1974). Coconut nutrition study from polybag nursery to fruit bearing. *Annual Report 1974-1975*. Quezon City, Philippine Coconut Authority.

Magat, S. S., Margate, R. Z., & Prudente, R. L. (1977). Utilization of common salt (sodium chloride) as a fertilizer and for the control of leaf spot disease of coconut seedlings [in the Philippines]. *Philippine Journal of Coconut Studies, 2*(3), 39-45.

Magat, S. S. (1996). Intercropping and toddy/sugar production in coconut-based farming systems, Possible integration with germplasm conservation and varietal improvement. In P. A. Batugal, R. V. Ramanatha, & C. Bong (Eds.), *Promoting multipurpose uses and competitiveness of the coconut. Proceedings of Workshop (pp. 57-146)*. Serdang, Thailand, Chumphon, IPGRI-APO.

Magat, S. S (2002). Coconut leaf nutrient levels of bearing dwarf varieties and physiological critical and adequacy levels in crop nutrition management. *Cord, XIX (2)*, 1-10.

Marar, M. M. K., & Shambhu, K. (1961). Coconut nursery studies III. Vigour of seedlings in relation to the floating position of seed nuts in water. *Indian Coconut Journal, 14*, 45-48.

Marsal, J., Mata, M., Arbones, A., Del Campo, J., Girona, J., & Lo´pez, G. (2008). Factors involved in alleviating water stress by partial crop removal in pear trees. *Tree Physiology, 28*, 1375-1382.

Mathes, D. T. (1984). Effect of extraction of inflorescence sap and the removal of immature fruit bunches on the production of female flowers in coconut. *COCOS, 2*, 44-47.

Mayer, A. M., & Poljakoff-Mayber, A. (1989). *The germination of seeds*. Oxford, Pergamon Press.

McKenna, J., & Woester, K. (2004). *Planting and Care of Fine Hardwood Seed, Fertilizing, Pruning and Thinning* (FNR-215). West Lafayette, Indiana, USA, Purdue University Department of Forestry and Natural Resources.

Ministry of Food and Agriculture (MoFA), (2011). *Policy for promotion of perennial crops in Ghana*. Technical Assistance for Developing Policy, Strategy and Implementation for Perennial Crops, France, AFD/SOFRECO.

Ministry of Food and Agriculture (MoFA), (2017). *Agriculture in Ghana, Fact and Figures 2016*. Statistics, Research and Information Directorate (SRID), Accra.

Ministry of Food and Agriculture (MoFA) (2018). *Crop Sector Studies, Draft report on coconut*. Crops Services Directorate, Accra.

Mohaptara, P. K., Masamoto, Y., Morita, S., Takanashi, J., Itani, T., Adu-Gyamfi, J. J., Muthiah, S., Nguyen, T., Nguyen, S., Saneoka, H., & Fujita, K. (2004). Partitioning of 13C - labelled photosynthate varies with growth

stage and panicle size in highyielding rice. *Functional Plant Biology, 31* (2), 131-139.

Mohammad, A. A. (2011). Effect of planting depth on germination and emergence of field bindweed (*Convolvulus arvensis* L.). *Asia journal of Agricultural sciences, 3*(6), 459-461.

Mohsen, F. S., & Osman, A. (2015). Improving physico-chemical aspects of wonderful pomegranate fruits through fruit thinning. *International Journal of Current Research in Biosciences and Plant Biology, 2* (9), 95-103.

Murungu, F. S. (2011). Effect of seed priming and water potential on seed germination and emergence of wheat (*Triticum aestivum* L.) varieties in laboratory assays and in the field. *African Journal of Biotechnology, 10* (21), 4365-4371.

Mylsamy, S. (2012). *Studies on synthesis and characterization of activated carbon prepared from cocoa (Theobroma cacao) shell and its adsorption modeling of dissolved organic pollutants*. Unpublished doctoral thesis, Faculty of Science and Humanities, Anna University, Chennai, India.

Mytton, L. R. (1973). The effect of seed weight on the early growth and nodulation of white clover. *Annals of Applied Biology, 73*, 329-338.

Nabi, G., Azhar, F.M., Farooq, J., & Khan, A. A. (2011). Responses of *Gossypium hirsutum* L. varieties/ lines to NaCl salinity at seedling. *Cercetari Agronomice in Moldova, 44* (1), 43-50.

Nathanael, W. R. N. (1955). Toddy yield from coconut palms in Ceylon. *Ceylon Coconut Quarterly, 6*, 8-16.

Nathanael, W. R. N. (1966). A tapping technique for the coconut palm. *Ceylon Coconut Planters' Review, 4* (4), 87-99.

Nelliat, E. V. (1972). NPK nutrition of coconut palm- a review. *Journal of Plantation Crops, 1 (Supplementary)*, 70-80.

Nkansa-Poku, J., Quaicoe, R. N., & Sam, G. (2015). Incidence of coconut mite, *Eriophyes guerreronis*, Keifer (Acari, Eriophyidae) infestation on coconut in the Western and Central Regions of Ghana. *Journal of Ghana Science Association, 16* (2), 36-44.

Noggle, G. R., & Fritz, G. S. (2006). *Introductory plant physiology* (2nd ed.). New Delhi, Prentice-hall of India.

Obeso, J. R. (2002). The cost of reproduction in plants. *New Phytologists, 155*, 321-348.

Ohler, J. G. (1984). FAO Plant Production and Protection. *Coconut, Tree of life.* Rome, FAO.

Oosterhuis, D., Loka, D., Kawakami, E., & Pettigrew, W. (2014). The physiology of potassium in crop production. *Advance Agronomy, 126*, 203-234.

Opande, G. T., Musyimi, D. M., & Muthoni, K. C. (2017). Effect of planting depth on seed germination and emergence of *Crotalaria brevidens* on Maseno Soils. *Journal of Agriculture and Veterinary Science, 10* (8), 30-34.

Ouma, G. (2012). Fruit thinning with specific reference to citrus species, a quick review. *Agricultural Biology Journal of North America, 3* (4), 175-191.

Owusu, O. K. (2014). *Raising quality seedlings for the coconut industry through organic soil amendment using cocoa bean shell in three coconut genotypes.* Unpublished B.Sc. dissertation, Department of Horticulture, Faculty of Agriculture, Kwame Nkrumah University of Science and Technology, Kumasi.

Pace, P. F., Cralle, H. T., Cothren, J. T., & Senseman, S. A. (1999). Photosynthate and dry matter partitioning in short- and long season cotton cultivars. *Crop Science, 39* (4), 1065-069.

Padrones, G. D., Secretaria, M. I., & Magat, S. S. (2000). Leaf pruning technique in bearing coconut palms, its effect on underplanting young coconut for pith or ubod production. *Philippine Journal of Coconut Studies, 251* (2), 1-11.

Patel, J. S. (1938). The Coconut - A Monograph. Govt. Press. Madras.

Patil, R. B. (2011). Role of potassium humate on growth and yield of soybean and black gram. *International Journal of Pharmacology and Bio-sciences, 2* (1), 242-246.

Perera, P. I. P., Hocher, V., Weerakoon, D. M. D., Yakandawala, S. C., & Verdeil, J. L. (2010). Early inflorescence and floral development in *Cocos nucifera* L. (Arecaceae, Arecoideae). *South African Journal of Botany,* 76 (3), 482-492.

Peries, R. R. A., & Everand, J. M. D. T. (1995). Is there ecological adaptation in coconut nursery seedling stage? A preliminary assessment. *Cocos, 19,* 10-19.

Pham L. J. (2016). Coconut (*Cocos nucifera*) In, McKeon, T. A., Hayes, D. G. & Weselake (Eds.). *Industrial Oil Crops* (pp. 231-242) Amsterdam, Netherlands, Elsevier.

Proctor, J. T. A., & Sullivan, J. A. (2013). Effect of seeding depth on seedling growth and dry matter partitioning in American ginseng. *Journal of Ginseng Research, 37* (2), 254-260.

Rangaswami, G. (1977). Palm tree crops in India. *Outlook-on-Agriculture (UK) 9* (4), 167-173.

Remison, S. U., & Mgbeze, G. (1987). Competitive effect of weed management and beneficial effect of mulching on coconut seedlings. *Cocos 5*, 19-28.

Remison, S. U., & Mbgeze, C. C. (1988). Effect of storage and planting methods on growth of coconut. *Nigerian Journal of Palms and Oil Seeds 9*, 59-70.

Rodrigues, J., Inzé, D., Nelissen, H., & Saibo, N. J. M. (2019). Source-sink regulation in crops under water deficit. *Trends in plant science, 24* (7), 652-663.

Rojo-Poveda, O., Barbosa-Pereira, L., Zeppa, G., & Stévigny, C. (2020). Cocoa bean shell - A by-product with nutritional properties and biofunctional potential. *Nutrients, 12* (1123), 1-29.

Rumulo, N. A. J. R. (2003). *CIDA's assistance to APCC's effort in organic certification of VCO*. Retrieved from http://www.asiatribune.com

Ronsenfeld, E. (2009). Effect of pruning on the health of palms. *Arboricult Urban Forestry, 35*(6), 294-299.

Rowell, D. L. (1994). *Soil science. Methods and applications*. Singapore, Longman Publication Ltd.

Saikh, H., Varadachari, C., & Ghosh, K. (1998). Changes in carbon, nitrogen and phosphorus levels due to deforestation and cultivation, a case study in Simlipal National Park, India. *Plant and Soil, 198*, 137-145.

Samara, B. N., & Shalan, A. M. (2013). Effect of thinning and bagging on yield and quality of wonderful pomegranate. *Journal of Plant Production, 4* (2), 219-227.

Samuelson, L., Stokes, T., Cooksey, T., & McLemore, P. (2001). Production efficiency of loblolly pine and sweet gum in response to four years of intensive management. *Tree Physiology, 21* (6), 369-376.

Santiago, R. M. (1978). Growth of coconut seedlings as influenced by different levels and three soil types. *Philippian Journal of Coconut Studies, 3* (4), 15-27.

Santos, G. A., Batugal, P. A., Othman, A., Baudouin, L., & Laboisse, J. P. (Eds.). (1996). *Manual on standardized research techniques in coconut breeding*. Serdang, Malaysia, IPGRI-APO.

Saravitz, C. H., Rideout, J. W., & Raper, C. D. Jr (1994). Nitrogen uptake and partitioning in response to reproductive sink size of soybean. *International Journal of Plant Sciences, 155* (6), 730-737.

Scott, S., Jones, R., & Williams, W. (1984). Review of data analysis methods for seed germination. *Crop Science, 24*, 1192-1199.

Sharma, S., Warren, J., Lofton, J., Henry, W., & Cameron Murley, C. (2019). Optimum planting depth for uniform germination and emergence of corn (Oklahoma Cooperative Extension Fact Sheets PSS-2192). USA,

Oklahoma State University.

Shen, J. P., Zhang, L. M., Guo, J. F., Ray, J. L. & He, J. Z. (2010). Impact of long-term fertilization practices on the abundance and composition of soil bacterial communities in Northeast China. *Applied Soil Ecology,* 46 (1), 119-124.

Shim, S. I., Moon, J. C., Jang, C. S., Raymer, P., & Kim, W. (2008). Effect of potassium nitrate priming on seed germination of seashore paspalum. *Horticultural Science, 43* (7), 2259-2262.

Smith, A. R., & Hall, M.A. (1993). Mechanism of ethylene action. *Plant Growth Regulation, 2*,151-165.

Sombroek, W. G., Nachtergaele, F. O., & Hebel, A., (1993). Amounts, dynamics and sequestering of carbon in tropical and subtropical soils. *Ambio, 22* (7), 417-426.

Spargo, J., Allen, T., & Kariuki, S. (2013). *Interpreting your results* (Ref. No. SPTTL_2). Amherst, Massachusetts: University of Massachusetts.

Stewarte, E. A., Grimshaw, H. M., Parkinson, J. A., & Quarmby, C. (1974). *Chemical analysis of ecological materials*. Oxford, Blackwell Scientific Publication.

Stopar, M., Black, B. L., & Bukovac M. J. (1997). The effect of NAA and BA on CO_2 assimilation by shoot leaves of spur type 'Delicious' and Empire apple trees. *Journal of America Horticultural Society, 122*, 837-840.

Sudha, R., Niral, V., Hebbar, K. B., & Samsudeen, K. K. (2019). Coconut inflorescence sap. *Current Science, 116* (11), 1809-1817.

Sugimura, Y. (1998). Ultrastructure observation of the haustorium in germinating coconut. *Japanese Journal of Tropical Agriculture, 42*, 179-181.

Sumback, J. H. (1970). Coconut seedling establishment as affected by seedling development at transplanting as well as agricultural practices. *Papua New Guinea Agricultural Journal, 61*, 525-530.

Taffin, D. G. (1998). *The Tropical Agriculturalist - Coconut*. London, Macmillan Education Ltd.

Terazawa, M. S., Horisawa, Y. T., & Yamashita, K. (1999). Biodegradation of lignocellulosic substance I, System for complete degradation of garbage using sawdust and aerobic soil bacteria. *Journal of Wood Science 45*, 354-358.

Thampan, P. K. (1981). *Hand book on coconut palm*. New Delhi, India, Oxford & IBH Publishing Co.

Thomas, T. C., & Thomas, A. C. (2009). Vital role of potassium in the osmotic mechanism of stomata aperture modulation and its link with potassium deficiency. *Plant Signal Behaviour, 4*(3), 240-243.

Thomas, G. V., Krishnakumar, V., Dhanapal, R., & Srinivasa Reddy, D. V. (2018). Agro-management practices for sustainable coconut production. In Nampoothiri, K. U. K., Krishnakumar, V., Thampan, P. K., & Achuthan Nair, M. (Eds.), *The Coconut Palm (Cocos nucifera L.) - Research and development perspectives (pp.227-321). New York, USA,* Springer.

Tian, Q., Chen, F., Zhang, F., & Mi, G. (2005). Possible involvement of cytokinin in nitrate-mediated root growth in maize. *Plant and Soil, 277* (1-2), 185-196.

Tomlinson, P. B. (1990). *The Structural Biology of Palms.* Oxford, London, Clarendon press.

Ugbah, M. M., & Akpan, E. E. J. (2003). Effect of nut positioning and husk slashing on nut germination and growth of two coconut varieties. *Nigerian Journal of Palms and Oil Seeds 15*, 11-21.

Untied, R. & Blanke, M. (2001). Effect of fruit thinning agents on apple tree canopy photosynthesis and dark respiration. *Plant Growth Regulation 35*, 1-9.

Valenzuela, J. R. C. (1992). *Regulating blue berry (V. Ahei) crop*. Unpublished doctoral dissertation, Department Crop Science, Mississippi State University.

Van Brunt, J. M. & Sultenfuss, J. H. (1998). Better crops with plant food. In Potassium, *Functions of Potassium, 82* (3) 4-5.

Van Die, J. (1974) The developing fruits of *Cocos nucifera* and *Phoenix dactylifera* as physiological sinks importing and assimilating the mobile aqueous phase of the sieve tube system. *Acta Botany Neerl, 23*(4), 521-540.

Varier, A., Vari, A. K., & Dadlani, M. (2010). The subcellular basis of seed priming. *Current Science, 99* (4), 450-456.

Wang, Y. T., & P. J. Breen. (1986). Partitioning of Carbon-14 in easter lily (*Lilium longiflorum)* as affected by growth stage and flower removal. *Scientia Horticulturae - Amsterdam, 29*, 273 - 282.

Wareing, P. F., & Patrick, J. W. (1975). Source-sink relations and the partition of assimilates in the plant. In J. P. cooper (Ed.), *Photosynthesis and productivity in different environments,* (pp. 481- 99). UK, Cambridge University Press.

Warner, J., Zhang, T. Q., and Hao, X. (2004). Effect of nitrogen fertilization on fruit yield and quality of processing tomatoes. *Canadian Journal of Plant Science, 84*, 865-871.

Wei, S. S., Wang, X. Y., Shi, D. Y., Li, Y. H., Zhang, J. W., & Dong, S. T. (2016). The mechanisms of low nitrogen induced weakened photosynthesis in summer maize (*Zea mays* L.) under field conditions. *Plant Physiology and Biochemistry, 105*, 118-128.

Westwood, M. N. (1993) *Temperate Zone Pomology*. Oregon, USA, Timber Press.

Wheaton, T. A. (1981). Fruit thinning of Florida Mandarins using plant growth regulator. *Proceedings of International Society of Citriculture*, Tokyo, Japan, 1981, 263-208.

Wickramaratne, M. R. T., & Padmasiri, M. H. L. (1986). Some observations on the positioning of the soft eye in *Cocos Nucifera*. *COCOS, 5*, 1-7.

Williamson, L., Ribrioux, S., Fitter, A., & Leyser, O. (2001). Phosphate availability

regulates root system architecture in Arabidopsis. *Plant Physiology, 126* (2), 875-882.

Wuidart, W. (1981a). Production of coconut planting material - Selection of hybrids in the seed-bed. *Oleagineux, 36* (10), 497-499.

Wuidart, W. (1981b). Production of coconut planting material - conduct of seed bed. *Oleagineux, 36* (6), 305-309.

Zareian, A., Hamidi, A., Sadeghi, H., & Jazaeri, M. R. (2013). Effect of seed size on some germination characteristics, seedling emergence percentage and yield of three wheat (*Triticum aestivum* L.) cultivars in laboratory and field. *Middle-East Journal of Scientific Research, 13*(8), 1126-1131.

APPENDICES

Appendix 1. Regression analysis of temperature for planting medium

Time of The day	Source of Variation	DF	DV	MDV	DR	Approx. Chi pr.
Morning 10.00 am	Regression	2	0.26	0.1283	0.13	0.880^{NS}
	Residual	258	19.09	0.0740		
	Total	260	19.35	0.0744		
Afternoon 3.00 pm	Regression	2	8.54	4.271	4.27	0.014*
	Residual	258	33.55	0.130		
	Total	260	42.10	0.162		

DF = Degrees of freedom; DV = Deviance; MDV = Mean deviance; DR = Deviance Ratio; Chi pr. = Chi-probability; NS = Not significant, P <0.05; ** = Significant, P <0.001

Appendix 2. LSD (0.05) of mean estimates for temperature of planting medium

Morning	CBS	*1*	*		
10.00 am	SD	*2*	1.649	*	
	TS	*3*	1.654	1.655	*
			1	*2*	*3*
Afternoon	CBS	*1*	*		
3.00 pm	SD	*2*	1.690	*	
	TS	*3*	1.716	1.721	*
			1	*2*	*3*

CBS = Cocoa bean shell; SD = Sawdust; TS = Topsoil

Appendix 3. Regression analysis of final germination percentage of SGD x VTT coconut hybrid seed nuts as influenced by soaking treatment and planting medium

Source	Df	Deviance	Mean Deviance	Deviance Ratio	Approx. Chi Prob.
Regression	8	498.5	62.32	62.32	< .001***
Residual	45	129.0	2.87		
Total	53	627.5	11.84		

Df = degrees of freedom; *** = Significant, P<0.001

Appendix 4. LSD (0.05) of mean estimates for final germination percentage of SGD x VTT coconut hybrid seed nuts as influenced by soaking treatment and medium

CBS*C	*1*	*								
CBS*P	*2*	7.316	*							
CBS*W	*3*	7.431	6.235	*						
TS*C	*4*	9.583	8.689	8.786	*					
TS*P	*5*	9.512	8.611	8.708	10.605	*				
TS*W	*6*	9.554	8.656	8.754	10.642	10.578	*			
SD*C	*7*	9.524	8.624	8.721	10.615	10.551	10.589	*		
SD*P	*8*	9.642	8.754	8.850	10.721	10.658	10.695	4.742	*	
SD*W	*9*	9.613	8.721	8.818	10.695	10.631	10.668	4.759	10.747	*
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*

CBS = Cocoa bean shell; TS = Top soil; SD = Sawdust; C = Seed nut without soaking treatment; W = Seed nut soaked in water; P = Seed nut soaked in 1% (w/v) KNO_3 solution

Appendix 5. Regression analysis of time to 50% germination of SGD x VTT coconut hybrid seed nuts as influenced by soaking treatment and medium

Source	Df	Deviance	Mean Deviance	Deviance Ratio	Approx. Chi Prob.
Regression	8	17.24	2.15	2.15	< .028*
Residual	45	17.95	0.40		
Total	53	35.19	0.66		

Df = degrees of freedom; * = Significant, P<0.028

Appendix 6. LSD (0.05) of mean estimates for time to 50% germination of SGD x VTT coconut hybrid seed nuts as influenced by soaking treatment and medium

CBS*C	*1*	*								
CBS*P	*2*	7.536	*							
CBS*W	*3*	7.640	7.461	*						
TS*C	*4*	8.028	7.858	7.958	*					
TS*P	*5*	7.750	7.573	7.677	8.063	*				
TS*W	*6*	7.887	7.713	7.815	8.195	7.922	*			
SD*C	*7*	7.944	7.771	7.872	8.250	7.979	8.112	*		
SD*P	*8*	8.021	7.851	7.951	8.325	8.056	8.188	8.243	*	
ingSD*W	*9*	7.951	7.779	7.880	8.257	7.986	8.119	8.174	8.250	*
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*

CBS = Cocoa bean shell; TS = Top soil; SD = Sawdust; C = Seed nut without soaking treatment; W = Seed nut soaked in water; P = Seed nut soaked in 1% (w/v) KNO_3 solution

Appendix 7. Regression analysis of germination index of SGD x VTT coconut hybrid seed nuts as influenced by soaking treatment and medium

Source	Df	Deviance	Mean Deviance	Deviance Ratio	Approx. Chi Prob.
Regression	8	20.15	2.52	2.52	< .010**
Residual	45	6.48	0.14		
Total	53	26.63	0.50		

Df = degrees of freedom; ** = Significant, P<0.01

Appendix 8. LSD (0.05) of mean estimates for germination index of SGD x VTT coconut hybrid seed nuts as influenced by soaking treatment and medium

CBS*C	*1*	*							
CBS*P	*2*	1.288	*						
CBS*W	*3*	1.584	1.380	*					
TS*C	*4*	1.523	1.868	1.865	*				
TS*P	*5*	1.555	1.902	1.899	2.278	*			
TS*W	*6*	1.517	1.862	1.858	2.245	2.273	*		
SD*C	*7*	1.509	1.853	1.849	2.237	2.265	2.232	*	
SD*P	*8*	1.553	1.901	1.897	2.277	2.305	2.272	2.264	*
SD*W	*9*	1.511	1.855	1.852	2.239	2.268	2.234	2.226	2.266
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*

CBS = Cocoa bean shell; TS = Top soil; SD = Sawdust; C = Seed nut without soaking W = treatment; Seed nut soaked in water; P = Seed nut soaked in 1% (w/v) KNO_3 solution

Appendix 9. Regression analysis of final germination percentage of SGD x VTT coconut hybrid seed nuts as influenced by planting depth and medium

Source	Df	Deviance	Mean Deviance	Deviance Ratio	Approx. Chi Prob.
Regression	5	31.89	6.38	6.38	< .001**
Residual	12	16.86	1.41		
Total	17	48.75	2.87		

Df = degrees of freedom; ** = Significant, P<0.01

Appendix 10. LSD (0.05) of mean estimates for final germination percentage of SGD x VTT coconut hybrid seed nuts as influenced by planting depth and medium

SD*PD0	*1*	*					
SD*PD1	*2*	14.52	*				
SD*PD2	*3*	15.06	16.24	*			
TS*PD0	*4*	14.25	15.49	15.99	*		
TS*PD1	*5*	14.71	15.91	16.40	15.66	*	
TS*PD2	*6*	15.06	16.24	16.72	15.99	16.40	*
		1	*2*	*3*	*4*	*5*	*6*

TS = Top soil medium; SD = Sawdust medium; PD0 = Planting by burying a quarter of the seed nut in medium; PD1 = Planting by burying half of the seed nut in medium; PD2 = Planting by fully burying seed nut in medium

Appendix 11. Regression analysis of time to 50% germination of SGD x VTT coconut hybrid seed nuts as influenced by planting depth and medium

Source	Df	Deviance	Mean Deviance	Deviance Ratio	Approx. Chi Prob.
Regression	5	11.334	2.267	2.270	0.045*
Residual	12	3.596	0.300		
Total	17	14.931	0.878		

Df = degrees of freedom; * = Significant, P<0.05

Appendix 12. LSD (0.05) of mean estimates for time to 50% germination of SGD x VTT coconut hybrid seed nuts as influenced by planting depth and medium

SD*PD0	*1*	*					
SD*PD1	*2*	13.40	*				
SD*PD2	*3*	12.60	12.10	*			
TS*PD0	*4*	13.51	13.22	12.41	*		
TS*PD1	*5*	13.38	13.09	12.27	13.20	*	
TS*PD2	*6*	13.34	13.05	12.22	13.16	13.02	*
		1	*2*	*3*	*4*	*5*	*6*

TS = Top soil medium; SD = Sawdust medium; PD0 = Planting by burying a quarter of the seed nut in medium; PD1 = Planting by burying half of the seed nut in medium; PD2 = Planting by fully burying seed nut in medium

Appendix 13. Regression analysis of germination index of SGD x VTT coconut hybrid seed nuts as influenced by planting depth and medium

Source	Df	Deviance	Mean Deviance	Deviance Ratio	Approx. Chi Prob.
Regression	5	12.912	2.582	5.58	0.049*
Residual	12	0.135	0.011		
Total	17	13.047	0.767		

Df = degrees of freedom; * = Significant, P<0.05

Appendix 14. LSD (0.05) of mean estimates for germination index of SGD x VTT coconut hybrid seed nuts as influenced by planting depth and medium

SD*PD0	*1*	*					
SD*PD1	*2*	1.783	*				
SD*PD2	*3*	1.164	1.375	*			
TS*PD0	*4*	1.590	1.843	1.617	*		
TS*PD1	*5*	1.818	1.053	1.403	1.878	*	
TS*PD2	*6*	1.107	1.321	1.646	1.161	1.35	*
		1	*2*	*3*	*4*	*5*	*6*

TS = Top soil medium; SD = Sawdust medium; PD0 = Planting by burying a quarter of the seed nut in medium; PD1 = Planting by burying half of the seed nut in medium; PD2 = Planting by fully burying seed nut in medium

Appendix 15. Regression analysis of final germination percentage of SGD x VTT coconut hybrid seed nuts as influenced by seed nut size and medium

Source	Df	Deviance	Mean Deviance	Deviance Ratio	Approx. Chi Prob.
Regression	13	3.8	2.904	0.292	0.145^{NS}
Residual	67	276.5	4.127		
Total	80	314.2	3.928		

Df = degrees of freedom; NS = Not significant, P>0.05

Appendix 16. Regression analysis of time to 50% germination of SGD x VTT coconut hybrid seed nuts as influenced by seed nut size and medium

Source	Df	Deviance	Mean Deviance	Deviance Ratio	Approx. Chi Prob.
Regression	13	38.6	2.969	2.97	< 0.01**
Residual	67	45.3	0.677		
Total	80	83.9	1.049		

Df = degrees of freedom; ** = Significant, P<0.01

Appendix 17. LSD (0.05) of mean estimates for time to 50% germination of SGD x VTT coconut hybrid seed nuts as influenced by seed nut size and medium

SD* SN_L	1	*						
SD* SN_M	2	9.6	*					
SD*SN_S	3	9.6	9.2	*				
SD*SN_{XL}	4	9.3	9.9	9.9	*			
TS*SN_L	5	9.0	9.6	9.6	9.2	*		
TS*SN_M	6	8.9	9.5	9.5	9.2	9.0	*	
TS*SN_S	7	8.9	9.5	9.5	9.2	9.0	8.6	*
TS*SN_{XL}	8	9.1	9.7	9.7	9.3	9.1	8.8	9.1	*
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*

TS = Top soil; SD = Sawdust; SN_L = Large seed nut; SN_M = Medium seed nut; SN_S = Small seed nut; SN_{XL}= Extra-large seed nut

Appendix 18. Regression analysis of germination index of SGD x VTT coconut hybrid seed nuts as influenced by seed nut size and medium

Source	Df	Deviance	Mean Deviance	Deviance Ratio	Approx. Chi Prob.
Regression	13	33.86	2.605	2.61	< 0.01**
Residual	67	2.997	0.045		
Total	80	36.86	0.461		

Df = degrees of freedom; ** = Significant, P<0.01

Appendix 19. LSD (0.05) of mean estimates for germination index of SGD x VTT coconut hybrid seed nuts as influenced by seed nut size and medium

SD* SN_L	1	*							
SD* SN_M	2	0.95	*						
SD*SN_S	3	0.96	1.03	*					
SD*SN_{XL}	4	0.95	0.99	1.03	*				
TS*SN_L	5	0.97	0.99	1.01	1.01	*			
TS*SN_M	6	0.96	0.96	1.02	1.00	0.98	*		
TS*SN_S	7	0.95	0.97	1.01	1.03	1.01	0.98	*	
TS*SN_{XL}	8	0.96	0.98	1.03	1.02	0.98	0.97	1.05	*
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*

TS = Top soil; SD = Sawdust; SN_L = Large seed nut; SN_M = Medium seed nut; SN_S = Small seed nut; SN_{XL}= Extra-large seed nut

Appendix 20. Regression analysis of germination percentage of SGD x VTT coconut hybrid seed nuts as influenced by KNO_3 soaking treatment and medium

Source	Df	Deviance	Mean Deviance	Deviance Ratio	Approx. Chi Prob.
Regression	9	4.55	0.5061	0.51	0.871^{NS}
Residual	19	17.76	0.9346		
Total	28	22.31	0.7969		

Df = degrees of freedom; NS = Not Significant, P>0.05

Appendix 21. Regression analysis of time to 50% germination of SGD x VTT coconut hybrid seed nuts as influenced by KNO_3 soaking treatment and medium

Source	Df	Deviance	Mean Deviance	Deviance Ratio	Approx. Chi Prob.
Regression	9	25.393	2.821	2.82	$< 0.01^{**}$
Residual	19	5.783	0.305		
Total	28	31.176	1.113		

Df = degrees of freedom; ** = Significant, P<0.01

Appendix 22. LSD (0.05) of mean estimates for time to 50% germination of SGD x VTT coconut hybrid seed nuts as influenced by KNO_3 soaking treatment and medium

TS*PN_0	1	*								
TS*PN_1	2	7.95	*							
TS*PN_2	3	7.96	8.03	*						
TS*PN_3	4	7.95	7.99	8.03	*					
TS*PN_5	5	7.98	8.02	8.01	8.03	*				
SD*PN_0	6	7.99	7.98	8.02	8.01	7.97	*			
SD*PN_1	7	7.95	7.97	8.01	8.03	7.99	8.02	*		
SD*PN_2	8	7.97	7.99	8.01	8.01	8.01	8.03	8.03	*	
SD*PN_3	9	7.96	7.96	8.02	8.00	7.99	8.01	8.01	7.98	*
SD*PN_5	10	7.95	7.97	8.01	8.03	7.98	8.02	8.02	8.01	7.98	*
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*

TS = Top soil; SD = Sawdust; PN_0 = 0% KNO_3 solution; PN_1 = 1% (w/v) KNO_3 solution; PN_2 = 2% (w/v)) KNO_3 solution; PN_3 = 3% (w/v) KNO_3 solution; PN_5 = 5% (w/v) KNO_3 solution.

Appendix 23. Regression analysis of germination index of SGD x VTT coconut hybrid seed nuts as influenced by KNO_3 soaking treatment and medium

Source	Df	Deviance	Mean Deviance	Deviance Ratio	Approx. Chi Prob.
Regression	9	22.742	2.527	2.53	0.01**
Residual	19	0.8330	0.0438		
Total	28	23.578	0.8421		

Df = degrees of freedom; ** = Significant, P<0.01

Appendix 24. LSD (0.05) of mean estimates for germination index of SGD x VTT coconut hybrid seed nuts as influenced by KNO_3 soaking treatment and medium

TS*PN_0	1	*									
TS*PN_1	2	0.49	*								
TS*PN_2	3	0.51	0.48	*							
TS*PN_3	4	0.52	0.50	0.49	*						
TS*PN_5	5	0.51	0.52	0.50	0.49	*					
SD*PN_0	6	0.52	0.52	0.51	0.51	0.50	*				
SD*PN_1	7	0.53	0.53	0.51	0.51	0.50	0.51	*			
SD*PN_2	8	0.53	0.52	0.52	0.52	0.51	0.52	0.50	*		
SD*PN_3	9	0.51	0.53	0.53	0.52	0.52	0.53	0.51	0.49	*	
SD*PN_5	10	0.53	0.50	0.53	0.53	0.52	0.53	0.52	0.51	0.48	*
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*

TS = Top soil; SD = Sawdust; PN_0 = 0% KNO_3 solution; PN_1 = 1% (w/v) KNO_3 solution; PN_2 = 2% (w/v)) KNO_3 solution;. PN_3 = 3% (w/v) KNO_3 solution; PN_5 = 5% (w/v) KNO_3 solution.

Appendix 25. Regression analysis of leaf nutrient of SGD x VTT coconut hybrid seedlings as influenced by spacing and fertilizer treatment

Leaf Nutrient	Source of Variation	DF	SS	MS	VR	Fpr.
Mg	Regression	7	0.000034	0.0000049	0.87	0.536^{NS}
	Residual	40	0.000223	0.0000056		
	Total	47	0.00026	0.0000055		
Ca	Regression	7	0.04519	0.006456	0.54	0.723^{NS}
	Residual	40	0.04773	0.01193		
	Total	47	0.09293	0.001977		
N	Regression	7	2.633	0.37612	7.74	<.001**
	Residual	40	1.945	0.04862		
	Total	47	4.578	0.09740		
P	Regression	7	0.09347	0.0133528	15.85	<.001**
	Residual	40	0.03369	0.0008422		
	Total	47	0.12716	0.0027055		
K	Regression	7	0.0934	0.013345	3.54	0.005**
	Residual	40	0.1507	0.003767		
	Total	47	0.2441	0.005194		

DF = Degrees of freedom; SS = Sum of Squares; MS = Mean square; VR = Variance Ratio; Fpr = F-probability; NS = Not significant, P>0.05; ** = Significant at P<0.01

Appendix 26. LSD (0.05) of mean estimates for leaf N of SGD x VTT coconut hybrid seedlings as influenced by spacing and fertilizer treatment

F0S1	*1*	*							
F0S2	*2*	0.2573	*						
F1S1	*3*	0.2573	0.2573	*					
F1S2	*4*	0.2571	0.2572	0.2573	*				
F2S1	*5*	0.2570	0.2571	0.2571	0.2573	*			
F2S2	*6*	0.2571	0.2571	0.2572	0.2572	0.2573	*		
F3S1	*7*	0.2571	0.2570	0.2571	0.2571	0.2572	0.2571	*	
F3S2	*8*	0.2572	0.2571	0.2573	0.2573	0.2570	0.2573	0.2574	*
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*

S1 = Spacing at 60 cm triangular; S2 = Spacing at 80 cm triangular; F0 = control; F1 = Fertilizer application at 28.4:58.0:75.6:17.0 g seedling^{-1} N:P_2O_5:K_2O:MgO; F2 = Fertilizer application at 47.3:96.6:126.0:28.4 g seedling^{-1} N:P_2O_5:K_2O:MgO; F3 = Fertilizer application at 66.2:135.2:176.4:39.7 g seedling^{-1} N:P_2O_5:K_2O:MgO

Appendix 27. LSD (0.05) of mean estimates for leaf P of SGD x VTT coconut hybrid seedlings as influenced by spacing and fertilizer treatment

F0S1	*1*	*							
F0S2	*2*	0.0340	*						
F1S1	*3*	0.0341	0.0339	*					
F1S2	*4*	0.0339	0.0338	0.0339	*				
F2S1	*5*	0.0338	0.0339	0.0340	0.0341	*			
F2S2	*6*	0.0339	0.0340	0.0339	0.0338	0.0339	*		
F3S1	*7*	0.0338	0.0337	0.0338	0.0339	0.0338	0.0338	*	
F3S2	*8*	0.0339	0.0339	0.0339	0.0337	0.0339	0.0339	0.0340	*
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*

S1 = Spacing at 60 cm triangular; S2 = Spacing at 80 cm triangular; F0 = control; F1 = Fertilizer application at 28.4:58.0:75.6:17.0 g seedling^{-1} N:P_2O_5:K_2O:MgO; F2 = Fertilizer application at 47.3:96.6:126.0:28.4 g seedling^{-1} N:P_2O_5:K_2O:MgO; F3 = Fertilizer application at 66.2:135.2:176.4:39.7 g seedling^{-1} N:P_2O_5:K_2O:MgO

Appendix 28. LSD (0.05) of mean estimates for leaf K of SGD x VTT coconut hybrid seedlings as influenced by spacing and fertilizer treatment

F0S1	*1*	*						
F0S2	*2*	0.1433	*					
F1S1	*3*	0.1432	0.1433	*				
F1S2	*4*	0.1430	0.1432	0.1432	*			
F2S1	*5*	0.1431	0.1431	0.1431	0.1432	*		
F2S2	*6*	0.1432	0.1432	0.1432	0.1431	0.1433	*	
F3S1	*7*	0.1431	0.1430	0.1431	0.1430	0.1431	0.1431	*
F3S2	*8*	0.1432	0.1432	0.1432	0.1432	0.1432	0.1432	0.1432 *
		1	*2*	*3*	*4*	*5*	*6*	*7* *8*

S1 = Spacing at 60 cm triangular; S2 = Spacing at 80 cm triangular; F0 = control; F1 = Fertilizer application at 28.4:58.0:75.6:17.0 g seedling^{-1} N:P_2O_5:K_2O:MgO; F2 = Fertilizer application at 47.3:96.6:126.0:28.4 g seedling^{-1} N:P_2O_5:K_2O:MgO; F3 = Fertilizer application at 66.2:135.2:176.4:39.7 g seedling^{-1} N:P_2O_5:K_2O:MgO

Appendix 29. Regression analysis of collar girth of SGD x VTT coconut hybrid seedlings as influenced by spacing and fertilizer treatment

MPO	Source of Variation	DF	SS	MS	VR	Fpr.
1	Regression	7	2.3	0.3227	0.70	0.670^{NS}
	Residual	261	119.9	0.4594		
	Total	268	122.2	0.4558		
2	Regression	7	4.6	0.652	0.64	0.719^{NS}
	Residual	297	300.7	1.012		
	Total	304	305.3	1.004		
3	Regression	7	21.8	3.119	2.89	0.007**
	Residual	190	204.8	1.078		
	Total	197	226.6	1.150		
4	Regression	7	41.8	5.971	3.98	<.001**
	Residual	188	281.9	1.500		
	Total	195	323.7	1.660		
5	Regression	7	400.1	57.153	16.65	<.001**
	Residual	252	864.9	3.432		
	Total	259	1265.0	4.884		
6	Regression	7	496.	70.869	13.75	<.001**
	Residual	214	1103.	5.152		
	Total	221	1599.	7.234		

MPO = Months after pricking-out; DF = Degrees of freedom; SS = Sum of Squares; MS = Mean square; VR = Variance Ratio; Fpr = F-probability; NS = Not significant, P>0.05; ** = Significant at P<0.01

Appendix 30. LSD (0.05) of mean estimates for collar girth of SGD x VTT coconut hybrid seedlings as influenced by spacing and fertilizer treatment 3 months after pricking-out

F0S1	*1*	*							
F0S2	*2*	0.5763	*						
F1S1	*3*	0.5718	0.5426	*					
F1S2	*4*	0.5976	0.5697	0.5651	*				
F2S1	*5*	0.5917	0.5635	0.5589	0.5852	*			
F2S2	*6*	0.6181	0.5912	0.5868	0.6119	0.6062	*		
F3S1	*7*	0.6107	0.5834	0.5790	0.6044	0.5986	0.6248	*	
F3S2	*8*	0.5862	0.5577	0.5531	0.5797	0.5736	0.6008	0.5932	*
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*

S1 = Spacing at 60 cm triangular; S2 = Spacing at 80 cm triangular; F0 = control; F1 = Fertilizer application at 28.4:58.0:75.6:17.0 g seedling^{-1} N:P_2O_5:K_2O:MgO; F2 = Fertilizer application at 47.3:96.6:126.0:28.4 g seedling^{-1} N:P_2O_5:K_2O:MgO; F3 = Fertilizer application at 66.2:135.2:176.4:39.7 g seedling^{-1} N:P_2O_5:K_2O:MgO

Appendix 31. LSD (0.05) of mean estimates for collar girth of SGD x VTT coconut hybrid seedlings as influenced by spacing and fertilizer treatment 4 months after pricking-out

F0S1	*1*	*							
F0S2	*2*	0.6998	*						
F1S1	*3*	0.6998	0.67	*					
F1S2	*4*	0.7062	0.6767	0.6767	*				
F2S1	*5*	0.6883	0.6579	0.6579	0.6647	*			
F2S2	*6*	0.7204	0.6915	0.6915	0.698	0.6798	*		
F3S1	*7*	0.7204	0.6915	0.6915	0.698	0.6798	0.7124	*	
F3S2	*8*	0.7204	0.6915	0.6915	0.698	0.6798	0.7124	0.7124	*
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*

S1 = Spacing at 60 cm triangular; S2 = Spacing at 80 cm triangular; F0 = control; F1 = Fertilizer application at 28.4:58.0:75.6:17.0 g seedling^{-1} N:P_2O_5:K_2O:MgO; F2 = Fertilizer application at 47.3:96.6:126.0:28.4 g seedling^{-1} N:P_2O_5:K_2O:MgO; F3 = Fertilizer application at 66.2:135.2:176.4:39.7 g seedling^{-1} N:P_2O_5:K_2O:MgO

Appendix 32. LSD (0.05) of mean estimates for collar girth of SGD x VTT coconut hybrid seedlings as influenced by spacing and fertilizer treatment 5 months after pricking-out

F0S1	*1*	*						
F0S2	*2*	0.9502	*					
F1S1	*3*	0.8911	0.8997	*				
F1S2	*4*	0.9020	0.9104	0.8486	*			
F2S1	*5*	0.9421	0.9502	0.8911	0.9020	*		
F2S2	*6*	0.9272	0.9355	0.8754	0.8865	0.9272	*	
F3S1	*7*	0.9344	0.9426	0.8830	0.8940	0.9344	0.9195	*
F3S2	*8*	0.9139	0.9223	0.8613	0.8725	0.9139	0.8986	0.9061	*
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*

S1 = Spacing at 60 cm triangular; S2 = Spacing at 80 cm triangular; F0 = control; F1 = Fertilizer application at 28.4:58.0:75.6:17.0 g seedling^{-1} N:P_2O_5:K_2O:MgO; F2 = Fertilizer application at 47.3:96.6:126.0:28.4 g seedling^{-1} N:P_2O_5:K_2O:MgO; F3 = Fertilizer application at 66.2:135.2:176.4:39.7 g seedling^{-1} N:P_2O_5:K_2O:MgO

Appendix 33. LSD (0.05) of mean estimates for collar girth of SGD x VTT coconut hybrid seedlings as influenced by spacing and fertilizer treatment 6 months after pricking-out

F0S1	*1*	*						
F0S2	*2*	1.142	*					
F1S1	*3*	1.179	1.231	*				
F1S2	*4*	1.208	1.259	1.293	*			
F2S1	*5*	1.085	1.142	1.179	1.208	*		
F2S2	*6*	1.179	1.231	1.266	1.293	1.179	*	
F3S1	*7*	1.166	1.219	1.253	1.281	1.166	1.253	*
F3S2	*8*	1.153	1.207	1.242	1.27	1.153	1.242	1.229	*
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*

S1 = Spacing at 60 cm triangular; S2 = Spacing at 80 cm triangular; F0 = control; F1 = Fertilizer application at 28.4:58.0:75.6:17.0 g seedling^{-1} N:P_2O_5:K_2O:MgO; F2 = Fertilizer application at 47.3:96.6:126.0:28.4 g seedling^{-1} N:P_2O_5:K_2O:MgO; F3 = Fertilizer application at 66.2:135.2:176.4:39.7 g seedling^{-1} N:P_2O_5:K_2O:MgO

Appendix 34. Regression analysis of height of SGD x VTT coconut hybrid seedlings as influenced by spacing and fertilizer treatment

MPO	Source of Variation	DF	SS	MS	VR	Fpr.
1	Regression	7	229.	32.68	0.79	0.595^{NS}
	Residual	261	10769.	41.26		
	Total	268	10997.	41.03		
2	Regression	7	779.	111.23	1.54	0.155^{NS}
	Residual	277	20041.	72.35		
	Total	284	20820.	73.31		
3	Regression	7	654.	93.50	1.39	0.212^{NS}
	Residual	188	12645.	67.26		
	Total	195	13300.	68.20		
4	Regression	7	1523.	217.64	2.94	0.006**
	Residual	190	14081.	74.11		
	Total	197	15605.	79.21		
5	Regression	7	8504.	1214.8	10.98	<.001**
	Residual	295	32625.	110.6		
	Total	302	41159.	136.2		
6	Regression	7	2912.	416.1	2.26	<.030*
	Residual	214	39321.	183.7		
	Total	221	42233.	191.1		

MPO = Months after pricking-out; DF = Degrees of freedom; SS = Sum of Squares; MS = Mean square; VR = Variance Ratio; Fpr = F-probability; NS = Not significant, P>0.05; * = Significant at P<0.05; ** = Significant at P<0.01

Appendix 35. LSD (0.05) of mean estimates for height of SGD x VTT coconut hybrid seedlings as influenced by spacing and fertilizer treatment 4 months after pricking-out

F0S1	*1*	*							
F0S2	*2*	4.919	*						
F1S1	*3*	4.838	4.625	*					
F1S2	*4*	5.012	4.807	4.724	*				
F2S1	*5*	4.877	4.666	4.58	4.764	*			
F2S2	*6*	4.964	4.757	4.673	4.853	4.713	*		
F3S1	*7*	5.064	4.861	4.779	4.955	4.818	4.906	*	
F3S2	*8*	5.064	4.861	4.779	4.955	4.818	4.906	5.007	*
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*

S1 = Spacing at 60 cm triangular; S2 = Spacing at 80 cm triangular; F0 = control; F1 = Fertilizer application at 28.4:58.0:75.6:17.0 g seedling^{-1} N:P_2O_5:K_2O:MgO; F2 = Fertilizer application at 47.3:96.6:126.0:28.4 g seedling^{-1} N:P_2O_5:K_2O:MgO; F3 = Fertilizer application at 66.2:135.2:176.4:39.7 g seedling^{-1} N:P_2O_5:K_2O:MgO

Appendix 36. LSD (0.05) of mean estimates for height of SGD x VTT coconut hybrid seedlings as influenced by spacing and fertilizer treatment 5 months after pricking-out

F0S1	*1*	*						
F0S2	*2*	5.164	*					
F1S1	*3*	5.022	4.727	*				
F1S2	*4*	4.997	4.701	4.544	*			
F2S1	*5*	5.164	4.878	4.727	4.701	*		
F2S2	*6*	5.103	4.814	4.66	4.634	4.814	*	
F3S1	*7*	5.048	4.755	4.6	4.572	4.755	4.688	*
F3S2	*8*	5.022	4.727	4.571	4.544	4.727	4.66	4.6
		1	*2*	*3*	*4*	*5*	*6*	*7*

S1 = Spacing at 60 cm triangular; S2 = Spacing at 80 cm triangular; F0 = control; F1 = Fertilizer application at 28.4:58.0:75.6:17.0 g seedling^{-1} N:P_2O_5:K_2O:MgO; F2 = Fertilizer application at 47.3:96.6:126.0:28.4 g seedling^{-1} N:P_2O_5:K_2O:MgO; F3 = Fertilizer application at 66.2:135.2:176.4:39.7 g seedling^{-1} N:P_2O_5:K_2O:MgO

Appendix 37. LSD (0.05) of mean estimates for height of SGD x VTT coconut hybrid seedlings as influenced by spacing and fertilizer treatment 6 months after pricking-out

F0S1	*1*	*						
F0S2	*2*	6.819	*					
F1S1	*3*	7.039	7.352	*				
F1S2	*4*	7.214	7.519	7.72	*			
F2S1	*5*	6.480	6.819	7.039	7.214	*		
F2S2	*6*	7.039	7.352	7.557	7.720	7.039	*	
F3S1	*7*	6.961	7.277	7.484	7.648	6.961	7.484	*
F3S2	*8*	6.887	7.207	7.416	7.581	6.887	7.416	7.341
		1	*2*	*3*	*4*	*5*	*6*	*7*

S1 = Spacing at 60 cm triangular; S2 = Spacing at 80 cm triangular; F0 = control; F1 = Fertilizer application at 28.4:58.0:75.6:17.0 g seedling^{-1} N:P_2O_5:K_2O:MgO; F2 = Fertilizer application at 47.3:96.6:126.0:28.4 g seedling^{-1} N:P_2O_5:K_2O:MgO; F3 = Fertilizer application at 66.2:135.2:176.4:39.7 g seedling^{-1} N:P_2O_5:K_2O:MgO

Appendix 38. Regression analysis of leaf number of SGD x VTT coconut hybrid seedlings as influenced by spacing and fertilizer treatment

MPO	Source of Variation	DF	SS	MS	VR	Fpr.
1	Regression	7	1.19	0.1693	0.70	0.669^{NS}
	Residual	261	62.84	0.2408		
	Total	268	64.02	0.2389		
2	Regression	7	0.72	0.1024	0.31	0.947^{NS}
	Residual	297	96.87	0.3262		
	Total	304	97.59	0.3210		
3	Regression	7	1.92	0.2736	0.83	0.567^{NS}
	Residual	190	62.96	0.3314		
	Total	197	64.87	0.3293		
4	Regression	7	1.34	0.1913	0.60	0.754^{NS}
	Residual	190	60.34	0.3176		
	Total	197	61.68	0.3131		
5	Regression	7	2.0	0.2835	0.33	0.941^{NS}
	Residual	311	269.0	0.8650		
	Total	318	271.0	0.8522		
6	Regression	7	1.9	0.2718	0.51	0.828^{NS}
	Residual	214	114.4	0.5345		
	Total	221	116.3	0.5262		

MPO = Months after pricking-out; DF = Degrees of freedom; SS = Sum of Squares; MS = Mean square; VR = Variance Ratio; Fpr = F-probability; NS = Not significant, P>0.05; ** = Significant at P<0.01

Appendix 39. Regression analysis of canopy diameter of SGD x VTT coconut hybrid seedlings as influenced by spacing and fertilizer treatment

MPO	Source of Variation	DF	SS	MS	VR	Fpr.
4	Regression	7	1057.	151.04	2.86	0.007**
	Residual	190	10051.	52.90		
	Total	197	11108.	56.39		
5	Regression	7	4985.	712.16	10.57	<.001**
	Residual	253	17044.	67.37		
	Total	260	22029.	84.73		
6	Regression	7	3722.	531.68	5.95	<.001**
	Residual	214	19107.	89.28		
	Total	221	22829.	103.30		

MPO = Months after pricking-out; DF = Degrees of freedom; SS = Sum of Squares; MS = Mean square; VR = Variance Ratio; Fpr = F-probability; NS = Not significant, P>0.05; ** = Significant at P<0.01

Appendix 40. LSD (0.05) of mean estimates for canopy diameter of SGD x VTT coconut hybrid seedlings as influenced by spacing and fertilizer treatment 4 months after pricking-out

F0S1	*1*	*						
F0S2	*2*	4.156	*					
F1S1	*3*	4.087	3.907	*				
F1S2	*4*	4.235	4.061	3.991	*			
F2S1	*5*	4.122	3.942	3.87	4.025	*		
F2S2	*6*	4.194	4.019	3.948	4.100	3.982	*	
F3S1	*7*	4.278	4.107	4.037	4.186	4.071	4.145	*
F3S2	*8*	4.278	4.107	4.037	4.186	4.071	4.145	4.231
		1	*2*	*3*	*4*	*5*	*6*	*7*

S1 = Spacing at 60 cm triangular; S2 = Spacing at 80 cm triangular; F0 = control; F1 = Fertilizer application at 28.4:58.0:75.6:17.0 g seedling^{-1} N:P_2O_5:K_2O:MgO; F2 = Fertilizer application at 47.3:96.6:126.0:28.4 g seedling^{-1} N:P_2O_5:K_2O:MgO; F3 = Fertilizer application at 66.2:135.2:176.4:39.7 g seedling^{-1} N:P_2O_5:K_2O:MgO

Appendix 41. LSD (0.05) of mean estimates for canopy diameter of SGD x VTT coconut hybrid seedlings as influenced by spacing and fertilizer treatment 5 months after pricking-out

F0S1	*1*	*						
F0S2	*2*	5.0012	*					
F1S1	*3*	4.9911	5.0197	*				
F1S2	*4*	4.9020	4.9104	4.9486	*			
F2S1	*5*	4.9421	4.9502	4.8911	4.902	*		
F2S2	*6*	4.9272	4.9355	4.8754	4.8865	4.908	*	
F3S1	*7*	4.9344	4.9426	4.883	4.8940	4.940	4.973	*
F3S2	*8*	4.9139	4.9223	4.8613	4.8725	4.849	4.981	4.914
		1	*2*	*3*	*4*	*5*	*6*	*7*

S1 = Spacing at 60 cm triangular; S2 = Spacing at 80 cm triangular; F0 = control; F1 = Fertilizer application at 28.4:58.0:75.6:17.0 g seedling^{-1} N:P_2O_5:K_2O:MgO; F2 = Fertilizer application at 47.3:96.6:126.0:28.4 g seedling^{-1} N:P_2O_5:K_2O:MgO; F3 = Fertilizer application at 66.2:135.2:176.4:39.7 g seedling^{-1} N:P_2O_5:K_2O:MgO

Appendix 42. LSD (0.05) of mean estimates for canopy diameter of SGD x VTT coconut hybrid seedlings as influenced by spacing and fertilizer treatment 6 months after pricking-out

F0S1	*1*	*						
F0S2	*2*	4.753	*					
F1S1	*3*	4.907	5.125	*				
F1S2	*4*	5.028	5.241	5.381	*			
F2S1	*5*	4.517	4.753	4.907	5.028	*		
F2S2	*6*	4.907	5.125	5.268	5.381	4.907	*	
F3S1	*7*	4.852	5.073	5.217	5.331	4.852	5.217	*
F3S2	*8*	4.801	5.024	5.17	5.285	4.801	5.17	5.118
		1	*2*	*3*	*4*	*5*	*6*	*7*

S1 = Spacing at 60 cm triangular; S2 = Spacing at 80 cm triangular; F0 = control; F1 = Fertilizer application at 28.4:58.0:75.6:17.0 g seedling^{-1} $N:P_2O_5:K_2O:MgO$; F2 = Fertilizer application at 47.3:96.6:126.0:28.4 g seedling^{-1} $N:P_2O_5:K_2O:MgO$; F3 = Fertilizer application at 66.2:135.2:176.4:39.7 g seedling^{-1} $N:P_2O_5:K_2O:MgO$

Appendix 43. Regression analysis of vigour index of SGD x VTT coconut hybrid seedlings as influenced by spacing and fertilizer treatment

MPO	Source of Variation	DF	SS	MS	VR	Fpr.
4	Regression	7	21.1	3.0152	3.53	0.001**
	Residual	188	160.4	0.8531		
	Total	195	181.5	0.9307		
5	Regression	7	25.55	3.6494	10.28	<.001**
	Residual	247	87.65	0.3549		
	Total	254	113.20	0.4457		
6	Regression	7	78.5	11.2094	16.70	<.001**
	Residual	214	143.6	0.6711		
	Total	221	222.1	1.0049		

MPO = Months after pricking-out; DF = Degrees of freedom; SS = Sum of Squares; MS = Mean square; VR = Variance Ratio; Fpr = F-probability; NS = Not significant, P>0.05; ** = Significant at P<0.01

Appendix 44. LSD (0.05) of mean estimates for vigour index of SGD x VTT coconut hybrid seedlings as influenced by spacing and fertilizer treatment 4 months after pricking-out

F0S1	*1*	*						
F0S2	*2*	0.5278	*					
F1S1	*3*	0.5278	0.5053	*				
F1S2	*4*	0.5326	0.5104	0.5104	*			
F2S1	*5*	0.5191	0.4962	0.4962	0.5013	*		
F2S2	*6*	0.5433	0.5215	0.5215	0.5264	0.5127	*	
F3S1	*7*	0.5433	0.5215	0.5215	0.5264	0.5127	0.5373	*
F3S2	*8*	0.5433	0.5215	0.5215	0.5264	0.5127	0.5373	0.5373 *
		1	*2*	*3*	*4*	*5*	*6*	*7* *8*

S1 = Spacing at 60 cm triangular; S2 = Spacing at 80 cm triangular; F0 = control; F1 = Fertilizer application at 28.4:58.0:75.6:17.0 g seedling^{-1} N:P_2O_5:K_2O:MgO; F2 = Fertilizer application at 47.3:96.6:126.0:28.4 g seedling^{-1} N:P_2O_5:K_2O:MgO; F3 = Fertilizer application at 66.2:135.2:176.4:39.7 g seedling^{-1} N:P_2O_5:K_2O:MgO

Appendix 45. LSD (0.05) of mean estimates for vigour index of SGD x VTT coconut hybrid seedlings as influenced by spacing and fertilizer treatment 5 months after pricking-out

F0S1	*1*	*						
F0S2	*2*	0.3169	*					
F1S1	*3*	0.2986	0.2893	*				
F1S2	*4*	0.3020	0.2928	0.2729	*			
F2S1	*5*	0.3169	0.3081	0.2893	0.2928	*		
F2S2	*6*	0.3098	0.3008	0.2815	0.2851	0.3008	*	
F3S1	*7*	0.3120	0.3031	0.284	0.2875	0.3031	0.2957	*
F3S2	*8*	0.3057	0.2966	0.277	0.2806	0.2966	0.289	0.2914 *
		1	*2*	*3*	*4*	*5*	*6*	*7* *8*

S1 = Spacing at 60 cm triangular; S2 = Spacing at 80 cm triangular; F0 = control; F1 = Fertilizer application at 28.4:58.0:75.6:17.0 g seedling^{-1} N:P_2O_5:K_2O:MgO; F2 = Fertilizer application at 47.3:96.6:126.0:28.4 g seedling^{-1} N:P_2O_5:K_2O:MgO; F3 = Fertilizer application at 66.2:135.2:176.4:39.7 g seedling^{-1} N:P_2O_5:K_2O:MgO

Appendix 46. LSD (0.05) of mean estimates for vigour index of SGD x VTT coconut hybrid seedlings as influenced by spacing and fertilizer treatment 6 months after pricking-out

F0S1	*1*	*						
F0S2	*2*	0.4121	*					
F1S1	*3*	0.4254	0.4443	*				
F1S2	*4*	0.4359	0.4544	0.4665	*			
F2S1	*5*	0.3916	0.4121	0.4254	0.4359	*		
F2S2	*6*	0.4254	0.4443	0.4567	0.4665	0.4254	*	
F3S1	*7*	0.4207	0.4398	0.4523	0.4622	0.4207	0.4523	*
F3S2	*8*	0.4162	0.4355	0.4482	0.4582	0.4162	0.4482	0.4437 *
		1	*2*	*3*	*4*	*5*	*6*	*7* *8*

S1 = Spacing at 60 cm triangular; S2 = Spacing at 80 cm triangular; F0 = control; F1 = Fertilizer application at 28.4:58.0:75.6:17.0 g seedling^{-1} $N:P_2O_5:K_2O:MgO$; F2 = Fertilizer application at 47.3:96.6:126.0:28.4 g seedling^{-1} $N:P_2O_5:K_2O:MgO$; F3 = Fertilizer application at 66.2:135.2:176.4:39.7 g seedling^{-1} $N:P_2O_5:K_2O:MgO$

Appendix 47. Regression analysis of leaf nutrient of SGD coconut variety 30 months after fruit thinning studies

Leaf Nutrient	Source of Variation	DF	SS	MS	VR	Fpr.
Mg	Regression	2	0.00001	0.000007	0.01	0.995^{NS}
	Residual	24	0.03124	0.001302		
	Total	26	0.03125	0.001202		
Ca	Regression	2	0.0152	0.007578	1.68	0.208^{NS}
	Residual	24	0.1083	0.004512		
	Total	26	0.1234	0.004747		
N	Regression	2	0.0140	0.00700	0.26	0.770^{NS}
	Residual	24	0.6347	0.02645		
	Total	26	0.6487	0.02495		
P	Regression	2	0.0009	0.00046	2.56	0.098^{NS}
	Residual	24	0.0043	0.00018		
	Total	26	0.0052	0.00020		
K	Regression	2	0.0246	0.012318	2.66	0.090^{NS}
	Residual	24	0.1111	0.004631		
	Total	26	0.1358	0.005222		

DF = Degrees of freedom; SS = Sum of Squares; MS = Mean square; VR = Variance Ratio; Fpr = F-probability; NS = Not significant at P<0.05

Appendix 48. Regression analysis of coconut button, fruit set and fruit drop in the SGD coconut plot for the fruit thinning study

Fruit Count	Source of Variation	DF	SS	MS	VR	Fpr.
Coconut button	Regression	2	29.	14.50	0.079	0.995^{NS}
	Residual	6	1107.	184.50		
	Total	8	1136.	142.00		
Fruit set	Regression	2	39.	19.50	0.097	0.788^{NS}
	Residual	6	1207.	201.17		
	Total	8	1246.	155.75		
Fruit drop	Regression	2	34.	17.00	0.101	0.523^{NS}
	Residual	6	1012.	168.67		
	Total	8	1046.	130.75		

DF = Degrees of freedom; SS = Sum of Squares; MS = Mean square; VR = Variance Ratio; Fpr = F-probability; NS = Not significant at P<0.05

Appendix 49. Regression analysis of fruit weight of SGD coconut variety as influenced by fruit thinning

Fruit Weight	Source of Variation	DF	SS	MS	VR	Fpr.
Fresh Fruit 18 MAFT	Regression	2	516007.	258003.	24.6	<.001**
	Residual	32	335398.	10481.		
	Total	34	180609.	113823.		
Fresh Fruit 24 MAFT	Regression	2	1474898.	737449.	81.28	<.001**
	Residual	13	117945.	9073.		
	Total	15	1592843.	106190.		
Fresh Fruit 30 MAFT	Regression	2	4807958.	2403979	18.33	<.001**
	Residual	20	2623554.	131178.		
	Total	22	7431512.	337796.		
Dry Fruit 18 MAFT	Regression	2	37712.	18856.	5.17	0.012**
	Residual	29	105834.	3649.		
	Total	31	143546.	4631.		
Dry Fruit 24 MAFT	Regression	2	139524.	69762.	6.62	0.006**
	Residual	21	221425.	10544.		
	Total	23	360949.	15693.		
Dry Fruit 30 MAFT	Regression	2	293174.	146587.	10.85	<.001**
	Residual	31	418816.	13510.		
	Total	33	711990.	21575.		

DF = Degrees of freedom; SS = Sum of Squares; MS = Mean square; VR = Variance Ratio; Fpr = F-probability; ** = Significant at P<0.01

Appendix 50. LSD (0.05) of mean estimates for fruit weight of SGD coconut variety as influenced fruit thinning

Fresh Fruit 18 MAFT	FT0	*1*	*		
	FT1	*2*	114.0	*	
	FT2	*3*	118.3	120.3	*
			1	*2*	*3*
Fresh Fruit 24 MAFT	FT0	*1*	*		
	FT1	*2*	124.6	*	
	FT2	*3*	124.6	130.1	*
			1	*2*	*3*
Fresh Fruit 30 MAFT	FT0	*1*	*		
	FT1	*2*	208.0	*	
	FT2	*3*	238.2	217.1	*
			1	*2*	*3*
Dry Fruit 18 MAFT	FT0	*1*	*		
	FT1	*2*	72.90	*	
	FT2	*3*	72.90	75.25	*
			1	*2*	*3*
Dry Fruit 24 MAFT	FT0	*1*	*		
	FT1	*2*	112.5	*	
	FT2	*3*	112.5	100.7	*
			1	*2*	*3*
Dry Fruit 30 MAFT	FT0	*1*	*		
	FT1	*2*	103.6	*	
	FT2	*3*	99.7	97.1	*
			1	*2*	*3*

MAFT = Month after fruit thinning; FT0 = Control; FT1 = Thinning to 10 fruits per bunch; FT2 = Thinning to 15 fruits per bunch

Appendix 51. Regression analysis of husk weight of SGD coconut variety as influenced by fruit thinning

Husk Weight	Source of Variation	DF	SS	MS	VR	Fpr.
Fresh husk 24 MAFT	Regression	2	749332.	374666.	39.82	<.001**
	Residual	13	122314.	9409.		
	Total	15	871646.	58110.		
Fresh husk 30 MAFT	Regression	2	2417862.	1208931.	13.51	<.001**
	Residual	20	1790198.	89510.		
	Total	22	4208060.	191275.		
Dry husk 30 MAFT	Regression	2	12327.	6164.	5.9	0.036*
	Residual	31	32615.	1052.		
	Total	33	44942.	7216.		

DF = Degrees of freedom; SS = Sum of Squares; MS = Mean square; VR = Variance Ratio; Fpr = F-probability; ** = Significant at P<0.01

Appendix 52. Least significant predictions (5% level) for husk weight of SGD coconut variety as influenced by fruit thinning

Fresh husk 24 MAFT	FT0	*1*	*		*		
	FT1	*2*	126.9		132.5	*	
	FT2	*3*	126.9	*1*	*2*	*3*	
Fresh husk 30 MAFT	FT0	*1*	*		*		
	FT1	*2*	337.0		303.2	*	
	FT2	*3*	328.9	*1*	*2*	*3*	
Dry husk 18 MAFT	FT0	*1*	*		*		
	FT1	*2*	29.2		30.1	*	
	FT2	*3*	30.9	*1*	*2*	*3*	
Dry husk 24 MAFT	FT0	*1*	*		*		
	FT1	*2*	34.2		31.2	*	
	FT2	*3*	32.9	*1*	*2*	*3*	
Dry husk 30 MAFT	FT0	*1*	*		*		
	FT1	*2*	50.2		54.7	*	
	FT2	*3*	52.9	*1*	*2*	*3*	

MAFT = Month after fruit thinning; FT0 = Control; FT1 = Thinning to 10 fruits per bunch; FT2 = Thinning to 15 fruits per bunch

Appendix 53. Regression analysis of nut weight of SGD coconut variety as influenced by fruit thinning

Nut Weight	Source of Variation	DF	SS	MS	VR	Fpr.
Fresh Nut 18 MAFT	Regression	2	290141	145071.	13.42	<.001**
	Residual	32	346013.	10813.		
	Total	34	636154.	18710.		
Fresh Nut 24 MAFT	Regression	2	128116.	64058.1	77.84	<.001**
	Residual	32	10698.	822.9		
	Total	34	138814.	9254.3		
Fresh Nut 30 MAFT	Regression	2	406943.	203472.	32.80	<.001**
	Residual	32	124062.	6203.		
	Total	34	531005.	24137.		
Dry Nut 18 MAFT	Regression	2	13353.	6677.	4.65	0.018**
	Residual	32	41622.	1435.		
	Total	34	54975.	1773.		
Dry Nut 24 MAFT	Regression	2	11077.	5539.	5.19	<.037**
	Residual	32	53094.	2528.		
	Total	34	64171.	2790.		
Dry Nut 30 MAFT	Regression	2	185594.	92797.	21.88	<.001**
	Residual	32	131499.	4242.		
	Total	34	317093.	9609.		

DF = Degrees of freedom; SS = Sum of Squares; MS= Mean square; VR = Variance Ratio; Fpr = F-probability; ** = Significant at P<0.01

Appendix 54. LSD (0.05) of mean estimates for nut weight of SGD coconut variety as influenced by fruit thinning

Fresh Nut 18 MAFT	FT0	*1*	*		
	FT1	*2*	50.15	*	
	FT2	*3*	48.18	49.88	*
			1	*2*	*3*
Fresh Nut 24 MAFT	FT0	*1*	*		
	FT1	*2*	48.58	*	
	FT2	*3*	49.18	50.88	*
			1	*2*	*3*
Fresh Nut 30 MAFT	FT0	*1*	*		
	FT1	*2*	45.53	*	
	FT2	*3*	43.13	42.20	*
			1	*2*	*3*
Dry Nut 18 MAFT	FT0	*1*	*		
	FT1	*2*	59.18	*	
	FT2	*3*	60.18	58.95	*
			1	*2*	*3*
Dry Nut 24 MAFT	FT0	*1*	*		
	FT1	*2*	80.13	*	
	FT2	*3*	79.11	79.29	*
			1	*2*	*3*
Dry Nut 30 MAFT	FT0	*1*	*		
	FT1	*2*	89.04	*	
	FT2	*3*	90.87	89.42	*
			1	*2*	*3*

MAFT = Month after fruit thinning; FT0 = Control; FT1 = Thinning to 10 fruits per bunch; FT2 = Thinning to 15 fruits per bunch

Appendix 55. Regression analysis of shell weight of SGD coconut variety as influenced by fruit thinning

Shell Weight	Source of Variation	DF	SS	MS	VR	Fpr.
Fresh Shell 18 MAFT	Regression	2	31119.	15559.	5.03	0.013*
	Residual	32	98970.	3093.		
	Total	34	130088	3826.		
Fresh Shell 24 MAFT	Regression	2	8935.	4467.3	41.60	<.001**
	Residual	13	1396.	107.4		
	Total	15	10331.	688.7		
Fresh Shell 30 MAFT	Regression	2	17184.	8592.0	25.35	<.001**
	Residual	20	6779.	338.9		
	Total	22	23963.	1089.2		
Dry Shell18 MAFT	Regression	2	509	254.50	10.42	<0.001**
	Residual	29	708	24.41		
	Total	31	1217	278.91		
Dry Shell 24 MAFT	Regression	2	2640.	1319.8	6.01	0.009**
	Residual	21	4611.	219.6		
	Total	23	7251.	315.3		
Dry Shell 30 MAFT	Regression	2	24987.	12493.	11.11	<.001**
	Residual	31	34864.	1125.		
	Total	33	59851.	1814.		

DF = Degrees of freedom; SS = Sum of Squares; MS = Mean square; VR = Variance Ratio; Fpr = F-probability; ** = Significant at P<0.01

Appendix 56. LSD (0.05) of mean estimates for shell weight of SGD coconut variety as influenced fruit thinning

Fresh Shell 18 MAFT	FT0	*1*	*		
	FT1	*2*	14.63	*	
	FT2	*3*	15.01	14.21	*
			1	*2*	*3*
Fresh Shell 24 MAFT	FT0	*1*	*		
	FT1	*2*	15.56	*	
	FT2	*3*	14.56	154.16	*
			1	*2*	*3*
Fresh Shell 30 MAFT	FT0	*1*	*		
	FT1	*2*	19.74	*	
	FT2	*3*	20.24	18.96	*
			1	*2*	*3*
Dry Shell 18 MAFT	FT0	*1*	*		
	FT1	*2*	20.24	*	
	FT2	*3*	18.24	19.53	*
			1	*2*	*3*
Dry Shell 24 MAFT	FT0	*1*	*		
	FT1	*2*	30.0.	*	
	FT2	*3*	28.94	29.53	*
			1	*2*	*3*
Dry Shell 30 MAFT	FT0	*1*	*		
	FT1	*2*	30.88	*	
	FT2	*3*	31.17	29.02	*
			1	*2*	*3*

MAFT = Month after fruit thinning; FT0 = Control; FT1= Thinning to 10 fruits per bunch; FT2 = Thinning to 15 fruits per bunch

Appendix 57. Regression analysis of kernel weight of SGD coconut variety as influenced by fruit thinning

Kernel Weight	Source of Variation	DF	SS	MS	VR	Fpr.
Fresh Kernel 18 MAFT	Regression	2	30479.	15239.	9.05	<.001**
	Residual	32	53862.	1683.		
	Total	34	84341.	2481.		
Fresh Kernel 24 MAFT	Regression	2	3485.	1742.6	13.99	<.001**
	Residual	13	1619.	124.6		
	Total	15	5104.	340.3		
Fresh Kernel 30 MAFT	Regression	2	16948.	8473.8	21.79	<.001**
	Residual	20	7777.	388.9		
	Total	22	24725.	1123.9		
Dry Kernel 24 MAFT	Regression	2	189.	94.5	10.2	<.001**
	Residual	21	196.	9.33		
	Total	23	385.	103.8		
Dry Kernel 30 MAFT	Regression	2	31356.	15678.	11.43	<.001**
	Residual	31	42533.	1372.		
	Total	33	73889.	2239.		

DF = Degrees of freedom; SS = Sum of Squares; MS = Mean square; VR = Variance Ratio; Fpr = F-probability; ** = Significant at P<0.01

Appendix 58. LSD (0.05) of mean estimates for kernel weight of SGD coconut variety as influenced fruit thinning

Fresh Kernel 18 MAFT	FT0	*1*	*		
	FT1	*2*	30.19	*	
	FT2	*3*	29.55	30.94	*
			1	*2*	*3*
Fresh Kernel 24 MAFT	FT0	*1*	*		
	FT1	*2*	29.60	*	
	FT2	*3*	28.60	30.25	*
			1	*2*	*3*
Fresh Kernel 30 MAFT	FT0	*1*	*		
	FT1	*2*	20.22	*	
	FT2	3	19.68	19.99	*
			1	*2*	*3*
Dry Kernel 24 MAFT	FT0	*1*	*		
	FT1	*2*	25.01	*	
	FT2	*3*	23.78	24.95	*
			1	*2*	*3*
Dry Kernel 30 MAFT	FT0	*1*	*		
	FT1	*2*	39.01	*	
	FT2	*3*	40.78	38.95	*
			1	*2*	*3*

MAFT = Month after fruit thinning; FT0 = Control; FT1 = Thinning to 10 fruits per bunch; FT2 = Thinning to 15 fruits per bunch

Appendix 59. Regression analysis of water weight of SGD coconut variety as influenced by fruit thinning

Water Weight	Source of Variation	DF	SS	MS	VR	Fpr.
Fresh fruit Water 18 MAFT	Regression	2	35926.	17963.	7.16	0.003**
	Residual	32	80328.	2510.		
	Total	34	116254.	3419.		
Fresh fruit Water 24 MAFT	Regression	2	43879.	21939.6	41.35	<.001**
	Residual	13	6898.	530.6		
	Total	15	50777.	3385.1		
Fresh fruit Water 30 MAFT	Regression	2	141947.	70974.	22.99	<.001**
	Residual	20	61730.	3087.		
	Total	22	203678.	9258.		
Dry fruit Water 18 MAFT	Regression	2	3337.	1668.7	13.84	<.001**
	Residual	29	3496.	120.5		
	Total	31	6833.	220.4		
Dry fruit Water 24 MAFT	Regression	2	3921.	1960.7	5.56	0.012**
	Residual	21	7401.	352.4		
	Total	23	11323.	492.3		
Dry fruit Water 30 MAFT	Regression	2	22708.	11354.1	12.04	<.001**
	Residual	31	29236.	943.1		
	Total	33	51944.	1574.1		

DF = Degrees of freedom; SS = Sum of Squares; MS = Mean square; VR = Variance Ratio; Fpr = F-probability; ** = Significant at P<0.01

Appendix 60. LSD (0.05) of mean estimates for water weight of SGD coconut variety as influenced fruit thinning

Fresh fruit Water 18 MAFT	FT0	*1*	*		
	FT1	*2*	28.31		
	FT2	*3*	27.86		
				*	
				29.23	
				2	*
					3
Fresh fruit Water 24 MAFT	FT0	*1*	*		
	FT1	*2*	29.13		
	FT2	*3*	30.83		
				*	
				31.97	
				2	*
					3
Fresh fruit Water 30 MAFT	FT0	*1*	*		
	FT1	*2*	50.59		
	FT2	*3*	51.08		
				*	
				49.31	
				2	*
					3
Dry fruit Water 18 MAFT	FT0	*1*	*		
	FT1	*2*	15.31		
	FT2	*3*	15.86		
				*	
				15.23	
				2	*
					3
Dry fruit Water 24 MAFT	FT0	*1*	*		
	FT1	*2*	25.13		
	FT2	*3*	24.83		
				*	
				25.97	
				2	*
					3
Dry fruit Fruit 30 MAFT	FT0	*1*	*		
	FT1	*2*	30.37		
	FT2	*3*	3134		
				*	
				30.66	
				2	*
					3

MAFT = Month after fruit thinning; FT0 = Control; FT1 = Thinning to 10 fruits per bunch; FT2 = Thinning to 15 fruits per bunch

Appendix 61. Regression analysis of crude protein content of SGD coconut variety as influenced by fruit thinning

Crude Protein	Source of Variation	DF	SS	MS	VR	Fpr.
Crude Protein 30 MAFT	Regression	2	2.5203	1.26013	26.61	0.001**
	Residual	6	0.2841	0.04736		
	Total	8	2.8044	0.35055		

DF = Degrees of freedom; SS = Sum of Squares; MS = Mean square; VR = Variance Ratio; Fpr = F-probability; ** = Significant at P<0.01

Appendix 62. LSD (0.05) of mean estimates for crude protein content of SGD coconut variety as influenced fruit thinning

Crude	FT0	*1*	*			
Protein 30	FT1	*2*	0.4348		*	
MAFT	FT2	*3*	0.4348		0.4349	*
			1		*2*	*3*

MAFT = Month after fruit thinning; FT0 = No fruit thinning; FT1 = Thinning to 10 fruits per bunch; FT2 = Thinning to 15 fruits per bunch

Appendix 63 Regression analysis of ascorbic acid (Vitamin C) content of SGD coconut variety as influenced by fruit thinning

Ascorbic Acid	Source of Variation	DF	SS	MS	VR	Fpr.
Ascorbic	Regression	2	1.2448	0.62241	11.08	0.010**
Acid 30	Residual	6	0.3371	0.05618		
MAFT	Total	8	1.5819	0.19774		

DF = Degrees of freedom; SS = Sum of Squares; MS = Mean square; VR = Variance Ratio; Fpr = F-probability; **= Significant at P<0.01

Appendix 64. LSD (0.05) of mean estimates for ascorbic acid (Vitamin C) content of SGD coconut variety as influenced fruit thinning

Ascorbic	FT0	*1*	*			
Acid 30	FT1	*2*	0.4735		*	
MAFT	FT2	*3*	0.4735		0.4736	*
			1		*2*	*3*

MAFT = Month after fruit thinning; FT0 = Control; FT1 = Thinning to 10 fruits per bunch; FT2 = Thinning to 15 fruits per bunch