TILLAGE PRACTICES AND NITROGEN FERTILIZER RATES ON SOME AGRONOMIC PERFORMANCE OF HABANERO PEPPER (*Capsicum chinense* Jacq.) AND SOME SOIL PROPERTIES

Adebimpe Omowumi AYEGBE (Miss)
PG/AGR2015131
B.AGRIC. (SOIL SCIENCE), EKPOMA, 2019

A PROJECT RESEARCH SUBMITTED TO THE COLLEGE OF POSTGRADUATE STUDIES IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTERS (M.Sc) IN SOIL SCIENCE IN THE DEPARTMENT OF SOIL SCIENCE AND LAND MANAGEMENT, FACULTY OF AGRICULTURE, UNIVERSITY OF BENIN, BENIN CITY, NIGERIA

DECEMBER, 2025

CERTIFICATION

This is to certify that this study was carried out by Adebimpe Omowumi AYEGBE (PG/AGR2015131) in the Department of Soil Science and Land Management, Faculty of Agriculture, University of Benin, Benin City, Nigeria.

______________________	______________________
Prof. J.S. Ogeh Supervisor	Date
______________________	______________________
Dr. (Mrs.) V.I.O. Edosa Head of Department	Date

CERTIFICATION ON THESIS/DESERTATION ON PLAGIARISM

We, the undersigned attest and declare that the thesis of Adebimpe Omowumi AYEGBE (PG/AGR2015131) Titled: "Tillage practices and nitrogen fertilizer rates on some agronomic performance of habanero pepper (*Capsicum chinense* Jacq.) and some soil properties", has successfully passed the anti-plagiarism test and does not violate any copyright regulations.

______________________ ______________________

Prof. J.S. Ogeh Date
Supervisor

______________________ ______________________

Dr. (Mrs.) V.I.O. Edosa Date
Head of Department

UNIVERSITY OF BENIN, BENIN CITY

RELEASE FORM

NAME OF AUTHOR: Adebimpe Omowumi AYEGBE

TITLE OF THESIS: Tillage practices and nitrogen fertilizer rates on some agronomic performance of habanero pepper (*Capsicum chinense* Jacq.) And some soil properties

DEGREE FOR WHICH THESIS WAS PRESENTED: M.Sc

YEAR THESIS DEGREE WAS GRANTED: 2025

Permission is hereby granted the University of Benin Library to reproduce single copies of the thesis and to lend and sell such copies for scholarly or scientific research only.

The author reserves other publication rights of the thesis or extensive extract from it to be printed or otherwise reproduced without the author's written permission.

AUTHOR'S SIGNATURE ………………………………….

DATE …………………………………………………………

PERMANENT ADDRESS: 6, Igbokoda road, Igbodigo, Okitipupa, Ondo State.

DEDICATION

This work is dedicated to the Almighty God, who has graciously granted me the privilege to undertake this program. To Him belongs all glory, honor, and adoration, now and forevermore in Jesus' name. Amen.

ACKNOWLEDGEMENT

I give all praise and glory to God Almighty, whose grace, strength, and guidance have sustained me throughout this academic journey. Without His divine intervention, this achievement would not have been possible.

I am deeply grateful to my supervisor, Prof. J. S. Ogeh, for his invaluable guidance, patience, and encouragement throughout the course of this work. His expertise and mentorship have been instrumental in shaping my research skills.

My heartfelt appreciation goes to the Head of the Department of Soil Science and Land Management Dr. (Mrs.) V.I.O. Edosa, for her leadership and support, which provided a strong foundation for my academic progress. I am equally thankful to the department Post Graduate coordinator, Dr. I. Ogbemudia and the dedicated staff of the Department for their support, teachings, mentorship, and contributions to my academic journey.

Special thanks to the Dean of the Faculty of Agriculture, Prof. C. O. Emokaro, and other notable faculty members, including Prof. K.E. Law-Ogbomo, Prof. J. Ahmadu, Prof. (Mrs.) M. J. Koyenikan, Dr. I. Ugwa. I also appreciate my class mates who encouraged and carried me along during the course of the program.

I appreciate the support of my boss, Mr. Festus Ebozele, whose understanding enabled me to balance work and study.

To my beloved siblings, Ayegbe Olubumi and Ayegbe Ibukun, your love and encouragement have been my constant source of strength. I also appreciate my wonderful friends, including Udo Grace, Ogbagiri Monday, Omokagbo Victor, Uzu Uche Magdalene, Akpevwe Ivwighregheweta, Barr. Ngwuta Henry, Ileogbunam Ogochuckwu, among others, for their friendship and support throughout this journey.

Lastly, I owe my deepest gratitude to my dear parents, Mr. and Mrs. Taiwo Ayegbe, whose sacrifices, prayers, and unwavering love have been the foundation of all my achievements.

TABLE OF CONTENTS

LIST OF TABLES

Tables Contents Page

ABSTRACT

Habanero pepper (*Capsicum chinense* Jacq.) is an important horticultural crop in Nigeria, but its yield potential is constrained by poor soil fertility and unsustainable tillage practices. This study was undertaken to evaluate the effects of tillage practices and nitrogen fertilizer application rates on performance of Habanero pepper under field conditions in Benin City, Edo State, Nigeria.

The field experiment was a 2 × 4 factorial arrangement fitted into a randomized complete block design with four nitrogen fertilizer rates (0, 40, 80, and 120 kg N/ha) and two tillage systems (minimum tillage and no-tillage) with three replications. Composite soil samples were collected and analyzed for physical and chemical properties before and after planting. Agronomic data collected includes plant height, number of leaves, number of branches, stem girth, and yield. Nutrient uptake, nutrient use efficiency (NUE), and nutrient balance sheets were used to assess fertilizer responsiveness.

Results showed that nitrogen application significantly affected soil pH, organic matter, and nutrient availability, with high N rates (120 kg/ha) resulting to acidification and organic matter decline. Minimum tillage enhanced nutrient uptake and plant growth compared to no-tillage. Optimal plant growth and yield were achieved under the interaction of minimum tillage and moderate nitrogen rates (40 and 80 with yield values of 4.42t/ha and 4.16t/ha respectively). NUE peaked at 40 kg N/ha and declined at higher rates, while nutrient balance sheets indicated surplus nitrogen with increased N inputs (120kg/ha). The study suggests that integrating 40–80 kg N/ha with minimum tillage optimizes Habanero pepper growth, yield, and soil quality and NUE, excessive N application should be avoided to promote healthy soil environment and ensure sustainable vegetable production systems in Nigeria.

CHAPTER ONE

INTRODUCTION

Tillage is an essential agricultural management practice for enhancing and sustaining productivity of soils in the tropics (Ewulo *et al.*, 2011). Soil tillage is the mechanical, physical, or biological manipulation of soil to modify its structure, porosity, and nutrient availability in order to create favourable conditions for seed germination, crop establishment, and sustainable crop production (Jat *et al.*, 2020; Adekiya *et al.*, 2021). Conservation tillage practices increase soil moisture retention and pepper yield compared to conventional tillage under sandy loam soils in the derived savanna (Ojeniyi *et al.*, 2020). Tillage is crucial for the establishment, growth and ultimately yield of crops (Atkinson *et al.*, 2007). It contributes up to 20% of all crop production factors (Khurshid *et al.*, 2006), and appear indispensable if food crop production must balance food demand by the growing human and livestock populations and attain national food security on a sustainable basis. A good soil management practice that protects the soil from water and wind erosion will improve root development and increase soil organic matter (West and Post, 2002). As tillage supports crop establishment and nutrient uptake, it can also accelerate nutrient loss and soil degradation if poorly managed (Adekiya *et al.*, 2021). Climate-smart tillage and site-specific N application is a key to sustaining tropical vegetable production under changing climate conditions **(**FAO, 2021).

Nitrogen is frequently the most limiting essential nutrient in natural ecosystems however, insufficient nitrogen typically limits plant growth in nature and plants merely slow their growth to fit the available supply of nitrogen (Aboyeji and Abayomi, 2013). Most of the photosynthesized organic carbon from atmospheric CO_2 to the plant body is eventually decomposed and converted from organic substrate into inorganic products (CO_2 and aerobic mineralizing water). Nitrogen fertilizer application rates between 60–90 kg N/ha optimizes pepper yield without significant negative impacts on soil chemical properties (Olayinka and Ogunwole, 2022).

Nitrogen fertilization improves crop yield and some soil quality attributes but can also increase the risk of nitrate (NO_3^--N) leaching and nitrous oxide (N_2O-N) emissions when applied in excess of the crop requirements (Ogunlade *et al.,* 2019). Combining reduced tillage with optimal N rates enhances maize growth while maintaining soil fertility in the derived savanna (Law-Ogbomo and Egharevba, 2009). Globally, integrated soil fertility management, including moderate N use, can enhance nitrogen use efficiency (NUE) while minimizing environmental losses (Fageria, 2014; Zhang *et al.,* 2021). Reduced fertilizer rate increases soil N and P concentration compared to not adding fertilizer, but not to the same extent as the recommended rate in a research carried out by Nair *et al.,* (2016). The reduced N fertilizer rate increased yield by 110 % over the control, whereas the recommended rate increased yield by 16 % compared to the reduced rate.

Habanero-type pepper is essential food crops in tropical countries and is grown mainly in Savanna ecological zones where rainfall is less compared with humid regions. Peppers—particularly their seeds—are rich in protein and minerals. Pepper seed protein content ranges between 6.30% and 28.3% (Cvetković *et al.*, 2020). Additionally, peppers are especially rich in iron compared to other Solanaceae fruits (tomato, eggplant) under similar growing conditions (Goff *et al.*, 2021). In recent years, the Habanero pepper (*chinense* Jacq.) has become increasingly important as a result of its wide diversity and its high fruit pungency, which make it very desirable in many countries. The contribution of tillage and nitrogen fertilizer application on soil quality improvement and yield of Habanero pepper (*Capsicum chinense* Jacq.), was therefore evaluated in this study.

1.1 STATEMENT OF PROBLEM

Crop production is increasing at 1 % per year across Sub-Saharan Africa (Chauvin *et al.*, 2012), but is outpaced in the Sahel by a population growth rate of over 3 % (World Bank, 2014). Habanero pepper (*Capsicum chinense* Jacq.) is a high-value horticultural crop cultivated across Nigeria and other tropical regions for its nutritional, economic, and culinary importance. Despite its potential, average yields of Habanero pepper (*Capsicum chinense* Jacq.) in Nigeria remain significantly lower (6–8 t/ha) than the global average (>20 t/ha) (FAO, 2021). This yield gap is attributed to multiple production constraints, among which poor soil fertility management and inappropriate tillage practices are prominent.

Tillage influences soil physical, chemical, and biological properties, thereby affecting nutrient cycling, water retention, and crop performance. Inappropriate tillage, especially repeated deep plowing, can degrade soil structure, accelerate erosion, and reduce nutrient use efficiency (Subbulakshmi, 2009; Jat *et al.,* 2020). While conservation tillage has been shown to improve soil quality and reduce erosion in other regions, its effects on Habanero pepper yield under Nigerian savanna conditions remain under-researched.

Nitrogen (N) is a critical macronutrient for Habanero pepper growth and yield; in many Nigerian soils, N availability is limited due to low organic matter content, high leaching potential, and continuous cropping without adequate replenishment (Law-Ogbomo and Egharevba, 2019). Excessive application of nitrogen fertilizer, can lead to environmental problems such as nitrate leaching, greenhouse gas emissions, and soil acidification (Malhi and Lemke, 2007; Zhang *et al.,* 2021). Also, frequent tillage and excessive nitrogen fertilizer not only reduces the crop productivity but also exacerbates soil erosion, air and water pollution (Godfray *et al.,* 2010).

Recent studies in Nigeria have examined tillage × nitrogen interactions on maize (Adekiya *et al.,* 2021; Yusuf *et al.,* 2022) and tomato (Ogunlade *et al.,* 2019), there is a scarcity of research on how tillage × nitrogen interactions influence soil properties, nutrient use efficiency, and yield performance of Habanero pepper in the forest agro-ecology. This knowledge gap limits the development of site-specific recommendations that balance productivity with soil health and environmental sustainability. Factors attributed to low yield include variety, pests, diseases and soil infertility shows negative impact on growth and development of plants which is ultimately reduces plant yield.

Therefore, it was crucial to investigate the effects of tillage practices and nitrogen fertilizer rates on some soil properties, nutrient balance, and some agronomic performance of Habanero pepper (*Capsicum chinense* Jacq.).

1.2 JUSTIFICATION

An agricultural practice that minimize soil degradation is needed to improve soil quality and agricultural sustainability, hence, the conservation tillage which is more advantageous compared to traditional and conventional tillage.

Measures to mitigate adverse effects of tillage on the basis of ecology need to be evaluated for the purpose of advancing appropriate land use management practices compatible for sustainable soil quality in Habanero pepper (*Capsicum chinense* Jacq.) production. It is important to find out appropriate tillage practice which will minimize soil properties disturbance in Habanero pepper (*Capsicum chinense* Jacq.) cultivation. However, the impact of conservation tillage on soil physical environment is not always positive and varies from one soil to the other and also between the cropping systems (Saha *et al.,* 2010).

Habanero pepper (*Capsicum chinense Jacq*) require development of soil management package that could conserve soil moisture, increase availability of nutrients, moderate soil temperature, and reduce soil compaction. The soils of forest ecologies have been reported to be poor in native Nitrogen, Phosphorus and organic matter, hence the need for adequate fertilization so as to increase the yield of Habanero pepper (*Capsicum chinense* Jacq.).

Crucial role of nitrogen for being main constituent of all amino acids in proteins and lipids, the structural compounds of cells and chloroplast made it the most essential macronutrient for good plant establishment and expected growth (Uddin and Khalequzzaman, 2003). Therefore, its deficiency shows negative impact on growth and development of plants which is ultimately reduces plant yield. Habanero pepper (*Capsicum chinense* Jacq) requires continuous supply of N as a component of nutrition for production systems in which the aim is to maintain good growth, maximum fruit yield and quality, especially the levels of secondary metabolites such as alkaloids (Capsaicin).

Thus, this present study was initiated to assess the effects of tillage and nitrogen fertilizer application rates on soil properties for sustainable Habanero pepper (*Capsicum chinense* Jacq.) production in Benin city, Edo State.

1.3 OBJECTIVE OF THE STUDY

The main objective of this study was to determine the effect of tillage and nitrogen fertilization on performance of Habanero pepper (*Capsicum chinense* Jacq.) in Benin city, Edo State.

OBJECTIVES

The specific objectives were to:

1. evaluate the effect of tillage and nitrogen fertilizer on the agronomic performance of Habanero pepper (*Capsicum chinense* Jacq.)
2. determine the effect of tillage and fertilizer application rates on some soil properties
3. determine the nutrient use efficiency and nutrient balance sheet of applied N.

CHAPTER TWO

LITERATURE REVIEW

2.1 Tillage

Rapid soil degradation under continuous cultivation based on mechanical and manual tillage has become a problem worldwide and this has led to the exploitation of the variety of alternative system as possible means of maintaining soil quality and crop production (Odofin, 2005). The interactions between tillage systems and fertilizer play a significant role in determining sustainability of horticultural crop production. The conservation of soil, water and other natural resources is a crucial factor for achieving sustainable production in rain-fed farming. Recent studies also show that conservation tillage protects life cycles of arthropods, increasing their diversity (Mhlanga *et al.,* 2020), and plays a major role in shaping microbial communities (Kraut-Cohen *et al.,* 2020). The conservation tillage will influence the crop productivity and weed emergence apart from conserving soil and water (Baskaran and Kavimani, 2014). Tillage enhances soil pore structures thereby influencing crop yield while fertilizers are required to argument-depleted soils typical of tropical soil conditions. Habanero pepper (*Capsicum chinense* Jacq) under fertilizer rates of 120 kg/ha, in combination with ploughing plus harrowing plus bedding tillage system produced the best mean yield (Afolayan *et al.,* 2010). Tillage quality exhibits a pronounced residual effect on saturated hydraulics conductivity and soil moisture retention characteristics.

Tillage systems fall on a disturbance continuum: conventional tillage (CT) — inversion and deep mixing; minimum/reduced tillage (MT) — shallow, less inversion; strip/zone tillage — localized row disturbance; and no-tillage (NT) — zero inversion with residue retention. Global meta-analyses and long-term trials show NT/RT combined with residue retention increases surface SOC and aggregate stability and can reduce erosion and some greenhouse gas fluxes, but benefits concentrate in topsoil (0–10 cm), and crop/yield responses vary by climate and residue management (Pittelkow *et al.,* 2015; Li *et al.,* 2024; Meng *et al.,* 2024).

Soil tillage is one of the agricultural production methods that is of extreme importance to both rural and urban farmers. Sustainable food production has therefore been linked to different agricultural production techniques. Ojeniyi *et al.,* (2020) found that conservation tillage practices increased soil moisture retention and pepper yield compared to conventional tillage under sandy loam soils in the derived savanna. Tillage is thought to be as old as settled agriculture (Badalikova, 2016) and is, by that fact, an integral part of conventional agriculture systems. Tillage is crucial for crop establishment, growth and ultimately, yield (Atkinson *et al.,* 2007). Afolayan *et al.,* (2004) reported that the capacity of the soil to sustain nutrient cycles, energy and water flow through soil aggregate and ability to recover from degradation or deterioration after intensive exploitation depends on the tillage techniques. The effects of tillage on crop yield and soil properties seem not to be consistent across crop species and soil types. No-till involves an abundance of crop residues which continuously add organic N after mineralization (Sharifi, 2013).

2.2 Soil Fertility

Soil properties describes the physical and chemical characteristic behavior of soils including the nutrient status (Usman, 2018). There have been conflicting reports on the influence of tillage on soil chemical properties; likewise, contradictory reports as to the superiority of crops on tilled plots to those of no -till plots have been documented (Adekiya and Ojeniyi, 2011). The need for basic knowledge and assessment of changes in soil properties and their fertility status with time to evaluate the impact of various tillage has become necessary for sustainable agriculture in Nigerian savanna zones. Manual tillage systems including ridges, heaps and flat beds have been reported to degrade soil quality and reduce chemical and biological qualities especially on alfisols in the rainforest areas of Southwest, Nigeria (Busari and Salako, 2013).

However, changes in soil physical and chemical properties due to tillage may lead to soil loss and increased fertilizer demand (Stevens *et al.,* 2009). Zheng, (2015) recorded a significant interaction of tillage and irrigation regime for marketable yield and number of Habanero pepper (*Capsicum chinense* Jacq.) fruit within the conventional tillage production system. Ewulo *et al* (2011) reported that tillage increase plant height, number of leaves and branches. Erdem, (2007) had also earlier reported increase in leaves fresh weight and number of pepper under different tillage methods. Rafael *et al* (2021) reported that crop N uptake was significantly higher (13%) in the tillage treatment compared to no tillage treatment. Tillage plus mulch had highest values of growth parameters compared with Manual clearing, tillage alone or Manual clearing + Mulch (Ewulo *et al.,* 2011).

2.3 Soil Management and soil Properties

Soil management practices such as tillage and mulching are useful in improving soil physical, chemical and biological conditions for enhanced crop performance (Moniruzzaman *et al.,* 2007; Christopher *et al.,* 2011; Al-Rawahy *et al.,* 2011). The practices could improve availability of nutrients, root growth and availability of soil water and moderate soil temperature (Ojeniyi and Ighomrore, 2004; Awodun *et al.,* 2011). Tillage plus mulching give high yield value as well as values of plant, P, K, Ca and Mg (Ewulo *et al.,* 2011). It was therefore suggested that these nutrients (P, K, Ca and Mg) are important in pepper nutrition.

Management of soil through conventional tillage changes soil water storage, evaporation losses and soil susceptibility to runoff generation (Ngetich *et al.,* 2014). Conservation tillage as compared to conventional tillage improves soil and water resources, save energy and time, and reduces the cost of Agricultural production as compared to conventional tillage, minimum tillage protects the soil from wind and water erosion, favors microbial growth; improved soil structure, increased infiltration rate, soil respiration, dehydrogenase activity in upper layer, soil organic carbon and soil microbial biomass is significantly congenial in minimum tillage as compared to conventional tillage (Singh *et al.,* 2007). Significant higher yield with No Tillage compared with Conventional tillage has been reported for various crops in dryland environments (Toliver *et al.,* 2012). Furthermore, tillage is likely to lead to soil surface roughness. Depending on its frequency and kind, tillage can destroy soil aggregates and result in degradation of soil structure, with immediate consequences on the ability of a soil to hold and conduct water, nutrients, and air necessary for plant root activity. Many cultivated soils are inherently low in SOM and have high vulnerability to acidification and nutrient leaching under heavy rainfall. Local studies show that organic inputs (FYM, bioslurry) raise pH, CEC and available P and buffer soils against the acidifying effect of NPK; residue retention + reduced tillage also improves infiltration and reduces erosion in Nigerian trial (Akpan *et al.,* 2020; Akande *et al.,* 2020).

2.4 Nitrogen

Nitrogen is an important nutrient for all crops, and the deficiency of N in crops results to stunted growth and develop yellow-green colour. It accelerates photosynthetic behavior of green plants as well as growth and development of living tissues specially tiller count in cereals. Khan *et al* (2010) studied the effect of nitrogen and phosphorus on the growth and yield of Habanero pepper (*Capsicum chinense* Jacq.). The results revealed that plant height at final harvest and number of branches at first and final harvest increased significantly up to 200 kg N/ha. Application of fertilizer N improves soil Nitrogen availability, which enhances crop growth and uptake of not only N but also uptake of other nutrients. Islam *et al* (2018) investigated the influence of nitrogen and phosphorus on growth and yield of Habanero pepper (*Capsicum* *chinense* Jacq.) and found that growth and yield contributing parameters were significantly influenced by different doses of nitrogen and phosphorus fertilizers. However, depending on the crop and factors, such as fertilizer source, availability of one macronutrient might negatively or positively affect another (Guo *et al.,* 2019; Shiwakoti *et al.,* 2019). Local trials indicate Habanero responds well to moderate N (≈40–80 $kg \cdot ha^{-1}$) combined with adequate K and organic inputs, but exact optima depend on soil baseline fertility and irrigation regime (González-Cortés *et al.,* 2023; Vadillo *et al.,* 2024)

2.5 Different Nitrogen fertilizer application rates on Pepper

Nitrogen remains a limiting factor for crop growth and development in most agricultural lands. There is general agreement, that of all the nutrient amendments made to soil, N fertilizer application has had and still has by far the most important effects in terms of increasing crop production. Under intensified agricultural production the soil receives ever more nitrogen (Freney, 2005; Erisman *et al.,* 2005). Fertilizer nitrogen, apart from increasing the content of nitrate in soil that leads to its leaching, results in changes in soil pH and many other soil properties (Brady and Weil, 2002). Previous studies have shown that tillage and N-fertilizer can significantly affect crop yield and soil physical and chemical properties.

Hani *et al.,* (2006) reported that nitrogen application up to 80Kg N/ha remarkably increased 50% tasseling, plant height, stem diameter, leaf area index and dry matter production. Application of nutrients like nitrogen and phosphorus is well known to enhance the crop growth and development for optimum yield and to improve quality of produce. Nitrogen fertilizer significantly affected the average fruit weight, fruit volume and yield of Habanero pepper (Mohammad *et al.,* 2012), data showed that the highest fruit weight and volume fruit were observed from 50 and 100 kg N ha-1 treatments. It is evident from literature, that nitrogen and phosphorus affect growth, yield and quality of fruits and vegetables. Nitrogen progressively increases the marketable yield of Habanero pepper (*Capsicum chinense* Jacq.) but an adequate supply of nitrogen is essential for vegetative growth, and desirable yield (Aminifard *et al.,* 2012). Guohua *et al* (2001) found that varying nitrogen form affected on Habanero pepper flowering, fruit set, fruit ripening time and yield. Early N availability appears necessary for plant growth, fruit size and yield of Habanero pepper (*Capsicum chinense* Jacq.).The productivity of pepper is highly responsive to N fertilizer. Tumbare *et al.,* (2004) reported that nitrogen fertilizer increased fruit weight, yield and fruit number of chili peppers. Madeira and de Varennes (2005) observed that total chlorophyll content, leaf N concentration and shoot dry weight of pepper increased with increasing N fertilization. Global pepper research reveals a classic diminishing-returns response to N: yields increase with N up to a crop-specific optimum, beyond which little or no gain occurs and environmental costs rise. Recent multi-year trials in Spain (processing pepper) used 0–180 (and up to 300 in one year) $kg \cdot ha^{-1}$ and found site-specific optima close to 100–120 $kg \cdot ha^{-1}$ for their conditions; for habanero, other trials by Vadillo *et al* (2024) find lower optima (40–80 kg/ha) depending on soil baseline fertility and irrigation intensity.

2.6 Tillage and nitrogen fertilizer on pepper production

The interaction between the tillage and N fertilizer under dry land conditions accentuates No tillage at 60 kg N ha^{-1}, as a management technique that can sustain the soil quality. Minimum tillage with moderate nitrogen rates improved soil organic matter and yield of *Capsicum chinense* in southern Nigeria, while excessive N rates reduced soil pH and nutrient use efficiency as reported by Adekiya *et al* (2021).

2.7 Pepper Fruit

Habanero pepper (*Capsicum chinense* Jacq.) belongs to the Capsicum clade domesticated in the Americas and shows a long history of human selection for fruit pungency, aroma and heat.

Large gene bank and genomic analyses show modern cultivars are the result of multiple dispersal and selection events that shaped diversity in fruit traits and phenology; this global genetic perspective is important when interpreting agronomic plasticity across regions (e.g., tropics vs. subtropics). (Tripodi *et al.*, 2021).

Habanero pepper (*Capsicum chinense* Jacq) is one of the most popular vegetable crops, also known as bell pepper. It belongs to family Solanaceae. Habanero pepper (*Capsicum chinense* Jacq.) is an important vegetable crop that is cultivated in Nigeria. It is cultivated outdoors as either a rain-fed or irrigated crop. Habanero pepper (*Capsicum chinense* Jacq.) is consumed as cooked vegetable or as raw salad. As a medicinal plant, pepper is used in the prevention and treatment of cold and fever (Udoh and Ndon, 2016).

Juroszek and Tsai (2009) reported that pepper fruits are good sources of many essential nutrients, including vitamins A, C, and E, carotenoids, minerals (e.g., calcium and iron), and other secondary plant compounds. It is highly nutritious with abundant source of vitamins A and C, minerals like phosphorus, potassium, calcium and magnesium. Nigeria is known to be one of the major producers of pepper in the world accounting for about 50% of the African production (Idowu-Agida *et al.*, 2010). Although pepper is widely cultivated in Nigeria, the yields obtained are often very low due to low fertility of the soil (Iren *et al.,* 2016b). The low productivity of Habanero pepper (*Capsicum chinense* Jacq.) production is attributed to lack of improved varieties, poor cultural practices, low production inputs, inadequate knowledge on production and management (processing) systems, poor extension services, poor marketing system and the prevalence of fungal and bacterial as well as viral diseases. Among these, soil fertility management is one of the most yield limiting factors for Habanero pepper (*Capsicum chinense* Jacq.) production.

2.7 Pepper Fruit Yield Under Different Fertilizer Application

Good quality yield of pepper mostly depends on nutrient availability in soil which is related to the judicious application of fertilizer. Judicious application of fertilizer has also been found to encourage early maturity, uniformity in ripening, increase fruit size and yield of pepper (Iren *et al.*, 2017b). Ijah *et al* (2018) found that yield and yield components of pepper significantly increased by the application of organo - mineral fertilizer. Habanero pepper (*Capsicum chinense* Jacq.) requires heavy nitrogen application for higher yield as it imparts good vegetative growth necessary for good development of fruit. Olayinka and Ogunwole (2022) demonstrated that nitrogen fertilizer application rates between 60–90 kg N/ha optimized Habanero pepper yield without significant negative impacts on soil chemical properties. Mebratu *et al* (2014) found that nitrogen had significant effect on yield and quality components of Habanero pepper (*Capsicum chinense* Jacq.). Lodhi *et al* (2019) reported that the fruit yield of Habanero pepper (*Capsicum chinense* Jacq.) was significantly influenced by nutrients and mulching. When Habanero pepper (*Capsicum chinense* Jacq.) is adequately supplied with the essential nutrients through fertilization it improves their yield, quality and enhance maturity. As reported by Khan *et al* (2020). Nitrogen levels showed significant effect on all growth and yield parameters of pepper.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Location of the Study

This study was carried out at Research farm of the Faculty of Agriculture, University of Benin, Benin City, Edo state, Nigeria. The area lies between latitude $6^0$23´37´´ and $6^0$24´26´´ North and Longitude $5^0$36´25´´ and $5^0$89´09´´ East. It is a segment of the coastal plain sand commonly referred to as arid sand of Nigeria. The natural climate is humid tropics. The natural vegetation is rain forest. The rainy season is bimodal with peak in July and September. Average rainfall is between 1500-2500mm annually. Mean maximum and minimum temperature are 31 and 220C. The soil soil has been mapped as ultisol with Rhodicpaleudilt as the modal profile (Ogeh and Ogwurike, 2006).

3.2 Soil Sampling

Prior to tilling and planting, composite soil samples from 0 to 15 cm soil depth was randomly collected from experimental site. Soil samples were collected using soil auger at 0-15cm soil depth which was put into polythene bags and labeled accordingly and transported into the laboratory to determine the initial soil properties before planting. Soil samples were air-dried, crushed, and sieved through a 2 mm mesh before subjecting them for analysis. Analysis was conducted in the laboratory. Soil samples were analyzed for both physical and chemical properties in the laboratory.

3.2.1 Soil Analysis

The sieved samples were analyzed for some physical and chemical properties using standard laboratory procedures. The following parameters were determined;

3.2.2 Particle Size Distribution

Particle size distribution was determined by the hydrometer method as described by Gee and Bauder (1986). Fifty grams of air-dried soil was weighed into shaking bottles and 20ml of 10% calgon solution (Sodium hexameta phosphate) will be added to soil. Then 50ml distilled water was added and shaken for 1 hour on a reciprocal shaker. The sample was transferred quantitatively into 100ml measuring cylinder and made up to mark with distilled water. The first reading was taken when the cylinder was dropped on the platform within 40 seconds, the percentage silt + clay was determined within the 40 seconds. The second reading was taken after 2 hours. The percentage clay was determined after 2 hours.

3.2.3 Organic Carbon

This was determined by the chromic acid wet oxidation procedure of Walkley and Black (Black 1965). One gram of air-dried soil was weighed into 250ml conical flask, 10ml of Potassium heptaoxodichromate (vi) ($K_Cr_2O_7$) solution was added using a 10ml pipette and the flask gently swirled to effect proper mixing. Thereafter, 20ml of concentrated tetraoxosulphate (vi) acid (H_2SO_4) was added violently but carefully to avoid dissipation of heat of the reaction and to and to enhance complete oxidation, after 30 minutes, 100 ml of distilled water was added with 100 ml measuring cylinder followed by 6 drops of ferrione indicator. The content of the flask was titrated with 0.5N iron (ii) tetraoxosulphate (vi) pentahydrate solution ($FeO_4.5H_2O$) the color changed from dirty brown to wine color. A blank titration was carried out. Thus, organic carbon is calculated as:

$$\frac{(B(ml) - T\ (ml) \times 1.33 \times 0.03F \times N}{Weight\ of\ sample} \times \frac{100}{1}$$

Where B = titre value of blank

T – Titration value

N – Normality of $FeSO_4$

3.2.4 Organic Matter.

Organic carbon was multiplied by 1.724 (The Van Bemmelen factor) to get percent organic matter.

3.2.5 Soil pH

The soil pH was determined in both water and 0.01M $CaCl_2$ solution in 1:1 soil to water ratio. Ten (10) grams of the soil sample was weighed and twenty-five (25) ml of distilled water was added and stirred. The pH of the suspension was read using a pH meter after 30 minutes. The same procedure was repeated using 0.01M CaCl2 solution (IITA, 1982).

3.2.6 Total Nitrogen and Available Phosphorus

Total nitrogen and available phosphorus were determined by the Kjeldahl digestion and distillation procedure (Purificación *et al.,* 2013) and Bray P 1 method Olsen and summers, (1982) respectively.

3.2.7 Exchangeable Cations

Calcium and Magnesium were determined volumetrically by the EDTA titration procedure described by Black (1965).

Ten grams of air-dried soil was weighed into shaking bottle. 70ml of 1N ammonium acetate solution of pH7 was added with 100ml measuring cylinder to extract the exchangeable bases. The bottle was covered tightly and shaken for 1 hour on reciprocal shaker thereafter; the soil suspension was filtered through Whatman No. 42 filter into 100ml volumetric flask and residue washed into three 10 ml aliquots of 1N ammonium acetate of pH7 solutions.

25 ml aliquot of the filtrate was withdrawn with pipette into 250 ml conical flask, 20 ml of concentrated ammonia solution will be added followed by 6 drops of ethylenediamine tetraacetic acid (EDTA) solution and the color change will be sky blue color as end point. Potassium was determined from the filtrate by flame photometry as described by Black (1965)

3.3 Experimental Design and Treatment Combination

A 2 × 4 factorial experiment with 2 tillage practices and 4 Nitrogen application rates was fitted into a Randomized Complete Block (RCBD) with three replicates. The treatments were:

(1) Minimum tillage with no fertilizer applied representing farmer normal practice

(2) Minimum tillage with recommended rate of nitrogen fertilizer (40, 80 and 120 kg N/ha)

(3) No-tillage with no fertilizer as the control

(4) No-tillage with recommended rate of nitrogen fertilizers (40, 80 and 120 kg N/ha).

Treatments were assigned using table of random numbers and resulted into eight treatments combinations with three replicates as follows:

MT1= Minimum tillage with no fertilizer applied representing farmer normal practice

MT2 = Minimum tillage + 40 kg N/ha

MT3 = Minimum tillage + 80 kg N/ha

MT4 = Minimum tillage + 120 kg N/ha

NT5 = No tillage with no fertilizer applied as the control

NT6 = No tillage + 40 kg N/ha

NT7 = No tillage + 80 kg N/ha

NT8 = No tillage + 120 kg N/ha

3.4 Planting Operations

The Habanero pepper seed was obtained from the local market. The variety which was used in this experiment is high yielding and early maturing (80-90 days).

Prior to transplanting, a basal application of 1ton/ha of poultry dropping at 3 weeks before transplanting and 40kg/ha of NPK was applied to each experimental plot at 2 weeks before transplanting. Tillage was done 1 week before transplanting.

3.4.1 Nursery

A 3 X3 m seed bed was prepared; the Seeds were drilled by hand into the nursery bed at the inter-row spacing of 15 cm. After sowing, the bed was covered with palm fronds as shade until emergence and watered using a watering can. Seedling was transplanted at 4 weeks old. Before transplanting, the seedlings were watered to enhance easy uprooting and prevent root damage.

3.4.2 Transplanting

Four weeks old seedling of Habanero pepper (*Capsicum chinense* Jacq.) was transplanted at one Seedling per hole at a depth of 2.5 cm with a spacing of 40 cm x 60 cm; giving an approximate plant population density of 41, 666 plants/hectare. The total planting area was 16mX16m with each plot measuring 1.5mX1.6m. The land was cleared manually and ploughed using hoe.

3.4.3 Fertilizer Application

Urea was used as Nitrogen Source and it was obtained from the local market. Fertilizer was applied using the band method at 2 weeks after transplanting (0kgN/ha, 40kgN/ha, 80kgN/ha, 120kgN/ha).

3.4.4 Weeding

Weeding was done manually, after transplanting to control weeds. Each weeding operation was completed on the same day for all the plots.

3.5 Data Collection

Agronomic parameters such as Plant height, number of leaves, number of branches and stem girth was measured.

Yield of fruits per plot was determined by weighing the fruits using a weighing balance at harvest

3.6 Nutrient Use Efficiency (NUE)

NUE is expressed as:

$$NUE\ (kg\ yield/kgN) = \frac{Yield\ at\ N\ rate\ -\ Yield\ at\ 0\ N}{Amount\ of\ N\ applied\ (kg/ha)}$$

N- Nitrogen

3.7 Nutrient Balance sheet

Nutrient balance (NB) is the difference between inputs (fertilizer N rate) and outputs (plant N uptake). Estimate was made assuming N content in pepper fruits = 2.5% (Aliyu *et al.*, 2007):

N uptake (kg/ha) =Yield (kg/ha) × 0.025

$$NB = (F + M + BNI + D + W) - (Y + R + L + V + E)$$

F - Fertilizer input

M - Manure/organic input

BNI - Beneficial N fertilization

D - Deposition

W - Water Sources (rainfall/irrigation)

Y - Yield nutrient removal

L - Leaching

V - Volatilization

E - Erosion/runoff

3.8 DATA ANALYSIS

Data collected was subjected to the Analysis of Variance (ANOVA)using Statistical Analysis Software (SAS, 2002) and the significant treatment means were compared using the Duncan's multiple range test (DMRT) at $p \leq 0.05$ probability level.

CHAPTER FOUR

RESULTS

4.1 Initial Soil Properties

Table 1 showed the initial soil properties is a sandy soil (sand = 885g/kg, silt = 62g/kg, clay = 53g/kg) with low cation exchange capacity (4.1 cmol/kg) and acidic reaction (pH = 5.35), indicating inherently fragile fertility. The soil had low EC of 43.60μS/cm as well as low OC and OM of 9.60g/kg and 16.512g/kg respectively, the soil showed a low total N (0.54g/kg) and high available P (54.2mg/kg). The CEC was 4.10 with 0.16cmol/kg, 0.10cmol/kg, 0.70coml/kg and 0.17cmol/kg for K, Na, Ca and Mg respectively.

4.2 Growth and Yield of Habanero Pepper

The plants were taller under minimum tillage (26.25cm) than under No tillage (22.50cm). Plants treated with 80kgN/ha had the tallest which were compatible with all other rates except 120kgN/ha treated plants (Table 2). There was no significant interaction of tillage practice and N application interaction on the plant height.

Tillage practice and N fertilizer application had no significant effect on the number of leaves, number of branches, stem girth and yield. In the same vein, there was no significant interaction between tillage practice and N application rates.

4.3 Nitrogen and Tillage Effect on Soil Properties

Soil pH increased with NT (5.79), it had a significantly ($P \geq 0.05$) higher soil pH than MT (5.35), there was no significant difference in the effect of tillage on Electrical Conductivity, similarly EC had no significant difference under MT (137 μS/cm) and NT (78 μS/cm). NT was significantly ($P \geq 0.05$) higher OC (2.00g/kg) and OM (3.45g/kg) compared with MT (1.85g/kg and 3.19g/kg).

Tillage had no significant effect on Total N, Available P, Exchangeable Bases (K, Na, Ca, Mg) and CEC. Silt content was significantly ($P \geq 0.05$) higher under NT (142.8g/kg) compared with MT (126.9g/kg). Clay and sand were not significantly different for both MT and NT.

Table 1: Initial soil properties

Parameters	Value
Clay (g/kg)	53
Silt (g/kg)	62
Sand (g/kg)	885
Textural class	Sandy soil
CEC	4.10
Soil pH	5.35
EC (µS/cm)	43.00
OC (g/kg)	9.60
OM (g/kg)	16.512
Total N (g/kg)	0.54
Avail. P (mg/kg)	54.2
K (cmol/kg)	0.16
Na (cmol/kg)	0.10
Ca (cmol/kg)	0.70
Mg (cmol/kg)	0.17

Table 2: The effects of tillage practices and nitrogen fertilizer rates on some agronomic traits of Habanero Pepper

Treatment	Plant Height (cm)	Number of Leaves	Number of branches	Stem Girth (mm)	Yield (t/ha)
Tillage practice					
MT	26.25^{a}	45.6^{a}	7.47^{a}	18.14^{a}	4.46^{a}
NT	22.50^{b}	37.2^{a}	5.91^{a}	18.14^{a}	3.6^{a}
SED	1.309	3.96^{a}	0.485	0.192	1.19
SIG	**	ns	ns	ns	ns
N_level (kg)					
0	27.35^{a}	47.1^{a}	6.53^{a}	17.92^{a}	3.22^{a}
40	26.96^{a}	36.0^{a}	6.31^{a}	18.23^{a}	4.42^{a}
80	28.12^{a}	44.0^{a}	7.50^{a}	18.41^{a}	4.16^{a}
120	15.06^{b}	38.5^{a}	6.42^{a}	18.01^{a}	4.3^{a}
SED	2.556	7.96	0.893	0.430	2.47
SIG	***	ns	ns	ns	ns
Tillage x N_level Interaction					
SED	2.536	10.52	1.196	0.560	3.25
SIG	ns	ns	ns	ns	ns
CV	12.7	33.3	23.1	4.1	2.13

Means with the same letters in the same column are not significantly different at $p>0.05$

MT – Minimum tillage **NT – No tillage**

Table 3: Interactive effect of tillage practices and nitrogen fertilizer levels on the growth performance of Habanero Pepper (*Capsicum chinese* Jacq.)

Tillage × N Level	Plant Height (cm)	Leaves	Branches	Stem Girth (mm)	Yield (t/ha)
MT × 0 kg	29.60[a]	49.27[a]	6.800[a]	17.99[a]	3.12[a]
MT × 40 kg	30.18[a]	44.13[a]	7.583[a]	18.30[a]	5.14[a]
MT × 80 kg	29.83[a]	48.00[a]	8.333[a]	18.30[a]	4.58[a]
MT × 120 kg	15.37[a]	41.00[a]	7.167[a]	17.98[a]	4.98[a]
NT × 0 kg	25.10[a]	44.87[a]	6.267[a]	17.86[a]	3.32[a]
NT × 40 kg	23.73[a]	27.80[a]	5.033[a]	18.15[a]	3.70[a]
NT × 80 kg	26.42[a]	40.08[a]	6.667[a]	18.53[a]	3.73[a]
NT × 120 kg	14.75[a]	36.08[a]	5.667[a]	18.04[a]	3.61[a]
SED	2.547	10.52	1.196	0.560	3.25
SIG	Ns	ns	ns	ns	ns

Means with the same letters in the same column are not significantly different at $p>0.05$

Soil pH declined significantly with increasing N rate with highest pH occurring at 0 kg N/ha (6.94) and lowest at 120 kg N/ha (4.32). Organic Carbon (OC) and Organic Matter (OM) was affected significantly by N application with the highest OC and OM occurring at 0 kg N/ha (3.70g/kg and 6.40g/kg respectively), they both significantly declined at higher N rates, especially 120 kg N (0.90% OC; 1.53% OM).

Total N increased significantly with N application with the highest rate at 80 kg N (0.450 g/kg) and the lowest at 0 kg N (0.100 g/kg) while available P declined significantly with the lowest rate at 120kgN/ha (13.7mg/kg) while 0 – 80 kg N/ha are similar. Exchangeable K and Na:K and Na was highest at 120 kg N (0.1300 cmol/kg and 0.1883cmol/kg respectively), while they both have similar content at 0–80 kg N/ha.

Nitrogen fertilizer had no significant effect on clay content of the soil, silt had the lowest and similar at rate at 40 kg N/ha and 80kg N/ha (106.1 g/kg), highest at 120 kg (154.4 g/kg). Sand had lower and significantly ($P \geq 0.05$) different value at 120kgN/ha (476 g/kg) while it has similar value at 0 – 80kg N/ha.

Soil pH, OC, OM, Total N, and exchangeable Na had significant interactions while other parameters (EC, Ca, Mg, CEC, Sand, Silt and Clay) were not significantly influenced by the interaction.

4.4 Interaction effect of tillage and Nitrogen on soil properties

MT × 0 kg N and NT × 0 kg N had the highest pH (6.94) while the lowest pH (3.64) occurred at MT × 80 kg N.

The OC and OM (3.70 g/kg and 6.40 g/kg respectively) were significantly ($P \geq 0.05$) higher in MT × 0 kg N/ ha and NT x 0 kgN/ha (3.70 g/kg), compared to other treatments. Closely followed by NT x 80kg (2.933g/kg OC and 5.10 g/kg OM) while the least OC and OM was found at MT × 80 kg N (0.200 g/kg and 0.300 g/kg), these are all significantly (P ≤0.05) lower compared to other treatment combinations except for MT x 0kgN/ha and NT x 0kgN/ha (3.70 g/kg)

NT x 80kg N/ha had the highest significant total N (0.80g/kg), 0 kg N (MT and NT) had similar total N which had the lowest total N (0.10 g/kg). MT x 0 kg N/ha and NT x 0 kg N/ha had significantly (P ≤0.05) lower Exchangeable Na both at 0.10 cmol/kg while Ex. Na at NT x 120kg N/ha (0.1967 cmol/kg) was significantly (P ≥0.05) higher compared to other treatment combinations.

Tillage x nitrogen application have no significant interactive effect on EC, available P, K, Ca, Mg, CEC, sand, silt and clay content of the soil.

Table 4: The Effects of Tillage Practices and Nitrogen Fertilizer levels on Soil Properties

Treatment	Soil pH	EC (µS/cm)	OC (g/kg)	OM (g/kg)	Total N (g/kg)	Avail. P (mg/kg)	K (cmol/kg)	Ex. Na (cmol/kg)	Ca (cmol/kg)	Mg (cmol/kg)	CEC	Clay (g/kg)	Silt (g/kg)	Sand (g/kg)
Tillage practice														
MT	5.346^{b}	137.0^{a}	1.85^{b}	3.19^{b}	0.275^{a}	18.43^{a}	0.1092^{a}	0.1467^{a}	1.527^{a}	0.4025^{a}	4.963^{a}	357^{a}	126.9^{b}	516^{a}
NT	5.786^{a}	78.0^{a}	2.00^{a}	3.45^{a}	0.333^{a}	17.18^{a}	0.0975^{a}	0.1367^{a}	1.635^{a}	0.4058^{a}	5.006^{a}	308^{a}	142.8^{a}	549^{a}
SED	0.0052	66.9^{a}	0.029	0.036	0.0993	3.077	0.0068	0.0043	0.0477	0.0044	0.069	2.58	0.301	2.52
SIG	***	ns	*	*	Ns	ns	ns	ns	ns	ns	ns	ns	*	ns
N_level (kg)														
0	6.940^{a}	100.0^{a}	3.70^{a}	6.40^{a}	0.100^{b}	24.11^{a}	0.0900^{b}	0.1000d	1.720^{a}	0.4100^{a}	5.050^{a}	305^{a}	112.8^{ab}	582^{a}
40	6.142^{b}	58.0^{a}	1.53^{b}	2.65^{b}	0.417^{a}	24.19^{a}	0.0950^{b}	0.1217c	1.517^{a}	0.4117^{a}	5.015^{a}	338^{a}	106.1^{b}	556^{a}
80	4.593^{c}	207.0^{a}	1.57^{b}	2.70^{b}	0.450^{a}	24.19^{a}	0.0950^{b}	0.1217b	1.517^{a}	0.4117^{a}	5.015^{a}	338^{a}	106.1^{b}	516^{ab}
120	4.318^{d}	67.0^{a}	0.90^{b}	1.53^{b}	0.250^{ab}	13.69^{b}	0.1300^{a}	0.1883a	1.590^{a}	0.4000^{a}	4.972^{a}	370^{a}	154.4^{a}	476^{b}
SED	0.1127	87.4	0.584	1.027	0.080	2.737	0.0083	0.0086	0.1315	0.0116	0.086	5.06	1.918	3.31
SIG	***	ns	**	**	**	***	**	***	ns	ns	ns	ns	*	*
Tillage X N_Level Interaction														
SED	0.1381	126.2	0.716	1.258	0.772	4.550	0.0123	0.0114	0.1680	0.0148	0.126	6.71	2.368	4.87
SIG	***	ns	*	*	*	ns	ns	*	ns	ns	ns	ns	ns	ns
CV	3.5	140.3	54.6	56.5	80	26.6	14.0	10.6	14.4	4.9	3.0	26.3	24.6	11.6

Means with the same letters in the same column are not significantly different at $p>0.05$

Ex. - Exchangeable; MT – Minimum tillage; NT - No tillage

Table 5: Interactive effect of tillage practices and nitrogen fertilizer levels on Soil Properties

Tillage × N Level	Soil pH	EC (µS/cm)	OC (g/kg)	OM (g/kg)	Total N (g/kg)	Avail. P (mg/kg)	K (cmol/kg)	Ex. Na (cmol/kg)	Ca (cmol/kg)	Mg (cmol/kg)	CEC	Clay (g/kg)	Silt (g/kg)	Sand (g/kg)
MT × 0 kg	6.940^{a}	100.0^{a}	3.70^{a}	6.40^{a}	0.1000^{c}	24.11^{a}	0.0900^{a}	0.1000^{c}	1.720^{a}	0.4100^{a}	5.050^{a}	30.48^{a}	11.28^{a}	58.24^{a}
MT × 40 kg	6.317^{b}	53.3^{a}	2.200^{abc}	3.833^{abc}	0.5667^{ab}	25.93^{a}	0.1000^{a}	0.1300^{b}	1.357^{a}	0.4067^{a}	5.027^{a}	35.81^{a}	9.95^{a}	54.24^{a}
MT × 80 kg	3.637^{f}	348.0^{a}	0.200^{d}	3.00^{d}	0.1000c	9.95^{a}	0.1133^{a}	0.1767^{a}	1.490^{a}	0.4033^{a}	4.767^{a}	33.15^{a}	17.95^{a}	48.91^{a}
MT × 120 kg	4.490^{d}	47.3^{a}	1.300^{bcd}	2.233^{bcd}	0.3333^{bc}	13.72^{a}	0.1333^{a}	0.1800^{a}	1.543^{a}	0.3900^{a}	5.010^{a}	43.52^{a}	11.60^{a}	44.88^{a}
NT × 0 kg	6.940^{a}	100.0^{a}	3.700^{a}	6.400^{a}	0.1000^{c}	24.11^{a}	0.0900^{a}	0.1000^{c}	1.720^{a}	0.4100^{a}	5.050^{a}	30.48^{a}	11.28^{a}	58.24^{a}
NT × 40 kg	6.507^{a}	62.0^{a}	0.867^{cd}	1.467^{cd}	0.2667^{bc}	22.45^{a}	0.0900^{a}	0.1133^{bc}	1.677^{a}	0.4167^{a}	5.003^{a}	31.81^{a}	11.28^{a}	56.91^{a}
NT × 80 kg	5.550^{a}	65.3^{a}	2.933^{ab}	5.10^{ab}	0.8000^{a}	8.48^{a}	0.0833^{a}	0.1367^{b}	1.507^{a}	0.3867^{a}	5.037^{a}	30.48^{a}	15.28^{a}	54.24^{a}
NT × 120 kg	4.147^{c}	86.7^{a}	0.500^{cd}	0.833^{cd}	0.1667^{bc}	13.66^{a}	0.1267^{a}	0.1967^{a}	1.637^{a}	0.4100^{a}	4.933^{a}	30.48^{a}	19.28^{a}	50.24^{a}
SED	0.1381	126.2	0.0716	0.1258	0.772	4.550	0.0123	0.0114	0.1680	0.0148	0.126	6.71	2.37	4.87
SIG	***	ns	*	*	*	Ns	ns	*	ns	ns	ns	ns	ns	ns

Means with the same letters in the same column are not significantly different at $p>0.05$

Ex. - Exchangeable; MT – Minimum tillage; NT - No tillage

4.5 Relationship Between Soil Physical and Chemical Properties and the Growth Performance of Habanero Pepper.

The relationship between soil physical and chemical properties and the growth performance of Habanero pepper, plant height exhibited positive associations with some growth and soil parameters, which includes number of leaves (r = 0.27), number of branches (r = 0.28), stem girth (r = 0.18), soil pH (r = 0.40), organic carbon (r = 0.36), organic matter (r = 0.36), available phosphorus (r = 0.30), total nitrogen (r = 0.13), magnesium (r = 0.07), cation exchange capacity (r = 0.02), and sand content (r = 0.31) (Table 4).

Number of branches correlated significantly and positively with number of leaves (r = 0.81*), and moderately with stem girth (r = 0.43). Yield, however, showed negative associations with several soil and plant variables, including stem girth (r = –0.38), organic carbon (r = –0.21), organic matter (r = –0.21), calcium (r = –0.34), magnesium (r = –0.43), cation exchange capacity (r = –0.23), and clay (r = –0.04). Conversely, yield correlated positively with available phosphorus, potassium, sodium, silt, and clay.

Soil pH was strongly and positively related with organic carbon (r = 0.72), organic matter (r = 0.71), and available phosphorus (r = 0.71), while showing negative correlations with electrical conductivity (r = –0.33), sodium (r = –0.88), potassium (r = –0.61), clay (r = –0.13), and silt (r = –0.68). It also exhibited moderate positive associations with total nitrogen, calcium, magnesium, cation exchange capacity, and sand.

Organic carbon and organic matter were almost perfectly correlated (r = 0.99), and both showed positive associations with soil pH, available phosphorus, cation exchange capacity, clay, and sand. They were negatively related to potassium (OC: r = –0.40; OM: r = –0.39), sodium (OC: r = –0.56; OM: r = –0.56), calcium (OC: r = –0.0064; OM: r = –0.0024), magnesium (OC: r = –0.11; OM: r = –0.10), and silt (OC: r = –0.59; OM: r = –0.59).

Total nitrogen correlated positively with organic matter (r = 0.41) and cation exchange capacity (r = 0.22), though these relationships were not significant. Available phosphorus had a strong positive correlation with soil pH (r = 0.71) and moderate correlations with organic carbon (r = 0.42) and organic matter (r = 0.42). Potassium was negatively related to soil pH (r = –0.61), organic carbon (r = –0.39), and organic matter (r = –0.39). Sodium correlated strongly and positively with potassium (r = 0.84) but negatively with soil pH (r = –0.88) and organic matter (r = –0.56). Magnesium showed a significant positive relationship with calcium (r = 0.71). Cation exchange capacity was positively correlated with organic matter (r = 0.43) and soil pH (r = 0.49), but negatively with electrical conductivity (r = –0.94). Clay showed positive relationships with sodium (r = 0.36) and potassium (r = 0.45), while silt was negatively correlated with soil pH (r = –0.68) and organic matter (r = –0.59). Sand was strongly and negatively correlated with silt (r = –0.86) but positively related to soil pH (r = 0.56).

4.6 Tillage and nitrogen effect on nutrient use efficiency and N balance.

Nutrient Use Efficiency (NUE) and Nutrient Balance Sheet with the effects of tillage, nitrogen application and their interaction are presented in Table 6. Tillage did not have significant effect on yield, NUE was significantly ($P \geq 0.05$) higher in MT (2.48 kg/kg N) compared to NT (2.12 kg/kg N) while MT statistically higher N Uptake (5.57 kg/ha) compared to NT (4.49 kg/ha). NT plots (55.51 kg/ha) had a significantly higher nitrogen balance than MT plots (54.43 kg/ha),

N levels did not significantly affect yields as they all had similar values, however, NUE varied significantly with N levels, the highest NUE was recorded at 40 kg N/ha (5.53 kg/kg N), followed by 80 kg N/ha and 120 kg/kg which are similar (2.59 kg/kg N and 1.79 kg/kg N respectively). Nitrogen uptake was similar across treatments (ranging from 4.03 to 5.53 kg/ha). N application statistically affect N balance, N balance increased with higher N rates, from –4.03 kg/ha at 0 kg N to 114.63 kg/ha at 120 kg N.

The interaction between tillage and nitrogen did not have any significant effect on yield, N uptake and N balance, except for only NUE.

4.7 Tillage and nitrogen interaction effect on NUE

MT x 40kgN/ha had significant efficient N use compared to other tillage x nitrogen interaction (6.43 kg/kgN) while the least efficient N use efficiency was found at MT x 0kgN/ha and NT x 0kgN/ha. NT x 40 kg N/ha (4.63 kg/kg N) followed closely but still significantly different. While MT x 80kgN/ha, MT x 120 kg N/ha and NT x 80 kg N/ha were all similar but significantly less efficient than NT x 40kg N/ha.

4.8 Tillage Effect on Nutrient Balance

MT recorded a significantly ($P \geq 0.05$) higher N uptake (5.57 kg/ha) compared with NT (4.49 kg/ha) while NT had a higher nitrogen surplus (55.51 kg/ha) compared to MT (54.43 kg/ha).

Table 6: Relationship between Soil Physical and Chemical Properties and the Growth Performance of Habanero Pepper

	PHeight	*Nleaves*	*Nbranches*	*Stem_Girth*	*YIELD*	*SOIL pH*	*EC*	*OC*	*OM*	*TOTAL N*	*AVAIL P*	*K*	*Ex. NA*	*Ca*	*Mg*	*CEC*	*CLAY*	*SILT*	*SAND*
PHeight																			
Nleaves	0.269717																		
Nbranches	0.283355	0.807184*																	
Stem_Girth	0.188109	0.388817	0.433688																
YIELD	-0.02142	-0.05966	0.152373	-0.38093															
SOIL PH	0.401679	0.029264	-0.17677	-0.0211	-0.2332														
EC	0.15871	-0.18622	0.125271	-0.20665	0.228331	-0.33439													
OC	0.358496	0.361225	0.112433	0.14919	-0.21062	0.715546*	-0.21246												
OM	0.359906	0.3578	0.111201	0.152864	-0.21197	0.714792*	-0.21385	0.999921											
TOTAL N	0.125813	0.148607	0.188702	0.438014	0.118281	0.103034	-0.22044	0.405312	0.410371										
AVAIL P	0.298608	-0.0139	-0.17901	-0.13087	0.043769	0.709166*	-0.28592	0.422451	0.423483	-0.07936									
K	-0.46914	0.049241	0.032347	0.077436	0.09303	-0.61286	-0.2311	-0.39709	-0.39398	-0.09393	-0.10195								
NA	-0.4684	-0.00923	0.101031	0.179177	0.08339	-0.87896	0.021743	-0.56331	-0.55897	0.062436	-0.50408	0.84204*							
Ca	-0.16677	-0.23141	-0.25012	-0.03496	-0.33473	0.181689	-0.06293	-0.00164	-0.00237	-0.42504	-0.04857	0.04497	-0.12413						
Mg	0.074489	-0.06194	-0.10059	0.236461	-0.42991	0.195224	-0.25987	-0.1065	-0.10385	-0.33905	0.097133	0.100112	-0.02479	0.714598*					
CEC	0.019845	0.317373	-0.01886	0.220355	-0.22508	0.489198	-0.94394	0.429562	0.43014	0.2217	0.368412	0.05339	-0.21773	0.048724	0.253713				
CLAY	-0.14095	-0.11354	-0.01235	0.159849	-0.03757	-0.12794	-0.11256	0.069434	0.074902	0.303772	-0.07496	0.451988	0.356735	0.104595	0.262655	0.085649			
SILT	-0.24409	0.082097	0.051594	-0.07302	0.026008	-0.67576	0.124002	-0.58509	-0.58848	-0.31421	-0.5718	0.221774	0.48083	-0.07728	-0.15366	-0.2417	0.53999		
SAND	0.313884	0.085496	-0.01632	-0.14592	0.028987	0.557635	0.059171	0.268886	0.264429	-0.17195	0.432317	-0.66973	-0.7122	-0.07776	-0.21954	0.043451	-0.8629*	0.040594	

*** Significant correlation**

Table 7: Nutrient Use Efficiency (NUE) and Nutrient Balance Sheet with the effects of Tillage, Nitrogen Application and their interaction

Treatment	Yield (t/ha)	NUE (kg/kg N)	Uptake (kg/ha)	N Balance (Input – Uptake)
Tillage practice				
MT	4.46^{a}	2.48^{a}	5.57^{a}	54.43^{b}
NT	3.6^{a}	2.12^{b}	4.49^{b}	55.51^{a}
SED	1.19	0.417	0.595	0.745
SIG	Ns	**	**	**
N_level (kg)				
0	3.22^{a}	0.00^{c}	4.03^{a}	-4.03^{d}
40	4.42^{a}	5.53^{a}	5.53^{a}	34.47^{c}
80	4.16^{a}	2.59^{b}	5.19^{a}	74.81^{b}
120	4.3^{a}	1.79^{b}	5.37^{a}	114.63^{a}
SED	2.47	0.517	1.235	1.344
SIG	Ns	***	ns	***
Tillage X N_Level Interaction				
SED	3.25	0.785	1.63	1.708
SIG	Ns	*	ns	ns
CV	2.13	41.3	42.6	3.3

Means with the same letters in the same column are not significantly different at p>0.05

Table 8: Tillage by Nitrogen Interaction Effect on Nutrient Use Efficiency, N Uptake and N Balance

Tillage X N level	NUE (kg/kg N)	Uptake (kg/ha)	N Balance
MT × 0kg	0.00^{d}	3.90	-3.90
MT × 40kg	6.43^{a}	6.43	33.57
MT × 80kg	2.86^{c}	5.71	74.29
MT × 120kg	2.08^{c}	6.23	113.77
NT × 0kg	0.00^{d}	4.21	-4.15
NT × 40kg	4.63^{b}	4.63	35.37
NT × 80kg	2.33^{c}	4.67	75.34
NT × 120kg	1.50^{cd}	4.51	115.49
SED	0.792	1.679	1.679
SIG	**	Ns	ns

Means with the same letters in the same column are not significantly different at p>0.05

Table 9: **Tillage Effect on Nutrient Balance**

Tillage Type	N Uptake (kg/ha)	N Balance
Minimum Tillage	Higher (5.57[a])	Lower surplus 54.43[b]
No Tillage	Lower (4.49[b])	Higher surplus 55.51[a]
SED	0.595	0.745
SIG	**	**

Means with the same letters in the same column are not significantly different at $p>0.05$

DISCUSSION

5.1 Growth and fruit yield of Habanero pepper

5.1.1 Plant Height

Plant height was significantly affected by both tillage and nitrogen fertilizer. Plants under minimum tillage (MT) and 80 kg N/ha had the tallest growth. This is consistent with the findings of Akanbi *et al.,* (2005) and Fageria *et al.,* (2010), they reported increased plant height with moderate nitrogen rates of between 60-90kg/ha. Ojeniyi, (2000) and Adekiya *et al.,* (2011) similarly observed improved plant height with MT due to enhanced moisture retention and reduced compaction. These findings also aligned with studies of Eze *et al* (2020), who reported benefits of MT tillage systems on plant growth metrics and significant effects of nitrogen fertilization on plant height

5.1.2 Number of Leaves

Number of leaves showed a numerical advantage under MT and 80 kg N/ha, although these differences were not statistically significant. Ogunlade *et al* (2009) and Olaniyi *et al* (2010) found nitrogen and tillage positively influenced leaf production in vegetables. Adekiya and Agbede, (2009) reported more leaf production in vegetables grown under minimum tillage due to improved soil fertility and structure.

5.1.3 Number of Branches

Number of branches was highest under MT and 80 kg N/ha with no statistical significance, the trend aligned with Olaniyi and Akanbi, (2007) and Adebayo *et al* (2012) they observed increased branching from improved nutrient uptake and aeration under MT.

5.1.4 Stem Girth

Stem girth values were similar across treatments with no significant difference across all levels of application, which agreed with findings by Olaniyi *et al* (2010), who reported that nitrogen fertilizer improves base stem thickness in sweet pepper.

5.1.5 Yield: Although not statistically significant, MT showed a higher mean yield (223 kg/ha) than NT (80 kg/ha). The improved tilth and seed-soil contact in MT likely enhanced early root development and nutrient uptake (Hobbs *et al.,* 2008). Singh *et al* (2021) concluded that MT and moderate N promote stable yields and soil health.

5.2 Soil properties

5.2.1 Effect of Tillage on Soil Properties

NT significantly maintained higher pH, likely due to less soil mixing and reduced organic acid mineralization. No-till increases surface pH, OM, OC and microbial diversity (Zuber and Villamil, 2016).

NT retained more organic matter and carbon, aligning with studies showing that no-till systems accumulate residues at the soil surface (Blanco-Canqui and Lal, 2008). Jin *et al.,* (2020) reported that MT improves nitrogen-use efficiency and organic carbon retention.

Tillage had no significant effect on CEC, available P and Potassium, sodium, calcium and magnesium. Tillage practice had minimal influence on most soil chemical properties, as CEC, available P, and exchangeable K, Ca and Mg did not differ significantly between minimum tillage (MT) and no-tillage (NT). This stability reflects the strong control of soil texture and organic matter on nutrient-retention capacity, properties that respond slowly to tillage changes, particularly in sandy soils (Zuber and Villamil, 2020; Choudhury *et al*., 2021).

Similar non-significant effects of tillage on P and K have been reported in tropical and subtropical systems, where fertilizer rate rather than soil disturbance explains most nutrient variability (Adhikari *et al.,* 2019; Nogueira *et al.,* 2022).

Textural changes were minimal and statistically non-significant for both NT and MT. Slight fluctuations in sand and silt content could result from tillage, erosion, or cultivation effects. Adekiya *et al* (2011) and Olayiwola and Alabi, (2015) reported seasonal texture variations in intensively cropped vegetable fields.

5.2.2 Effect of Nitrogen on Soil Properties

Soil pH declined significantly with increased N due to acidification from ammonium-based fertilizers (Barak *et al.,* 1997). Application of nitrogen significantly reduced soil pH from 6.94 (0 kg N/ha) to 4.32 (120 kg N/ha), confirming that higher nitrogen application promotes soil acidification due to nitrification and increased hydrogen ion concentration. Similar effects were reported by Adetunji, (1994) and Ojeniyi, (2000) in Nigerian cropping systems. Akanbi *et al.,* (2005) and Ayeni, (2008) also observed that excess nitrogen causes progressive acidification in vegetable soils.

Soil total N increased up to 80 kg/ha, peaking at 0.045%, but declined slightly at 120 kg/ha. This may suggest leaching losses or reduced microbial immobilization at excessive N levels. (Fageria and Baligar, 2005). Akintoye *et al.,* (2011) recommended moderate N rates to balance soil enrichment and minimize environmental losses.

Available P: Decreased sharply at 120 kg N/ha, likely due to fixation under low pH environments (Richardson *et al.,* 2009).

Available phosphorus remained stable across 0–80 kg N but dropped sharply at 120 kg, possibly due to reduced microbial mineralization under acidic conditions (Richardson *et al.,* 2009). Available P increased at 40–80 kg N/ha but declined at 120 kg/ha, possibly due to reduced availability under acidic conditions. This is consistent with Ogunlade *et al* (2009) and Olaniyi *et al* (2010) noted P fixation in acidic vegetable soils in southwestern Nigeria. Okalebo *et al* (2006) emphasized the importance of maintaining optimal pH for phosphorus solubility in tropical soils.

Exchangeable Bases (K, Na, Ca, Mg): Potassium and sodium levels increased with higher nitrogen input, but calcium and magnesium showed no significant response. Oladiran and Ojo, (2006) and Aliyu *et al* (2019) reported similar responses in semi-arid Nigerian soils where excess fertilizer increases base saturation but may cause imbalances. Obi and Ebo, (1995) warned that unbalanced nutrient input could lead to nutrient competition and soil structure degradation.

CEC was not significantly affected by nitrogen levels, indicating its resistance to short-term chemical changes. Zuber and Villamil, (2016) stated that CEC shifts require long-term management through organic matter buildup. Enwezor *et al* (1990) emphasized that soil type and clay content often dominate CEC behavior over nutrient input.

Both OC and OM declined significantly with increased N rates. The reduction could be attributed to accelerated decomposition of organic matter induced by added nitrogen. This aligns with Adekiya and Agbede, (2009) and Lawal *et al* (2014) observed lower carbon stocks in plots treated with high chemical fertilizers. Oluwatoyinbo *et al* (2009) emphasized the importance of organic amendments in maintaining soil carbon under high N use.

5.2.3 Interaction of Tillage and Nitrogen on Soil Properties

Significant interactions were found for soil pH, OC, OM, total N and Na. NT + 0 kg N/ha had the highest pH and organic matter, supporting the concept that long-term nutrient supply under NT may require supplementation with moderate N.

5.3 Interactive Effect of Tillage Practices and Nitrogen Fertilizer Levels on Soil Properties

5.3.1 Soil pH:

The highest soil pH values were found in the control plots (MT × 0 kg and NT × 0 kg), with values of 6.94, while the lowest pH (3.64) was recorded in MT × 80 kg. Singh *et al* (2021) noted that acidification intensifies under tilled systems due to enhanced microbial turnover. Increasing nitrogen significantly ($P \leq 0.05$) decreased soil pH**,** indicating acidification due to nitrification of Ammonium-N fertilizers. Barak *et al* (1997) and Fageria and Baligar, (2005) established that acidification occurs when Ammonium-N fertilizers are nitrified, releasing hydrogen ions into the soil.

5.3.2 Soil OC and OM

NT × 0 kg and MT X 0kg maintained the highest OC and OM (3.7g/kg and 6.40g/kg respectively), while MT × 80 kg had the lowest OC and OM (0.2 g/kg and 0.300 g/kg respectively). No tillage systems preserve residues at the soil surface, protecting organic carbon from rapid oxidation (Zuber and Villamil, 2016). Organic carbon and Organic matter decreased with increased nitrogen, particularly under MT. This is consistent with Blanco-Canqui and Lal, (2008) who observed that tillage accelerates organic matter mineralization.

5.3.3 Total N

The highest TN (0.080%) occurred in NT × 80 kg, suggesting greater nitrogen retention in undisturbed soils**.**

5.3.4 Exchangeable Na

Na was significantly affected, with the highest values in NT × 120 kg (0.1967 cmol/kg) and lowest in NT × 0 kg and MT x 0 kg (both at 0.1000 cmol/kg). Sharma and Chaudhari, (2012) observed that excessive N application in cereal systems increases ionic strength and EC, especially when crop uptake is limited.

5.4 Relationship between Plant parameters and Soil Properties

Plant Branches and number of leaves showed a significant ($P \geq 0.05$) positive correlation with soil pH, OC and available P. There was a Positive Balance correlation between Na–K, and Ca–Mg this suggest ionic competition and complementarily in soil. Soil physical properties trade-offs was observed as sand had a negative significant correlation with Clay. Other parameters showed no significant correlation

Plant height has moderately positive correlation with soil pH ($r = 0.40$), organic carbon (OC, $r = 0.36$), and organic matter (OM, $r = 0.36$) and Negative correlation with exchangeable potassium (K, $r = -0.47$) and sodium (Na, $r = -0.47$). These results align with Lal, (2004) and Six *et al* (2002) who found that higher soil organic matter improves water retention and nutrient cycling, promoting plant height. Negative effects of Na and K may indicate salinity stress or nutrient antagonism, consistent with Bar-Tal *et al* (2001) and Marschner, (2012), they reported that excess Na interferes with Ca and K uptake, impairing growth. Number of leaves was positively correlated with OM and OC ($r = 0.36$) and CEC ($r = 0.32$). Number of branches showed weak correlation with total nitrogen (TN, r = 0.19) and stem girth (r = 0.43). Leaf expansion and branching are strongly influenced by N availability and soil moisture, which are enhanced by higher CEC and OM (Tisdale *et al.,* 2002 and Fageria *et al.,* 2010). CEC reflects the soil's ability to retain and exchange nutrients, supporting sustained nutrient supply to developing shoots. Positive correlation with TN (r = 0.44) and Mg (r = 0.24). Nitrogen promotes cambial activity and stem thickening (Fageria and Baligar, 2005). However, negative correlation with yield (r = -0.38) might reflect resource allocation trade-offs, where vegetative growth reduces reproductive output (Zhang *et al.,* 2011).

5.4.1 Relationship between Yield and Soil Properties

Yield showed a moderate negative correlation with Mg (r = -0.43), Ca (r = -0.33), and CEC (r = -0.23). Soil CEC and OM are strong predictors of crop responsiveness to fertilization (Tisdale *et al.,* 2002). Clay, silt, and sand had very weak or negligible correlations with yield and plant traits, which is expected in the short term, as texture is a stable, slowly changing soil property (Hobbs *et al.,* 2008).

However, CEC showed moderate negative correlation with yield (r = -0.23) and strong negative correlation with Electronic Conductivity r = -0.94, which may point to deeper systemic or statistical interactions. Soil nutrient interactions must be managed with consideration of tillage and N levels (Singh *et al.,* (2021). Weak positive correlation with TN (r = 0.12) and available P (r = 0.04). These results suggest potential nutrient imbalances or toxicities. High Mg and Ca levels can disrupt K uptake and enzyme activities (Mengel and Kirkby, 2001; Rietra *et al.,* 2017).

Weak response to P and TN may indicate that other factors— such as root disease, water availability, or suboptimal soil pH—limit nutrient uptake or utilization (Sanchez, 2019 and

Nziguheba *et al.*, 2021). Soil pH correlated strongly with OM (r = 0.71), OC (r = 0.72) and Available P (r = 0.71). These results are consistent with the findings of Blanco-Canqui and Lal, (2008) and Zuber and Villamil, (2016) that improved organic matter enhances CEC and pH buffering, promoting nutrient availability. Richardson *et al* (2009) and Lal and Stewart, (2010) confirm that pH modulation via organic inputs enhances P solubility and overall nutrient retention and uptake

CEC had strong negative correlation with conductivity (r = -0.94) and moderate positive with Total Nitrogen (r = 0.22), OM (r = 0.43), and OC (r = 0.43). While CEC generally enhances nutrient retention, excessive levels may lead to nutrient imbalances or buffering against essential nutrients like P (Zuber and Villamil, 2016; Brady and Weil, 2016). Strong negative correlation with EC suggests over accumulation or dilution effects in soils with very high CEC. According to Mengel and Kirkby, (2001) excess base cations interfere with enzymatic processes and nutrient uptake.

5.5 Tillage Effect on NUE and Nutrient Balance

Minimum Tillage (MT) significantly ($P \geq 0.05$) improved NUE estimate compared to no tillage. At 40 kg N/ha, NUE value was 2.48 kg/kg N under MT, compared to 2.12 kg/kg N under NT. This suggests that there was higher nitrogen retention and root uptake under tilled soils due to improved aeration and root penetration. Adebayo *et al* (2012), reported that the minimum tillage had higher NUE compared to no-tillage in pepper fields. NT had significantly ($P \geq 0.05$) higher nutrient balance compared to MT (MT 54.43 and NT 55.51).

5.5.1 Nitrogen Effect on NUE and nutrient balance

The highest NUE was recorded at 40 kg N/ha application rate, for both MT and NT after which efficiency declined. NUE declined at 80 and 120 kg N/ha application rate due to diminishing returns and possible losses (e.g., leaching, volatilization). This aligns with the findings of Ali *et al* (2018), who reported peak NUE at 40 kg N/ha application rate in sweet pepper, and Akintoye *et al* (2011). Nitrogen application had a significant effect on N balance, as there was significant ($P \geq 0.05$) increase in surplus nitrogen with increasing N rate ranging from 114.63 to -4.03 at 120 kg N/ha and 0 kg N/ha respectively. Wang *et al* (2025) found that nitrogen loss and nitrogen surplus significantly increased with increase in the nitrogen application rate.

5.5.2 Yield Stability and Management Implications

Yield of pepper increased from 161 kg/ha to 221 kg/ha at application rate of 40 kg N/ha, then slightly declined. Similar trend was reported by Ali *et al* (2018) and Sánchez-González *et al* (2020) they observed that yield peaks at 40–60 kg N/ha in pepper. Singh *et al* (2021) confirmed MT with moderate N improves productivity and sustainability.

As nitrogen rates increased from 0 to 120 kg/ha, the nutrient balance (input – uptake) became more positive, meaning surplus nitrogen was left unused in the soil. Higher N rates (80–120 kg/ha) resulted in large nutrient surpluses, indicating inefficient uptake and risk of leaching or environmental pollution. This aligns with Fageria and Baligar, (2005) and Nziguheba *et al.*, (2021) they report diminishing returns and higher N loss at excessive rates of application.

5.5.3 Interaction effect of tillage and nitrogen on NUE

Highest NUE was observed in MT × 40 kg N while the lowest nutrient balance (least surplus) in NT × 40 kg N, indicating efficient use and minimal wastage. Nziguheba *et al* (2021), emphasized integrating tillage and moderate N for nutrient efficiency and yield optimization in tropical vegetables as observed in Minimum Tillage × 40 kg N/ha application.

5.5.4 Tillage Effect on N Balance

Minimum Tillage (MT) supported higher nitrogen uptake than No-Tillage (NT), leading to slightly lower N surpluses (54.43), enhanced nitrogen absorption likely improved the soil aeration and root penetration under MT. This is confirmed by Adekiya *et al.*, (2011) and Adebayo *et al.*, (2012), who reported higher nutrient use and growth under MT.

CHAPTER FIVE

CONCLUSION

It was observed from the study that both tillage system and nitrogen fertilizer rate exert significant and interactive effects on some agronomic parameters of Habanero pepper (*Capsicum chinense* Jacq.), some soil properties and nutrient dynamics.

Minimum tillage (MT) generally improved soil conditions which led to enhanced vegetative growth with significant ($P \geq 0.05$) higher plant height and yields compared to no-tillage (NT).

Nitrogen application had a dual effect on soil properties; at moderate rates (40–80 kg N/ha), it improved yield, total nitrogen content, and plant growth traits (significant different in plant height), while excessive rates (120 kg N/ha) caused soil acidification, reduced available phosphorus (P) availability, and significant declines in OM and OC. MT significantly affected soil pH, OM and OC but had no effect on other soil properties.

At 40 kg N/ha application rate there was significant ($P \geq 0.05$) influence on NUE compared to other N levels while MT X 40 kg N/ha had a better NUE compared to other treatment interactions.

Tillage had significant effect on N uptake and N Balance. Nitrogen fertilizer application had significant effect on N balance while it had no significant effect on N uptake.

Tillage and Nitrogen interaction had no significant effect on both nutrient uptake and Nutrient balance sheet of applied N

RECOMMENDATIONS

Based on the findings, the following recommendations are made:

Adopting Moderate Nitrogen application rate of 40–80 kg N/ha for optimal yield and soil sustainability in Habanero pepper cultivation. Use of Minimum Tillage enhances root development, soil structure, and nutrient uptake, particularly when paired with moderate fertilizer rates.

Combination of Minimum Tillage and N fertilizer at moderate rate (40-80 kg N/ha) enhance soil health and provide a sustainable environment for growth of Habanero Pepper (*Capsicum chinense* Jacq.)

High N rates (>80 kg/ha) should be avoided to prevent soil acidification, nutrient wastage, and environmental degradation.

REFERENCES

Aboyeji, F. O. and Abayomi, O. (2013). The role of nitrogen in plant growth. *Journal of Plant Physiology*, 150(2): 45-58.

Adebayo, T. A., Akinlosotu, T. A. and Akinbode, O. A. (2012). Tillage methods and fertilizer use: Influence on growth and yield of pepper (*Capsicum annuum*) in rainforest zone. *Nigerian Journal of Horticultural Science, 17*(1), 24–31.

Adekiya, A. O., Agbede, T. M., Aboyeji, C. M., Dunsin, O. and Simeon, V. T. (2021). Effects of tillage and nitrogen fertilizer on soil chemical properties, growth, yield, and nitrogen use efficiency of maize. *Scientific Reports, 11*(1), 1–11. *https://doi.org/10.1038/s41598-021-03085-9*

Adekiya, A. O., Agbede, T. M. and Ojeniyi, S. O. (2011). The effect of different tillage systems on soil properties and cucumber yield in southwestern Nigeria. *Soil and Tillage Research, 112*(1), 7–13. https://doi.org/10.1016/j.still.2010.11.002

Adekiya, A. O., Agbede, T. M. and Ojomo, A. O. (2009). Effect of tillage methods on soil properties, nutrient contents, growth and yield of tomato on an Alfisol of southwestern Nigeria. *American-Eurasian Journal of Sustainable Agriculture*, *3*(3), 348–353.

Adekiya, A. O. and Agbede, T. M. (2009). Growth and yield of tomato as influenced by poultry manure and NPK fertilizer. *Leonaardo Electronic Journal of Practices and Technologies, 8*(14), 95–102.

Adekiya, A. O. and Ojeniyi, S. O. (2011). Soil physical properties and cocoyam performance as influenced by tillage on an Alfisol in Southwest Nigeria. *Nigerian Journal of Soil Science, 21*, 16–21.

Adetunji, M. T. (1994). The effects of nitrogen fertilizer levels on soil pH and availability of other nutrients. *Fertilizer Research*, 3(1), 45–52.

Adhikari, K., Owens, P. R., Libohova, Z., Miller, D. M., Wills, S. A. and Nemecek, J. (2019). Assessing soil phosphorus variability and its relationship with tillage and fertilization practices using geospatial techniques. *Geoderma, 341*, 78–88. https://doi.org/10.1016/j.geoderma.2019.01.029

Afolayan, S.O., Oladapo, M.O., Olaosebikan, F.O. and Muibi, E.F. (2010). Effects of Tillage Systems and Four Fertilizer Rates on Growth Parameters and Fruit Yield of Okra (*Abelmoscus esculentus*) and Pepper (*Capsicum annum*). *World Journal of Agricultural Sciences* 6 (1): 23-28, 2010.

Afolayan, S.O., Babalola, O. and Igbeka, J.C. (2004). Effect of tillage on soil physical properties, growth and yield of Amaranth. *African Crop Science Journal*., 12(20): 141-151.

Akanbi, W. B. (2002). Growth, nutrient uptake and yield of maize and okra as affected by compost and nitrogen fertilizer. *Ph.D. Thesis, University of Ibadan, Nigeria*.

Akanbi, W. B., Togun, A. O. and Afolabi, W. A. (2005). Growth, dry matter and fruit yield components of pepper (*Capsicum frutescens*) as affected by nitrogen fertilizer levels. *World Journal of Agricultural Sciences, 1*(1), 5–10.

Akande, G. M., Olaiya, P. A. and Iyagin, F. O. (2020). Hot pepper (*Capsicum annum* L.) production using different organic manure and inorganic fertilizer in Akure, Nigeria. *Journal of Medicinal Plants Studies*, 8(2), 49–53.

Akintoye, H. A., Olaniyi, J. O. and Adebooye, O. C. (2011). Nitrogen use and yield performance of pepper under different management practices. *African Journal of Plant Science, 5*(9), 507–512.

Akpan, J. F., Etim, E. E. and Udoh, B. T. (2020). Influence of biofertilizer on soil properties, growth, and yield of hot pepper (*Capsicum* spp.). *International Journal of Agriculture and Environmental Research*, *6*(4), 307–316. https://doi.org/10.

Ali A., Usman, M. and Adaikwu, A.O. (2018). Effect of Tillage Methods on Soil Properties, Growth and Yield of Maize (*Zea mays* L.) in Makurdi, Nigeria, *International Journal of Science and Healthcare Research*. Vol.3; Issue: 1pp.48-55. ISSN: 2455-7587

Ali, A., Tahir, M., Shahzad, A. N. and Naveed, M. (2021). Impact of nitrogen and phosphorus fertilization on nutrient dynamics and crop productivity: A review. *Archives of Agronomy and Soil Science*, 67(3), 356–374. https://doi.org/10.1080/03650340.2020.1731139

Ali, M., Ado, S. G. and Ahmed, H. G. M. D. (2018). Effect of nitrogen and irrigation regimes on yield and nutrient use in pepper. *Nigerian Journal of Horticultural Science*, 23(1), 60–72.

Ali, R., Mahmood, I. A., Salim, M. and Jahangir, M. M. (2018). Efficiency of nitrogen use under different tillage practices in vegetable crops. *Journal of Plant Nutrition*, *41*(3), 292–304. https://doi.org/10.1080/01904167.2017.1382531

Aliyu, L., Odeleye, F. O. and Elega, A. A. (2007). Growth and yield of pepper as affected by N and spacing. *International Journal of Vegetable Science*, 13(1), 45–54.

Aliyu, L., Olarewaju, J. D. and Abdullahi, M. (2007). Influence of nitrogen and phosphorus fertilizer on the growth and yield of pepper (*Capsicum annuum* L.). *Journal of Agriculture and Social Sciences, 3*(2), 67–70.

Aliyu, L., Yusuf, H. Y. and Muhammad, A. (2019). Effect of nutrient sources on soil salinity and yield of okra in semi-arid Nigeria. *Bayero Journal of Agricultural Research and Development*, *20*(2), 12–20.

Al-Rawahy S.A, Dhuhli H.S., Prathapar H.A. and Abdelrahman .H. (2011). Mulching material impact on yield, soil moisture and salinity in saline-irrigated sorghum plots. *International Journal of Agricultural Research* 6 (1): 75-81.

Aminifard M.H., Aroiee, H., Ameri, A. and Fatemi H., (2012). Effect of plant density and nitrogen fertilizer on growth, yield and fruit quality of Habanero pepper. *African Journal of Agricultural Res*earch, 7(6): 859- 866.

Atkinson, A., Donev, A. and Tobias, R. (2007). *Optimum experimental designs, with SAS* (Vol. 34). Oxford University Press. *Biotech*, 2(10): 345-349.

Awodun, M.A., Odogiyan, S.O. and Ojeniyi S.O. (2011). Effect of gliricida pruning on soil and plant nutrient status and yield of cowpea. *International Journal of Agricultural Research.* 2: 402-405

Ayeni, L. S. (2008). Integrated application of cocoa pod ash and NPK fertilizer on soil chemical properties and yield of tomato in southwestern Nigeria. *American-Eurasian Journal of Sustainable Agriculture*, *2*(3), 333–337.

Badalikova, B. and Hruby, J. (2016). Influence of land use types on soil fertility status of Montance Grassland, New Zealand. *Journal of plant and soil*. 176:255-265.

Barak, P., Jobe, B. O., Krueger, A. R., Peterson, L. A. and Laird, D. A. (1997). Effects of long-term soil acidification due to nitrogen fertilizer inputs in Wisconsin. *Journal of Plant and Soil*, *197*(1), 61–69. https://doi.org/10.1023/A:1004297607070

Bar-Tal, A., Aloni, B., Karni, L. and Rosenberg, R. (2001). Nitrogen, phosphorus, and potassium uptake and utilization by pepper plants as affected by salinity and rootstock. *Journal of the American Society for Horticultural Science*, *126*(3), 285–290.

Baskaran, R. and Kavimani, R. (2014). Productivity of sunflower as influenced by tillage and weed management. *Indian Journal of Weed Science*, *46*(2), 138–141.

Black, C.A. (1965) Methods of Soil Analysis: Part I, Physical and Mineralogical Properties. *American Society of Agronomy*, Madison, Wisconsin.

Blanco-Canqui, H. and Lal, R. (2008). No-tillage and soil-profile carbon sequestration: An on-farm assessment. *Soil Science Society of America Journal*, *72*(3), 693–701.

Blanco-Canqui, H. and Ruis, S. J. (2018). No-tillage and soil physical environment. *Geoderma, 326*, 179–200.

Brady, N. C. and Weil, R. R. (2002). *The Nature and Properties of Soils* (13th ed.). Prentice Hall.

Brady, N. C. and Weil, R. R. (2016). *The Nature and Properties of Soils* (15th ed.). Pearson Education.

Busari, M. A. and Salako, F. K. (2013). Effects of manual tillage systems on soil quality in rainforest alfisols. *Nigerian Journal of Soil Science, 23*(2), 206–218.

Chauvin, N. D., Mulangu, F. and Porto, G. (2012). Food production and consumption trends in Sub-Saharan Africa: Prospects for the transformation of the agricultural sector. *World Development, 41*, 236–251. https://doi.org/10.1016/j.worlddev.2012.06.007

Choudhury, B. U., Neogi, S., Singh, R. K. and Fiyaz, R. A. (2021). Effects of conservation tillage on soil organic matter, aggregation, and nutrient dynamics: A global synthesis. *Soil and Tillage Research*, *206*, 104840. https://doi.org/10.1016/j.still.2020.104840

Christopher O.A. and Mohd S.Y. (2011). Effect of tillage methods and fertilizer application on *amarathus curentus* in Nigeria. *International Journal of Agriculture. Res*. 6 (3): 280-289.

Cvetković, S. and Valdez-Morales, M. (2020). A comprehensive review on characterization of pepper seeds: *Unveiling potential value and sustainable agrifood applications Foods, 14*(11), Pp. 8, 1969. https://doi.org/10.3390/foods14111969

Eneji, A. E., Tsuneo, H. and Masayuki, Y. (2017). Salt accumulation and EC in soils fertilized with urea and irrigated with different water qualities. *Archives of Agronomy and Soil Science*, 63(10), 1402–1412. https://doi.org/10.1080/03650340.2016.1270257

Enwezor, W. O., Udo, E. J. and Ayotade, K. A. (1990). A review of soil nutrient management strategies in Nigeria. *Fertilizer Research Program Bulletin*, 1(1), 12–27.

Erdem, G., Yildirim, S., Dilmac, M. and Ece, A. (2007). The effect of soil tillage on stem development of pepper plant. *Journal of Applied Sciences.* 7 (3): 342-348

Ewulo, B.S., Ojeniyi, S.O. and Morenikeji, C.I. (2011). Tillage and mulch influence on soil physical properties, plant nutrient composition and performance of pepper (*Capsicum annum* L) and sorghum (*sorghum bicolor* L.). *International Research Journal of Agricultural Science and Soil Science*. 1(11) Pages**:** 485–490

Eze, S. C., Okon, P. M. and Nwosu, K. I. (2020). Effects of tillage systems and nitrogen fertilization on crop growth and yield. *Journal of Agricultural Research*. 58(3), 211-223.

Fageria, N.K. (2014). Integrated soil fertility management and nitrogen use efficiency. *Journal of Plant Nutrition, 37*(8): 1235–1246.

Fageria, N.K. and Baligar, V.C. (2005). Enhancing nitrogen use efficiency in crop plants. *Advances in Agronomy, 88*, 97–185. https://doi.org/10.1016/S0065-2113(05)88004-6

Fageria, N. K., Baligar, V. C. and Jones, C. A. (2010). *Growth and Mineral Nutrition of Field Crops* (3rd ed.). CRC Press.

Fageria, N.K., Baligar, V.C. and Li, Y.C. (2010). The role of nutrient efficient plants in improving crop yields in the twenty-first century. *Journal of Plant Nutrition, 33*(7): 915–940.

FAO, (2011). The State of Food Insecurity in the World. FAO, Rome. Fertilizers in Southern Nigeria. In the *World Journal of Agricultural Sciences* 5(4): 400-407.

FAO, (2021). *Climate-smart agriculture sourcebook*. Food and Agriculture Organization. Retrieved from FAO website.

Food and Agriculture Organization of the United Nations. (2021). *FAOSTAT statistical database*. https://www.fao.org/faostat/en

Freney, J. R. (2005). Historical nitrogen fertilizer use and impacts. *Agriculture, Ecosystems and Environment*, 109(1–2), 1–14.

Gee, G. W. and Bauder, J. W. (1986). Particle-size analysis. In A. Klute (Ed.), *Methods of soil analysis* (Part 1, 2nd ed., Vol. 9, pp. 383–411). American Society of Agronomy / Soil Science Society of America.

Godfray, H.C., Beddington, J.R., Crute, I.R., Haddad, L., Lawrence, D., Muir, J.F., Pretty, J., Robinson, S., Thomas, S.M. and Toulmin, C. (2010): Food security: The challenge of feeding 9 billion people. *Science*, *327*: 812–818.

Goff, S. A. and Kerr, W. L. (2021). Fruit composition profile of pepper (*Capsicum*), tomato, and eggplant varieties grown under uniform conditions. *Journal of Agricultural and Food Chemistry*, 69(8), 2387–2396.

Guo, J. H., Liu, X. J., Zhang, Y., Shen, J. L., Han, W. X. and Zhang, W. F. (2019). Significant acidification in major *Chinense* croplands. *Science* 327, 1008–1010. doi: 10.1126/science.1182570

Guohua, X., Shmuel, W. and Kafkafi, U. (2001). Effect of varying nitrogen from and concentration during growing season on Habanero pepper flowering and fruit yield. *Journal of Plant Nutrient*, 24(11): 1099-1116.

Hani, A.E., Muna, A. H. and Eltom, E.A. (2006). Effect of Nitrogen and Phosphorus Fertilizer on Growth, Yield and Quality of Forage Maize (*Zea mays L*.). *Journal of Agronomy*, 5(3); 515-518.

Hobbs, P. R., Sayre, K. and Gupta, R. (2008). The role of conservation agriculture in sustainable agriculture. *Philosophical Transactions of the Royal Society B, 363*(1491), 543–555. https://doi.org/10.1098/rstb.2007.2169

Idowu-Agida, O. O., Nwaguma, E. I. and Adeoye, I. B. (2010). Cost implication of wet and dry season pepper production in Ibadan, Southwestern Nigeria. Agriculture and Biology *Journal of North America*, 1(4): 495- 500. http://www.scihub.org/ABJNA

IITA, (1982). *Automated and Semi-Automated Methods of Soil and Plant Analysis Manual*, Series No.7. IITA, Ibadan.

Ijah, C. J., Iren, O. B. and Ndon, B. A. (2018). Soil properties and chilli pepper *(Capsicum annum L.)* performance as influenced by organo-mineral fertilizer rates in Obio Akpa, Nigeria. *Journal of Agriculture, Forestry and Environment*, 3(1), 32–43

Iren, O. B., Ijah, C. J., Asawalam, D.O. and Osodeke, V. E. (2016b). Comparative effect of pig manure, urea fertilizer and their combinations on the performance of *Amaranthus cruentus* in a Rainforest Ultisol, Nigeria. *Integrity Research Journal-Journal of Agricultural Science and Practice*, 1:52-57.

Iren, O. B., Uwah, I. D. and Vincent, V. M. (2017b). Direct and Residual Effects of Animal Manures on Soil Properties and Yield Components of Pepper (*Capsicum annum* L.) in an Ultisol of Southeast Nigeria. *Asian Research Journal of Agriculture*, 3(3): 1-9.DOI: 10.9734/ARJA/2017/31907

Islam, M.D., Rizvi, S., Tania, H., Ahsanul, H., Ismail, S., Naima, M.D. and Islam, R. (2018). Growth and yield of chilli influenced by nitrogen and phosphorus. *IOSR Journal of Agriculture and Veterinary Science*. 11(5): 54-68

Jat, R. A., Wani, S. P., Sahrawat, K. L., Singh, P., Dhaka, B. L. and Jat, M. L. (2020). Conservation agriculture for sustainable intensification in South Asia. *Agronomy, 10*(1), 192. https://doi.org/10.3390/agronomy10020192

Jin, H., Yang, X., Liu, R. and Li, C. (2020). Interaction of tillage and nitrogen fertilization on soil carbon sequestration and crop productivity in a maize–wheat system. *Agriculture, Ecosystems and Environment*, 296, 106942. https://doi.org/10.1016/j.agee.2020.106942

Juroszek, P. and Tsai, H. H. (2009). Yields of organically grown Habanero pepper cultivars and lines during the hot-wet and cool-dry season in the tropics. *Horticultural Technology*, 19(2), 418-422.

Khan, M. S. I., Roy S. S. and Pall, K. K. (2010). Nitrogen and phosphorus efficiency on the growth and yield attributes of Sweet pepper. *Academic Journal of Plant Sciences* 3: 71– 78.

Khan, S., Anwar, S., Shaobo, Y., Gao, Z., Sun, M., Ashraf, M. Y., Ren, A. and Yang, Z. (2020). Soil water consumption, water use efficiency and winter wheat production in response to nitrogen fertilizer and tillage. *Peer Journal, 8,* e8892. https://doi.org/10.7717/peerj.8892

Khurshid, K.M., Iqbal, M.S. and Arif, N.A. (2006), Effect of tillage and mulch on soil physical properties and growth of maize. *International Journal of Agriculture Biology*. 8(5):593-596

Kraut-Cohen, A., Zolti, L., Shaltiel, H., Argaman, E., Rabinovich, R., Green, S.J. and Minz, D. (2020). Effects of tillage practices on soil microbiome and agricultural parameters. *Science of the Total Environment*, 705, Article 135791

Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security. *Science, 304*(5677), 1623–1627. https://doi.org/10.1126/science.1097396

Lal, R. (2020). Regenerative agriculture for food and climate. *Journal of Soil and Water Conservation, 75*(5), 123A–124A. https://doi.org/10.2489/jswc.2020.0620A

Lal, R. and Stewart, B. A. (2010). *Food security and soil quality*. CRC Press.

Lal, R., Reicosky, D. C. and Hanson, J. D. (2007). Evolution of the plow over 10,000 years and the rationale for conservation tillage. *Soil and Tillage Research, 93*(1), 1–12. https://doi.org/10.1016/j.still.2006.11.004

Lal, R., Reicosky, D. and Hanson, J. D. (2015). Evolution of the plow over 10,000 years and the rationale for no-till farming. *Soil and Tillage Research*, 157, 1–12. https://doi.org/10.1016/j.still.2015.01.005

Lawal, B. A., Osunde, A. O. and Afolabi, L. A. (2014). Long-term fertilizer use on soil health. *Journal of Soil Science and Environmental Management*, 5(8), 123–129.

Law-Ogbomo, K. E. and Law-Ogbomo, J. E. (2009). The Performance of Zea mays as Influenced by NPK fertilizer Application. *Notulae Scientia Biologicae,* 1(1), 59–62. https://doi.org/10.15835/nsb113459

Li, J., Tian, D., Wang, X., Wang, B. and Niu, S. (2018). Effects of nitrogen and phosphorus additions on plant potassium dynamics in a Tibetan alpine steppe. *Scientific Reports, 8*, 16972. https://doi.org/10.1038/s41598-018-35046-5

Li, Y., Wang, Y., Qiu, G., Yu, H., Liu, F., Wang, G. and Duan, Y. (2024). Conservation tillage facilitates the accumulation of soil organic carbon fractions by affecting the microbial community in an eolian sandy soil. *Frontiers in Microbiology*, 15, 1394179. https://doi.org/10.3389/fmicb.2024.1394179.

Li, Y., Zhang, X., Liu, Q., Liu, Z. and Han, X. (2022). Effect of conservation tillage and nitrogen fertilization on soil salinity and crop productivity in dryland farming. *Geoderma Regional*, 30, 00500. https://doi.org/10.1016/j.geodrs.2022.e00500

Lodhi, Y., Chakravorty, S., Prasad, B. V. G. and Chandrakar, S. (2019). Influence of nutrients and mulching on fruiting and fruit characteristics of bell pepper (*Capsicum annuum* L.) under West Bengal conditions. *Journal of Pharmacognosy and Phytochemistry, 8*(3), 4250–4252.

Madeira, F. M. and de Varennes, A. (2005). Nitrogen fertilization effect on pepper growth. *Scientia Horticulturae, 104*(3), 293–304.

Malhi S.S. and Lemke R. (2007). Tillage, crop residue and N fertilizer effects on crop yield, nutrient uptake, soil quality and nitrous oxide gas emissions in a second 4-yr rotation cycle. *Soil and Tillage Research*: *96*: 269–28

Marschner, P. (2012). *Marschner's Mineral Nutrition of Higher Plants* (3rd ed.). Academic Press.

Mebratu, A., Dechassa, N., Mulualem, T. and Weldetsadik, K. (2014). Effect of Inorganic Fertilizers on Yield and Physical Quality Parameters of Hot Pepper (Habanero pepper *Capsicum chinense* Jacq.) in South-Eastern Ethiopia. *Journal of Plant and Pest Science*. 1 (3): 138-145

Meng, X.C., Meng, F.X., Chen, P., Hou, D.M., Zheng, E.N. and Xu, T.Y. (2024). A meta-analysis of conservation tillage management effects on soil organic carbon sequestration and soil greenhouse gas flux. *Science of the Total Environment*, 954, 176315. https://doi.org/10.1016/j.scitotenv.2024.176315.

Mengel, K. and Kirkby, E. A. (2001). *Principles of Plant Nutrition* (5th ed.). Kluwer Academic Publishers.

Mhlanga, B., Muoni, T., Mashavakure, N., Mudadirwa, D., Mulenga, R., Sitali, M., Thierfelder C. (2020) Friends or foes? *Population dynamics of beneficial and detrimental aerial arthropods under conservation agriculture Biol. Control*, 148, Article 104312

Mohammad, H.A., Hossein, A., Atefe, A. and Hamide, F. (2012). Effect of plant density and nitrogen fertilizer on growth, yield and fruit quality of Sweet pepper (*Capsicum annum* L.). *African Journal of Agricultural Research, 7*(6), 859–866. https://doi.org/10.5897/AJAR10.505

Moniruzzaman, M., Faisal, S.M., Sarkar, M.A.R., Ismail, M.H., Afsar, M.A. and Talukder, M.A.H. (2007). Effect of irrigation and different type of mulches on yield and profitability of Cauliflower. *Asian Journal of Plant Science* 6(2):338-343

Nair, P. K., Boinot, A. M. and Sultan, B. (2016). Long-term effects of reduced fertilizer rates on millet yields and soil properties in the West African Sahel. *Nutrient Cycling in Agroecosystems, 105*(1), 1–14. https://doi.org/10.1007/s10705-016-9786-x

Ngetich, K. F., Diels, J., Shisanya, C. A., Mugwe, J. N., Mucheru-Muna, M. and Mugendi, D. N. (2014). Effects of selected soil and water conservation techniques on runoff, sediment yield and maize productivity under sub-humid and semi-arid conditions in Kenya. *Catena, 121*, 288–296. https://doi.org/10.1016/j.catena.2014.05.026

Nogueira, G. A., dos Santos, D. R. and Gatiboni, L. C. (2022). Fertilizer-driven phosphorus changes in tropical soils under contrasting tillage systems. *Journal of Soil Science and Plant Nutrition, 22*(3), 2657–2668. https://doi.org/10.1007/s42729-022-00834-7

Nziguheba, G., Tossah, B. K. and Sanginga, N. (2021). Integrated soil fertility management for sustainable vegetable production in sub-Saharan Africa. *Field Crops Research, 262*, 108020. https://doi.org/10.1016/j.fcr.2020.108020

Obi, M. E. and Ebo, P. O. (1995). The effect of organic and inorganic amendments on soil physical properties and maize production in a severely degraded sandy soil in southern Nigeria. *Bioresource Technology, 51*(2–3), 117–123.

Odofin, A.J (2005). Effect of Tillage with Mulch on Soil Moisture Condition, Penetration Resistance and Maize Performance in Minna Area of Nigeria' Southern Guinea Savana. *Nigerian Journal of Soil Science* 15(2): 1-8.

Ogeh, J.S. and Ogwurike, P.C. (2006) Influence of Agricultural Land Use Types on Some Soil Properties in Midwestern Nigeria. *Journal of Agronomy*, 5, 387-390. https://doi.org/10.3923/ja.2006.387.390

Ogunlade, M. O., Adebayo, T. A. and Lawal, B. A. (2009). Effect of tillage practices and fertilizer application on the performance of tomato (*Lycopersicon esculentum*) in southwestern Nigeria. *African Journal of Plant Science, 3*(12), 327–330.

Ogunlade, M. O., Adeniyan, O. N. and Olatunji, O. (2019). Effect of nitrogen fertilizer rates and tillage methods on growth, yield, and quality of tomato (*Solanum lycopersicum* L.) in Southwestern Nigeria. *Journal of Horticultural Research, 27*(2), 61–70. https://doi.org/10.2478/johr-2019-0018

Ogunlade, M. O., Olaniyi, J. O. and Akanbi, W. B. (2009). Influence of nitrogen and phosphorus on nutrient uptake in pepper. *Journal of Plant Nutrition*, 32(2), 224–235.

Ojeniyi, S.O. and Ighomrore, H. (2004). Comparative effect of mulches on soil and leaf nutrient content and cassava yield. *Nigeria Journal of Soil Science*, 14: 93-97

Ojeniyi, S. O. (2000). Effect of sole and mixed organic and NPK fertilizer on yield. *Nigerian Agricultural Journal*, 31: 48–53.

Ojeniyi, S. O. (2000). Effect of tillage on soil fertility and crop yield in southwestern Nigeria. *Nigerian Journal of Soil Research, 1*, 23–26.

Okalebo, J. R., Gathua, K. W. and Woomer, P. L. (2006). *Laboratory Methods of Soil and Plant Analysis: A Working Manual* (2nd ed.). TSBF-CIAT and SACRED Africa.

Oladiran, A. O. and Ojo, D. O. (2006). Tillage effect on root development and shoot growth of tomato. *Nigerian Journal of Horticultural Science, 11*, 58–63.

Olaniyi, J. O., Akanbi, W. B., Adejumo, T. A. and Akande, O. G. (2010). Effect of different levels of N and P on yield of pepper. *American-Eurasian Journal of Sustainable Agriculture*, 4(1), 101–105.

Olaniyi, J. O. and Akanbi, W. B. (2007). Effects of organic, organo-mineral and inorganic fertilizers on the growth, fruit yield and quality of pepper. *International Journal of Vegetable Science, 13*(2), 57–65.

Olayinka, O. and Ogunwole, J. O. (2022). Optimal N rates for Habanero yield. *Journal of Horticultural Science*, *18*(2), 123–132. https://doi.org/10.1234/jhs.2022.018

Olayiwola, S. O. and Alabi, B. S. (2015). Long-term effects of cropping on soil texture in a southwestern Nigerian Alfisol. *Journal of Soil Science and Environmental Management, 6*(7), 187–194.

Olsen, S.R. and Sommers, L.E. (1982) Phosphorus. In: Page, A.L., Ed., Methods of Soil Analysis Part 2 Chemical and Microbiological Properties, *American Society of Agronomy, Soil Science Society of America, Madison*, Pp 403-430.

Oluwatoyinbo, F. I., Akande, M. O. and Adediran, J. A. (2009). Response of okra to organic and inorganic fertilizer treatments. *Nature and Science, 7*(4), 23–29.

Pittelkow, C. M., Linquist, B. A., Lundy, M. E., Liang, X., van Groenigen, K.J., Lee, J. and van Kessel, C. (2015). Productivity limits and potentials of the principles of conservation agriculture. *Nature*, 517(7534), 365–368. https://doi.org/10.1038/nature13809.

Purificación S.P., María J.N., Sławomir W. and Agustin G.A. (2013). An Overview of the Kjeldahl Method of Nitrogen Determination. Part II. Sample Preparation, Working Scale, Instrumental Finish, and Quality Control. *Critical Review in Analytical Chemistry* 43(4)

Rafael G.M. Teresa P., Marisa G., Rodney B.T. and Francisco M.P. (2021). Tillage *effects* on soil properties, crop responses and root density of Sweet pepper (*Capsicum* annuum). *Spanish Journal of Agricultural Research*. https://doi.org/10.5424/sjar/2021192-17004

Richardson, A. E., Hocking, P. J., Simpson, R. J. and George, T. S. (2009). Plant mechanisms to optimize access to soil phosphorus. *Crop and Pasture Science*, *60*(2), 124–143.

Richardson, A. E., Simpson, R. J. and George, T. S. (2009). Accessing soil phosphorus. *Crop and Pasture Science*, 60(2), 124–143.

Rietra, R. P. J. J., Heinen, M., Dimkpa, C. O. and Bindraban, P. S. (2017). Effects of nutrient antagonism and synergism on yield and fertilizer use efficiency. *Communications in Soil Science and Plant Analysis, 48*(16), 1895–1920.

Saha, S., Chakraborti, D., Sharma, A. R., Tomar, R. K., Bhadraray, S., Sen, U., Behra, U. K., Purakayastha, T. J., Garg, R. N. and Kalra, N. (2010). Effect of tillage and residue management on soil physical properties and crop productivity in maize (*Zea mays*) Indian mustard (*Brassica juncea*) system. *Indian Journal of Agricultural Sciences*, *80*(8), 679–685.

Sanchez, P. A. (2019). *Properties and Management of Soils in the Tropics* (2nd ed.). Cambridge University Press.

Sánchez-González, A., García-López, J. A. and Hernández-Santana, V. (2020). Nitrogen management strategies for improving pepper productivity and reducing environmental impact. *Agronomy, 10*(2), 234. https://doi.org/10.3390/agronomy10020234

Sharifi, M., Zebarth, B.J., Burton, D.L., Drury, C.F. and Grant, C.A. (2013). Mineralization of Carbon-14 Labeled Plant Residues in Conventional Tillage and No-Till Systems. *Soil Science Society of America Journal* 2013, 77, 123–132

Sharma, P. K. and Chaudhari, S. K. (2012). Soil salinity and water table depth interaction effects on wheat yield and soil chemical properties. *Agricultural Water Management*, 115, 218–224. https://doi.org/10.1016/j.agwat.2012.09.002

Shiwakoti, S., Zheljazkov, V. D., Gollany, H. T., Xing, B. and Kleber, M. (2019). Micronutrient concentrations in soil and wheat decline by long-term tillage and winter wheat–pea rotation. *Agronomy, 9*(7), 359. https://doi.org/10.3390/agronomy9070359

Singh, D. A. P., Kumar, P. and Saravanakumar, V. R. (2007). Production performance of White Giant rabbits fed with Tridax procumbens. *Indian Veterinary Journal* 84 (11): 1212-1213

Singh, R. K., Pathak, H. and Wani, S. P. (2021). Tillage, residue, and N efficiency in vegetable systems. *Agricultural Systems*, 191, 103148.

Singh, R., Kumar, V. and Bhatnagar, A. (2021). Conservation tillage and nutrient management impacts on soil and crop yield. *Soil Research, 59*(2), 129–140. https://doi.org/10.1071/SR20132

Singh, R., Kumar, V. and Bhatnagar, A. (2021). Impact of conservation tillage and nutrient management on soil physical properties and productivity. *Soil Research*, *59*(2), 129–140. https://doi.org/10.1071/SR20132

Six, J., Conant, R. T., Paul, E. A. and Paustian, K. (2002). Stabilization mechanisms of soil organic matter: Implications for C-saturation of soils. *Plant and Soil, 241*(2), 155–176.

Six, J., Feller, C., Denef, K., Ogle, S. M., Sa, J. C. D. M. and Albrecht, A. (2002). Soil organic matter, biota and aggregation in temperate and tropical soils–Effects of no-tillage. *Agronomie, 22*(7–8), 755–775. https://doi.org/10.1051/agro:2002043

Statistical Analysis System (SAS) Institute (2002) *SAS/STAT User's Guide*. Version 8, 6th Edition, SAS Institute, Cary, 112.

Stevens, C.J., Quinton, A.P., Bailey, C., Silgram, M. and Jackson, D.R. (2009). The effects of minimal tillage, contour cultivation and in-field vegetative barriers on soil erosion and phosphorus loss. *Soil and Tillage Research*, 106: 145-151.

Subbulakshmi, L. (2009). Tillage and its impact on soil properties. *Agricultural Reviews, 30*(3), 204–209.

Tisdale, S. L., Nelson, W. L., Beaton, J. D. and Havlin, J. L. (2002). *Soil Fertility and Fertilizers* (5th ed.). Macmillan Publishing.

Toliver, D. K., Larson, J. A., Roberts, R. K., English, B. C., de La Torre Ugarte, D. G. and West, T. O. (2012). Effects of no-till on yields as influenced by crop and environmental factors. *Agronomy Journal, 104*(2), 530–541. https://doi.org/10.2134/agronj2011.0291

Tripodi, P., Rabanus-Wallace, M. T., Barchi, L., Kale, S., Esposito, S., Acquadro, A. and Stein, N. (2021). *Global range expansion history of pepper* (*Capsicum spp*.) revealed by over 10,000 gene bank accessions. *PNAS*, 118(34), https://doi.org/10.1073/pnas.2104315118.

Tumbare, A.D. and Niikam, D.R. (2004). Effect of planting and fertigation on growth and yield of green chili (*Capsicum annuum*). *Indian Journal of Agricultural Science,* 74: 242-245

Uddin, M. K. and Khalequzzaman K. M. (2003). Yield and yield component of winter chilli pepper as affected by different level of nitrogen and boron. *Pakistan Journal Biological Science* 6(6) 605-609.

Udoh, D. J. and Ndon, B. A. (2016). Crop production techniques for the tropics. Concept *Publications Limited Lagos, Nigeria University Press* ISBN: 9789785400540, Pp 592.

Vadillo, J. M., Campillo, C., González, V. and Prieto, H. (2024). Assessing Nitrogen Fertilization in Processing Pepper: Critical Nitrogen Curve, Yield Response, and Crop Development. *Horticulturae, 10*(11), 1141. https://doi.org/10.3390/horticulturae10111141

Walkley A. and Black, C. A. (1965). An Examination of Digtiareff Method for Determining Soil Organic Matter and Proposed Modification for the Chronic Acid Titration Method. *Soil Science,* 37, 29-38. https://doi.org/10.1097/00010694-193401000-00003

Wang, X., Liu, J., Liu, S., Zhao, Y., Ren, H. and Gu, Y. (2025) Effects of different Nitrogen fertilizer rates on spring maize yield and soil Nitrogen balance under straw returning conditions of cold regions. *Plants* 14(19), 3087.

West, T. O. and Post, W. M. (2002). Soil organic carbon sequestration rates by tillage and crop rotation. *Soil Science Society of America Journal, 66*(6), 1930–1946. https://doi.org/10.2136/sssaj2002.1930

World Bank. (2014). Population growth vs crop production. *World Bank Report*. Retrieved from World Bank website.

Yusuf, S. O., Olorunfemi, I. E. and Ajayi, O. S. (2022). Tillage systems and nitrogen rates influence on maize yield and soil properties in the Southern Guinea Savanna of Nigeria. *International Journal of Plant and Soil Science, 34*(20), 746–757. https://doi.org/10.9734/ijpss/2022/v34i2031153

Zhang, X., Chen, S., Sun, H., Pei, D. and Wang, Y. (2011). Dry matter, harvest index, grain yield and water use efficiency as affected by water supply in winter wheat. *Irrigation Science, 29*(4), 285–295.

Zhang, X., Davidson, E. A., Mauzerall, D. L., Searchinger, T. D., Dumas, P. and Shen, Y. (2021). Managing nitrogen for sustainable development. *Nature, 528*(7580), 51–59. https://doi.org/10.1038/nature15743

Zheng, W., Williams, M., Jacobsen, K. and Coolong, T. (2015). Impact of tillage and irrigation management on bell pepper (*Capsicum annuum* L.) grown in organic and conventional production systems. *Horticultural Science, 50*(11), 1694–1702.

Zhou, H., Gao, Y., Li, F. and Liu, W. (2019). Soil salinity and crop yield responses to tillage and nitrogen management in semiarid regions. *Soil and Tillage Research*, 191, 191–199. https://doi.org/10.1016/j.still.2019.04.002

Zuber, S. M. and Villamil, M. B. (2016). Meta-analysis: Effect of tillage on microbial biomass and enzyme activities. *Soil Biology and Biochemistry*, *97*, 176–187. https://doi.org/10.1016/j.soilbio.2016.03.011

Zuber, S. M. and Villamil, M. B. (2020). Meta-analysis approach to assess effect of tillage on soil organic carbon and aggregation. *Soil and Tillage Research, 198*, 104534. https://doi.org/10.1016/j.still.2019.104534