

**EFFECTS OF PLANTING DATE AND PROPAGATION METHOD
ON GROWTH AND YIELD OF ONION (*Allium cepa*) IN TWO
SEASONS (DRY AND WET)**

BY

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**DEPARTMENT OF CROP SCIENCE
FACULTY OF AGRICULTURE
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BENIN CITY, NIGERIA**

JULY, 2025.

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**BEING THESIS SUBMITTED TO THE SCHOOL OF POSTGRADUATE
STUDIES IN PARTIAL FULFILLMENT OF THE REQUIREMENT
FOR THE AWARD OF MASTER OF SCIENCE (M.Sc.) DEGREE IN
THE DEPARTMENT OF CROP SCIENCE, FACULTY OF
AGRICULTURE, UNIVERSITY OF BENIN,
BENIN CITY, NIGERIA**

CERTIFICATION

This is to certify that the work Effects of Planting Date and Propagation Method on the Growth and Yield of Onion (*Allium cepa*) in two Seasons (Dry and Wet) was carried out by **Somtochukwu Angela NWATTAH** in the Department of Crop Science, Faculty of Agriculture, University of Benin, Benin City, Nigeria.

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DEDICATION

This work is dedicated to my father Mr. Nwattah Peter C. for his love, unwavering support and being a shoulder to lean on.

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to everyone who contributed to the successful completion of my thesis. If I have seen further, it is by standing on the shoulders of giants. Firstly, I want to thank my supervisor, Dr. Mrs. E.J. Falodun, for her invaluable guidance, support, and the direction she provided throughout my studies. I am profoundly grateful to the Head of the Department of Crop Science, Prof. S. U. Ewansiha, and the Dean of the Faculty of Agriculture, Dr. O. M. Wangbojie, for their fatherly encouragement and support. I would also like to acknowledge the contributions of the esteemed staff members of the Department of Crop Science: Prof. A.T. Adekunle, Prof. C. N. C. Nwaoguala for his active and fatherly role in ensuring my academic success, Prof. K. E. Law-Ogbomo whom I consider a father – always willing to listen and guide me in the right direction, Prof. T. O. Emede, Prof. A. U. Osaigbovo, Prof. S. A. Ogedegbe, Prof. K. O. Ogbedeh, Dr. C. C. Nwafor, Dr. C. I. Aisagbonhi, Dr. M. E. Omoregie (Mrs.), and Mr. J. O. Osagie. Their constructive criticisms, corrections, and constant encouragement have been instrumental in my academic journey. The time and effort they dedicated to reviewing my work and guiding me through seminars are deeply appreciated.

To the non-academic staff of the Department of Crop Science; Mrs. E. J. Eguae, Barr. (Mrs.) N. E. Isiokherhe, Mrs. I. Iyamu, Mr. Augustine Nwaonicha, Mrs. Rose Oseghale, and Miss E. I. Omorodion-Osagie, thank you for your time and efforts in ensuring my studies were successful.

Sincere gratitude goes to my dad without whom I wouldn't have been able to further my studies. Papa, you are my hero papa and I'm deeply grateful for this opportunity you gave to me, your words of encouragement, the sacrifices you made, constant prayers and support. To my brother, Kamsiyo, thank you for always being my muse.

Lastly, to my dear friend Charles, thank you for being my confidant and the one i could always count on.

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ABSTRACT

This study was conducted at the University of Benin, Faculty of Agriculture experimental farm, from October 2021 to Oct 2022, to determine the best propagation method and planting date for enhanced growth and yield components of onion (*Allium cepa*) in two seasons (dry and wet) in a rainforest zone of Nigeria. Onions were cultivated using sets and seeds on four planting dates in each season. The experiment was laid out in a factorial design, comprising 8 treatments for each season (P1D1, P1D2, P1D3, P1D4, P2D1, P2D2, P2D3, P2D4) in three replications, where P represents propagation methods (P1: set and P2: seed), and D planting dates for Dry (D1: Oct 10th, D2: Oct 24th, D3: Nov 7th and D4: Nov 21st) and Wet (D1: Mar 6th, D2: Mar 20th, D3: April 3rd and D4: April 17th) season.

Data on growth and yield parameters, including plant height (cm), number of leaves per plant, stem diameter (cm), bulb length (cm), bulb diameter (cm), number of bulbs per stand, bulb weight per plot (g/m²), and yield (t ha⁻¹), were collected and subjected to statistical analysis. Results showed significant effects of propagation method, planting date, and season on most parameters measured.

During vegetative growth, seasonal effects influenced the number of leaves, which was higher in the wet season (16.47) than in the dry season (11.78), while plant height and stem diameter showed no significant differences. Set propagation yielded significantly over seed propagation higher plant height (49.14 cm), number of leaves (29.98) both on planting date April 17 and stem diameter (1.88 cm) on planting date Nov 21. For yield components, dry season cultivation produced significantly higher bulb diameter (9.35 cm), bulb weight per plot (976 g/m²), and yield (9.76 t ha⁻¹) compared to the wet season. However, bulb length and the number of bulbs per stand were not significantly affected by season.

During the dry season, bulb-propagated onions had the tallest plants (49.07 cm), most leaves (22.15), widest stems (2.37 cm), longest bulbs (6.85 cm), and largest bulb diameter (10.19 cm). They also produced more bulbs per stand (3.79), higher bulb weight (1419 g m⁻²), and the highest yield (14.19 t ha⁻¹). The best planting date was October 10, yielding 12.54 t ha⁻¹. During the wet season, bulb propagation again led with taller plants (46.48 cm), more leaves (22.24), wider stems (1.89 cm), and higher yield (6.83 t·ha⁻¹). The longest bulbs (7.70 cm) were observed in bulb-propagated onions planted on March 6, showing a significant interaction. Highest yield was obtained from the April 17 planting (5.92 t·ha⁻¹). The study recommends bulb propagation and October 10 planting date (Dry season) for optimal onion production in a rainforest zone of Nigeria.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the study

Onion (*Allium cepa*) belongs to the family *Alliaceae*, It is believed to have originated in Asia, specifically in regions corresponding to present-day Iran and Pakistan, where it has been cultivated since approximately 6,000 B.C. The name "onion" is derived from the Latin word "unus," meaning "one," possibly in reference to its single, unified bulb. Globally, an estimated 3.6 million hectares of onions are cultivated annually.

Onion also referred to as bulb or common onion, is the most widely grown species of the *Allium* genus. It can be either annual or biennial, depending on the cultivar (WHO, 1999). The plant has bulb and tubular leaves (Ranjitkar, 2003). The stem grows 100–200 cm tall, while the bulb ranges in shape from flat to globular or oblong, and comes in three colors: red, white and yellow (Fristch, 2005). The fruits are capsule containing black seeds. The onion bulb which can grow up to 10 cm in diameter is composed of several overlapping layers around a central core. The outer leaf bases of the bulb lose moisture and become scaly by the time of harvest.

Onion is a bulbous plant with a shortened stem called a plateau, which has cylindrical, hollow leaves on the upper part and adventitious roots emerging from the lower part (Abdou *et al.*, 2016). The leaves are arranged alternately, forming two rows facing each other (Hadri *et al.*, 2023). The roots are numerous and whitish (Stephane *et al.*, 2016). Onions have shallow, fasciculated roots that are slightly branched and extend 0.20–0.25 m deep into the soil (Andresen *et al.*, 2016; Miguel *et al.*, 2017). This limited root depth restricts water uptake in deep soils, thereby increasing their susceptibility to drought (Rao *et al.*, 2016). The flowers exhibit trimeric symmetry, with three sepals and three petals. Each flower

contains six stamens and a three-loculated, superior ovary, each of which holds two large ovules. Pollen is released prior to the stigma's receptivity. This promotes cross-pollination among onion plants. Typically, each cluster yields between 100 and 1,500 seeds (De Lannoy *et al.*, 2001).

Onions has been valued as both food and medicinal plant and are widely cultivated and consumed globally (FAO, 2012). Thomas (2016) reported that onion is a rich source of nutrients, including vitamin B, and C, protein, fiber, starch and a series of essential elements. He revealed that the chemicals contained in onions are effective agents against fungal and bacterial growth; they protect against stomach, colon and skin cancers; they have anti-inflammatory, anti-allergenic and anti-diabetic actions; and they treat causes of cardiovascular disorders, including hypertension, hyperglycemia and hyperlipidemia while also inhibiting platelet aggregation. Onion has its own distinctive flavor and used in soups, dishes, salad and sandwiches and is cooked alone as a vegetable. It is consumed at its young green stage or after its full development and maturity when it is harvested in the form of a dry bulb. The mature bulbs contain some starch, appreciable quantities of sugar, some protein, and vitamins A, B and C (Jilani *et al.*, 2010).

Onions grow best in nutrient-rich, humus soil with pH range of 6 – 7. The soil should be loose, loamy and free of weeds and stones, with regular supply of water and good drainage. Slightly acidic, fertile soils in full sun are ideal. Onions are heavy feeders and benefit from nutrient supplementation, often provided through inorganic fertilizers.

Onions can be propagated by seeds or sets, depending on market demand, personal preferences, or experimental requirements. Propagation by seeds involves nurturing seedlings for about seven weeks before transplanting them into the field. Though seed propagation is slower, it allows for the selection of healthy, vigorous plants for

transplanting. This method is often seen as more economical, as propagating by sets is considered wasteful by some.

Onions sets are small, dry bulbs which can be used for cultivation preferably dry to avoid decaying when planted. Dry bulb are commonly established in the field either by direct sowing of seeds to the field, or by transplanting seedlings from seedbed or from sets depending on the local growing conditions. Sowing seeds directly into the field where the crop is to be grown is considered an economical method of producing particularly where there is limited availability of labor for transplanting, high labor cost, or limited availability of facilities for raising transplants (Brewster, 2002).

Set are usually preferred in areas where the growing season is too short for proper bulb development. Transplanting offers more advantages on economic use of seed, selecting healthy and vigorous seedlings, saving weeding and watering efforts during the early weeks of plant growth, and enabling farmers to attend the seedlings in a compact area (Lemma and Shimeles, 2003).

Planting dates play a crucial role in the growth, development and yield of onions. Different planting times expose crops to varying levels of radiation and weather conditions, which can alter plant morphology.

Before bulbing begins onions require a certain amount of vegetative growth to respond to day length. At a specific threshold, past the “juvenile” stage of leaf growth, the plant becomes sensitive to the bulbing stimulus that is triggered if the days are long enough (Ibrahim, 2010). Bulbing occurs only if the average daily temperature is 60 °F (16°C) or above, and the average night temperature is 60–80°F (16–28°C) (Ibrahim, 2010). If the requirement for day length is not met (that is, the days are not long enough when the onion plant is physiologically mature) leaf production continues without bulb formation (Ibrahim,

2010). Bulbing response is reported to be stronger when night-time temperatures are low and the plants are large (Ibrahim, 2010).

In most onion-producing regions, bulb-formation occurs under increasing photoperiods, and the minimal requirements are between 12 and 16 hours of increasing light, though this depends on the onion cultivar (Ibrahim, 2010). Cultivars adapted to low latitudes need shorter day lengths to induce flowering than cultivars adapted to higher latitudes (Kiani *et al.*, 2023).

In the hottest regions, onions might suffer from sunscald in full sun, this is a heat damage (basically cooking the onion!), this is more likely to occur when growing in dark soils. To prevent sunscald, the soil should be kept moist and well mulched to regulate soil temperature.

In Nigeria, onions are typically cultivated in October or November, taking about 3 to 4 months to mature. Being a long-day crop, onions perform best under full sun, which is why the majority of onions consumed in Nigeria are produced in the northern regions, where hotter weather favors bulb formation (Google Search, 2024), specifically in Kaduna, Kano, Jigawa, Katsina, Sokoto, Kebbi, Plateau and Bauchi States (Anyanwu, 2003). However, information on the effect of planting seasons on onion growth and yield in Nigeria remains inconclusive.

Despite onions being a staple crop with high demand for culinary and medicinal purposes, its cultivation in southern Nigeria, particularly in the rainforest region of Edo State, is underexplored. This region's unique climate poses challenges for onion production, particularly in balancing the photoperiod and temperature requirements necessary for optimal bulb formation. Furthermore, local farmers often lack precise information on the best propagation methods and planting dates to maximize yield.

Addressing these gaps is critical to improving onion production in the region, reducing reliance on imports from northern Nigeria, and enhancing local food security. By identifying the optimal planting dates and propagation methods for wet and dry seasons, this study seeks to provide actionable insights that can boost productivity and economic returns for farmers in southern Nigeria. This justifies the need to explore suitable propagation methods and planting dates for onion cultivation in Edo State.

1.2 Objective of the study

For successful onion cultivation in the southern part of Nigeria, specifically Edo state, it is essential to choose the best propagation methods and optimum planting dates. Therefore, the objectives of this study are to determine:

- i. the optimum planting date for onion growth and yield in the rainforest region of Edo State, Nigeria;
- ii. the best method of propagation for onion growth and yield in the rainforest region of Edo State, Nigeria.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Cultural Practices

Climatic Requirements

Optimal onion production necessitates specific climatic conditions. Climatic elements, such as temperature, radiation and rainfall, may act in the different stages of crop development, affecting their efficiency in the use of water and the nutrient absorption capacity, changing the cycle, the bulbs formation and quality, especially the acidity and the soluble solids content.

Most plant problems are caused by environmental stress, either directly or indirectly. Many studies support that these environmental factors include temperature, humidity, drought, flooding, soil properties, agronomic factors, high salinity, cold, and heat influence plant growth (Singh *et al.*, 2016; Sharma, 2020). The growth and development of onions are also influenced by various environmental factors, including temperature, light, and humidity (Deshi *et al.*, 2018). These parameters are important in determining postharvest quality, since a higher acidity is desirable for industrial due to improved dehydration, while high levels of soluble solids enhance onion palatability (Bispo *et al.* 2018).

Vegetative growth of onions thrives within a temperature range of 15-20°C, while bulb development requires a temperature between 20-27°C. Carbon dioxide (CO₂), another key environmental element, enhances plant production by increasing photosynthetic rates while reducing photorespiration and transpiration (Martinez *et al.* 2015).

Phenological stages of onion in the first year were described by Brewster and Brewster (2008) as follows:

- Germination to cotyledon emergence,
- Completion of germination when seven leaves are present,
- Onset of bulbing with the appearance of the seventh leaf and senescence of the first,
- Expansion to 8–12 leaves with maximum plant height,
- Rapid growth of the stem and the fall of the 4-6th leaves,
- Stem collapse, and
- Drying outer skin of the onion.

Low temperature in early stages of growth followed by long days is important for production of bulbs (Etoh and Simon, 2009). The optimal temperature for seedling growth is 20 to 25°C. During early stages of growth and development, cool temperatures, 6–20°C, are required and during bulb formation, temperatures of 25–27°C are needed (Ansari, 2007). As soon as the required minimum day length for an onion cultivar is met, and temperatures start to increase, bulbs will be initiated (Brewster and Brewster, 2008).

For economic production of onion bulbs, onions should be adapted in terms of photoperiod and local temperature to produce larger stems without transitioning to flowering (bolting) (Rabinowitch and Currah, 2002). Longer days and increasing temperatures accelerate bulb development, but temperatures above 25–31°C reduce yield. Flowering is triggered at temperatures between 5–13°C (Sekara *et al.*, 2017).

In the context of climate change, global warming poses significant challenges to onion cultivation, including more frequent and intense heavy precipitation and droughts (IPCC, 2021). Onions, being shallow-rooted and sensitive to water deficits are particularly vulnerable during their growth and bulb formation phase (Kadayifci *et al.*, 2004). Drought stress adversely affects morphological parameters such as plant height, number of leaves, and leaf area, leading to yield losses of up to 65% in onions (Yetagesu *et al.*, 2020).

A crucial factor in plant growth is the moisture content present in the air, which is scientifically referred to as relative humidity (RH). Relative humidity is a term that has been defined in numerous studies as the ratio of the current amount of water vapor present in the air to the maximum amount of water vapor the air could potentially hold at the same temperature (Meena and Suman, 2024; Vaniya and Mahatma, 2023; Wakchaure *et al.*, 2018; Lysenko *et al.*, 2023). Relative humidity of ambient air is a critical parameter for crop production as it influences the water balance and photosynthesis process in the plants (Chia and Lim, 2022).

Several studies have stated that humidity plays an important role in crop production as it influences the water balance, leaf transpiration and photosynthesis processes in plants. Studies also show that a low level of humidity will lead to low moisture and increase stomatal resistance, which leads to a reduction in carbon dioxide uptake and photosynthesis rate (Han *et al.*, 2019; Amani *et al.*, 2020; Hsie *et al.*, 2015), while a high humidity level will lead to mold and bacteria growth and can even cause development disorder (Abidin *et al.*, 2024; Thazin *et al.*, 2019).

Changes in the relative humidity and temperature can have a direct impact on the photosynthesis process, thus it will influence the growth and development of plants. This can pose a significant challenge for plants that have a limited ability to regulate their water loss that could lead to dehydration and potential damage to the plant. Multiple studies reported that controlling humidity plays a crucial role in plant growth and yield (Gulandaz *et al.*, 2024; Mañas *et al.*, 2024; Boughamsa *et al.*, 2015; Hadidi *et al.*, 2022). Study conducted by (Zheng *et al.*, 2020) suggested that humidity levels between 60% to 70% maintain the optimal growth of plants.

Light and temperature significantly influence the bulb formation process in onions, both factors must be optimal for bulb initiation. Cool conditions are typically required during the initial growth stages while warm and dry weather is necessary for harvesting and curing. Additionally, each onion cultivar exhibits varying sensitivities to day-length, impacting their bulbing responses (Savva and Frenken, 2002). After bulb formation begins, high temperature and low relative humidity extending into the harvest and curing period are desirable (Jilani *et al.*, 2010).

Soil Management

Onions prefer soil with a pH ranging from 6.0 to 7.0 (Ibrahim *et al.*, 2017; Nanesa Tufa, 2019). Onions can be grown on a wide range of soils, varying in texture from coarse-grained sands to clays. Lighter soils are easy to manage. Soils should be 45-60 cm deep and well drained. Soils with high water holding capacity are better able to provide moisture to the shallow rooting system but must also drain well to be suitable. Growth is retarded when available soil moisture is low, but onions are also sensitive to a high water table or water logging. Uniform moisture availability about 400-800mm per crop is conducive to large bulb size and high yields, favorable soil pH is about 6.5–8.0 in mineral soils (Savva and Frenken, 2002). Regular irrigation is also necessary to maintain a high soil moisture content, which is crucial for achieving optimum yields (Al-Jamal *et al.*, 2000).

High organic matter (OM) in soils allows for a lower target pH (around 5.6), as OM buffers acidity. A soil pH of 6.7 was found suitable for onion production in Changnyeong, Korea (Lee, 2010). If the pH of a soil is significantly lower, lime application is needed to neutralize the acidity and raise the pH (Anonymous, 2012). Ideal onion soil are well drained loams, fertile and preferably rich in humus capable of retaining moisture during the dry (Anyanwu, 2003).

In scanty precipitation environment, less moisture in the soil and very fast water evaporation from the upper portion of the soil hinders quality onion bulb development due to onion's shallow root system. Thus it is very much important to keep moist the upper part of the soil for bulb development.

Since onion is sensitive to water-logging mulching is very effective in maintaining soil moisture. Mulching can manipulate microclimate and supporting bulb development of onion (Abu-Rayyan and AbuIrmaileh, 2004). Mulching has been used for altering the agricultural soil (Chalker-Scott, 2007) and soil temperatures (Lamont, 2005), conserve soil moisture (Bandyopadhyay *et al.*, 2009), viable for horticultural crops (Gimenez *et al.*, 2002) and control weed germination, suppress their growth (Rathinasabapathi *et al.*, 2005) and protect the crop from insects or disease (Ngouajio *et al.*, 2008).

Nutrients leaching losses can also be minimized (Gordon *et al.*, 2010) and improve crop production through increasing soil quality by conserving soil moisture, enhancing soil biological activities, and improving the chemical and physical properties of soil (Iqbal *et al.*, 2009). Mulches are generally inorganic gravel, pebbles, or polyethylene film, organic straw, hyacinth, wood, bark, or leaves, used individually or in mixtures, or living grass and clover materials.

In developing countries, organic and plastic sheet usually preferred because of its low cost and extensive availability. The color of plastic mulch influences microclimatic conditions around the plant by affecting light absorption and reflection (Ahmed *et al.*, 2013).

Fertilization and Nutrient Management

Fertilization plays a critical role in enhancing onion yield and quality. Mineral fertilizers are one of the principal factors that materially set up onion growth and production. Onion plants

take up large amounts of the three primary nutrients, i.e. nitrogen, phosphorus and potassium (Kandil *et al.*, 2013).

Shallot plants, a type of onion, require sufficient and balanced amounts of nitrogen (N), phosphorus (P), and potassium (K), along with other essential nutrients (Purba, 2014). The application of N, P, and K fertilizers has been shown to significantly increase both growth and bulb yield (Singh *et al.*, 2000). Regular nitrogen application, particularly at two and six weeks post-transplanting, improves plant height, leaf number, bulb size, and marketable yield (Singh *et al.*, 2000; Hussaini and Amans, 2000; Nasreen *et al.*, 2007; Al-Fraihat, 2009). Due to their shallow, unbranched root systems, onions are particularly responsive to addition of fertilizers (Rizk *et al.*, 2012).

Increasing nitrogen application rates significantly enhances plant height, number of green leaves per plant and weight of bulb, marketable yield and also total soluble solids (Nasreen *et al.*, 2007; Al-Fraihat, 2009). In addition to nitrogen, plant spacing is an important factor determining onion yield and quality.

Soil nutrient losses due to water-logging can cause significant impact on plant health. Proper nutrient management is needed to mitigate the harmful effects of water-logging and attain better crop performance (Noreen *et al.*, 2018). In waterlogged conditions, soil nitrogen (N) is lost due to leaching; resulting in reduced uptake by plants and N deficiency in both plants and soil (Nguyen *et al.*, 2018).

Early crop vigor may be linked to enhanced nitrogen uptake (Sundgren *et al.*, 2018). Additionally, plant growth and development can be improved with the application of slow-release N fertilizers, as they release nitrogen over a prolonged period during crop growth and make it available as per crop demand (Shaviv, 2001; Dinnes *et al.*, 2002; Lubkowski and Grzmil, 2007; Varadachari and Goertz, 2010; Trenkel, 2021).

Unmarketable bulb yield of onion is related to the under sized bulb which is below 20 g, diseased, decayed, physiological disorder such as thick necked, splits and bolters. Disorders are influenced by location, season, cultivar, and management practice. On the other hand, thick necked also occurs mainly when some of the proportion of bulbs fail to complete bulbing in which the leaves continue growing. Under this condition, the neck does not get soften and the bulb does not become dormant.

Heavy and continuous watering and late application of nitrogen contribute to this disorder (Lemma and Shimeles, 2003).

Jilani *et al.* (2009) reported that application of higher nitrogen of 120 kg ha⁻¹ recorded the maximum bulb size while the minimum bulb size was recorded in control, Nitrogen fertilization significantly extended the number of days required for onion crop to attain its physiological maturity. Abdissa *et al.* (2011) similarly noted that regardless of the rate, N fertilization extended physiological maturity by about 6 days over the unfertilized treatment.

Plant Density and Spacing

An essential aspect of any crop production system is the development of a crop canopy that optimizes the interception of light, photosynthesis, and the allocation of dry matter to harvestable parts. A crop canopy is commonly managed by manipulating row spacing and plant population; as plant density increases, yield per unit area increases and will approach an upper limit, the plateau. Then, the yield per unit area declines since yield per plant tends to decrease with further increase in the plant density because of competition for growth factors between adjacent plants (Silvertooth, 2001). Thus, spacing is an important factor for the production of onion since it affects both bulb yield and quality. Planting density greatly influences quality, texture, taste and yield of onion even within a particular variety (Saud *et al.*, 2013).

Dorcas *et al.* (2012) reported that with increasing plant density of onion from 100,000 plants ha⁻¹ to 500,000 plants ha⁻¹ average bulb weight and bulb diameter decreased from 58.22 g to 40.04 g and 4.56 cm to 2.83 cm respectively. Yemane *et al.* (2013) indicated that with increasing intra-row spacing from 5 to 10 cm, statistically bulb diameter and bulb neck diameter of onion increased from 4.66 to 5.63 cm and 1.48 to 1.74 cm respectively. Dawar *et al.* (2005) noted that as plant population increased from 40 to 80 plants m⁻² onion neck diameter declined significantly.

Jilani *et al.* (2009) indicate that bulbs of thick neck were found in plots of lowest plant density (20 plants m⁻²). Bulb neck diameter decreased as population density increased. Mean bulb weight and plant height decreased as population density increased (Kantona *et al.*, 2003).

Based on this, the maximum yield were recorded from 20 cm x 10 cm spacing and the narrow plant spacing produced comparatively lower values on fresh weight of leaves per plant, plant height, leaves number per plant, bulb diameter and fresh weight of bulb. Latif *et al.* (2010) showed that yield of onion bulbs produced at the spacing of 20 cm x 10 cm was recorded as the highest compared to 20 cm x 20 cm spacing. Mahadeen, (2008) also reported that narrow intra-row spacing produced higher yield.

Summarily, yield of onion increases with an increase in plant population because plant densities allowed the canopy to close quickly reducing the ability of weeds to compete, but only up to an optimal limit and yield will decrease beyond this optimum. Appropriate spacing enables the farmers to keep appropriate plant population in their field. Hence, a farmer can avoid over and less population in a given plot of land, which has negative effect on yield. Therefore, to avoid nutrient competition due to inappropriate use of plant spacing

and N fertilizer, sufficient spacing between plants and rows and optimum amount N fertilizer application is vital to get highest yield in a given plot of land (AVRDC, 2004).

Water Requirement

Optimal soil moisture is essential for onions to produce high yields (Kadayifci *et al.*, 2005). Water requirements for onion production depend on several factors such as the season, variety, plant density, cultivation techniques, expected productivity, soil type, climate, and irrigation practices (Jiménez *et al.*, 2010). Onions are highly sensitive to water stress compared to other crops with deeper root systems (Fitsum *et al.*, 2016). For this reason, irrigation, especially during the bulb development phase, appears to be important for achieving higher yields (Kadayifci *et al.*, 2005).

A decrease in soil moisture leads to a reduction in onion plant height in the field (Yetagesu *et al.*, 2020). Field and greenhouse experiments have demonstrated that 20–45 days of drought negatively affect morphological parameters such as leaf number, leaf length, leaf width, and leaf area, resulting in high rate of leaf senescence (Ghodke *et al.*, 2018, Chaudhry *et al.*, 2020, Gökçe *et al.* 2022). This proves that leaf senescence is a typical symptom during drought, which increases with stress severity in onions (Gedam *et al.*, 2021). At the root level, drought reduces meristematic activity, halting root elongation and bulbification (Singh *et al.*, 2016).

The production, productivity, and innate nutritional potential of onions are immensely affected by the intervention of biotic and abiotic stresses. Diseases like Purple Blotch, Stemphylium Blight, the Anthracnose-Twister Complex, Fusarium Basal Rot, and insect pests such as thrips are the challenging biotic stresses affecting onion production. Among abiotic stresses, drought, water-logging, extreme temperatures, salinity, and nutrient stress

affect onion production; however, due to its shallow-rooted nature, it is extremely sensitive to water-logging stress (Rao, 2016).

Onions require 350–550 mm of water for optimum yield (FAOSTAT, 2023). Seasonal supply of 225–1040 mm of water to onion crops results in yields ranging from 10 to 77 t/ha (Pérez Ortolá and Knox, 2015). Many studies have investigated the water requirements of onions in relation to productivity (Bandyopadhyay *et al.*, 2003; Martín de Santa Olalla *et al.*, 2004) - These have demonstrated that applying 225–602 mm of water to onion results in productivity ranging from 10 to 75 t/ha. Other studies have reported that applying 1040 mm per furrow and 602 mm per drip to onion crops gives an average yield of 59 t/ha and 77 t/ha, respectively. These studies show that bulb yield increases are proportional to the amount of supplied water. However, bulb yield decreases with irrigation above 602 mm and is almost zero yield when the amount of water is greater than 1,184.3 mm (Igbadun *et al.*, 2012).

Onion field and greenhouse experiments have shown that 20–45 days of drought negatively affects morphological parameters such as leaf number, length, width, and area, with a high rate of leaf senescence (Ghodke *et al.*, 2018; Chaudhry *et al.*, 2020; Gökçe *et al.*, 2022). This proves that leaf senescence is a typical symptom during drought, which increases with stress severity in onions (Gedam *et al.*, 2021). At the root level, drought reduces meristematic activity, which stops root elongation and bulbing of the root system (Singh and Roy, 2016).

Water deficit at the bulbing stage reduces bulb yield parameters in onion genotypes (Chaudhry *et al.*, 2020; Zheng *et al.*, 2012). Similarly, Dirirsa *et al.* (2017) observed that water stress imposed at 50% of the maximum crop water requirement had a significant effect on bulb size. Srinivasa Rao *et al.* (2009) demonstrated in two onion

cultivars (Arka Kalyan and Agrifound Dark Red) that drought stress induces a reduction in soil moisture, leading to a decrease in bulb fresh mass and consequently yield.

Low water availability in the soil can promote a reduction in cell expansion and division, reducing the plant gas exchange and leaf area and resulting in lower growth and yield rates (Taiz *et al.* 2017). On the other hand, the excess of water, combined with high temperatures, favors the incidence of pathogens, compromising the bulbs production and quality (Marouelli *et al.* 2011). Lower values for water availability in the soil may have caused a series of physiological and metabolic changes, immediately resulting in a reduced growth and, consequently, a reduced shoot dry matter (Perdomo *et al.* 2017). The water deficit in the onion may alter the partition of assimilates between roots and shoots, with a great effect on the plant productivity, also decreasing the accumulation of shoot biomass.

According to Menezes Junior *et al.* (2014), The low water availability in the soil induces the onion plant to stomatal closure and, when this occurs, both photosynthesis and the flow of nutrients from soil to roots are reduced (Taiz *et al.*, 2017). Therefore, the occurrence of water deficits during cultivation, especially in the bulbing period, may hinder the normal development of plants, promote the formation of smaller bulbs and, consequently, reduce yield (Wordell Filho and Stadnik 2010).

2.2 Propagation Methods

Onions (*Allium cepa*) can be cultivated from seeds or from partially grown bulbs called "sets" or starter bulbs, onion seeds are short-lived and fresh seeds germinate more effectively when sown in shallow rows, or "drills" (USDA, 2011).

The most economical method for growing onions is from seed. Seed also provides the greatest availability in terms of variety selection. However, growing onions from seed is also the most difficult, with uneven germination common (Toscano, 2024).

When propagated from seeds, onion seedlings typically require 50-55 days or the development of 3-4 true leaves before transplanting. At this stage, the seedlings establish roots and recover quickly after transplanting. Seedlings generally have a diameter of 0.5-0.6 cm and reach a height of about 25 cm (Wang, 2013).

Transplants have the advantage on economic use of seed and selecting of superior (healthy and vigorous) seedlings. It saves weeding and watering effort during the early weeks of onion growth it enables the farmers attend to the seedlings in a compact area (Lemma and Shimeles, 2003).

Research indicates that seed propagation, whether through direct seeding or transplants, typically yields more uniform bulbs with superior storage quality (Brewster, 2008; Rahim *et al.*, 2020). This method benefits from genetic diversity, particularly with hybrid varieties and adaptability to varying climatic conditions (Brewster, 2008). However, seed-grown onions require a prolonged growing season (180–200 days) and meticulous management of irrigation and weed control, making them less suitable for short-season climates (Shock *et al.*, 2000; Kumar and Pandey, 2022).

Growing onions from sets (immature bulbs) is the easiest and fastest way to grow them, and will produce an earlier crop. Plants grown from sets are also less likely to be affected by disease. However, they are more prone to bolting - when a flower is produced instead of a bulb, especially if improperly stored (RHS Garden, 2011; Khokhar *et al.*, 2007; Rahim *et al.*, 2020).

Despite lower yields and higher costs due to labor and storage needs, sets offer a market advantage by maturing one to two months earlier than direct-seeded onions (Shock *et al.*, 2011; FAO, 2021; University of Minnesota Extension, 2023). Sets perform better in cooler climates, while seeds are more suited to warmer, drought-prone areas (Brewster, 2008).

According to Boyhan *et al.* (2008), using sets may reduce exposure to pests and weeds due to the shorter field duration.

Economically, seeds are more cost-effective for large-scale production, whereas sets incur higher costs due to labor-intensive planting and storage requirements (Kumar and Pandey, 2022).

2.3 Planting Date

Day-length plays a pivotal role in flowering and bulb formation in onions, which are sensitive to photoperiods. Bulbs begin to grow only after the number of daylight hours surpasses a certain threshold (Salgado *et al.*, 2011). Previous research has established that sowing dates significantly affect various growth parameters of onions, such as plant height, number of leaves per plant (Hamma, 2013), foliage fresh weight (Kandil, 2013), number of flowering stalks, number of umbels per plant, number of capsule umbels, number of seed capsules per umbel, and seed yield per umbel (Jagtap *et al.*, 2014; Mehri *et al.*, 2015)..

Onion yield is very much related to its planting time. Early planting allows plants to have sufficient time and relatively higher temperature to induce maximum vegetative growth (Ud-Deen, 2008; Hamma, 2013).

The choice of sowing date is critical for onion production because if the seed is sown too late the plants may not be long enough to respond to photoperiod, thus no bulb will develop (Anonymous, 2012). It is essential also that there is an adequate period of growth from sowing to bulbing. However, Nayee *et al.* (2009) reported that some growth parameters, like the number of leaves per plant, are not influenced by planting date.

Mosleh and Deen (2008) also reported that, onion requires long days for bulb production and maturation. He further added that, due to plant response to day length the planting time

is the most important factor that influenced plant growth and yield of onion crop. (Karim and Ibrahim, 2013) reported that, sowing date is critical for onion production because the plants from too late sowing may not produce bulbs due to their response to photoperiod. (Ikeda *et al.*, 2020) found that the critical day length required for each cultivars bulb development differs based on their genetic characteristics and the length of day is calculated from the critical day-lengths for bulb development of each cultivar. A significant interaction between day length and variety was also reported by (Habiba and Namo, 2014) on mean bulb weight, bulb diameter, bulb size, bulb length and number of bulb rings.

Late planting often restricts the required photoperiod for vegetative growth, and as the temperature increases, plants begin bulb formation prematurely, leading to poor bulb yields (Misra *et al.*, 2014). Day-length requirements vary among onion varieties: short-day varieties require less than 12 hours of daylight, intermediate-day varieties require between 12 to 14 hours, and long-day varieties need more than 14 hours of light for optimal bulb formation (Rana and Hore, 2005; Atif *et al.*, 2020). The best time for planting depends on locality, cultivar and production methods employed. Early planting results in higher yields by allowing more leaves to develop before bulb initiation.

Bachie *et al* (2019) reported that, onion plants cultivated under short day length and high temperature had higher photosynthetic rates and stomatal conductance as compared to onions cultivated under the long day. They found that, onion stomatal conductance and photosynthesis increased at bulb initiation stage, to provide carbohydrates desired for plant growth and bulb enlargement.

On the marketable yield of onion, Sekara *et al* (2017) reported that marketable yield of onion was decreased when the length of growing season reduced due to increase temperature.

This is positively correlated with the number of rainy days and increased with increasing rainy days. The marketable yield of onion decreased with increasing temperature during the months from June to August in Southern Ontario, a temperate humid climate with average temperature of 22–28°C (Tesfaendrias *et al.*, 2011).

Furthermore, the planting date will solve the problem of bolting which is the process of seed production in onion. Bolting results in a poor harvest as the plant divert its energy into developing the seeds at the expense of leaves. Bolting is influenced by plant mass and cold units in a process called vernalisation. Some varieties bolt after much or less vernalisation than others. Some of the best tasting, most attractive and highest-yielding short-day onion varieties are characterized by early and profuse bolting. Planting after vernalisation is the only partial solution because bulb initiation is determined by daylight and to a lesser extent heat. However, if the bulb is vernalized, a smaller, poor quality products results (Farmer's weekly, 2018).

Yamasaki and Tanaka (2005) highlighted that bolting is triggered in response to exposure of the onion plant to conditions like low temperature or limited N supply which induces flowers to emerge before bulb are adequately grown to suppress flower initiation. Gimdil *et al.* (2012) observed that cold treatment and day length stimulate flower stem production, larger sets have more ability to produce more flower stems. By cutting the flowering stem, growth points of the stem are stimulated and increase numbers of twin bulbs, thereby increasing the size and yield of the stem. Al-Fraihat (2009) also stated that highest percentage of bolting was obtained from plants fertilized with the lowest level of nitrogen (100 kg N ha⁻¹). Abdissa *et al.* (2011) verified that nitrogen fertilization significantly reduced bolting in onion.

Report by Khokhar (2014) stated that a delay in flowering using devernalization can increase plant height and put the plant in the vegetative phase for a longer time. Cutting the flower stem can limit sugar diversion and enhance bulb sugar concentration (Tendaj *et al.*, 2013), while devernalisation has been shown to extend the vegetative phase and increase plant height (Khokhar, 2014).

Bolting cuts the storage potential and quality of the bulbs as the whole of the energy of the plant is exhausted and nothing is left in the bulbs to accumulate. Thus, bulbs become fibrous and lightweight (Rana and Hore, 2015; Khan *et al.*, 2019). This was in agreement with (Cramer, 2003) who stated that bolting is premature seed stalk development that decreases the marketability of onion bulbs.

Despite numerous studies examining the influence of planting dates on onion growth and yield across various regions, there is limited research specifically focusing on the influence of propagation methods on onions, as well as the combined effects of planting dates and propagation methods in Nigeria, particularly in Edo State. The interaction between planting date and propagation methods remains largely undocumented, leaving a gap in understanding how these two factors may complementarily or antagonistically affect onion performance. This lack of localized and interaction specific data emphasizes the need for further research to optimize cultivation practices tailored to the agro-ecological conditions of Edo State, Nigeria.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental Site

The experiment was conducted at the University of Benin's Experimental Farm (6°20'N-6°30'N, 5°30'E-5°45'E) during two cropping seasons: the dry season (October 2021-April 2022) and wet season (April-October 2022). Located in Benin City, Edo State, the experimental site lies within Nigeria's tropical monsoon climate zone, characterized by distinct wet (April-October) and dry (November-March) seasons. The area receives 1,800-2,500 mm annual rainfall, with temperatures ranging from 22°C to 34°C and relative humidity of 70-90% during peak rains (NiMET, 2021). The predominant ultisols and alfisols at the site are typical of southern Nigeria's rainforest agro-ecology, supporting diverse crop production (EADP, 2020).

3.2 Experimental Materials

Onion seeds and sets were obtained from a certified seed supplier.

3.3 Experimental Design and Treatments

The experiment was conducted in a 2 x 4 factorial design arranged in a Randomized Complete Block Design (RCBD). The treatments consisted of eight combinations of propagation methods and planting dates, designated as P1D1, P1D2, P1D3, P1D4, P2D1, P2D2, P2D3, and P2D4. Here, "P" represents the propagation method, with P1 denoting seed propagation and P2 denoting bulb propagation, while "D" represents the planting date. The planting dates were scheduled as follows: D1 (October 10th for the dry season and March 6th for the wet season), D2 (October 24th for the dry season and March 20th for the

wet season), D3 (November 7th for the dry season and April 3rd for the wet season), and D4 (November 21st for the dry season and April 17th for the wet season). The dry season is referred to as "D" and the wet season as "W" throughout the study. Each treatment was replicated three times to ensure the reliability and statistical validity of the experimental results. Organic manure was incorporated both in nursery and field at the rate of 10 t ha⁻¹ prior to cultivation. The field beds were mulched with dead plant materials after planting.

3.4 Land Preparation, Planting and Cultural Practices

Propagation was carried out using both seed and set. Depending on the planting dates, bulbs of 3 – 5 cm and average weight of 10g were directly sown in the field on 1m by 1m beds, with a plant spacing of 25 x 25 cm. The soil is well-drained, loose, and free of weeds, making it suitable for cultivation.

3.4.1 Nursery Operation

The soil used was loamy to sandy loam, also well-drained and weed-free. The soil was well tilled, clods broken and debris worked into the soil before bed preparation. Nursery beds were raised to a height of 15 cm and measured 1m x 1m. Seeds were sown using the drilling method, mixed with dry sand, and spread evenly over the nursery beds. Insect nets were used to protect the seedlings from pests.

Germination occurred within three to four days after sowing, and seedlings were transplanted using the ball-of-earth method at the 7th week after germination.

Table 1: Physical and chemical properties of the soil of the experimental site

Parameters	Value
pH _{H₂O} 1: 2	5.11
pH CaCl 1: 2	5.01
Organic carbon (% OC)	0.62
Total nitrogen (%TON)	0.03
Available phosphorus (mg/kg)	31.53
Sulphur (mg/kg)	36.62
Calcium (cmol/kg)	1.30
Potassium (cmol/kg)	0.14
Sodium (cmol/kg)	0.25
Magnesium (cmol/kg)	0.30
CEC	1.98
ECEC	2.22
EA (cmol/kg)	0.24
Sand (%)	86.84
Silt (%)	6.56
Clay (%)	6.60
Texture Loamy soil	

Table 2: Meteorological Data of the Experimental Farm Site (2021, Dry cropping Season)

Months	Temperature (°C)	Humidity (%)	Sunshine Duration (hrs/day)	Rainfall (mm)
October	28	79	6.0	240.0
November	29	76	8.0	75.0
December	30	53	6.0	30.0
January	30	41	8.0	40.0
February	30	57	6.8	50.0
March	32	72	8.0	70.5
April	28	76	6.0	160.0

Source: TimeAndDate, Nigerian Meteorological Agency (NiMET).

Table 3: Meteorological Data of the Experimental Farm Site (2022, Wet cropping Season)

Months	Temperature (°C)	Humidity (%)	Sunshine Duration (hrs/day)	Rainfall (mm)
April	28	76	6.0	160.0
May	28	80	5.0	185.0
June	28	84	3.0	198.0
July	26	87	2.0	188.8
August	25	85	4.0	180.4
September	25	87	4.0	150.4
October	26	82	5.9	180.0

Source: TimeAndDate and Nigerian Meteorological Agency (NiMET).

Table 4: Experimental Layout

Season	Treatment		
	Planting Date (D)	Propagation Method (P)	
		Seeds (P1)	Bulbs (P2)
Dry Season	October 10th (D1)	P1D1	P2D1
	October 24th (D2)	P1D2	P2D2
	November 7th (D3)	P1D3	P2D3
	November 21st (D4)	P1D4	P2D4
Wet Season	March 6th (D1)	P1D1	P2D1
	March 20th (D2)	P1D2	P2D2
	April 3rd (D3)	P1D3	P2D3
	April 17th (D4)	P1D4	P2D4

3.4.2 Cultural Practices

Manual weeding using hoe was done at two weeks interval, watering was done daily, thinning was performed to ensure the correct plant population, and gaps caused by poor emergence or pest damage were filled through supplying. Mulching was applied immediately after planting to help conserve soil moisture.

Foliar organic fertilizer applied two weeks after bulb germination and seedling transplant at the rate of 75 ml to 10 liters of water and reapplied at four weeks after planting (WAP) following manufacturer's recommendations.

Harvest commenced after approximately four months when 85% of the plant tops had fallen over, the leaves have senesced and neck of the onion plants were sealed. Irrigation was discontinued at 15 days before harvesting. Harvesting was done by manually pulling the bulb, which were then left to cure on the soil surface.

3.5 Data Collection

Data were collected from four randomly selected plants per plot. The following parameters were measured at four weeks after planting (WAP) on vegetative and reproductive stages:

Plant Height (cm): Measured from the ground level to the tip of the apical shoot using a measuring tape and recorded.

Number of Leaves: This was taken by manual counting of emerged leaves.

Stem Diameter (cm): Measured with the aid of vernier caliper.

Bulb Length (cm): Measured from top to bottom of harvested bulbs using a vernier caliper.

Bulb Diameter (cm): Measured by gently closing a vernier caliper around the onion bulbs.

Number of Bulbs per Stand: The total number of onion bulbs per stand was observed and recorded.

Bulb Weight per Plant (g): The weights of bulbs per plant were recorded after harvest using a measuring scale.

Bulb Weight per Plot (g): All harvested bulbs from each plot were weighed collectively using a measuring scale.

Yield (t ha⁻¹): Bulb yield was calculated using the formula:

$$\text{Yield} = \frac{\text{Plot Yield} \times 10,000}{\text{Plot Size(m}^2\text{)}}$$

3.6 Data Analysis

Data collected was subjected to analysis of variance (ANOVA) using GENSTAT statistical package. Differences between the treatments means were separated using Duncan's Multiple Range Test (DMRT) at 5% level of probability.

CHAPTER FOUR

4.0 RESULTS

Results indicated that both vegetative growth parameters (plant height, stem diameter and number of leaves) and reproductive parameters (bulb length, bulb diameter, number of bulb per stand, bulb weight per plot and overall yield) were significantly influenced by the chosen propagation methods and planting dates.

4.1 Effect of Planting Dates and Propagation Methods on Vegetative Features of Onion (*Allium cepa*)

4.1.1 Effect of Planting Date and Propagation Method on Plant Height (cm) of Onion (*Allium cepa*) during the Dry Season cultivation

As presented in Table 5, the tallest onion plants were observed in those propagated using bulbs, reaching a height of 49.07 cm at 10 weeks after planting (WAP). In contrast, the shortest plants, with a height of 10.39 cm, were recorded in seed-propagated crops at 4 WAP.

Across the different WAPs, bulb-propagated onions consistently exhibited superior plant heights compared to those propagated by seeds. Specifically, at 4 WAP, bulb-propagated plants measured 38.75 cm versus 10.39 cm in seed propagation, at 6 WAP, bulb propagated onion had plant height of 43.84 cm while seed recorded 12.19 cm; at 8 WAP, 46.70 cm vs. 14.40 cm; at 10 WAP, 49.07 cm vs. 15.76 cm; and at 12 WAP, 42.80 cm vs. 17.50 cm.

Among the planting dates, onions planted on November 7th attained the greatest height at 10 WAP (34.48 cm), while the shortest plants (24.91 cm) were observed in the October 10th planting date. However, no statistically significant differences were observed in plant height across the different planting dates throughout the weeks of observation.

Plant height increased progressively with time in both propagation methods and across all planting dates, peaking at 10 WAP. A slight decline was observed at 12 WAP, indicating that maximum vegetative growth occurred at 10 weeks. The interaction between planting date and propagation method was not statistically significant at any stage, except at 12 WAP.

4.1.2 Interaction of Planting Date and Propagation Method on the Plant Height (cm) of Onion (*Allium cepa*) at 12 weeks after planting during the Dry Season cultivation

As presented in Table 6, a significant interaction was observed between planting date and propagation method on the plant height of onions at 12 weeks after planting (WAP). Overall, onions propagated through bulbs exhibited greater plant heights compared to those propagated by seeds.

The highest plant height recorded at 12 WAP was 46.30 cm, observed in bulb-propagated onions planted on November 7th. In contrast, the lowest value, 12.30 cm, was recorded in seed-propagated onions planted on October 24th. Among seed-propagated onions, the tallest plants were observed in the November 21st planting date, with a height of 23.30 cm, whereas the shortest remained in the October 24th planting date.

For bulb-propagated onions, November 7th again produced the tallest plants (46.30 cm), while the lowest value among the bulb group was recorded in onions planted on November 21st, with a height of 35.10 cm.

These findings highlight the superior vegetative performance of bulb propagation, particularly when combined with optimal planting dates such as November 7th, which appears to provide favorable conditions for maximum plant growth at 12 WAP.

Table 5: Effect of Planting Date and Propagation Method on Plant Height of Onion (*Allium cepa*) during the Dry Season cultivation

Treatment	Weeks after planting				
	4	6	8	10	12
Preparation:					
Seed	10.39	12.19	14.40	15.76	17.50
Bulbs	38.75	43.34	46.70	49.07	42.80
LSD(0.05)	5.092	5.383	6.820	4.099	7.54
Planting date:					
October 10	24.91	28.22	30.70	31.72	31.70
October 24	25.43	26.41	28.60	30.33	28.90
November 7	22.73	27.09	31.90	34.48	30.80
November 24	25.20	30.34	31.10	33.07	29.20
LSD(0.05)	ns	ns	ns	ns	ns
Interaction	ns	ns	ns	ns	*

* = Significant at 0.05 level of probability. ns = not significant at 0.05 level of probability.

Table 6: Interaction of Planting Date and Propagation Method on the Plant Height (cm) of Onion (*Allium cepa*) at 12 WAP during the Dry Season cultivation

Planting date	Propagation method	
	Seed	Bulb
October 10	18.90	44.40
October 24	12.30	45.30
November 7	15.30	46.30
November 21	23.30	35.10
LSD(0.05)		10.670

4.1.3 Effect of Planting Date and Propagation Method on Plant Height of Onion (*Allium cepa*) during the Wet Season cultivation.

As highlighted in Table 7, the interaction between planting date and propagation method did not result in a statistically significant difference in plant height during the wet season cultivation of onion. Nonetheless, clear trends were observed in the performance of the propagation methods.

The tallest plants were recorded in onions propagated via bulbs, reaching a height of 46.48 cm at 10 weeks after planting (WAP), while the shortest plants were observed in seed-propagated onions at 4 WAP, with a height of 17.00cm. Across all WAP, bulb-propagated onions consistently outperformed seed-propagated ones in terms of plant height. At 4 WAP, bulb-propagated onions attained a height of 39.15 cm, compared to 17.00 cm in seed-propagated plants; at 6 WAP, 41.90 cm versus 19.17 cm; at 8 WAP, 45.48 cm versus 21.81 cm; at 10 WAP, 46.48 cm versus 23.33 cm; and at 12 WAP, 45.71 cm versus 23.71 cm.

With regard to planting dates, the tallest plants were observed in onions planted on April 17, which recorded a height of 38.34 cm at 8 WAP. The lowest plant height was recorded at 4 WAP in onions planted on March 20, with a value of 25.31 cm. However, across all planting dates and weeks, no statistically significant differences were observed in plant height, indicating that planting date had limited influence under wet season conditions.

Furthermore, plant height was observed to increase progressively from 4 WAP to 10 WAP, indicating active vegetative growth during this period. A slight decline in plant height was noted at 12 WAP, suggesting a plateau or onset of senescence following the peak growth phase.

Table 7: Effect of Planting Date and Propagation Method on Plant Height of Onion (*Allium cepa*) during the Wet Season cultivation

Treatment	Weeks after planting				
	4	6	8	10	12
Preparation:					
Seed	17.00	19.17	21.81	23.33	23.37
Bulbs	39.15	41.90	45.48	46.48	45.71
LSD(0.05)	2.514	2.520	2.728	3.138	3.121
Planting date:					
March 6	29.39	31.58	33.75	35.90	38.39
March 20	25.31	27.82	31.13	32.36	32.26
April 3	26.56	28.86	31.36	33.95	32.67
April 17	31.03	33.89	38.34	37.42	36.81
LSD(0.05)	3.555	3.564	3.858	4.432	ns
Interaction	ns	ns	ns	ns	ns

ns = not significant at 0.05 level of probability.

4.1.4 Effect of Planting Date and Propagation Method on Stem Diameter (cm) of Onion (*Allium cepa*) during the Dry Season

As presented in Table 8, during the dry season cultivation, onion plants propagated through bulbs consistently exhibited significantly larger stem diameters compared to those propagated by seeds. The maximum stem diameter recorded was 2.37 cm at 12 weeks after planting (WAP) in bulb-propagated onions, while the smallest diameter was 0.14 cm, observed in seed-propagated onions at 4 WAP.

With respect to planting date, the highest stem diameter (2.02 cm) was recorded at 12 WAP in onions planted on October 10, while the lowest (0.37 cm) was observed at 4 WAP in onions planted on November 21. However, the interaction between propagation method and planting date did not show a statistically significant effect on stem diameter across all weeks.

Across the weeks of observation, bulb propagation consistently resulted in greater stem diameter compared to seed propagation. Specifically: At 4 WAP, bulb-propagated plants recorded a diameter of 0.84 cm versus 0.14 cm in seed propagation, at 6 WAP, 1.39 cm (bulb) versus 0.21 cm (seed), at 8 WAP, 1.91 cm (bulb) versus 0.31 cm (seed), at 10 WAP, 2.35 cm (bulb) versus 0.41 cm (seed), at 12 WAP, 2.37 cm (bulb) versus 0.57 cm (seed).

In terms of planting dates: At 4 WAP, the highest stem diameter (0.62 cm) was observed in onions planted on October 10, while the lowest (0.47 cm) was recorded for November 7, at 6 WAP, the highest value was 1.08 cm from November 21, while the lowest (0.62 cm) came from October 24, at 8 WAP, November 21 again recorded the highest value (1.30 cm), while October 24 had the least (0.77 cm), at both 10 and 12 WAP, no significant differences in stem diameter were observed among the different planting dates.

Table 8: Effect of Planting Date and Propagation Method on Stem Diameter (cm) of Onion (*Allium cepa*) during the Dry Season Cultivation

Treatment	Weeks after planting				
	4	6	8	10	12
Propagation Method:					
Seed	0.14	0.21	0.31	0.41	0.57
Bulb	0.84	1.39	1.91	2.35	2.37
LSD(0.05)	0.089	0.192	0.275	0.224	0.189
Planting date:					
October 10	0.62	0.85	1.15	1.36	1.53
October 24	0.50	0.62	0.77	1.26	1.39
November 7	0.47	0.64	1.22	1.39	1.50
November 21	0.37	1.08	1.30	1.51	1.48
LSD(0.05)	0.127	0.272	0.388	ns	ns
Interaction	ns	ns	ns	ns	ns

ns = not significant at 0.05 level of probability.

4.1.5 Effect of Planting Date and Propagation Method on Stem Diameter (cm) of Onion (*Allium cepa*) during the Wet Season cultivation

As shown in Table 9, during the wet season cultivation of onions, plants propagated via bulbs consistently produced larger stem diameters compared to those propagated by seed across all stages of growth. The largest stem diameter recorded was 1.89 cm at 12 weeks after planting (WAP) in bulb-propagated onions, whereas the smallest was 0.22 cm at 4 WAP in seed-propagated onions. A notable trend observed was that stem diameter increased significantly as the weeks after planting progressed, indicating continuous growth and development of the onion plants.

With respect to the effect of propagation method, bulb-propagated onions exhibited superior stem diameter at all observation points. At 4 WAP, the stem diameter in bulb-propagated plants was 0.72 cm, while that in seed-propagated plants was 0.22 cm. At 6 WAP, the bulb-propagated onions measured 0.97 cm, compared to 0.37 cm in seed-propagated onions. This trend continued at 8 WAP, with bulb propagation recording 1.26 cm and seed propagation at 0.67 cm. At 10 WAP, the values increased further to 1.62 cm and 0.85 cm for bulb and seed propagation respectively. By 12 WAP, bulb-propagated plants reached 1.89 cm, while seed-propagated onions recorded 1.09 cm.

Regarding the effect of planting date, the highest stem diameter at 4 WAP was recorded in onions planted on March 6 with a value of 0.56 cm, while the lowest was observed in the April 3 planting date with a diameter of 0.44 cm. At 6 WAP, onions planted on March 6 again recorded the highest value at 0.70 cm, whereas those planted on March 20 had the least at 0.59 cm. At 8 WAP, no significant differences in stem diameter were observed across the various planting dates. However, at 10 WAP, onions planted on April 17 showed the highest stem diameter of 1.41 cm, while the lowest value of 1.11 cm was recorded in

plants established on March 20. A similar pattern was observed at 12 WAP, where April 17 planting resulted in the highest stem diameter of 1.69 cm, and March 20 showed the lowest at 1.39 cm.

The interaction between planting date and propagation method was not statistically significant at 4 and 8 weeks after planting. However, significant interaction effects were observed at 6, 10, and 12 WAP, suggesting that the combined influence of these factors on stem diameter became more pronounced in the later stages of plant development.

Table 9: Effect of Planting Date and Propagation Method on Stem Diameter (cm) of Onion (*Allium cepa*) during the Wet Season Cultivation

Treatment	Weeks after planting				
	4	6	8	10	12
Propagation Method:					
Seed	0.22	0.37	0.67	0.89	1.09
Bulbs	0.72	0.97	1.26	0.62	1.89
LSD(0.05)	0.046	0.064	0.268	0.126	0.090
Planting Date:					
March 6	0.56	0.70	1.01	1.26	1.47
March 20	0.54	0.59	0.85	1.11	1.39
April 3	0.44	0.61	1.08	1.17	1.42
April 17	0.45	0.68	0.93	1.41	1.69
LSD(0.05)	0.064	0.090	ns	0.178	0.127
Interaction	ns	*	ns	*	*

ns = not significant at 0.05 level of probability. * = Significant at 0.05 level of probability.

4.1.6 Interaction of Planting Date and Propagation Method on Stem Diameter (cm) of Onion (*Allium cepa*) at 6, 10 and 12 WAP during the Wet Season cultivation

Table 10 presents the interaction effect between planting date and propagation method on the stem diameter of onion plants at 6, 10, and 12 weeks after planting (WAP) during the wet season. The highest stem diameter was recorded at 12 WAP in onions propagated via bulbs and planted on April 17, reaching a value of 2.07 cm. Conversely, the smallest stem diameter was observed at 6 WAP in onions propagated by seed and planted on March 20, with a value of 0.29 cm. This highlights the significant influence of both propagation method and planting date on stem development as the crop matures.

At 6 WAP, the most notable stem diameter was found in onions propagated by bulbs and planted on March 6, with a value of 1.19 cm. The least diameter was recorded in seed-propagated onions planted on March 20, at 0.29 cm.

By 10 WAP, bulb-propagated onions continued to outperform those propagated by seed. The highest stem diameter, 1.84 cm, was observed in bulb-propagated onions, while the lowest value, 0.67 cm, was recorded in seed-propagated onions planted on March 6.

At 12 WAP, stem diameter peaked in bulb-propagated onions planted on April 17, recording the highest value of 2.07 cm. In contrast, the lowest stem diameter at this stage was 0.90 cm, found in seed-propagated onions planted on March 6.

Table 10: Interaction of Planting Date and Propagation Method on Stem Diameter (cm) of Onion (*Allium cepa*) during the Wet Season cultivation

Propagation method	Planting date	Weeks after planting		
		6	10	12
Seed	March 6	0.41	0.69	0.90
	March 20	0.29	0.77	1.02
	April 3	0.33	0.89	1.12
	April 17	0.44	1.06	1.31
Bulb	March 6	1.19	1.84	2.03
	March 20	0.89	1.45	1.75
	April 3	0.89	1.44	1.72
	April 17	0.92	1.75	2.07
LSD(0.05)		0.128	0.251	0.180

4.1.7 Effect of Planting Date and Propagation Method on the Number of Leaves of Onion (*Allium cepa*) during the Dry Season cultivation

Table 11 presents the effect of planting date and propagation method on the number of leaves of onion (*Allium cepa*) during the dry season cultivation. The interaction effect between propagation method and planting date on the number of leaves was statistically significant at 6 and 8 weeks after planting (WAP), but not significant at 4, 10, and 12 WAP.

Among the propagation methods, the highest leaf count was observed in bulb-propagated onions at 8 WAP, with a value of 22.15 leaves, while the lowest number of leaves (2.12) was recorded at 4 WAP in onions propagated via seeds. Bulb propagation consistently resulted in a greater number of leaves compared to seed propagation across all weeks. Specifically, at 4 WAP, bulb-propagated onions had 14.31 leaves, while seed-propagated had 2.12. At 6 WAP, bulb propagation had 18.66 leaves and seed propagation had 3.10. At 8 WAP, bulbs had 22.15 leaves while seeds had 3.92. At 10 WAP, bulbs had 21.79 leaves, and seeds had 3.97. However, at 12 WAP, there was a marked decline in leaf count, with bulb propagation recording 2.37 leaves and seed propagation dropping to 0.57 leaves.

Regarding the effect of planting date, the highest leaf count was recorded at 8 WAP in onions planted on November 21, with a value of 15.79, while the lowest was recorded at 4 WAP in onions planted on October 24, with a value of 7.42. At 6 WAP, the number of leaves ranged from a high of 13.71 in the November 21 planting to a low of 9.18 in the October 24 planting. No significant differences in the number of leaves were observed among planting dates at 4, 10, and 12 WAP.

Notably, the number of leaves increased significantly from 4 to 10 weeks after planting, indicating progressive vegetative growth during this period. However, a sharp decline in

leaf number was observed at 12 WAP, likely reflecting the onset of plant senescence or physiological maturity.

Table 11: Effect of Planting Date and Propagation Method on the Number of Leaves of Onion (*Allium cepa*) during the Dry Season cultivation

Treatment	Weeks after planting				
	4	6	8	10	12
Preparation:					
Seed	2.12	3.10	3.92	3.97	0.57
Bulbs	14.31	18.66	32.15	21.79	2.37
LSD(0.05)	1.601	1.431	1.835	2.628	0.189
Planting date:					
October 10	8.52	10.96	13.25	13.00	1.53
October 24	7.42	9.18	10.67	11.46	1.39
November 7	7.83	9.68	12.42	13.75	1.50
November 24	9.04	13.71	15.79	13.31	1.48
LSD(0.05)	ns	2.024	2.595	ns	ns
Interaction	ns	*	*	ns	ns

ns = not significant at 0.05 level of probability * = Significant at 0.05 level of probability

4.1.8 Interaction effect of Planting Date and Propagation Method on Number of Leaves of Onion (*Allium cepa*) at 6 and 8 WAP during the Dry Season cultivation

Table 12 presents the interaction effect between planting date and propagation method on the number of leaves of onion at 6 and 8 weeks after planting (WAP) during the dry season cultivation. A significant interaction was observed between planting date and propagation method on leaf development at both 6 and 8 WAP.

At 6 WAP, the highest number of leaves (23.92) was recorded in onions propagated via bulbs and planted on November 21. In contrast, the lowest number of leaves (2.58) was observed in seed-propagated onions planted on October 24. Similarly, at 8 WAP, the highest leaf count (27) was also recorded in bulb-propagated onions planted on November 21, while the lowest (3.25) was observed in seed-propagated onions planted on October 24.

Overall, bulb propagation consistently resulted in a significantly higher number of leaves compared to seed propagation across the planting dates in both weeks of observation.

Table 12: Interaction Effect of Planting Date and Propagation Method on Number of Leaves of Onion (*Allium cepa*) during the Dry Season

Propagation method	Planting date	Weeks after planting	
		6	8
Seed	October 10	33.33	4.00
	October 24	2.58	3.25
	November 7	3.00	3.83
	November 21	3.50	4.58
Bulb	October 10	18.58	22.50
	October 24	15.78	18.08
	November 7	16.35	21.00
	November 21	23.92	27.00
LSD(0.05)		2.863	3.670

4.1.9 Interaction effect of Planting Date and Propagation Method on Number of Leaves of Onion (*Allium cepa*) during the Wet Season

Table 13 presents the interaction effect of planting date and propagation method on the number of leaves of onion during the wet season cultivation. No significant interaction was observed between planting date and propagation method on leaf development during this period. However, variations were noted across propagation methods and planting dates.

The highest leaf count was recorded at 10 WAP (22.24) in bulb-propagated onions. In contrast, the lowest number of leaves, 3.07, was observed at 4 WAP in onions propagated by seed. Overall, bulb propagation consistently resulted in a higher number of leaves compared to seed propagation throughout the observation period.

In terms of propagation method, bulb propagation demonstrated superior performance across all weeks of observation. At 4 WAP, bulb-propagated onions had an average of 17.78 leaves, while seed-propagated onions had 3.07, at 6 WAP, the leaf count was 23.95 for bulb propagation and 4.50 for seed, at 8 WAP, bulb propagation recorded 30.04 leaves compared to 5.98 in seed propagation, at 10 weeks, the values were 33.48 and 7.72 respectively, while at 12 WAP, bulb propagation had 31.00 leaves compared to 7.15 in seed propagation.

Regarding planting dates, the highest number of leaves was observed in onions planted on April 17, with a value of 22.24 at 10 WAP. The lowest was recorded in onions planted on March 20, with a value of 9.08 at 4 WAP. At 4 weeks after planting, no significant difference was observed in the number of leaves across the planting dates. At 6 WAP, the highest number of leaves (16.88) was recorded in onions planted on April 17, while the lowest (12.49) was observed in onions planted on March 20. Similarly, at 8 WAP, April 17 again recorded the highest number of leaves (20.71), while March 20 recorded the least

(16.21). At 10 and 12 WAP, no significant differences were observed in the number of leaves among the planting dates.

4.1.10 Seasonal Effect on Plant Height, Number of Leaves, and Stem Diameter of Onion

As presented in Table 14, there was no significant difference in plant height and stem diameter of onions between dry and wet season cultivation, indicating that seasonal variations had a negligible impact on these growth parameters. However, onions cultivated in the wet season had a significantly higher number of leaves (16.47) compared to those grown in the dry season (11.78).

Table 13: Effect of Planting Date and Propagation Method on the Number of Leaves of Onion (*Allium cepa*) during the Wet Season cultivation

Treatment	Weeks after planting				
	4	6	8	10	12
Preparation:					
Seed	3.07	4.50	5.98	7.72	7.15
Bulbs	17.78	23.95	30.04	33.48	31.00
LSD(0.05)	2.078	2.134	2.068	2.378	2.616
Planting date:					
March 6	10.25	13.88	17.46	18.99	19.83
March 20	9.08	12.49	16.21	19.66	18.38
April 3	9.77	13.66	17.67	21.50	20.08
April 17	12.60	16.88	20.71	22.24	18.00
LSD(0.05)	Ns	3.018	2.924	ns	ns
Interaction	Ns	ns	ns	ns	ns

ns = not significant at 0.05 level of probability.

Table 14: Seasonal Effect of Planting Dates and Propagation Methods on Plant Height, Number of Leaves and Stem Diameter of Onion (*Allium cepa*)

Season	Plant Height (cm)	Number of Leaves	Stem Diameter (cm)
Dry Season	29.14 ^{ns}	11.78	1.05 ^{ns}
WetSeason	32.34 ^{ns}	16.47 ^{**}	0.97 ^{ns}
LSD	3.679	0.953	0.185

**Significant at 0.05 level of probability, ns: not significant,

4.2 Effects of Planting Dates and Propagation Methods on Yield and Yield components of Onion

4.2.1 Effect of Planting date and Propagation Method on the Yield and Yield components of Onion (*Allium cepa*) during the Dry Season cultivation

Table 15 presents the effect of planting date and propagation method on the yield and yield components of onions during the dry season. Although no significant interaction was observed between propagation method and planting date on the yield and its components, notable differences were recorded when each factor was considered independently.

Bulb length was greater in onions propagated via bulbs, with an average length of 6.85 cm, compared to 5.82 cm in onions propagated from seeds. Regarding planting dates, onions planted on October 10 produced the longest bulbs, with an average length of 7.01 cm. The shortest bulbs were recorded in onions planted on October 24, with a length of 5.71 cm.

Bulb-propagated onions recorded the highest bulb diameter with a value of 10.19 cm, while seed-propagated onions showed a lower diameter of 8.51 cm. In terms of planting dates, no significant differences were observed in bulb diameter across the different planting dates during the dry season cultivation.

Regarding the number of bulbs per stand, all seed-propagated onion plants produced only one bulb per stand, whereas bulb-propagated onions had an average of 3.79 bulbs per stand. In terms of planting date, no significant differences were observed among the treatments. Overall, bulb-propagated onions demonstrated superior yield performance compared to seed-propagated onions.

Bulb-propagated onions recorded a higher total weight compared to those propagated by seed, with an average yield of 1,419 g/m², whereas seed-propagated onions yielded 533 g/m². Regarding the effect of planting date, onions planted on October 10 produced the

highest weight with an average of 1,254 g/m², while the lowest yield was observed in onions planted on October 24, with a value of 691 g/m².

For the overall yield, bulb-propagated onions produced the highest output with a value of 14.19 t ha⁻¹, while seed-propagated onions yielded 5.33 t ha⁻¹. In terms of planting date, the highest yield was recorded for onions planted on October 10, with a value of 12.54 t ha⁻¹. The lowest yield was observed for the October 24 planting date, with a value of 6.91 t ha⁻¹.

Table 15: Effect of Planting Date and Propagation Method on the Yield and Yield Components of Onion (*Allium cepa*) during the Dry Season cultivation

Treatment	Bulb length (cm)	Bulb diameter (cm)	No. of bulb per strand	Bulb weight (g/m²)	Bulb gain t ha⁻¹
Preparation:					
Seed	5.82	8.51	1.00	5.33	5.33
Bulbs	6.85	10.19	3.79	14.19	14.19
LSD(0.05)	0.548	1.446	0.416	366.7	3.664
Planting date:					
October 10	7.01	10.18	2.21	1254	12.54
October 24	5.71	8.32	2.33	691	6.91
November 7	6.69	10.28	2.38	1029	10.29
November 21	5.94	8.56	2.67	929	9.29
LSD(0.05)	0.775	ns	ns	518.5	5.182
Interaction	Ns	ns	ns	ns	ns

ns = not significant at 0.05 level of probability.

4.2.2 Effect of Planting date and Propagation method on the yield and yield components of Onion (*Allium cepa*) during the wet season

As shown in Table 16, during the wet season cultivation of onions, bulb-propagated onions exhibited significantly better yield and yield components compared to those propagated by seed. A significant interaction was observed between planting date and propagation method only in relation to bulb length.

For bulb length, onions propagated via bulbs recorded a higher average value of 6.73 cm, while those propagated by seed averaged 5.84 cm. In terms of planting date, the longest bulbs were observed in onions planted on March 20, with an average length of 6.70 cm, while the shortest bulbs were recorded on April 3, with an average length of 5.54 cm.

For bulb diameter, onions propagated via bulbs had a superior diameter, averaging 7.76 cm, compared to 6.37 cm in those propagated from seed. Regarding the effect of planting dates, no significant differences were observed in bulb diameter across the various planting dates.

In terms of the number of bulbs per stand, the highest count was recorded in plants propagated via bulbs, with an average of 4.13 bulbs per stand, while seed-propagated plants produced only one bulb per stand. Regarding planting dates, the highest number of bulbs per stand was observed on March 20, with a value of 2.71, whereas the lowest was recorded on April 3, with a value of 2.38.

In terms of bulb weight (g/m^2), plants propagated via bulbs recorded a higher weight of 683 g/m^2 compared to 306 g/m^2 in seed-propagated plants. Regarding the effect of planting date, the highest bulb weight was observed in onions planted on April 17, with a value of 592 g/m^2 , while the lowest was recorded on April 3, with a value of 400 g/m^2 .

For the overall yield, plants propagated via bulbs produced a higher yield of 6.83 tha^{-1} compared to 3.06 tha^{-1} for seed-propagated plants. Regarding the effect of planting date on bulb yield, the highest yield was recorded for plants planted on April 17, with a value of 5.92 tha^{-1} , while the lowest yield was observed for plants planted on April 3, with a value of 4.00 tha^{-1} .

Table 16: Effect of Planting Date and Propagation Method on the Yield and Yield Components of Onion (*Allium cepa*) during the Wet Season cultivation

Treatment	Bulb length (cm)	Bulb diameter (cm)	No. of bulb per strand	Bulb weight (g/m²)	Bulb gain t ha⁻¹
Propagation method:					
Seed	5.84	6.37	1.00	3.06	3.06
Bulbs	6.73	7.76	4.130	6.83	6.83
LSD(0.05)	0.55	0.994	0.212	101.8	1.016
Planting date:					
March 6	6.69	7.16	2.54	5.33	5.34
March 20	6.70	7.20	2.71	4.52	4.52
April 3	5.54	6.34	2.38	4.00	4.00
April 17	6.21	7.55	2.63	5.92	5.92
LSD(0.05)	0.785	ns	0.299	143.9	1.437
Interaction	*	ns	ns	ns	ns

ns = not significant at 0.05 level of probability. * = Significant at 0.05 level of probability.

4.2.3 Interaction of Planting Date and Propagation Method on the bulb length (cm) of Onion (*Allium cepa*) during the Wet Season cultivation

As shown in Table 16, the interaction between planting date and propagation method significantly influenced bulb length of onions during wet season cultivation. The highest bulb length, 7.70 cm, was recorded in bulb-propagated onions planted on March 6. Likewise, the shortest bulb length, 5.40 cm, was also recorded in bulb-propagated onions on April 3. This indicates that while bulb propagation produced the longest bulbs under optimal conditions, results varied depending on planting date.

Table 17: Interaction of Planting Date and Propagation Method on the bulb length (cm) of Onion (*Allium cepa*) during the Wet Season cultivation

Propagation method	Planting date	Value
Seed	March 6	5.88
	March 20	5.83
	April 3	5.67
	April 17	6.19
Bulb	March 6	7.70
	March 20	7.58
	April 3	5.40
	April 17	6.23
LSD(0.05)		1.111

4.2.4 Seasonal Effect on Bulb Length, Bulb Diameter, Number of Bulbs per Stand, Bulb Weight per Plot, and Yield of Onion

As shown in Table 18, there was no significant difference in bulb length and the number of bulbs per stand between dry and wet season cultivation, suggesting that seasonal variations had minimal impact on these yield-related parameters. However, in terms of bulb diameter, crops propagated in the dry season (9.35 cm) had significantly higher values. A similar pattern was observed for bulb weight per plot (97 g/m²) and yield (9.76 t/ha) of onions.

Table 18: Seasonal Effects of Planting Dates and Propagation Methods on Yield and Yield components of Onion (*Allium cepa*)

Season	Bulb Length (cm)	Bulb Diameter (cm)	No Bulb/Stand	Bulb Weight/Plot (g/m ²)	Yield (t ha ⁻¹)
Dry Season	6.33 ^{ns}	9.35 ^{**}	2.40 ^{ns}	976 ^{**}	9.76 ^{**}
Wet Season	6.29 ^{ns}	7.06	2.56 ^{ns}	494	4.94
LSD	0.598	0.953	0.911	280.8	2.807

** : Significant at 0.05 level of probability. ns: not significant.

CHAPTER FIVE

5.0 DISCUSSION, SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

5.1 Discussion

Seasonal Effects

The significant variation in growth and yield components observed across treatments align with established climatic influences on onion development, particularly water availability, photoperiod and temperature (Ansari, 2007). Photoperiod is a key environmental cue for bulbing in onions. Short-day varieties require longer daylight exposure to initiate bulb development, a condition more reliably met during the dry season in tropical climates. Reduced day length and cloud cover in the rainy season may delay or inhibit bulbing (Brewster, 2008).

Several studies have demonstrated that the incorporation of organic matter into sandy and clayey soils significantly improves onion growth and yield. For instance, Sharma and Singh (2011) reported that the application of farmyard manure (FYM) to sandy soil enhanced its nutrient and water-holding capacities, resulting in increased onion seed yield.

Prolonged soil saturation during the rainy season leads to oxygen depletion in the root zone, reducing oxygen availability to hypoxic levels (Yan *et al.*, 2023). This condition impairs aerobic respiration and decreases ATP production by up to 67% (Zhang *et al.*, 2022). The resulting oxygen deficit limits nutrient uptake efficiency, reducing phosphorus and potassium assimilation by 42% and 37%, respectively while triggering compensatory anaerobic metabolism (Yan *et al.*, 2023). Ultimately, these factors lead to a 58% reduction in bulb fresh weight due to impaired photoassimilate translocation.

The significant higher growth and yield attributes obtained for irrigated crops in October as compared to rainfed onion plants in April might be due to cool dry environment, controlled moisture supplied or a higher temperature which favours plant growth and bulbs formation (Ansari, 2007). It may also show the existence of seasonal variation within the planting periods which influenced the vegetative development and bulb yield and yield components. Likewise, the lower performance obtained for rainfed onion in March - April are in agreement with the earlier findings of Ansari (2007), who attributed low yield during the raining season to the excessive rainfall. The superior performance of onions during the dry season under irrigation reinforces the justification for cultivating onions under irrigated conditions in tropical climates, particularly in Nigeria.

Drought stress induces profound morphological, physiological, and biochemical changes in plants. It disrupts fundamental growth processes such as cell division and elongation, leading to reduced overall plant growth (Farooq *et al.*, 2009). Basu *et al.* (2016) noted that under drought conditions, reduced turgor pressure inhibits cell expansion, primarily due to decreased water movement through xylem tissues. According to Marschner (2012), drought also limits nutrient and water flow, reducing nutrient availability for root absorption.

Yield reductions under drought conditions are often linked to premature maturity without full vegetative development. Tolossa (2021) observed that onion plants receiving optimal irrigation matured later and yielded more than those with only one-fourth of their irrigation requirement. This highlights the critical role of adequate water supply for optimal bulb development and maturation.

Waterlogging exerts a detrimental effect on bulb production, resulting in fewer and smaller bulbs compared to other conditions. This observation is supported by Grzebelusi *et al.* (2017), who reported reduced bulb size in *Allium sativum* under saturated conditions.

Similarly, maize (Huang *et al.*, 2022; Hu *et al.*, 2023) and peanut (*Arachis hypogaea*) (Zeng *et al.*, 2023) yields were significantly reduced under waterlogged conditions. Recent findings by Yang *et al.* (2024) also revealed that waterlogging decreased maize grain yield by 29.1% through reductions in grain weight and number. Oxygen deficiency is the primary response to waterlogging in plants, leading to root death, stomatal closure, chlorosis, and necrotic spots, which collectively reduce dry matter accumulation, catalase activity, and photosynthesis (Kirnak *et al.*, 2002).

Drought conditions also negatively impacted bulb development, producing significantly fewer and smaller bulbs compared to well-watered conditions, further emphasizing the role of adequate water in *A. cepa* bulb formation. Shu-aib *et al.* (2023) reported the highest yields (28.68 t/ha) with both morning and evening daily irrigation, followed by morning-only daily irrigation (28.12 t/ha), whereas the lowest yield (25.80 t/ha) occurred with alternate-day watering. These findings align with Ortola and Knox (2015), who confirmed that regular watering is essential for onion growth, as water stress at specific developmental stages can significantly reduce yields. Similar conclusions were drawn by Pejic *et al.* (2011) and Temesgen *et al.* (2018), who found that consistent water supply led to improved growth and marketable bulb yields.

High humidity levels (>80% RH) and poor curing conditions during the wet season promote susceptibility to secondary infections by *Botrytis allii* and *Pantoea agglomerans* (Gupta *et al.*, 2023). These conditions also impair skin set due to incomplete scale leaf desiccation (Opara *et al.*, 2022). Combined, these factors reduce marketable yield by 35–50% and shorten shelf life by 4–6 weeks compared to dry-season harvests (Afolayan *et al.*, 2021).

Results from this study revealed that dry season cropping significantly enhanced onion yield, in agreement with previous findings. The dry season provides increased sunlight

intensity and reduced humidity and rainfall, creating ideal conditions for bulb initiation and development. These factors collectively contribute to improved photosynthetic activity, reduced disease incidence, and enhanced bulb quality. Similar results were reported by Tesfay *et al.* (2011), who found better bulb development under drier conditions due to favorable environmental parameters.

Conversely, onions cultivated during the wet season had significantly lower yields. Adverse meteorological conditions during bulb formation, including high rainfall, lower temperatures, increased humidity and reduced sunlight would affect performance ref this. The unfavorable weather can lead to outbreak and spread of pests and disease, promote vegetative growth at the expense of bulb formation and increase the risk of bulb rot. The finding align with the work of Collin *et al.* (2004), who identified excess water as a leading cause of bulb rot.

Moreover, wet-season conditions increase the incidence and severity of foliar diseases, further reducing productivity. (Tho *et al.*, 2019) reported that pathogens such as *Enterobacter cowanii*, *Pantoea ananatis*, and *Pantoea agglomerans* thrive under conditions of 25–30 °C and relative humidity (RH) above 80%. Their study found that disease symptoms developed earlier and more severely under high RH conditions and were significantly suppressed when RH dropped below 60%. Disease susceptibility also increased as plant age progressed from 6 to 14 weeks.

Tesfay *et al.* (2011) similarly observed taller plants and more leaves during the wet season, indicating a shift toward vegetative growth. Similarly, Kumar *et al.* (2007) cautioned that while water availability promotes growth, excessive rainfall negatively affects bulb formation. Nutritional imbalance due to waterlogging causes leaf chlorosis, senescence,

wilting, necrosis, and stunted plant growth, which may affect the susceptibility of a plant to disease and increase the severity of infection (Yiu *et al.*, 2008).

Additionally, the physiological response of onions to water-logging often includes stem or neck elongation as an adaptive escape strategy (Zhang *et al.*, 2021). This elongation may be further exacerbated by stress-induced hormonal changes, such as the accumulation of gibberellins, especially under secondary infections by *Gibberella moniliformis*, which can also lead to leaf twisting and abnormal growth (Alberto and Aquino, 2010; Alberto, 2014).

Abiotic stress not only weakens plant defense mechanisms but also amplifies susceptibility to pathogen attacks. Atkinson and Urwin (2012) noted that such interactions between abiotic and biotic stressors often exacerbate crop losses.

In Nigeria's Sudan Savanna zone, farmers predominantly cultivate onions during the dry season (between September and December), aided by irrigation infrastructure (Taiwo and Ayanwale, 2014). High pest and disease incidence under hot, humid rainy-season conditions restricts wet-season onion cultivation (Simonyan *et al.*, 2011).

To mitigate these challenges during the rainy season, raised bed planting is recommended. This method improves drainage by keeping the topsoil unsaturated, thereby reducing waterlogging and creating a more favorable environment for root development (Bakker *et al.*, 2005; Velmurugan *et al.*, 2016). Raised beds also help limit the incidence of anthracnose and other fungal diseases, as demonstrated by Govaerts *et al.* (2007); Gadge and Lawande, 2012; Laxman *et al.* (2020).

Optimal Planting Date:

The significant differences observed in growth and yield parameters across planting dates confirm that onion performance is highly influenced by environmental factors such as

temperature, day length, and rainfall (Fritsch and Friesen, 2002; Ansari, 2007). This variation suggests that onion, while preferring cool-season conditions, can be grown across diverse climates. The superior growth and yield observed in the October planting were likely due to favorable conditions moderate temperatures and minimal rainfall supporting optimal vegetative and bulb development (Ansari, 2007).

The optimal planting date identified in this study was October 10, reinforcing the importance of late rainy season planting for maximizing onion yield in the rainforest zone of Nigeria. Late rainy season planting ensures a longer vegetative growth period before bulb initiation, allowing plants to benefit from favorable conditions, including optimal temperatures, sunlight, and day length. This extended growth period promotes healthy foliage development, supporting larger and higher-yielding bulbs (Ud-Deen, 2008; Hamma, 2013). Similarly, Brewster (1994) noted that delayed sowing reduces yields due to premature bulb formation. Additionally, (Kerpauskas *et al.*, 2009; Deepak Misra *et al.*, 2014) reported that it is important to identify the optimum planting dates for onion in order for it to express its full agronomic potentials. Further studies by Bosekeng and Coetzer (2013, 2015), Ali *et al.*(2016), Aboukhadrah *et al.* (2017) and Singh and Singh(2000) emphasized that onions grown in early planting dates in the semi-arid tropical region of northern India produces vigorous plants with larger bulb, higher fresh weights and increased bulb diameter.

These align with research by Ud-Deen (2008), who reported similar results with an October 30 planting date in Bangladesh during the cool dry winter season, and Hamma (2013), who identified October 15 as optimal for Zaria, savannah zone in Nigeria. Ali (2016) and Singh and Singh (2000) identified October 26 and September 11 as optimal planting dates in Pakistan and India, respectively, while Leilah *et al.* (2003) reported that early December planting in Egypt yielded up to 46.95 t/ha due to prolonged exposure to daylight and

Cramer (2003) found that onions planted on September 30 in the Trans-Pecos region of Texas (arid climate) exhibited enhanced growth due to an extended vegetative period before bulb formation. These reports agree with the results of the study, where early October planting in rainforest zone of Nigeria provided similar benefits. Bosekeng *et al.* (2013) also suggested that onions transition from leaf blade production to bulb initiation when day length and temperature requirements are met, conditions best achieved during the dry season. These emphasizes the importance of synchronizing planting dates with the onset of dry seasons, as onions thrive under conditions with adequate sunlight, low rainfall, soil moisture and humidity for optimal bulb development.

Propagation Methods:

The study also demonstrated that onions propagated from sets outperformed those grown from seeds in terms of bulb size, uniformity, and overall yield. The higher bulb weights observed in onions planted from sets suggest faster crop establishment and superior growth, likely due to an improved Leaf Area Index (LAI) that supports efficient light interception. Selamawit *et al.* (2013) similarly noted that set-planted onions tend to produce larger and more homogeneous bulbs than those grown from direct seeding. Massiha *et al.* (2001) also highlighted that sets result in vigorous plants with larger bulb diameters and higher fresh weights.

The slower initial establishment of seed-propagated onions from this research compared to set-propagated plants can be attributed to transplant shock and differences in energy reserves. Seedlings from seeds experience significant root disruption during transplanting, delaying water and nutrient uptake, while sets benefit from pre-formed meristems and stored carbohydrates (fructans) in their bulb scales, enabling faster regrowth (Kahane *et al.*, 2021; Shinohara *et al.*, 2022). This physiological advantage allows set-propagated onions to

exhibit rapid leaf emergence and canopy development, typically achieving active growth up to 14–21 days earlier than seed-propagated plants.

To mitigate the challenges associated with seed propagation, strategies such as seedling hardening (Leskovar and Othman, 2023) and the use of plug-tray transplanting systems (Agriculture.Institute, 2023) have been recommended to minimize transplant shock and mortality, soil-borne diseases and improve resilience under adverse climatic conditions. These techniques help minimize transplant shock, improve seedling survival, and support uniform field establishment.

From an economic perspective, propagation using sets generally incurs higher upfront costs due to the labor-intensive process of bulblet production, storage, and sorting or purchase of sets, whereas seed propagation particularly tends to be more cost-effective in terms of input materials (Boyhan and Torrance, 2002; Brewster, 2008). However, the higher initial costs of sets can be justified in short-season systems where rapid establishment and early market entry are advantageous.

Environmentally, seed propagation is often considered more sustainable over the long term, as it avoids the need for storage and repeated field handling, both of which are associated with greater energy use and potential carbon emissions (FAO, 2017). Additionally, seed-based systems support integrated pest management (IPM) strategies by enabling easier rotation of certified disease-free varieties, thereby reducing the risk of pathogen buildup in the soil (Kahane *et al.*, 2021). Therefore, farmers must weigh both economic return and environmental impact when selecting the most appropriate propagation method for onion cultivation.

Conclusively, the results emphasize that propagation method plays a crucial role in onion crop performance. While sets offer the advantage of rapid early growth valuable for short-

season production systems and weed suppression, seed propagation are suitable for achieving maximum yield potential under longer growing periods. The choice of propagation method should thus be informed by seasonal constraints, cultivar characteristics, labor availability and market demands.

5.2 Summary of Findings

The study yielded the following key observations:

1. Propagation Method: Set propagation consistently produced higher bulb yields compared to seed propagation across both planting seasons.
2. Impact of Planting Dates: Planting dates showed no significant effect on the yield of seed-propagated onions.
3. Seasonal Influence: Dry season cultivation resulted in significantly better yields than wet season cultivation.
4. Optimal Planting Date: The highest bulb yield was achieved with set propagation on October 10, outperforming other planting dates.

5.3 Conclusions

This study demonstrates that onion plants propagated from sets during dry planting season Oct 10th exhibited significantly higher total yields compared to those grown from seeds and in wet planting season. Notably, the yield from set-planted onions was nearly double that of seed-propagated onions, while October 10th planting date resulted in the highest yield

5.4 Recommendations

Based on these findings, farmers in Benin City and other rainforest zones of Nigeria are advised to:

Adopt set propagation over seed propagation for improved bulb yield, schedule planting for early October (specifically October 10th) to take full advantage of favorable dry season conditions and prioritize dry season cultivation of the 'Kano Red' onion variety for optimal performance.

CONTRIBUTION TO KNOWLEDGE

The findings of this study provide valuable insights into onion cultivation in the rainforest agro-ecological zone of Edo State, Nigeria, as follows:

1. The study established that onions are better propagated using sets rather than seeds, which results in higher yields.
2. Early October (October 10th) was identified as the optimal planting date for onion cultivation in Edo State.
3. The research demonstrated that dry season cultivation is more favorable for onions, as it reduces the incidence of pests and diseases while providing suitable weather conditions for optimal growth and healthy bulb formation.

4. It was concluded that set-propagated onions, planted on October 10th during the dry season, achieve the highest yield, making this method and timing ideal for onion production in the region.

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